A critical understanding of eutrophication governance in South Africa

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PREFACE

South Africa's water resources, in terms of both availability and quality, increasingly threaten the socio-economic well-being of its citizens and the health of aquatic ecosystems. In response, the Department of Water and Sanitation (DWS) initiated a comprehensive process in 2015 to enhance its water quality management approach, culminating in the publication of a new apex policy and strategy as part of the Integrated Water Quality Management Policies and Strategies for South Africa (2017) series. During this time, addressing eutrophication, which was identified as a significant threat, was underscored as a critical priority.

I extend my gratitude to the DWS for entrusting me with the responsibility of authoring the *Eutrophication Management Strategy for South Africa (EMSSA)*. It was both a privilege and an honour to work on this Strategy while pursuing my doctoral studies. This synergy between the initiatives greatly enhanced my ability to fulfil my departmental duties.

I would like to acknowledge the pivotal roles of five colleagues: Mr William Mosefowa, for his insights on pollution source control; Ms Koleka Makanda and Mr Samkele Mnyango, for their assistance with research and data collection; Mr Pieter Viljoen, my supervisor, for his guidance; and Ms Tovhowani Nyamande, the departmental project director, for her input. The EMSSA successfully completed stakeholder consultation and departmental quality assessment, receiving technical approval on 9 February 2023, and was given final endorsement for implementation during a Water Resource Management Branch meeting on 9 June 2023.

This thesis formed part of a Ph.D. programme in science focusing on geography and environmental management at the Potchefstroom Campus of North-West University. With more than three decades of experience in water quality management within the Department, I felt well prepared to formulate the EMSSA and complete this thesis.

Entitled *"A critical understanding of eutrophication governance in South Africa"*, this research aimed to identify reasons for failures in eutrophication governance despite numerous interventions and to propose novel and revised policy and strategy responses to improve water resource conditions. I hope the outcomes of this work will enhance water quality management in South Africa and offer valuable insights to the global community, particularly regarding effective eutrophication management practices.

J.J. van Wyk, ***Pr. Sci. Nat.*** **|** ***M.Sc.*** *(Biochemistry)* **|** ***M.Sc.*** *(Environmental Management & Analysis)*

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RESEARCH CONTEXT

Introduction

This section sets out the research context for the doctoral thesis and its relationship with the Department of Water and Sanitation's *Eutrophication Management Strategy for South Africa* (EMSSA) [DWS, 2023b]. This doctoral thesis and the EMSSA arose from a single, integrated research process. The two documents were developed substantially in parallel but were intended for different purposes, audiences and institutional processes. The thesis represents the primary scholarly output of the research process, whereas the EMSSA represents an applied government policy and strategy output derived from, and informed by the same body of research.

Integrated research process and chronology

The relationship between the two outputs is reflected in the chronology of their development. The research proceeded through the parallel and integrated development of the doctoral thesis and EMSSA, with both outputs drawing on the same underlying body of work as it developed. The underlying research, conceptual development and drafting progressed concurrently, initially through an integrated working process that culminated in two outputs. Material required by both outputs was developed once and subsequently incorporated, adapted and further developed according to the distinct requirements of the doctoral thesis and the EMSSA. The principal milestones were as follows:

Period or date	Research and development milestone
2016 – 2017	Initial doctoral studies commenced but were subsequently discontinued because of workload pressures.
2020	After being tasked by the DWS with authoring a national eutrophication management strategy, the doctoral research was resumed, and an integrated PhD-EMSSA research process was conceptualised. Preparatory research commenced and engagement with the North-West University (NWU) promotor resumed.
15 October 2020	The broad structure/Table of Contents for the proposed EMSSA, developed and presented by the Main Author, J.J. van Wyk, was considered by the National Eutrophication Strategy Sub-Task Team. The proposed structure was supported, with suggestions for additions within the framework, and thereafter provided the foundational architecture for further development of the EMSSA.
2020 – 2022	Doctoral literature research, conceptual development, evaluation and drafting progressed alongside the EMSSA component, which advanced through DWS project procedures and stakeholder consultation. An integrated working approach meant that research and material relevant to both outputs were developed once and subsequently adapted to their different purposes.
October 2021	A first formal PhD Research Proposal was submitted to the NWU. The proposal defined the doctoral research as directed towards developing a pollutant-specific policy and strategy for the management of eutrophication in South Africa, using, *inter alia*, causal chain and DPSIR analysis to identify governance responses for translation into policy statements and management strategies. The doctoral research was expressly designed to develop policy and strategy responses that also formed central components of the EMSSA.

Period or date	Research and development milestone
2023	Formal doctoral registration commenced after substantial preparatory research and drafting had already been undertaken, partly to optimise study costs. Edition 2 of the EMSSA received DWS technical approval on 9 February 2023. A first complete draft of the doctoral thesis was submitted to the NWU supervisors on 25 April 2023.
9 May 2023	The DWS issued a copyright declaration reproduced as **Annexure A** to this thesis, recognising the relationship between the doctoral research and the EMSSA, accepting that the two documents would intrinsically share content, and requiring that the EMSSA be acknowledged in the thesis as a source. The EMSSA also incorporated stakeholder input generated through the DWS consultation process, which informed the parallel doctoral research.
9 June 2023	The EMSSA was endorsed for implementation through the DWS Water Resource Management Branch process.
January 2024	Following formal doctoral registration in 2023, the Research Proposal was further refined and the final version was approved by the NWU.
2023 – 2024	The thesis continued through academic processes and requirements additional to those applicable to the departmental strategy, including the NWU ethics process, further supervisory refinement, academic referencing and formatting, language editing and preparation for independent examination. Ethics clearance was obtained in 2024.
2024 – 2025	The final thesis was submitted for examination in 2024. The doctoral qualification was obtained on 6 March 2025, and the degree was conferred on 6 June 2025.

The chronology indicates the relationship between the completion dates of the two outputs. A first complete thesis draft had been submitted to the NWU supervisors on 25 April 2023, before the EMSSA received final endorsement for implementation on 9 June 2023. Thereafter, the thesis continued through the additional academic, ethics, supervisory and examination processes applicable to a doctoral study. Consequently, although a complete thesis draft existed by April 2023, the final academic process extended beyond the completion and departmental approval of the EMSSA.

The chronology also provides context for the original referencing approach adopted in the two outputs. When the first complete thesis draft was submitted to the NWU promotors on 25 April 2023, the EMSSA had not yet received final endorsement for implementation and had not been published. Ethics clearance was granted in 2024; the ethics application required DWS confirmation of the relationship between the doctoral research and the DWS eutrophication project (see **Annexure A**). Conversely, when the EMSSA was finalised in 2023, the thesis had not yet been examined or published, and the doctoral degree had not yet been conferred. Against this chronology, the shared material was not reciprocally referenced at passage level in the two documents during the relevant stages of their drafting and finalisation, although the broader relationship between the EMSSA and the doctoral research is acknowledged in the thesis front matter. The two outputs developed substantially in parallel and drew on the same underlying body of research. This Research Context explicitly records the relationship between the two outputs, the areas of shared material and the original absence of reciprocal passage-level referencing.

Nature of the textual relationship

Contemporary research integrity and publication ethics guidance distinguishes plagiarism from text recycling and other forms of textual reuse between related outputs. Plagiarism concerns the presentation of another person's words, ideas or intellectual contribution as one's own, whereas text recycling generally concerns the reuse of text across outputs where authorship is wholly or partly common. Such reuse is assessed contextually, with considerations including the purpose and intended readership of the respective outputs, transparency regarding the relationship between them, authorship and contributor roles, copyright, and whether the presentation may mislead the reader [COPE, 2019; ALLEA, 2023; Singapore Statement, 2010].

Such textual reuse may take different forms depending on the chronology and circumstances in which the related outputs were developed. In the present case, the thesis and the EMSSA were developed substantially in parallel through an integrated research process. Accordingly, areas of common text do not necessarily represent the sequential reuse of text first developed for one completed output and subsequently incorporated into the other. Material required by both outputs was developed within the integrated process and was incorporated, adapted and further developed according to their respective academic, and government policy and strategy purposes.

These distinctions are pertinent when considering the relationship between an academic thesis and a government policy and strategy document, which perform different functions. The thesis had to document the research problem, methodology, analytical reasoning, evidence, findings and original scholarly contribution in sufficient depth to meet doctoral requirements. The EMSSA had to translate relevant outcomes from the same research process into a practical national policy and strategy instrument capable of guiding eutrophication management.

The common scientific, conceptual, policy and legal foundation was therefore developed within the integrated research process and informed both outputs. Where material served both purposes, it was developed within the integrated research process and carried into both documents. This accounts for areas of identical, closely similar and adapted text. In other areas the thesis is substantially more extensive, particularly in respect of research methodology, philosophical and theoretical grounding, detailed evaluation, causal chain and DPSIR analyses, critical interpretation, academic synthesis, the evaluation of the research framework, and the articulation of the scholarly knowledge contribution.

The principal relationships between the thesis chapters and the EMSSA are summarised below:

Doctoral thesis	Corresponding EMSSA component(s)	Nature of the relationship
Chapter 1: Introduction and research outline	Mainly Part 1, Chapter 1 (*The eutrophication challenge*) and Chapter 3 (*Towards a eutrophication management strategy for South Africa*).	The two outputs share the underlying national problem and broad research context. No material extended verbatim overlap has been identified in Chapter 1. The thesis, additionally, establishes the doctoral problem statement, research aim and objectives, research approach, scope, limitations and thesis structure.
Chapter 2: Methodology	Selected concepts reflected mainly in Part 1, Chapter 1 and Chapter 3, particularly the problem analysis, DPSIR and EMSSA development processes.	Limited wording and methodological concepts are shared, particularly in relation to causal chain/ DPSIR analysis, and policy and strategy development. The thesis contains substantially more extensive philosophical and theoretical grounding and detailed method descriptions for literature research, the national survey, stakeholder engagement, qualitative forecasting, evaluation and policy/ strategy formulation.
Chapter 3: Literature review	Part 1, Chapter 2 (*Defining the subject*) and Chapter 4 (*Policy, strategy and law context*).	This is the area of greatest shared foundational content. Sections 3.2 – 3.9 and 3.11 contain substantial identical, closely corresponding and adapted scientific, conceptual, policy and legal material also used in the EMSSA. This material was developed once as the common research and scholarly foundation for both outputs.
Chapter 4: Evaluation of eutrophication governance in South Africa	Mainly Part 1, Chapter 1 (*The eutrophication challenge*), its DPSIR-based problem declaration, and Chapter 5 (*Evolution of eutrophication management in South Africa*).	Shared research findings include the key challenges, aspects of the historical, current and prospective assessment, and elements of the causal chain/ DPSIR analysis. Some wording is common to both outputs. The thesis develops the evaluation considerably further through detailed challenge analyses, survey analysis, causal chain analysis, DPSIR evaluation and integration of stakeholder evidence.
Chapter 5: Towards a eutrophication governance policy for South Africa	Part 2 – *Eutrophication management policy for South Africa*, particularly the visionary perspective and policy intent.	There is substantial conceptual and textual correspondence because the policy component of the EMSSA is the applied governmental expression of the policy response developed through the integrated research process and analysed in the doctoral thesis. The fourteen technical and five supporting policy statements are therefore closely aligned. The thesis additionally demonstrates their derivation from the preceding research and provides the fuller scholarly reasoning and evidential basis.
Chapter 6: Towards a eutrophication governance strategy for South Africa	Part 3 – *Eutrophication management strategy for South Africa*: core, operational and supporting strategies and governance.	There is extensive substantive and textual correspondence in the core strategies, the Plan-Do-Check-Act operational strategies, the supporting strategies, strategic actions and governance arrangements. These constitute the applied strategy output of the integrated research. The thesis situates these responses within the preceding doctoral evaluation and provides their scholarly and analytical derivation.

Doctoral thesis	Corresponding EMSSA component(s)	Nature of the relationship
Chapter 7: Research findings and way forward	Mainly Part 4 – *The way forward*, together with conclusions and implementation-oriented material in the EMSSA.	The relationship is primarily thematic rather than one of extensive textual overlap. The thesis uniquely evaluates achievement of the research objectives, critically evaluates the DPSIR framework, states the knowledge contribution and develops academic and implementation-related future perspectives. The EMSSA focuses instead on an implementation-oriented way forward for the policy and strategy.

The relationship between **Chapters 3 - 6** and the corresponding parts of the EMSSA is particularly important. **Chapter 3** provides much of the common scientific and regulatory foundation. **Chapter 4** then evaluates the governance problem and identifies causal relationships and intervention needs. **Chapters 5 and 6** translate those findings into policy and strategy responses. Relevant outputs from that research process were incorporated and adapted into Parts 1 – 3 of the EMSSA as the integrated research process progressed. The EMSSA, therefore, represents an applied translation of the broader research process for a national water sector audience, while the thesis records the comprehensive scholarly process through which those responses were developed.

Different purposes and institutional processes

The two outputs differ in both purpose and depth. The doctoral thesis is an academic research product that had to demonstrate methodological rigour, critical evaluation, independent scholarly reasoning and a contribution to knowledge. It therefore includes detailed philosophical and theoretical grounding, explicit research methods, critical evaluation of eutrophication governance, detailed causal chain and DPSIR analyses, analysis of survey and stakeholder evidence, the derivation of policy and strategy responses, critical reflection on the analytical framework and an explicit statement of the knowledge contribution.

The EMSSA [DWS, 2023b], by contrast, is an applied national government policy and strategy document. Its purpose is to provide the water sector with a coherent policy position and practical strategic guidance for managing anthropogenic eutrophication. It therefore draws on the relevant research foundation and findings but organises them for a policy, regulatory, planning and implementation audience. It underwent a separate DWS process of technical review, project governance, stakeholder consultation, departmental quality assessment and approval.

The different purposes also provide context for the retention of consistent wording in some parts of the two outputs. Scientific definitions, descriptions of established processes, statutory and policy context, formal policy statements and precise strategy formulations benefit from consistent terminology and formulation where they serve the same function in both outputs. Where the same

research result or technical formulation was required in both outputs, consistent wording assisted in maintaining technical accuracy and coherence. Where the purposes differed, the thesis contains additional research, analysis, explanation and critical discussion that was either unnecessary or unsuitable for inclusion at the same level of detail in the government strategy.

Authorship, research assistance and other contributions

The EMSSA was developed through an author-led process within a broader DWS departmental project and stakeholder-consultation process. The published EMSSA formally credits J.J. van Wyk as Main Author, W. Mosefowa as Co-Author, and K. Makanda and S. Mnyango as Researchers. These formal credits are retained here, while the respective functions performed during development are clarified below.

As Main Author, J.J. van Wyk was tasked by DWS with authoring the EMSSA and conceptualised its foundational structure and architecture. He remained responsible for integrating the doctoral research and departmental project; synthesising source material, research findings and stakeholder input; drafting, editing and revising the manuscript; developing the policy and strategy responses; and considering whether and how comments, and other inputs should be incorporated. He authored and drafted the EMSSA technical manuscript as a whole and provided guidance and capacity development to the two researchers during manuscript preparation.

The consultation and review process was iterative rather than a division of the manuscript among stakeholders for independent authorship. Draft text, concepts and proposals, developed through the author-led process, were circulated through project and stakeholder structures for comment and refinement. The contemporaneous *Issues and Response Register* [DWS, 2023c] and *Document Change Log* [DWS, 2023e] record this process, including substantive explanations by the Main Author and his decisions to accept, adapt or decline proposed changes. The co-author, researchers, project team, reviewers and stakeholders therefore contributed technical, substantive, editorial and contextual inputs that informed and refined the developing manuscript, while the overall conceptualisation, synthesis and drafting remained with the Main Author.

W. Mosefowa contributed technical material and comments principally concerning pollution source control, source directed controls, water use authorisation, the Waste Discharge Charge System, monitoring, compliance and related regulatory instruments. His submissions drew on existing DWS policies, strategies, legislation and earlier eutrophication management guidance, and relevant material was incorporated where appropriate. His contribution was therefore focused principally on specific technical and regulatory areas and differed in nature and scope from the overall conceptualisation, research synthesis and drafting undertaken by the Main Author.

K. Makanda and S. Mnyango served as Researchers, sourcing literature and other material, extracting potentially relevant information and submitting research inputs for assessment and possible use. S. Mnyango also acted as project coordinator, participated in stakeholder engagement and project administration, reviewed drafts and proposed technical, editorial and presentational changes. Neither researcher was responsible for drafting or taking responsibility for the EMSSA manuscript as a whole. Their contributions formed part of the research, consultation, coordination and review processes supporting development of the EMSSA.

The contributions of other DWS officials, project structures, reviewers and stakeholders were likewise important to the development and quality assurance of the EMSSA. Their comments and specialist inputs helped test, refine and improve the policy and strategy, while responsibility for synthesising those inputs and considering their incorporation remained with the Main Author. The contemporaneous *Issues and Response Register* [DWS, 2023c] and *Document Change Log* [DWS, 2023e] record their contributions. Through the integrated research process, these inputs also informed and contributed to the development of the final doctoral thesis.

Chapter-specific *Research Context* sections are included in each chapter to identify that chapter's specific relationship to the EMSSA and, where applicable, to note areas of shared, related or textually overlapping material and to acknowledge relevant contributions.

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Upon concluding the study, I would like to express my sincere gratitude and thanks to the following individuals and organisations:

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  - Mr Pieter Viljoen for tasking me with authoring the *Eutrophication Management Strategy for South Africa (EMSSA)*, providing valuable input and encouraging me to continue my studies;
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  - the DWS for permitting me to conduct my doctoral study in tandem with the development of the EMSSA and for allowing me to integrate my research work into the EMSSA and *vice versa*. Therefore, I wish to fully acknowledge the EMSSA [DWS, 2023b].

    See **Annexure A** for a formal copyright declaration from the DWS.

- **And above all, I want to thank my heavenly Father, *El Shaddai – Lord God Almighty*, who granted me the strength, willpower and wisdom to complete the study.**

ABSTRACT

Anthropogenic nutrient enrichment of water resources is a pressing global matter, particularly acute in densely populated areas where industrial effluent, sewage, urban runoff, atmospheric deposition and agricultural practices elevate nutrient levels in waterbodies. This nutrient influx accelerates primary production, leading to biodiversity loss and water quality degradation. Despite global regulatory efforts, eutrophication remains a critical concern, with South Africa facing escalating threats to its freshwater resources. This urgency underscores the need for effective actions to combat eutrophication in the interest of ecologically sustainable development.

This research aimed to **develop a critical understanding of eutrophication governance in South Africa** by focusing on **(1)** evaluating eutrophication governance, **(2)** recommending policy responses, and **(3)** proposing strategic management approaches. The study employed a four-phase methodology based on evaluation research. Data collected through literature research, surveys and stakeholder engagement in **Phase 1** informed the evaluation process in **Phase 2**, which involved designing an evaluation framework based on the DPSIR Framework to analyse the data and identify root causes for intervention responses. These responses were then translated into policy statements in **Phase 3** and strategies in **Phase 4** to guide eutrophication governance in South Africa.

By linking theoretical frameworks with practical policy and strategy for implementation, this research methodology aimed to provide effective solutions to combat anthropogenic eutrophication. Grounded in a philosophical and theoretical foundation, the research contributed significantly to South Africa's water resource sustainability, highlighting the urgent need for comprehensive governance mechanisms. The findings revealed major gaps, particularly in monitoring, enforcement and coordination. Through the DPSIR Framework, the study established essential linkages between drivers, pressures and water quality impacts, facilitating a targeted governance approach. The proposed policy prioritised long-term sustainable water management, adaptive strategies and resource allocation. Ultimately, this study called for continuous strategy adjustments to meet changing ecological and social demands, ensuring a responsive and effective governance framework.

KEY WORDS: phosphorus, nitrogen, nutrient, enrichment, primary production, algae, trophic status, eutrophication, DPSIR, water quality management

ABBREVIATIONS AND ACRONYMS

	2-MIB	2-methylisoborneol
A	**AIA (2:2000)**	Access to Information Act, 2000 (Act No. 2 of 2000), as amended
	API	Application Programming Interface
	APP	Annual Performance Plan
	APTT	Anti-Pollution Task Team
B	**BARDENPHO**	BARnard DENitrification and PHOsphorus removal
	BC	Before Christ
	BMP	Best Management Practice
	BNR	Biological Nutrient Removal (also often referred to as the Bardenpho Process)
	BOD	Biological Oxygen Demand
	BPEO	Best Practicable Environmental Option
	BPG	Best Practice Guideline
C	**Capex**	Capital expenditure
	CARA (43:1983)	Conservation of Agricultural Resources Act, 1983 (Act No. 43 of 1983)
	CBA	Cost-Benefit Analysis
	Chl-α	Chlorophyll-α
	CMA	Catchment Management Agency
	CMF	Catchment Management Forum
	CMS	Catchment Management Strategy
	COD	Chemical Oxygen Demand
	CoGTA	Department of Cooperative Governance and Traditional Affairs
	CSD	United Nations Commission on Sustainable Development
	CSIR	Council for Scientific and Industrial Research
D	**DAFF**	Currently DALRRD, previously the Department of Agriculture, Forestry and Fisheries
	DALRRD	Department of Agriculture, Land Reform and Rural Development
	DBE	Department of Basic Education
	DEA	Currently DFFE, previously the Department of Environment Affairs
	DEFF	Currently DFFE, previously the Department of Environment, Forestry and Fisheries
	DFFE	Department of Forestry, Fisheries and the Environment
	DHET	Department of Higher Education and Training
	DIN	Dissolved Inorganic Nitrogen
	DMRE	Department of Mineral Resources and Energy

	DNA	Deoxyribonucleic acid
	DO	Dissolved Oxygen
	DOH	Department of Health
	DPME	Department of Planning, Monitoring and Evaluation
	DPSA	Department of Public Service and Administration
	DPSER	Driver-Pressure-State-Ecosystem-Response
	DPSIR	Driver-Pressure-State-Impact-Response
	DPSWR	Driver-Pressure-State-Welfare-Response
	DSR	Driving force-State-Response
	DST	Currently DSI, previously the Department of Science and Technology
	DSI	Department of Science and Innovation
	DWA	Currently DWS, previously the Department of Water Affairs
	DWAF	Currently DWS, previously the Department of Water Affairs and Forestry
	DWS	Department of Water and Sanitation
E	**EEA**	European Environment Agency
	EIA	Environmental Impact Assessment
	ELU	Existing Lawful water Use
	EMF	Environmental Management Framework
	EMI	Environmental Management Inspector
	EMPR	Environmental Management Programme Report for mining
	EMSSA	Eutrophication Management Strategy for South Africa
	EONEMP	Earth Observation National Eutrophication Management Programme
	EPA	United States Environmental Protection Agency
	EPMDS	Employee Performance Management and Development System
	ERA	Environmental Risk Assessment
	EWR	Ecological Water Requirement
	EWSETA	Energy and Water Sector Education and Training Authority
F	**FEPA**	Freshwater Ecosystem Priority Area
	FETwater	Framework Programme for Education and Training in Water
G	**GA**	General Authorisation
	GDP	Gross Domestic Product
	GDS	Green Drop System
	GEMS	Global Environmental Monitoring System
	GEMStat	Global Freshwater Quality Database

	GG	Government Gazette
	Global G.A.P.	Global Partnership for Good Agricultural Practice
	GN	Government Notice
	GNP	Gross National Product
H	**HETMIS**	Higher Education and Training Management Information System
I	**IDP**	Integrated Development Plan
	IHI	Index for Habitat Integrity method
	IRiS	Integrated Regulatory information System
	ISO	International Organisation for Standardisation
	IUCMA	Inkomati-Usuthu Catchment Management Agency
	IUA	Integrated Units of Analysis
	IWQM	Integrated Water Quality Management
	IWRM	Integrated Water Resource Management
L	**LCA**	Life Cycle Assessment
	LGSETA	Local Government Sector Education and Training Authority
	LIMCOM	Limpopo Watercourse Commission
M	**MC**	Management Class/ Water Resource Class
	MDG	Millennium Development Goal
	MERIS	Medium Resolution Imaging Spectrometer
	MISA	Municipal Infrastructure Support Agent
N	**NAEHMP**	National Aquatic Ecosystem Health Monitoring Programme
	NDMC	National Disaster Management Centre
	NDP	National Development Plan, 2030
	NEM	National Environmental Management
	NEMA (107:1998)	National Environmental Management Act, 1998 (Act No. 107 of 1998), as mended
	NEM ICMA (24:2008)	NEM: Integrated Coastal Management Act, 2008 (Act No. 24 of 2008), as mended
	NEM WA (59:2008)	NEM: Waste Act, 2008 (Act No. 59 of 2008), as amended
	NEMP	National Eutrophication Monitoring Programme
	NEsMP	National Estuaries Monitoring Programme
	NFEPA	National Freshwater Ecosystem Priority Areas
	NGO	Non-Governmental Organisation
	NIWIS	National Integrated Water Information System
	NIWR	National Institute of Water Research

	NLO	Nutrient Load Objective
	NPC	National Planning Commission
	NPDF	National Policy Development Framework
	NPS	Non-Point Source
	NQF	National Qualifications Framework
	NRF	National Research Foundation
	NTU	Nephelometric Turbidity Unit
	NW&S MP	National Water and Sanitation Master Plan
	NWA (36:1998)	National Water Act, 1998 (Act No. 36 of 1998), as amended
	NWMP	National Wetland Monitoring Programme
	NWQMF	National Water Quality Management Forum
	NWRS	National Water Resource Strategy
	NWSF	National Water Security Framework
	NWU	North-West University
O	**O&M**	Operation and Maintenance
	OECD	Organisation for Economic Cooperation and Development
	Opex	Operational expenditure
	ORASECOM	Orange Senqu River Commission
	ORCID	Open Researcher and Contributor Identifier
P	**PICC**	Presidential Infrastructure Coordinating Commission
	PMC	Project Management Committee
	PSC	Project Steering Committee
	PSR	Pressure-State-Response
R	**R.**	Regulation
	R&D	Research and Development
	RBO	River Basin Organisation (often referred to in a transboundary context)
	RDI	Research, Development and Innovation
	RDM	(statutory) Resource-Directed Measure
	RDP	Reconstruction and Development
	REMP	River Eco-status Monitoring Programme
	RHP	River Health Programme
	RNA	Ribonucleic acid
	RQIS	Resource Quality Information Services
	RQO	Resource Quality Objective

	RSA	Republic of South Africa
	RU	Resource Unit
	RWQO	Resource Water Quality Objective
S	**S.**	Section
	SABS	South African Bureau of Standards
	SADC	Southern African Development Community
	SALGA	South African Local Government Association
	SANBI	South African National Biodiversity Institute
	SANParks	South African National Parks
	SAPS	South African Police Service
	SAQA	South African Qualifications Authority
	SARS	South African Revenue Service
	SAWQG	South African Water Quality Guideline
	SDBIP	Service Delivery Budget and Implementation Plans
	SDC	Source-Directed Control
	SDG	Sustainable Development Goal
	SEA	Strategic Environmental Assessment
	SEIAS	Socio-Economic Impact Assessment System
	SEMA	Specific Environmental Management Act
	SETA	Sector Education and Training Authorities
	SIA	Social Impact Assessment
	SMART	Specific, Measurable, Agreed-upon, Realistic and Time-based
	SO	Strategic Objective, as per the IWQM Strategy for South Africa (2017)
	spp.	Botanical shorthand for multiple species
	S-R	Stress-Response
	SRP	Soluble Reactive Phosphorus
	SSC	Strategy Steering Committee
T	**TDS**	Total Dissolved Solids
	THM	Trihalomethane
	TIA	Technology Innovation Agency
	TIN	Total Inorganic Nitrogen
	TKN	Total Kjeldahl Nitrogen
	TMDL	Total Maximum Daily Load
	TN	Total Nitrogen
	TNS	The Natural Step, as in TNS funnel

	TON	Threshold Odour Number
	TON	Total Organic Nitrogen
	TP	Total Phosphorus
	TPTC	Tripartite Permanent Technical Committee
	TSI	Trophic State Index
	TSP	Trophic Status Project
	TTT	Technical Task Team
U	**UN**	United Nations
	UNCED	United Nations Conference on Environment and Development (1992)
	UNEP	United Nations Environment Programme
	UNESCO	United Nations Educational, Scientific and Cultural Organisation
	URL	Uniform Resource Locator, colloquially termed an internet web address
V	**V&V**	Validation and Verification of water use
	VIP	Ventilated improved pit latrine
W	**w**	Weight
	WA (54:1956)	Water Act, 1956 (Act No. 54 of 1956), as amended
	WAR	Water Allocation Reform
	WARMS	Water use Authorisation and Registration Management System
	WDCS	Waste Discharge Charge System
	WDS	Waste Discharge Standard
	WLO	Waste Load Objective
	WMA	Water Management Area
	WMS	Water Management System
	WQPL	Water Quality Planning Limit
	WRCS	Water Resources Classification System
	WSA	Water Services Authority
	WSA (108:1997)	Water Services Act, 1997 (Act No. 108 of 1997), as amended
	WSDP	Water Services Development Plan
	WSP	Water Services Provider
	WSSD	World Summit on Sustainable Development (2002)
	WTWs	Water Treatment Works
	WwTWs	Wastewater Treatment Works

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THE RESEARCH CONTEXT OF CHAPTER 1

Chapter 1 provides the academic framing of the integrated research process. Its broad problem context corresponds with aspects of Part 1, Chapter 1 of the EMSSA, while its discussion of the purpose and development context of the research relates to Part 1, Chapter 3 of the EMSSA [DWS, 2023b]. No material extended verbatim overlap between this chapter and the EMSSA has been identified; the relationship is primarily contextual and structural.

In keeping with its academic function, the chapter is substantially more extensive. In addition to introducing the eutrophication governance problem, it defines the doctoral problem statement, research aim and objectives, research approach and layout, scope and limitations, and the structure of the thesis. These components establish the academic research framework within which the later evaluation, policy and strategy responses were developed. The shared context in the two outputs reflects their origin in the same integrated research process and their common focus on addressing eutrophication in South Africa.

CHAPTER 1 INTRODUCTION AND RESEARCH OUTLINE

1.1 INTRODUCTION

Anthropogenic nutrient enrichment of water resources is a global water resource problem [Chakrabarti, 2018:1; Rast & Thornton, 1996:295-313]. It is most evident in highly populated and developed areas where industrial effluent, water-borne sewage systems, wash-off from built-up areas, atmospheric fall-out (mostly from fossil fuel combustion) and agricultural practices contribute to elevated loads of nutrients entering receiving water resources [UK EA, 2019:4; UK EA, 2022:5; Walmsley, 2003:1]. Elevated nutrient loading promotes excessive primary production in natural systems, which can result in a wide array of biological diversity issues [Cook, *et al.*, 2018:47] and water quality problems [Chislock, *et al.*, 2013:(8)3; Dunst, *et al.*, 1974:2]. This phenomenon, known as the ***"paradox of enrichment"***, occurs when elevated nutrient levels initially stimulate primary production and biota proliferation but eventually destroy ecosystems, either through elevated interspecific competition within a trophic level or by destabilising trophic interactions. [Gounand, *et al.*, 2014:752; Jerrold, *et al.*, 2013:1]. *"Trophic status"* constitutes an indicator of water utility and ecosystem health [Carlson, 1977:361; Gudmundsson, 2003:1]. Unless eutrophication due to human activities is ceased, the world's aquatic ecosystems and the fitness-for-use of the world's water resources will be at risk [Chakrabarti, 2018:5]. Because of the intertwined relationship that exists between human development, economic advancement, their dependence on water resources and susceptibility to the negative effects of eutrophication – continuous socio-economic growth linked to unabated anthropogenic eutrophication will inevitably culminate in what can be regarded as a ***"eutrophication dilemma"*** [Jerrold, *et al.*, 2013:1-7; Schindler, 2012:4322]. Under such a scenario, **poorly** or **uncontrolled** *"development"* is likely to limit the progressive social and economic development that is so eagerly desired [Chislock, *et al.*, 2013:6; Rast & Thornton, 1996:295-313].

1.2 PROBLEM STATEMENT

Global Eutrophication Watch, as cited by De Raús Maúre, *et al.* (2021:1), regards eutrophication as an **expanding global issue**. Impacts from land-based development often reach coastal marine waters, making seawater eutrophication an indicator of the effectiveness of land-based controls. According to Diaz, *et al.* (2004:1), human activities have contributed to the globalisation of many environmental problems, with some of the most serious impacts in marine systems being directly related to eutrophication. Jarvie, *et al.* (2013:295) note that eutrophication-control

policies are under increasing scrutiny, as evidence of ecological improvements through phosphorus mitigation remains elusive. Meals, *et al.* (2010), as cited by Jarvie, *et al.* (2013:295), report that many catchment diffuse source intervention initiatives have shown little, or sometimes no net improvement in phosphorus reduction in receiving waters over the past four decades, even following extensive implementation of best management practices. In some instances, reduced phosphorus concentrations, largely attributed to point source controls, have led to ecological health improvements in receiving rivers [Bowes, *et al.*, 2011:3418; Kelly & Wilson, 2004:1559]. However, in other cases, despite significant reductions in river water phosphorus concentrations through source mitigation, ecological health improvements have not occurred; in some cases, nuisance algal growth has even increased [Bowes, *et al.*, 2012:201; Jarvie, *et al.*, 2004:641; Neal, *et al.*, 2010:5306]. The challenges of demonstrating the benefits of catchment management are not limited to reducing land-based phosphorus inputs that impact river eutrophication. More broadly, the successes and benefits of water resource management, river remediation and agri-environmental programmes have proven tenuous [Bernhardt & Palmer, 2011:1926; Harris, 2012:1; Harris & Heathwaite, 2012:93].

The increasing pressures from human-induced eutrophication, **despite various controls** [Jarvie, *et al.*, 2013:295], are also evident in South Africa. For example, the Vaal Barrage Reservoir receives return flows from parts of Gauteng Province and the upstream Upper Vaal River Catchment. These areas are characterised by dense urban settlements, multiple industries, atmospheric fallout from coal-burning activities and various forms of agriculture. Together, they generate significant point wastewater discharges and diffuse wash-off [DWAF, 2009a:28; DWAF, 2009b:23]. Since there is a close relationship between the characteristics of catchment areas and their receiving water resources [Oszczapińska, *et al.*, 2018:1], nutrient enrichment of the Vaal Barrage Reservoir (**FIGURE 1**) acts as a barometer for the effectiveness of current eutrophication controls (or the lack thereof) in the upstream Vaal Barrage Catchment, South Africa. In this context, **FIGURE 2** shows an escalating trend in phosphorus loading in the Vaal Barrage Reservoir,[1] suggesting that eutrophication controls in the Upper Vaal Area are inadequate or ineffective. **This is worrisome, since the Vaal Barrage Catchment can in many respects be regarded as proxy for the water quality situation in several other developed catchments in the country** [DWS, 2017a:13; DWS, 2018b:115].

[1] Data were obtained from the Department of Water and Sanitation's Water Management System (WMS) for surface water samples, obtained for the following monitoring point: Vaal Barrage on Vaal River near Barrage Wall (WMS ID 90780).

FIGURE 1: **Hypertrophic conditions observed during summer months in the Vaal Barrage Reservoir.**
Main and insert photos were taken on 26 February 2012, © Rand Water.

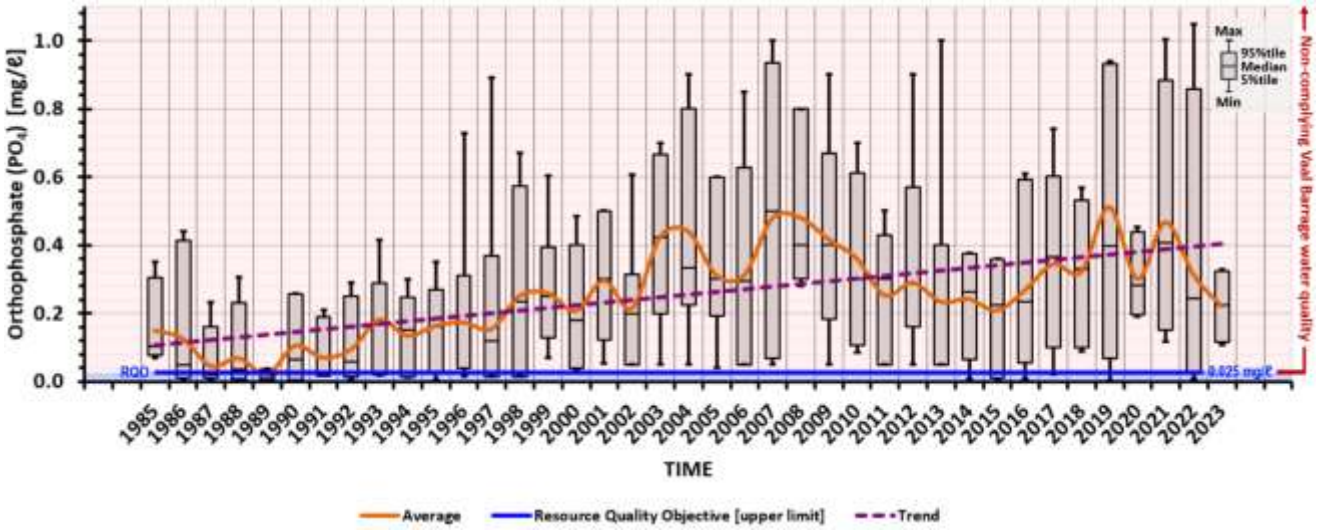

FIGURE 2: **The graph demonstrates worsening enrichment with phosphorus in the Vaal Barrage Reservoir, as observed over the nearly 40-year period.**

The persistence of eutrophication as a global problem, amidst several interventions, is attributed to numerous interconnected shortcomings and challenges, including data

limitations [Conley, *et al.*, 2009:1014-1015], symptom-focused interventions [Smith & Schindler, 2009:201-207], lack of integrated management [Álvarez, *et al.*, 2017:4-6], gaps in public awareness [Paerl & Paul, 2012:1349-1363], insufficient political will [Turpie, *et al.*, 2017:27-43], increasing misappropriation of public funds that were destined for wastewater infrastructure development and maintenance [Muller & Erasmus, 2020:47-62], inadequate wastewater infrastructure [Larsen, *et al.*, 2046:930-932], enforcement challenges [Carpenter, *et al.*, 1998:559-568], governance and policy disconnect, jurisdictional overlaps [Galloway, *et al.*, 2008:889-892] and the need for scalable solutions tailored to specific contexts [Macrae, *et al.*, 2021:529-541], among others. These issues likely also impact South Africa's performance in managing eutrophication.

Despite legislation aimed at moderating the impact of nutrient loading from wastewater treatment facilities since the 1980s, eutrophication of freshwater resources has become widespread in South Africa [Van Ginkel, 2011:693]. Over the past 40 years, eutrophication has increasingly threatened the usability of the country's freshwater resources [Harding, 2015:2; Van Ginkel, 2011:693]. Without a radical improvement in eutrophication management approaches, the ongoing degradation will continue to diminish the benefits and elevate the costs associated with the use of South Africa's freshwater resources [Oberholster & Ashton, 2008]. **These observations underscore the ineffectiveness of South Africa's current approach to governing eutrophication.** According to DWS (2017a:13) and DWS (2017e:9), the rising nutrient content in South Africa's water resources, attributed to the discharge of nutrient-rich treated and untreated domestic effluents into rivers, among other factors, **is a concern that requires urgent and focused attention**.

It is posited that the **D**river-**P**ressure-**S**tate-**I**mpact-**R**esponse (DPSIR) Framework will provide a structured approach that can be highly effective in addressing the complex challenges of eutrophication, both globally and within South Africa. By clearly delineating each component of this Framework, stakeholders can assist to identify and understand the underlying drivers leading to nutrient loading. Furthermore, it facilitates the assessment of pressures and their impacts on ecosystem health and water quality [Lewison, *et al.*, 2016:110-119; Wantzen, *et al.*, 2019:3-4].

The DPSIR Framework enables interventions to be strategically aligned to **address not only immediate symptoms but also the root causes of eutrophication** [Gregory, *et al.*, 2013:560-562]. This holistic understanding encourages integrated management and policy responses that are scalable, context-specific and encompass both short-term mitigation and long-term prevention strategies [Ramachandran, *et al.*, 2014:4-18].

Moreover, by incorporating public awareness and education as part of the *"response"* component, the Framework can help bridge gaps in community understanding and engagement, promoting

the behavioural changes necessary for sustainable solutions. The structure of the DPSIR Framework aligns well with fostering political will and enforcing compliance by making the cause-effect relationships and necessary actions clear, measurable and actionable. Thus, its application in South Africa could enhance the effectiveness of existing, often *ad hoc*, governance systems and inspire innovative, cooperative strategies to tackle the pressing issue of eutrophication [Marci-Boehncke & Cobs-Muñoz, 2024:4234-4242].

The **problem statement researched** in this thesis is that **the escalating negative effects of anthropogenic eutrophication, both globally and in South Africa, often persist despite numerous interventions being instituted** [Bernhardt & Palmer, 2011:1926; Bowes, *et al.*, 2012:201; DWS, 2017a:13; Harris & Heathwaite, 2012:9; Neal, *et al.*, 2010:5306]**. This situation is of significant concern and necessitates effective governance as a matter of urgency to address the causes of human-induced eutrophication and promote ecologically sustainable development**.[2]

1.3 RESEARCH AIM AND OBJECTIVES

Given the established problem statement, the **aim of this research** is to ***"develop a critical understanding of eutrophication governance in South Africa"***.

To achieve the research aim, three **research objectives** have been defined, namely:

- *"To design a framework for the evaluation of eutrophication governance in South Africa"*;
- *"To recommend a response in the form of eutrophication governance policy"*; and
- *"To recommend a response in the form of eutrophication governance strategy"* for implementation.

1.4 RESEARCH APPROACH, LAYOUT, SCOPE AND LIMITATIONS

1.4.1 Research approach

Saunders, *et al.* (2009:5) define research as *"…something that people undertake to find out new things in a systematic way, thereby increasing their knowledge…"*, whereas the Oxford Dictionary

[2] The *"eutrophication dilemma"* describes a situation in which anthropogenic development exacerbates the adverse effects of eutrophication, ultimately diminishing the benefits associated with that development. This phenomenon is crucial for understanding the problem statement [Schindler, 2012; Jerrold, et al., 2013]. The dilemma is further compounded by the fact that many interventions intended to address eutrophication seem to be ineffective.

[Allen, 1990:1022] defines the same term as *"the systematic investigation into and study of materials, sources, etc. in order to establish facts and reach new conclusions"*. From these definitions, it follows that **research is regarded as a planned activity, aimed at establishing new facts and information about a particular phenomenon**.

In recent decades, *"evaluation research"* has emerged as a favoured method for uncovering new insights into specific phenomena. Researchers have effectively used it to– (1) inform decision-making; (2) improve research outcomes; and (3) optimise resource efficiency [Fitzpatrick, *et al.*, 2011:78-83; Patton, 2008:45-50; Powell, 2006:103; Shadish, *et al.*, 1991:20-25]. Evaluation research helps bridge the gap between theory and practice [Patton, 2008:78-82] by providing evidence on what works and what does not [Weiss, 1998:45-50]. Policymakers, practitioners and stakeholders can utilise this evidence to make informed decisions about programme continuation, expansion or modification [Scriven, 1991:68-71; Weiss, 1998:63].

According to Preskill & Rus-Eft (2016:1), all approaches to evaluation tend to share several important commonalities. **Firstly**, evaluation is a systematic process. It should not be conducted as an afterthought; rather, it is a planned and purposeful activity. **Secondly**, evaluation involves collecting data and information regarding questions or issues about society, in general, and organisations and programmes, in particular. **Thirdly**, evaluation is a process for enhancing knowledge and decision-making, whether the decisions are for improving or refining a programme, process, product, system or organisation, or for determining whether to continue or expand a programme. **Ultimately**, evaluation is concerned with asking questions about issues that arise out of everyday practice. It is a means for gaining better understanding of what we do and the effects of our actions in the context of society and the environment.

In planning the research approach [Fossey, *et al.*, 2002:717-732; Voit, 2019:1-14] for this study, reaching a critical understanding of eutrophication governance in South Africa is essential, especially given that many management interventions have not yielded the desired improvements in trophic conditions, both globally and locally. This phenomenon must be analysed to formulate new approaches that can reverse the *"over-enrichment tide"* adversely affecting our receiving water resources in recent years. As much as possible – root causes of over-enrichment must be pin-pointed and linked to the development of appropriate intervention responses. Thus, the approach includes evaluating eutrophication governance in South Africa, proposing governance solutions, reporting the findings and making recommendations for implementation.

Literature suggests that the DPSIR Framework presents a suitable framework to analyse eutrophication-related causal concerns, propose appropriate intervention responses and developing effective policies and strategies for improved governance [Cosme & Olsen, 2014:1; Kristensen, 2004:1-10; Mosaffaie, *et al.*, 2021:1-8; Ramos, *et al.*, 2018:16].

Although examples of catchment-specific remedies for eutrophication-related problems have been noted, a comprehensive governance framework that incorporates appropriate instruments to address the full range of challenges associated with anthropogenic eutrophication is lacking in the international literature and does not currently exist in South Africa. While implementing effective management measures in catchments is essential, there is also an urgent need to provide strategic guidance and standardise the national approach to eutrophication governance.

Without the necessary policies and strategies, catchment actions run the risk of becoming *ad hoc*; conversely, without practical actions in catchments, policies and strategies may remain static documents on a shelf. This highlights the importance of implementation, monitoring and evaluation as critical components of a viable solution.

1.4.2 Research layout and scope

This section provides an overview of the research layout (**FIGURE 3**) by outlining the research steps and indicating what was included and excluded from the research scope [Hofstee, 2006:107-154]. To maximise value and present a comprehensive research approach, the outlined research layout includes steps that extend beyond the aims and objectives of this study. The following six-step systematic research layout was adopted:

- **Step 1:** Design the research methodology and document method descriptions;
- **Step 2:** Research the literature, and collect data and information;
- **Step 3:** Evaluate eutrophication governance in South Africa;
- **Step 4:** Develop solutions to address the problem statement;
- **Step 5:** Conclude the research and implement the recommendations; and
- **Step 6:** Monitor and evaluate the implementation progress.

By placing this research within a broader framework designed to implement solutions to eutrophication, the practical value and options for roll-out of the research outcomes can be highlighted. The implementation of the recommendations (included in Step 5) and Step 6 of the adopted research layout (**FIGURE 3**) fall outside the scope of this study. All six steps are discussed in **Sections 1.4.2.1** to **1.4.2.6** below, with linkages to the respective thesis chapters indicated in **FIGURE 3**. Additional details about the eutrophication governance policy and strategy design are provided in **Section 2.5.2**, which expands on the scope of the proposed policy and strategy.

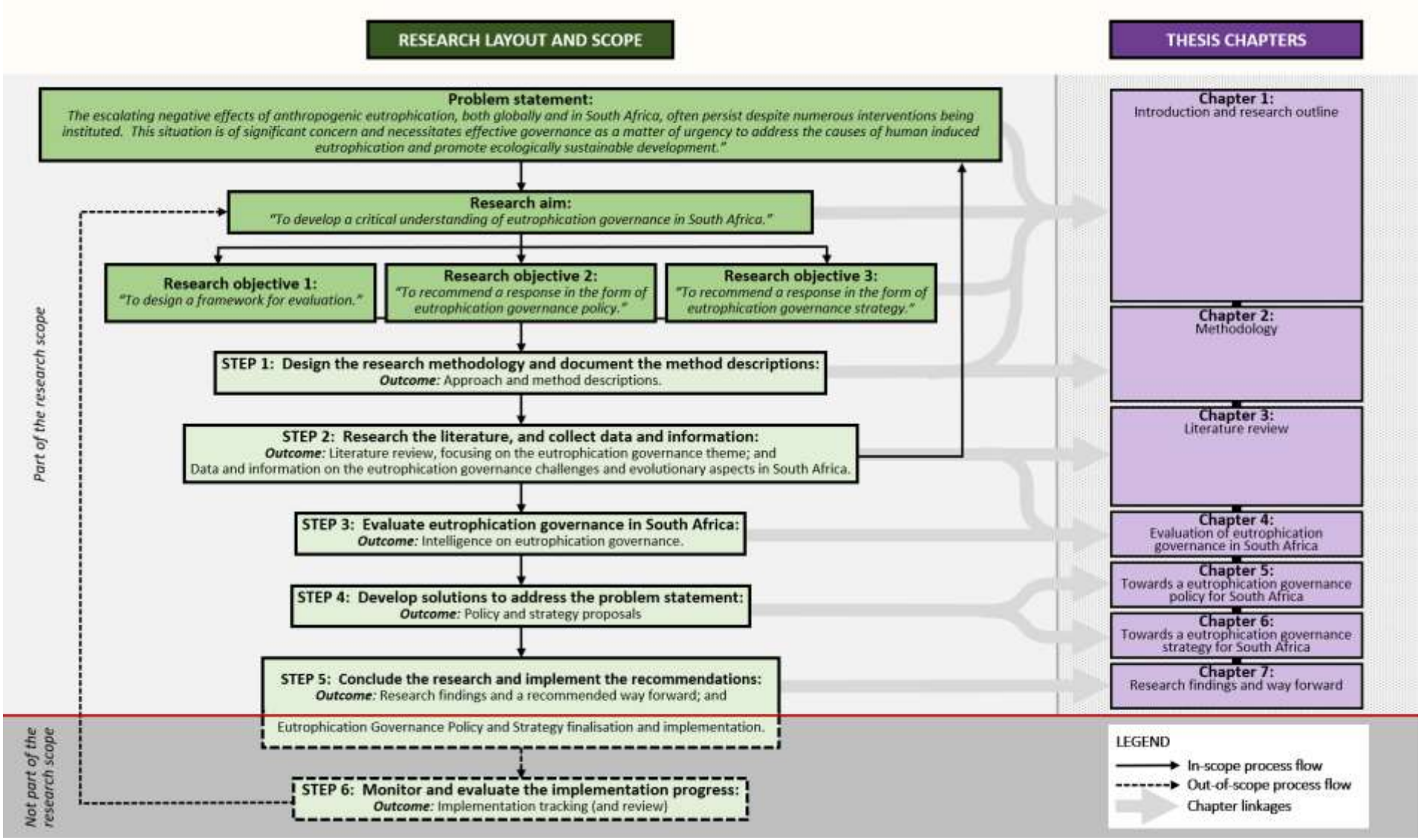

FIGURE 3: Conceptual research layout and scope.

1.4.2.1 Step 1: Design the research methodology and document method descriptions

Step 1 focussed on designing the research methodology and method descriptions. The formulation of a research aim and concomitant objectives helped focus the research methodology and guide method description.

The research methodology encompassed method descriptions for–

- applying selected data and information collection techniques;
- designing and applying a framework to evaluate eutrophication governance in South Africa; and
- developing solutions to tackle the eutrophication dilemma amidst several interventions already existing in South Africa.

1.4.2.2 Step 2: Research the literature, and collect data and information

Step 2 involved:

- **Researching relevant literature to–**
  - establish a reference point of knowledge on eutrophication governance and related aspects of the study;
  - identify key challenges associated with eutrophication governance; and
  - assess the evolutionary aspects of this governance in South Africa.
- **Collecting relevant data and information from–**
  - a nationally conducted survey;[3] and
  - a series of stakeholder engagements.[4]

The collection process provided supplementary data that enriched the study's execution and specifically supported the creation of a critical understanding of eutrophication governance in South Africa.

---

[3] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[4] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

Thus, the literature review, along with the data and information gathered, provided a solid foundation for the research motivation, design and execution while also acknowledging other key scientific contributions.

1.4.2.3 Step 3: Evaluate eutrophication governance in South Africa

"Data" [5], *"information"* [6] and *"evidence-based knowledge"* (or intelligence) [7] are interrelated concepts [Zins, 2007:479] that exhibit both convergent and divergent relationships [Oyedokun, *et al.*, 2022:51]. Although they differ in hierarchy and definition, they are considered part of the same continuum [Oyedokun, *et al.*, 2022:51]. The data and information collected during Step 2 needed to be converted into intelligence.

"Intelligence on eutrophication governance" refers to the ability to acquire, adapt, change, extend and apply relevant data and information to develop a critical understanding of causal relationships and requisite intervention responses. An evaluation framework (based on the DPSIR Framework) which was complemented with data and information obtained during the previous step, played an important role in the establishment of a suitable base of intelligence (on eutrophication governance in South Africa) that could be used to identify appropriate intervention responses.

1.4.2.4 Step 4: Develop solutions to address the problem statement

Step 3 provided a structured approach to analysing causal chains and linking them to suitable intervention responses. Although both the causes and effects of anthropogenic eutrophication were considered during the assigning of intervention responses, an effort was made to address the root causes rather than just the symptoms.

In Step 4, the identified responses were utilised to prompt the formulation of rules (in the form of policy proposals) and the establishment of implementation arrangements (in the form of strategy proposals) for eutrophication governance.

1.4.2.5 Step 5: Conclude the research and implement the recommendations

Step 5 consisted of two parts. Part 1 formed part of the research scope, whereas Part 2 did not.

---

[5] Data are raw, individual and unarguable facts [Unsupervised Learning, 2023].

[6] Information is the combination of data into a form that can answer an everyday question [Unsupervised Learning, 2023].

[7] Intelligence is the combination of information into a form that tells a story and informs decisions [Unsupervised Learning, 2023].

The **first part** of Step 5 concluded the study with an in-depth discussion of the research findings, which included:

- An evaluation of how the research objectives were met;
- A critical assessment of the DPSIR Framework;
- Contributions to the knowledge base; and
- Future perspectives with recommendations.

The **second part** of Step 5 called for the Department of Water and Sanitation (DWS) to finalise the eutrophication governance policy and strategy for implementation, based on the policy and strategy proposals, and recommendations contained in this study.

1.4.2.6 Step 6: Monitor and evaluate the implementation progress

Step 6 does not form part of the research scope.

Step 6 involves monitoring the implementation progress of eutrophication governance policy and strategy, as well as evaluation and ultimately measuring impact, by the DWS. This step supports continuous improvement, adaptive responses to policy and strategy implementation and management review.

1.4.3 Research limitations and mitigation

In any research, limitations need to be acknowledged [Olufowote, 2017:862; Theofanidis & Fountouki, 2018:156] to enable the researcher to adjust methodologically in the most efficient way possible [Brause, 2000:95]. The following aspects (and their associated limitations) were central to the research approach and method descriptions:

- Data and information collection by means of literature research;
- Data and information collection by means of surveys;[8]
- Data and information collection by means of stakeholder engagement;[9]
- Causal chain and response analyses, based on the DPSIR Framework; and
- Policy and strategy compilation.

---

[8] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[9] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

These aspects, their key limitations (as sourced from the literature) and synopses of mitigatory measures (if any) are discussed in **Sections 1.4.3.1** to **1.4.3.5** below. Detail on the research methodology and incorporation of the mitigatory approaches, follow in **Chapter 2**.

1.4.3.1 Data and information collection by means of literature research

The following limitations were acknowledged and mitigated where possible:

- Publication bias occurs when research reporting significant results or certain types of messages is more likely to be published than studies with nonsignificant findings or less popular messages [Loannidis, 2005:700]. This bias can distort the research landscape and may lead to an overemphasis on certain topics while neglecting contradictory evidence.

  Mitigation: The potential effects of publication bias were mitigated by also employing surveys and stakeholder consultation, in addition to literature research.

- Literature research takes time and by the time a research paper is published, the information may have become outdated or superseded by newer studies. This limitation is particularly relevant for rapidly evolving fields where the literature is constantly being updated [Creswell, 2014:77-78].

  Mitigation: The most recent statistics, advancements and information were considered to maintain the relevance and accuracy of the research findings.

1.4.3.2 Data and information collection by means of surveys

The following limitations, needed to be acknowledged and mitigated where possible:

- Non-response bias occurs when individuals who choose not to participate in a survey differ systematically from those who do participate, leading to biased results. This bias can compromise the representativeness and generalisability of the survey findings [Groves & Peytcheva, 2008:167].

  Mitigation: Non-response bias was mitigated by selecting respondents mainly from the DWS and instructing them to participate in the surveys.

- Response bias refers to systematic errors in participants' responses, leading to inaccurate or biased information. It can occur due to respondents' desire to present themselves favourably or conform to societal norms, resulting in socially desirable answers instead of their true beliefs or behaviours [Schuman & Presser, 1981:297; Tourangeau, *et al.*, 2000:1].

Mitigation: Response bias was mitigated by appealing to respondents to answer questions truthfully and professionally. Stakeholder engagement was utilised to complement the information.

- Survey findings are only representative of the specific sample surveyed and may not generalise to the broader population. Sample selection methods and sample size can affect the generalisability and reliability of survey results [Groves, *et al.*, 2009:45-47].

  Mitigation: The survey findings from the sample surveyed were augmented with data and information sourced from literature research and stakeholder engagement to improve the generalisability and reliability of the survey results.

1.4.3.3 Data and information collection by means of stakeholder engagement

The following limitations, needed to be acknowledged and mitigated where possible:

- Stakeholder engagement processes may face limitations in representing the full range of perspectives and voices within a community or organisation. This limitation can lead to an incomplete understanding of stakeholders' views and potentially exclude marginalised or underrepresented groups [Carver & Fudge, 2006:409; Reed, 2008:2424-2425].

  Mitigation: Engagement with the public was supplemented by engaging with representatives nominated from selected sectors.

- Power imbalances among stakeholders can hinder equal participation and influence the data collection process. Dominant voices or specific stakeholder groups with more power or resources may disproportionately influence the outcomes, potentially overshadowing the perspectives of less powerful stakeholders [Cleaver, 2004:998; Cornwall, 2008:271].

  Mitigation: Care was taken to consider all views and to provide non-technical stakeholders with *"friendly explanations"* of technical content, empowering them to contribute effectively.

- Stakeholder engagement processes can be time-consuming and resource-intensive, making it challenging to involve a wide range of stakeholders or sustain meaningful participation throughout the data and information collection process. Limited time or resources may restrict the depth and breadth of engagement, limiting the comprehensiveness of the data and information collected [Colvin & de Waal, 2016:122; Shenton, 2004:70].

  Mitigation: Opportunity was afforded to stakeholders to submit written representations following such stakeholder engagements.

1.4.3.4 Causal chain and response analyses, based on the DPSIR Framework

Whereas the DPSIR Framework has been invaluable in many environmental assessment applications [Smeets & Weterings, 1999:5-7], it has some limitations that needed to be acknowledged and mitigated where possible:

- Application of the DPSIR Framework has a tendency to oversimplify complex social-ecological systems by breaking them down into distinct components. This reductionist approach can lead to a lack of understanding of the dynamic interactions and feedback loops that exist between different components [Maxim, *et al.*, 2009:14];
- The DPSIR Framework assumes linear relationships between driving forces, pressures, states, impacts and responses. The relationships between these components, however, are often non-linear and complex [Svarstad, *et al.*, 2008:119-120]. Additionally, the Framework assumes a direct causal relationship between each component, whereas in reality, the interactions are often multi-directional, with feedback loops and indirect effects [Ness, *et al.*, 2010:482-483];
- The DPSIR Framework tends to focus on the biophysical aspects of the environment, while neglecting the social, economic and cultural dimensions. This limited focus may result in an inadequate consideration of the broader social and economic context in which environmental issues arise [Svarstad, *et al.*, 2008:117-118].
- The DPSIR Framework provides a conceptual understanding of the interactions between different components but lacks a clear methodology for quantifying and measuring these interactions. The framework lacks a standardised set of indicators that can be used consistently across different applications and contexts [Maxim, *et al.*, 2009:17-18]. This limitation makes it challenging to compare and evaluate the effectiveness of different intervention responses.

Mitigation: The application of the DPSIR Framework was paired with extensive stakeholder engagement[10] to mitigate many of the limitations mentioned above.

[10] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

1.4.3.5 Policy and strategy compilation

The following limitations, needed to be acknowledged and mitigated where possible:

- One limitation is the lack of involvement of relevant stakeholders in the policy and strategy compilation process. Without input from those who will be directly affected by the policies and strategies, there is a risk of overlooking critical perspectives and potential unintended consequences [Reed, 2008:2419].
- Policy and strategy compilation processes often rely on a limited pool of expertise, which can restrict the range of solutions considered and result in a narrow focus. This limitation can hinder innovation and alternative approaches to addressing complex problems [Stirling, 2008:274-276].
- Compiling policies and strategies requires significant time, resources and coordination. However, limited budgets, time pressures and other resource constraints can impede the thorough examination and analysis of relevant information, potentially leading to incomplete or insufficient policies and strategies [Howlett, 2009:82].
- Even with well-designed policies and strategies, implementation may not always meet expectations. Inconsistencies may arise due to factors such as changes in leadership, lack of dedicated resources, organisational resistance or differing local contexts. These inconsistencies can undermine the effectiveness of policies and strategies [Sabatier & Mazmanian, 1980:542].
- Policy and strategy compilation often occurs within dynamic and rapidly changing environments, making it challenging to anticipate and adapt to emerging trends, technologies and societal changes. This limitation can result in outdated policies and strategies that are ill-suited to address current challenges [Mintzberg, 1994:16-18].

Mitigation: A well-planned stakeholder engagement process was integral to the policy and strategy compilation process. Engaging specialists in the field of focus, as well as peer reviewers was also included as part of the process[11]. Additionally, monitoring and evaluation, along with the principle of learning by doing, were incorporated into policies and strategies to cater for dynamic circumstances.

[11] The DWS consulted stakeholders, including specialists, from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. The input received from the stakeholders was treated as an additional reference source of information. The data and insights gained from involving stakeholders have provided invaluable contributions to this study.

1.5 THESIS STRUCTURE

FIGURE 4 contains a high-level diagrammatic overview of the structure of this thesis, which consists of nine discrete parts:

Chapter 1 (this part) introduced the study subject and provided the research outline. **Chapter 2** details the research methodology that was employed. **Chapter 3** contains a literature review elaborating on the actuality of the *"eutrophication governance"* theme. **Chapter 4** evaluates eutrophication governance in South Africa and discusses the obtained results. **Chapter 5** utilises the outputs from Chapter 4 (and the previous chapters) to formulate a series of desired ground rules, in the form of policy proposals, whereas **Chapter 6** builds on Chapter 5 (and the previous chapters) by establishing implementation arrangements, in the form of strategy proposals, to address the challenges of eutrophication in South Africa. Chapters 4, 5 and 6 collectively represent the study results. **Chapter 7** concludes with the research findings and a proposed way forward with recommendations. Chapters 3, 4, 5, 6 and 7 collectively represent the study outputs, following the execution of the research methodology. The last two parts of the thesis comprises a comprehensive **bibliography** with study references, followed by a series of **annexures**, containing topical and relevant supporting resource materials.

FIGURE 4: High-level thesis structure (Y*ou are in Chapter 1*).

1.6 CONCLUSION

Chapter 1 set the scene for the remaining thesis chapters. It introduced the study and provided a research outline (**FIGURE 5**) by–

- Introducing the eutrophication dilemma in **Section 1.1**;
- defining a problem statement in **Section 1.2**;
- formulating the research aim and objectives in **Section 1.3**;
- providing an overview of the research approach, scope and limitations in **Section 1.4**;
- providing an overview of the thesis structure in **Section 1.5**; and
- providing concluding remarks on Chapter 1 in **Section 1.6** (this section).

Anthropogenic eutrophication was presented as a contemporary phenomenon that threatens developmental progress globally, including in South Africa, despite many interventions being implemented. Using logical thinking [Negley, 2022:151-160; Van Cleave, 2016:1-49], this dilemma (aggravated by seemingly ineffective interventions) was translated into a problem statement linked to a research aim and objectives. To pursue this aim, a research approach, layout and scope were defined, considering limitations and implementing mitigation strategies to ensure an effective methodology and execution of the study. Finally, a thesis structure was devised to ensure effective documentation of the study and its execution.

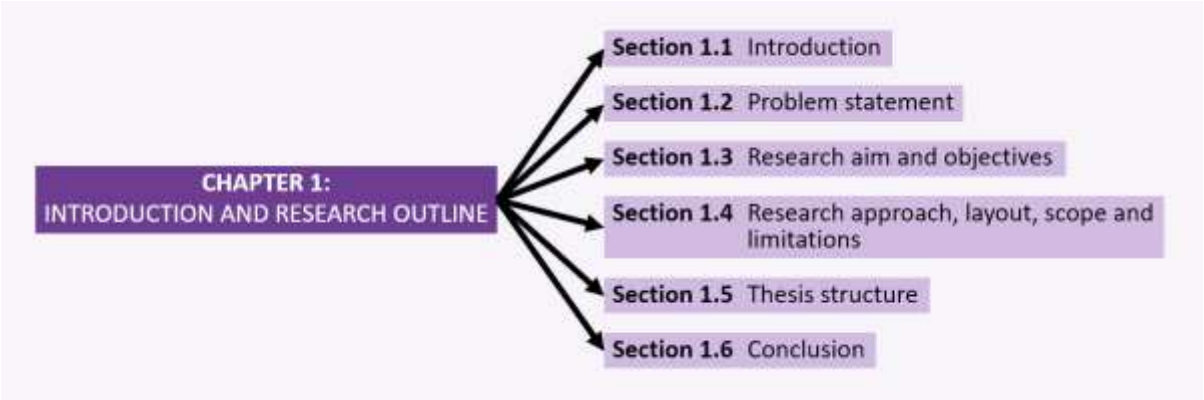

FIGURE 5: Section topics covered in Chapter 1.

The foundation provided in Chapter 1 (**FIGURE 5**) serves as basis for Chapter 2, which will detail the research methodology.

THE RESEARCH CONTEXT OF CHAPTER 2

Chapter 2 documents the research methodology through which the doctoral findings and the policy and strategy responses were developed. Limited textual and conceptual overlap with the EMSSA occurs in descriptions of causal chain and DPSIR concepts and in aspects of the process used to progress from problem analysis to policy and strategy development. Related material is reflected principally in the DPSIR-based problem declaration in Part 1, Chapter 1 and the EMSSA development process described in Part 1, Chapter 3 [DWS, 2023b].

The chapter itself is predominantly thesis-specific and considerably more detailed than the methodological information required for the purposes of the EMSSA. It establishes the philosophical and theoretical grounding of the research and documents the methods applied to literature research, the national survey, stakeholder engagement, qualitative forecasting, causal chain and DPSIR analyses, and policy and strategy development. The EMSSA reflects outputs generated through these methods but presents them within an applied policy and strategy context, rather than reproducing the fuller academic methodological framework through which they were developed.

CHAPTER 2 METHODOLOGY

2.1 INTRODUCTION

FIGURE 6 positions the reader in terms of the high-level thesis structure, whereas **FIGURE 7** depicts the section content of Chapter 2 (this chapter). **Chapter 2** provides details on the research methodology employed, as briefly contextualised in **Chapter 1**.

FIGURE 6: High-level thesis structure (Y*ou have arrived at Chapter 2*).

FIGURE 7: Section topics covered in Chapter 2.

The research methodology is anchored in *"evaluation research"*, as detailed in **Section 1.4.1**, which outlined the research approach. **A four-phase research methodology** (**FIGURE 8**) **was adopted** to comprehensively address the research aim and objectives:

- **Phase 1** involved a three-stage data and information collection process, comprising a literature review, a nationally conducted survey[12] and stakeholder engagement.[13] This multi-stage approach ensured the redundancy necessary for obtaining sufficient and high-quality data for further evaluation and synthesis;
- **Phase 2** entailed evaluating and presenting the findings from the literature review and survey. A crucial part of this phase, and the research as a whole, was an evaluation framework designed according to the DPSIR Framework. This framework facilitated a critical understanding of eutrophication governance in South Africa and identified root causes of failure linked to suitable interventions. Inputs from stakeholder engagement significantly enhance the research outputs in Phases 2, 3 and 4;
- **Phase 3** involved transforming the intervention responses identified in Phase 2 into a series of ground rules (or policy statements) for eutrophication governance in South Africa; and
- **Phase 4** established a series of implementation arrangements (or strategies) to enact the policy statements developed in Phase 3.

This four-phase methodology is supported by a philosophical and theoretical foundation, detailed in **Section 2.2**. The method descriptions, which were employed during Phases 1 to 4, are elaborated in **Sections 2.3**, **2.4** and **2.5**, following the structure shown in **FIGURE 8**.

With the DWS's permission, this study was conducted alongside a departmental initiative to develop a Eutrophication Management Strategy for South Africa (EMSSA) (see **Annexure A** for a copyright declaration letter from the DWS). This created synergy between the DWS's efforts to develop the Strategy and this study, benefiting all parties. It should be noted that the research methodology described here was inadvertently intertwined with the DWS's work plan to develop the EMSSA. Following adoption of the Strategy by the DWS, the Department will be responsible for strategy implementation, evaluation and future revisions as necessary.

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[12] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[13] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

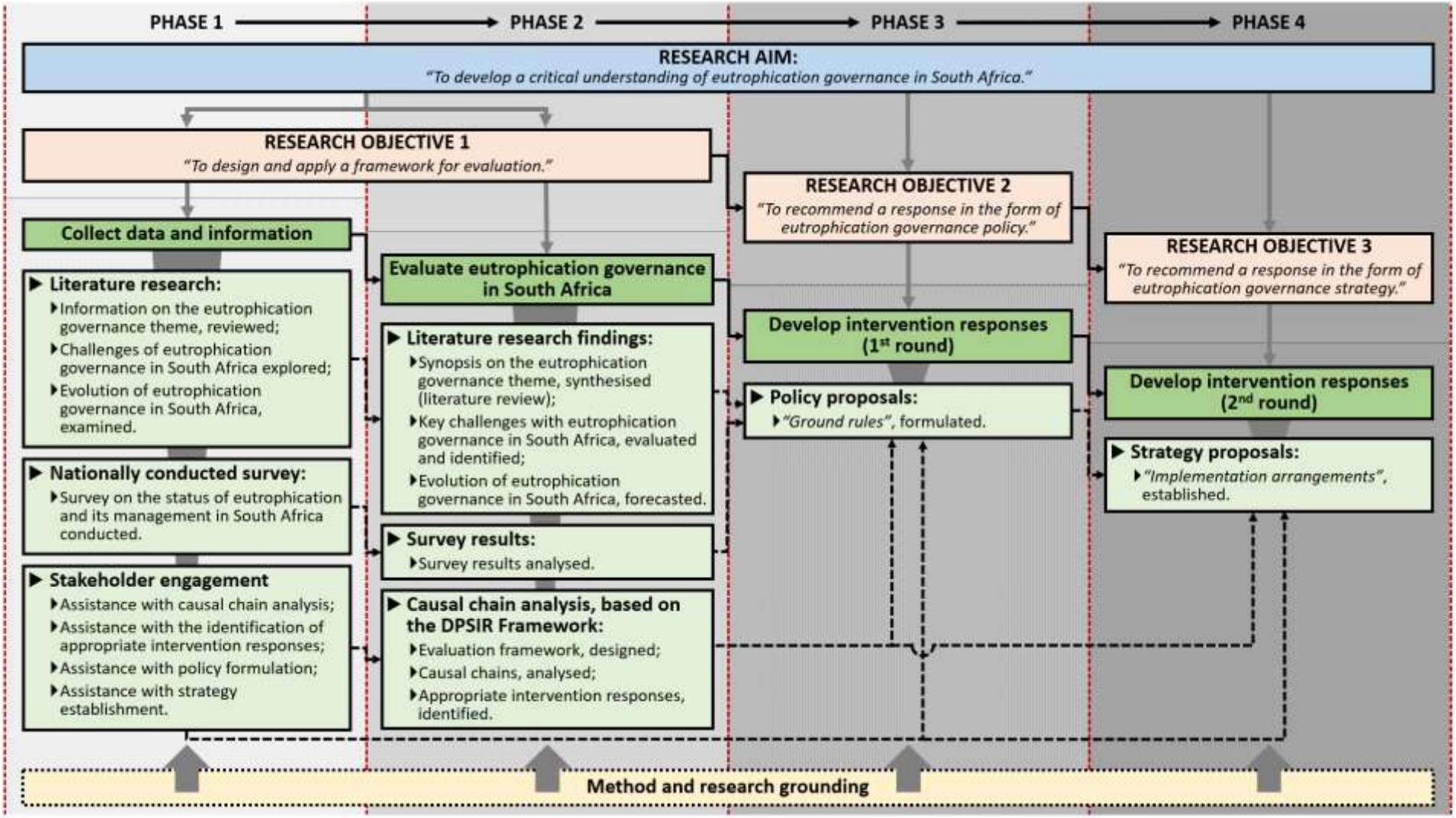

FIGURE 8: Phased research methodology.

2.2 METHOD AND RESEARCH GROUNDING

2.2.1 Grounded scientific research

Grounded scientific research involves developing theory from data rather than starting with a hypothesis [Tie, *et al.*, 2019:3]. As described by Corbin & Strauss (2014:6-11), it is ***"a qualitative method that uses systematic procedures to inductively derive theory about a phenomenon"***.[14] The primary aim is to deepen understanding by identifying key elements and their interrelationships within the investigation's context and process [Davidson, 2001].

Unlike traditional hypothesis-driven research, where a hypothesis is tested for validity, grounded research uses an inductive approach to discover new theories through iterative data collection and analysis [Copi, *et al.*, 2006:1-45]. This process continues until theoretical saturation is achieved, meaning further data adds little or no new insight into the new theory [Tie, *et al.*, 2019:6].

There is often an interplay between inductive reasoning, which generates broad theories and deductive reasoning, which tests specific observations [Kell & Oliver, 2004:100-101]. The **goal** of grounded scientific research is to advance and refine knowledge, establish facts and draw new conclusions through systematic inquiry aimed at solving a **defined problem** (Section 1.2) [Strauss & Corbin, 1998:23-30]. The research approach (Section 1.4) provides a broad plan to achieve this goal [Creswell & Creswell, 2018:Part 2]. Research approaches are underpinned by **philosophical and theoretical foundations** (Section 2.2.2) and specified **research methods** (Sections 2.3, 2.4 and 2.5).

2.2.2 Philosophical and theoretical grounding

Philosophy and theory are inherently interconnected. Philosophy shapes how individuals perceive the world, while theory guides their interactions with it [Saunders, *et al.*, 2019:124]. A philosophical standpoint influences the framing of critical problems, while theories provide strategies for addressing these challenges [Bechtel & Abrahamsen, 2010:325-328]. According to Solomon & Higgins (2010:3), **philosophy** is the systematic studies of fundamental questions

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[14] The ***"phenomena"*** investigated in this study is *"eutrophication, and its governance"*. The ***"grounded theory"*** that emerged was a *"critical understanding of eutrophication governance in South Africa"*. The three-stage process of collecting data and information, the application of the DPSIR Framework for evaluation purposes and the development of appropriate intervention responses constituted key components of the ***"systematic set of procedures"*** of the research method. These important aspects are detailed in the subsequent discussions in Chapter 2.

related to existence, reason, knowledge, values, mind and language. Winther (2021:2-8) describes **theory** as a rational form of abstract thinking about a phenomenon or its outcomes.

Contemplative and rational thinking often aligns with practices such as observational study and research [NAS-US, 1999:1-2]. Together, philosophy and theory shape diverse perspectives and support effective problem-solving approaches. In the governance of eutrophication, considering both **philosophy** (Section 2.2.2.1) and **theory** (Section 2.2.2.2) frameworks is essential for focused solution-seeking and effectively addressing challenges.

2.2.2.1 Philosophical grounding

Incorporating philosophy of science in research deepens one's understanding of the nature of scientific knowledge and its limitations. The following philosophical aspects, elaborated in **Sections 2.2.2.1.1** to **2.2.2.1.5**, are crucial for grounding the research methodology and enriching the search for solutions to the *"eutrophication dilemma"* in South Africa:

- The limitations of science;
- The status of humankind in nature;
- Optimal scientific reasoning in policy and strategy development;
- Cultural considerations; and
- Political considerations.

Footnotes were included to illustrate how these philosophical considerations influenced the research outcomes.

2.2.2.1.1 The limitations of science

While science is a powerful tool for understanding the natural world, it has inherent limitations and uncertainties. It can only address observable phenomena, and observations may be flawed, biased and unable to produce universal statements. Philosopher Paul Feyerabend (1993:9) argued for epistemological anarchism, asserting that strict methodological rules hinder scientific progress and are unrealistic. **In eutrophication governance, recognising these shortcomings is crucial:**

- **Shortcomings in scientific knowledge**

  Scientific paradigms may not fully explain all phenomena and uncertainty is inherent. Theories evolve as new evidence emerges [Kuhn, 1996:66-76], so decisions in eutrophication

governance must acknowledge and address this uncertainty through precautionary or risk-based approaches[15] that consider various outcomes.

- **The role of models and simulations**

Models and simulations are essential for understanding complex systems in eutrophication management[16] [Messina, *et al.*, 2008:11-25]. However, they are simplifications based on underlying assumptions and data. Ensuring the accuracy and reliability of models through empirical validation is crucial.

- **The need for interdisciplinary collaboration**

Effective eutrophication management requires collaboration across disciplines, including hydrology, ecology, chemistry, economics and sociology. Engaging scientists, policymakers and stakeholders[17] ensures decisions are informed by comprehensive knowledge and consider social, economic and ecological factors [Blackstock, *et al.*, 2010:256-264].

2.2.2.1.2 The status of humankind in nature

The question of whether humankind is part of nature or superior to it has been debated for centuries. One perspective argues that humans are part of nature, subject to the same natural laws and processes as other organisms [Jenkins, 2002:111-138]. From this viewpoint, humans are not fundamentally different from animals or plants and depend on the natural world for survival and well-being. Conversely, anthropocentrism posits that humans are distinct and superior to nature [Jenkins, 2002:111-138], seeing human life as intrinsically valuable while viewing other entities as resources to be justly accessed for human benefit. This belief, rooted in interpretations of the biblical Genesis, suggests humans hold dominion over the Earth, fostering an instrumental view of nature that values it for its utility to humankind [Bruce & Taylor, 1999:1-2].

However, many scholars and activists now challenge this dichotomy, arguing that humans are interconnected with and dependent on the natural world. They assert that human activities significantly impact the environment and a sustainable future requires a greater understanding of, and respect for, our ecosystems [Fu-yang, 1999:217-223].

In the context of eutrophication governance, this debate has crucial implications. Viewing humans as separate from nature may lead to treating water resources solely as commodities to exploit,

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[15] Refer to **POLICY STATEMENT 5**: The application of the Precautionary Principle; **POLICY STATEMENT 9**: The application of the Best Practicable Environmental Option; and **POLICY STATEMENT 14:** Water resource assessment and planning to inform decision-making.

[16] Refer to **Section 6.4.1.2.2, [A]:** Configuration, calibration and use of predictive tools

[17] Refer to **Section 6.5.3:** Collaboration and management participation**.**

neglecting the needs of other organisms and ecosystems. In contrast, recognising the centrality of the natural world in decision-making promotes protective measures for water resources.

This study advocates for a stewardship role, emphasising humanity's responsibility toward all life forms. Eutrophication management should prioritise sustainable water use, biodiversity and the well-being of all living beings. When developing governance policies and strategies, it is essential to consider the philosophical and ethical implications of our relationship with nature. Engaging diverse stakeholder perspectives, especially those who are marginalised, is vital to create policies that are scientifically sound and socially responsible [Blackstock, *et al.*, 2010:256-264].

2.2.2.1.3 Optimal scientific reasoning in policy and strategy development

The optimal reasoning approach for developing water resource and services management policies and strategies depends on the specific context, goals, available data and expertise. Typically, a combination of **inductive**, **abductive** and **deductive** reasoning is employed, [Pomeroy, *et al.*, 2013:41-61] alongside input from stakeholders and experts in various fields.

- **Inductive reasoning**

Inductive reasoning moves from **specific observations to broader generalisations**. This approach ensures that policies are grounded in empirical evidence and responsive to local conditions [Harman, 1965:88-95]. For example, a policy aimed at reducing water pollution may arise from specific observations of local water quality, leading to broader conclusions about effective pollution reduction measures for that context.

- **Abductive reasoning**

Abductive reasoning focuses on **cause-and-effect relationships**, often in cases with limited data or complex issues [Patel, *et al.*, 2005:734-735]. It allows policy developers to generate hypotheses about the underlying causes of problems, facilitating the creation of targeted strategies. While both abductive and inductive reasoning rely on available evidence, abduction specifically investigates potential causes,[18] whereas induction seeks to establish general rules.

- **Deductive reasoning**

Deductive reasoning works from **general principles to specific instances**, allowing for high certainty in conclusions [Masomi, *et al.*, 2015:32-33]. This reasoning type ensures consistency with overarching policy frameworks and broader principles. For instance, a policy promoting

[18] The DPSIR Framework is utilised in structured analyses of causal chains. Refer to **Section 2.4** for more detail on this topic.

sustainable water use might start from the general principle that water is a finite resource and derive specific management strategies aligned with that principle.

2.2.2.1.4 Cultural considerations

Cultural, religious and customary practices, along with the roles of traditional leaders, significantly shape water resource management policies and strategies in South Africa. These values influence the protection, use, conservation and control of water resources [Kapfudzaruwa & Sowman, 2009:683]. Understanding and incorporating cultural perspectives are vital for creating effective and culturally appropriate eutrophication governance policies, fostering trust and collaboration among stakeholders.

Many traditional African religions regard water as sacred, believing in its healing properties [Singh & Bhagwan, 2020:403]. This belief cultivates a strong connection between individuals and water, motivating conservation efforts.[19] Additionally, indigenous water management practices reflect a deep understanding of local hydrology and the social contexts of water usage. By integrating indigenous knowledge[20] into policy development, researchers can ensure that water management respects cultural values and enhances community well-being.

In some cultures, water is viewed as a communal resource, aligned with the concept of ubuntu, which emphasises interconnectedness. This encourages collaborative water management, as water scarcity affects everyone. Mkandawire & Suseno (2014:555-564) note that ubuntu reinforces social norms around water sharing,[21] prioritising collective[22] over individual strategies.

Traditional governance systems in rural areas also play a role, with traditional leaders responsible for allocating water resources [Pollard & Cousins, 2008:44].

Incorporating cultural perspectives into water management policies enhances stakeholder trust and collaboration.[23] Engaging local communities and integrating their knowledge ensure that policies are effective, sustainable and responsive to local needs.

2.2.2.1.5 Political considerations

Water is a finite resource and its management often involves complex trade-offs between competing interests. Political considerations play a crucial role in shaping water management policies. A significant influence in South Africa is the National Water Act, 1998 (Act No.36

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[19] **POLICY STATEMENT 2**: The Mitigation Hierarchy for decision-making on eutrophication places a high premium on water resource protection.

[20] Refer to **Section 6.4.1.2.1, [B]**: Examination of existing and available information.

[21] Refer to **Section 6.4.1.2.4, [C]**: Reconciliation and allocation of water quality.

[22] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

[23] Refer to **Section 6.5.3**: Collaboration and management participation.

of 1998),[24] which establishes a framework for resource management and allocation in the country [RSA, 1998a].

From a eutrophication governance perspective, policies and regulations determine nutrient input sources and levels in waterbodies. Mwenge Kahinda, *et al.* (2014:71-88) found that political support is essential for effective eutrophication management, noting that political interference, bureaucratic inefficiencies and funding constraints hinder governance. Ndlela & Ochieng (2019:1-8) reported that, despite solid regulatory frameworks, gaps in implementation[25] and enforcement[26] exist, with political will and adequate resources[27] critical for addressing these issues.

Pillay, *et al.* (2016: 189-196) identified political interference, corruption and funding shortages as significant challenges in sewage management in Durban, recommending improved political will, transparency[28] and accountability.[29] Dzwairo, *et al.* (2007: 137-155) further emphasised the need for political commitment and multi-stakeholder engagement[30] to enhance wastewater treatment works (WwTWs).

While political factors are vital in developing water management strategies, these policies must be based on sound scientific evidence, data[31] and analysis.[32] Overly politicised policies and strategies lacking scientific rigor may fail to tackle fundamental management challenges. Therefore, political considerations should complement evidence-based decision-making and focus on achieving sustainable and equitable outcomes for all water users.

2.2.2.2 Theoretical grounding

Incorporating a range of theoretical considerations in research enhances the understanding of scientific knowledge, its limitations and the importance of evidence-based decision-making. The theoretical concepts presented in **Sections 2.2.2.2.1** to **2.2.2.2.5** are essential for grounding the research methodology and contributing to solutions for the *"eutrophication dilemma"* in South Africa:

- Tragedy of the commons;

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[24] Hereafter referred to as the NWA (36:1998).
[25] Refer to **Section 7.5.2.2**: Towards the development of an Implementation Plan.
[26] Refer to **Section 6.4.4.2.2:** Enforcement**.**
[27] Refer to **POLICY STATEMENT 15**: Resourcing of eutrophication management.
[28] Refer to **POLICY STATEMENT 17**: Transparency.
[29] Refer to **POLICY STATEMENT 11**: Eutrophication management responsibility and accountability.
[30] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.
[31] Refer to **Section 6.4.3.2.1**: International and transboundary status and trends monitoring and reporting**.**
[32] Refer to **Section 6.4.1.2.1**: Assessment**.**

- Integrated decision-making and integrated water resource management;
- Adaptive management;
- Precaution; and
- Ecological infrastructure.

Footnotes were used to show how the theoretical considerations influenced the research results.

2.2.2.2.1 Tragedy of the commons

The concept of the *"Tragedy of the Commons"* was popularised by ecologist Garrett Hardin in his 1968 paper published in Science [Hardin, 1968:1243-1248]. It posits that when a public resource is shared among many individuals or entities, it is often overused and degraded, as no single party has a strong incentive to conserve it. This theory explains how individuals often prioritise personal needs over collective well-being, justifying selfish behaviour based on the belief that others will not act in the group's best interest. Such a mindset can lead to unsustainable practices and neglect, resulting in environmental harm.

In South Africa, the *"Tragedy of the Commons"* is particularly evident in water resource management, where both legal and illegal usage have led to over-extraction and pollution, adversely affecting the environment and public health [DWS, 2018b:114]. According to a study by Magombeyi, *et al.* (2019:866), insufficient regulation in some areas hinders sustainable water management. To address these challenges, effective policies and strategies [33] must be established, regulatory frameworks strengthened[34] and cooperation promoted among all water users[35] to manage and protect water resources for current and future generations.

2.2.2.2.2 Integrated decision-making and integrated water resource management

Another theoretical consideration for developing water resource management policies involves determining the desired level of integration for decision-making and management (**FIGURE 9**). The following approaches to water quality management issues are particularly important:

- **Water pollution control**

  Water pollution control involves actions taken to reduce or prevent pollutants from entering water resources, such as rivers, typically through effluent or Waste Discharge Standards (WDSs). This aims to protect the health of animals, ecosystems and humans using the water for domestic purposes [adapted from DWAF, 1991:8].

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[33] The aim of this study, amongst others, is to develop effective policy and strategy for the purpose of eutrophication governance.

[34] Refer to **Section 6.4.2.2.2:** Water use authorisation and conditional regulation**.**

[35] Refer to **Section 6.5.3**: Collaboration and management participation**.**

- **Water quality management in catchments**

  This refers to management actions taken in a catchment context to maintain the water quality of water resources in a state that remains fit for recognised receiving water users [adapted from DWAF, 1991:8].

- **Integrated water resource management**

  This approach integrates the management of water resources within a catchment context, recognising that all components of the hydrological cycle are interconnected. It asserts that human activities, particularly water use, must be regulated to maintain the resource quality, which includes water quality, water quantity, habitat and biota considerations, within pre-determined parameters [adapted from DWS, 2017b:11].

- **Integrated catchment management**

  This systems approach manages natural resources, especially water, within the geographical boundaries of a river system's catchment [DWS, 2017b:11].

- **Integrated environmental management**

  This philosophy ensures environmental considerations are integrated into all development stages to achieve a balance between protection and development [DWS, 2017b:11].

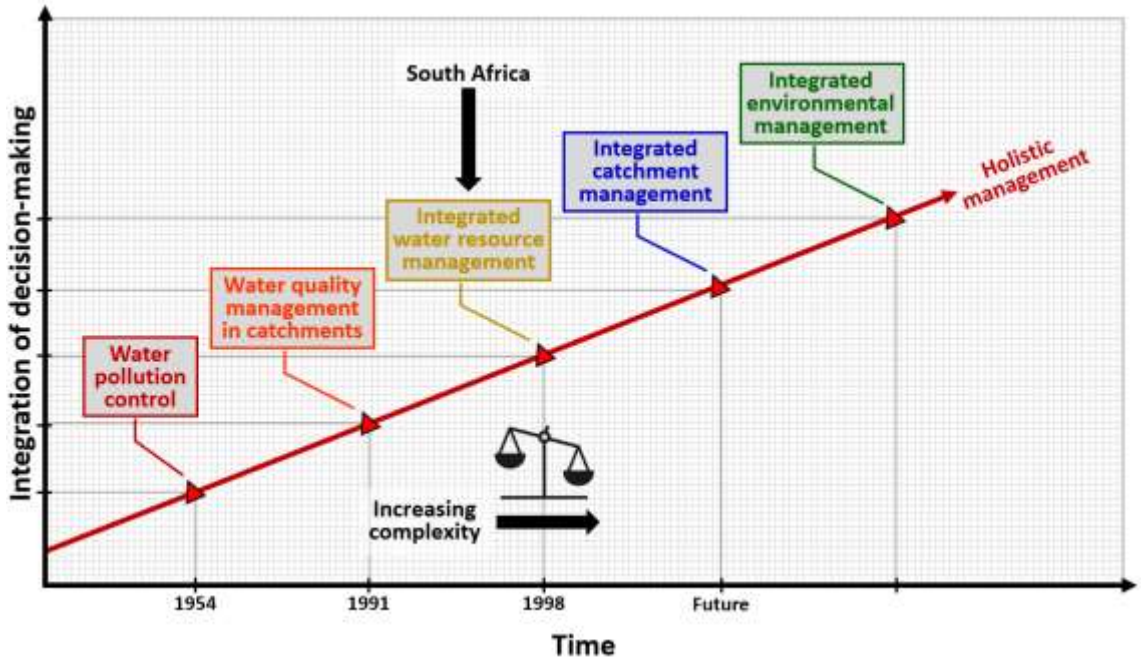

FIGURE 9: Journey towards holistic management of environmental media, from a water quality management perspective.

In South Africa, the NWA (36:1998) provides the legal framework for implementing integrated water resource management [DWS, 2013:3].[36] This approach encourages decision-making that considers social, economic and ecological factors, emphasising stakeholder involvement across sectors. Monitoring and assessing water resource status are crucial for adapting management strategies to ensure sustainability [De Lange, 2012:21-36].

Effective eutrophication management should adhere to these integrated water resource management principles, including the need for integrated,[37] participatory[38] and adaptive[39] management, whole life cycle nutrient management,[40] sustainable development[41] and good governance.[42] Effective eutrophication management, however, would need to lean towards *"integrated catchment management"* since land-use management practices affect nutrient inputs to waterbodies. This can be achieved through improved cooperative governance and inter-governmental relations,[43] acknowledging the need for more complex management systems to achieve greater integration (**FIGURE 9**).

2.2.2.2.3 Adaptive management

Another crucial theoretical consideration in developing water resource management policies and strategies is the concept of *"adaptive management"*. This approach emphasises ongoing learning and adaptation in response to changing conditions and uncertainties commonly found in natural and socio-economic systems [Cundill, *et al.*, 2015:1188-1198].

In eutrophication governance, adaptive management helps policy and strategy developers create responsive approaches that account for changes like nutrient input variations, population growth and climate variability. This process may involve establishing monitoring and evaluation systems[44] to assess policy and strategy effectiveness and identify necessary adjustments[45] [Haasbroek & Van Koppen, 2011:797-807].

By integrating principles of adaptive management and water resource management into eutrophication governance, developers can formulate policies and strategies that better address

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[36] Refer to **Section 3.11.2.3**: National Water Act, 1998 (Act No.36 of 1998) and Water Services Act, 1997 (Act No.108 of 1997).

[37] Refer to **Section 6.4.1.2.4, [D]**: Identification and development of linkages with land use planning and management.

[38] Refer to **POLICY STATEMENT 19:** Cooperative eutrophication management.

[39] Refer to **Section 6.4.4.2.3, [B]**: Continuous management improvement – closing the loop!

[40] Refer to **POLICY STATEMENT 6:** A life cycle view on nutrient loading.

[41] Refer to **POLICY STATEMENT 5:** The Receiving Water Quality Objectives Approach applied to eutrophication management.

[42] Refer to **Section 6.6**: Governance.

[43] Refer to **Section 6.5.3**: Collaboration and management participation.

[44] Refer to **Section 6.4.3**: The *"check"* stage.

[45] Refer to **Section 6.4.4**: The *"act"* stage.

the complex and dynamic nature of water resources, ensuring their sustainable use and management over the long term.

2.2.2.2.4 Precaution

The *"Precautionary Principle"* advocates for cautious, proactive measures in situations of uncertainty or potential risk to prevent harm [EU, 2000:1]. In eutrophication management, this principle encourages conservative decision-making when faced with uncertainty.[46] Implementing precautionary measures may involve:

- **Reducing fertiliser use:** Reducing fertiliser application in agriculture and households to reduce the amount of nutrients that reach water resources [Bomans, *et al.*, 2005:10-12];
- **Improving wastewater treatment:** Reducing sewage discharge into waterbodies by improving wastewater treatment and collection systems [Carey & Migliaccio, 2009:208-210];
- **Promoting natural vegetation:** Encouraging the growth of natural vegetative cover along shorelines, riverbanks and wetlands to absorb excess nutrients and prevent them from entering aquatic ecosystems [Nõges, *et al.*, 2010:18-20];
- **Eco-friendly farming practices:** Supporting the use of plant-based or environmentally friendly fertilisers [Srivastav, *et al.*, 2004:5-7]; and
- **Strengthening regulations:** Enhancing regulations for industries that discharge pollutants, promoting waste-reducing technologies and products [Kraemer, *et al.*, 2001:12-14].[47]

2.2.2.2.5 Ecological infrastructure

Another crucial theoretical consideration in developing water resource management policies is the concept of *"ecological infrastructure"*. This concept acknowledges the numerous benefits that ecosystem goods and services provide to humans, such as clean water, regulation of water flows and support for biodiversity [Costanza, *et al.*, 1997:254].

In eutrophication governance, this means recognising how water resources are interconnected with ecological infrastructure. It is essential to take measures to protect and restore aquatic ecosystems to ensure the sustainable management of water resources and services.[48]

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[46] Refer to **POLICY STATEMENT 4**: The application of the Precautionary Principle.

[47] Many of the interventions referred to in **TABLE 52** are precautionary in nature.

[48] Refer to **POLICY STATEMENT 8**: Nature-based solutions.

2.3 COLLECTION OF DATA AND INFORMATION (PHASE 1)

Generally, two modes of data collection are distinguished: *"qualitative"* and *"quantitative"*. **Qualitative** methods, such as literature research, participant observations and stakeholder interviews, mostly gather **non-numerical** data to provide insights into concepts, opinions and experiences – aiming to uncover deeper meanings and patterns. In contrast, **quantitative** methods focus on **numerical** data that can be quantified and analysed statistically – with examples including surveys and observational studies using structured instruments like questionnaires [Bryman, 2016:392-395].

This research, however, employs a **mixed method**, combining both quantitative and qualitative data collection and analysis techniques within a single study. Data were obtained through a three-stage collection process, each involving distinct drives for data collection. The individual drives included literature research on eutrophication and its governance in South Africa (qualitative method), described in **Section 2.3.1**, a nationwide survey [49] on the status of eutrophication and its management (quantitative method), described in **Section 2.3.2**, and stakeholder engagement [50] to solicit input from experts and laypeople about eutrophication governance (qualitative method), described in **Section 2.3.3**.

Together, the different data collection methods created redundancy, ensuring the availability of sufficient high-quality data for further evaluation and synthesis. This mixed approach provided a comprehensive understanding of the individual issues, considering matters from multiple perspectives, enriching result interpretations and validating findings across methods. Quantitative data offers *"breadth"*, while qualitative data adds *"depth"* – providing *"context"* to the *"numbers"* (Creswell & Creswell, 2018: 237-238).

2.3.1 Literature research

Literature research is not only a critical source of existing knowledge in literature reviews supporting research and academic compilations [Cooper, *et al.*, 2019:5-7; Linnenluecke, *et al.*, 2020:177-178; McGowan & Sampson, 2005:77-78], but it also serves as an effective instrument for collecting data and information for analyses and empirical purposes [Flynn, *et al.*, 1990:250-252; Okoli & Schabram, 2010:4-6]. A comprehensive method description for gathering data and

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[49] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[50] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

information was adopted, incorporating established research practices and guidelines from the academic community [Oakleaf, 2010:6-10; Pickard, 2013:22-26; Williamson, 2002:45-50]. As such, the method description includes discussions on the literature research **objective**, **research design**, **implementation**, **data and information analysis**, **interpretation of findings** and **reporting** in **Sections 2.3.1.1** to **2.3.1.5**, below.

2.3.1.1 Objective

In general terms, the objectives of literature research are designed to direct the methodological descriptions of the research, including the design, implementation, data analysis, interpretation of findings and reporting [Snyder, 2019:333-337]. For this study, the specific objectives of the literature research were to–

- ***"establish a critical source of existing knowledge through a literature review in support of the study"*;**
- ***"obtain insights into the key challenges associated with eutrophication in South Africa"*; and**
- ***"examine the history and evolution of eutrophication governance in South Africa".***

2.3.1.2 Research design

The foundation of the literature research involved selecting reputable peer-reviewed journals, academic textbooks, conference proceedings, scholarly sources, datasets and reports that contain the desired content [Baas, *et al.*, 2020:380-382]. To access these literature sources, suitable databases, libraries and research platforms were considered [Gusenbauer & Haddaway, 2020:181–213]. The selection of relevant keywords and phrases capturing the main aspects of the research topic, such as *"eutrophication"* and *"causes and effects of eutrophication in South Africa"*, was necessary to facilitate online and electronic literature research efforts. The application of inclusion and exclusion filter criteria was also considered to enhance literature search efforts [Cooper, *et al.*, 2018:4-6].

To collect data and information on the governance of eutrophication in South Africa, literature research efforts focussed on consulting data and information held by the DWS, such as Green Drop Assessments, policies, strategies, plans, water quality assessments, intervention descriptions, catchment assessments and Water Research Commission (WRC) reports, as primary literature source. This search was complemented by including journal articles and other scholarly sources to find additional and supporting content on the key challenges associated with eutrophication and the evolution of eutrophication governance in South Africa.

2.3.1.3 Implementation

After concluding the literature search and identifying relevant sources, these materials were evaluated to select those aligning with the research aim and literature research objectives. Consideration was given to publication dates to ensure the inclusion of up-to-date, and recent data and information. A record of the screened sources was maintained and those available in electronic format were saved for ease of reference on subsequent occasions. The selected literature sources were accurately referenced within all research chapters applying the Harvard style [Cooke, 2001:55-58 ; Fink, 2019:89-92].

2.3.1.4 Data and information analyses

After collecting data and information from the literature, they were sifted and analysed to derive meaningful insights. Techniques such as descriptive statistics and qualitative forecasting were employed to support the research aim [O'Halloran, *et al.*, 2018:11-30; Onwuegbuzie & Leech, 2006:477-479]. The analysis of the collected data and information from the literature is presented in **Chapter 3,** which contains the *"literature review"* and **Chapter 4**, which focuses on the *"evaluation of eutrophication governance in South Africa"*.

2.3.1.5 Interpretation of findings and reporting of results

The results of the literature research were interpreted in alignment with the research aim, while acknowledging potential limitations (**Section 1.4.3**). This information served three main purposes: (1) contributing to a literature review focused on the theme of eutrophication governance; (2) identifying challenges associated with eutrophication in South Africa; and (3) assessing the historical context and forecasting the evolution of eutrophication governance in South Africa (refer to **Section 2.4.1** for a detailed method description). The outputs of the literature research have played a crucial supporting role in the evaluation of eutrophication governance in South Africa.

Findings were presented as clearly, concisely and visually appealing as possible [Bekker & Clark, 2018:5-7; Carter, 2012:15-18], utilising appropriate tables, charts and narratives. The literature research findings were primarily included in **Chapter 3** and **Chapter 4**, and further interpreted in **Chapter 5** and **Chapter 6**. Overall study findings were summarised in **Chapter 7**.

2.3.2 Nationally conducted survey

Surveys are powerful instruments for collecting data and information, and extracting valuable insights from targeted populations [De Vaus, 2013:5-7]. A comprehensive method description was adopted, incorporating practical considerations and best practices for survey design and

execution [Aday & Cornelius, 2011:25-30; Aguinis & Bradley, 2014:368-372]. As such, the method description includes details on the survey **objective**, **sample selection**, **design**, **implementation**, **data and information analysis**, **interpretation of findings and reporting** in **Sections 2.3.2.1** to **2.3.2.6**, below.

2.3.2.1 Objective

Survey objectives direct survey method descriptions, including sample selection, design, implementation, data analysis, interpretation of findings and reporting [Rea & Parker, 2014:3]. During 2002 and 2003, the DWAF utilised the survey to collect information on the status of eutrophication and its control [Walmsley, 2003:11]. The results were further evaluated in this research to inform the policy and strategy development process. Specifically, the objective of the survey in this research was to ***"obtain insights on the status of eutrophication and its management in support of policy and strategy development in South Africa"***.

2.3.2.2 Sample selection

The process of survey sample selection holds a pivotal role as it directly shapes the validity and generalisability of survey findings [Keiding & Louis, 2016:25-27; Speklé & Widener, 2018:10-12]. Common methods for selecting survey samples include *"random sampling"*, *"stratified sampling"* and *"quota sampling"* [Adeoye, 2023:88-92; Burger & Silima, 2006:656–668]. Each method has its own distinct strengths and weaknesses. Random sampling aids in reducing bias and improving the likelihood of obtaining representative results [Thompson, 2012:20-22], while stratified sampling enhances the precision of estimates within subgroups [Singh & Masuku, 2014:5-7]. Quota sampling, known for its convenience and cost-effectiveness, finds utility in areas such as market research and opinion polls [Rea & Parker, 2014:50-52].

This survey employed the stratified sampling technique to gather insights on the status and management of eutrophication from both the Regulator and water utility entities. Survey questionnaires were distributed to the nine regional offices of the former Department of Water Affairs and Forestry (DWAF), to collect responses that reflected conditions across each of the 19 Water Management Areas (WMAs),[51] as shown in **FIGURE 10**. Furthermore, the survey questionnaires were extended to the DWAF's Head Office and a select group of municipalities and other water service institutions to capture a diverse range of perspectives.

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[51] Initially, nineteen (19) WMAs were declared [GN 1160, 1999], which were later reduced to nine (9) WMAs [GN 1056, 2016]. This number of WMAs was subsequently reduced further to six (6) through the amalgamation of some WMAs [GN 2792, 2022; GN 2795, 2022; GN 3898, 2023].

The use of stratified sub-groups enhanced the breadth of geographic representation [Cochran, 1977:89] across the country, which in turn improved the accuracy [Feldman, *et al.*, 2024:8] of comparisons made between different WMAs. This approach also proved to be cost-effective [Schonlau & Couper, 2017:10-12], focusing primarily on the Regulator and a targeted selection of water utility entities.

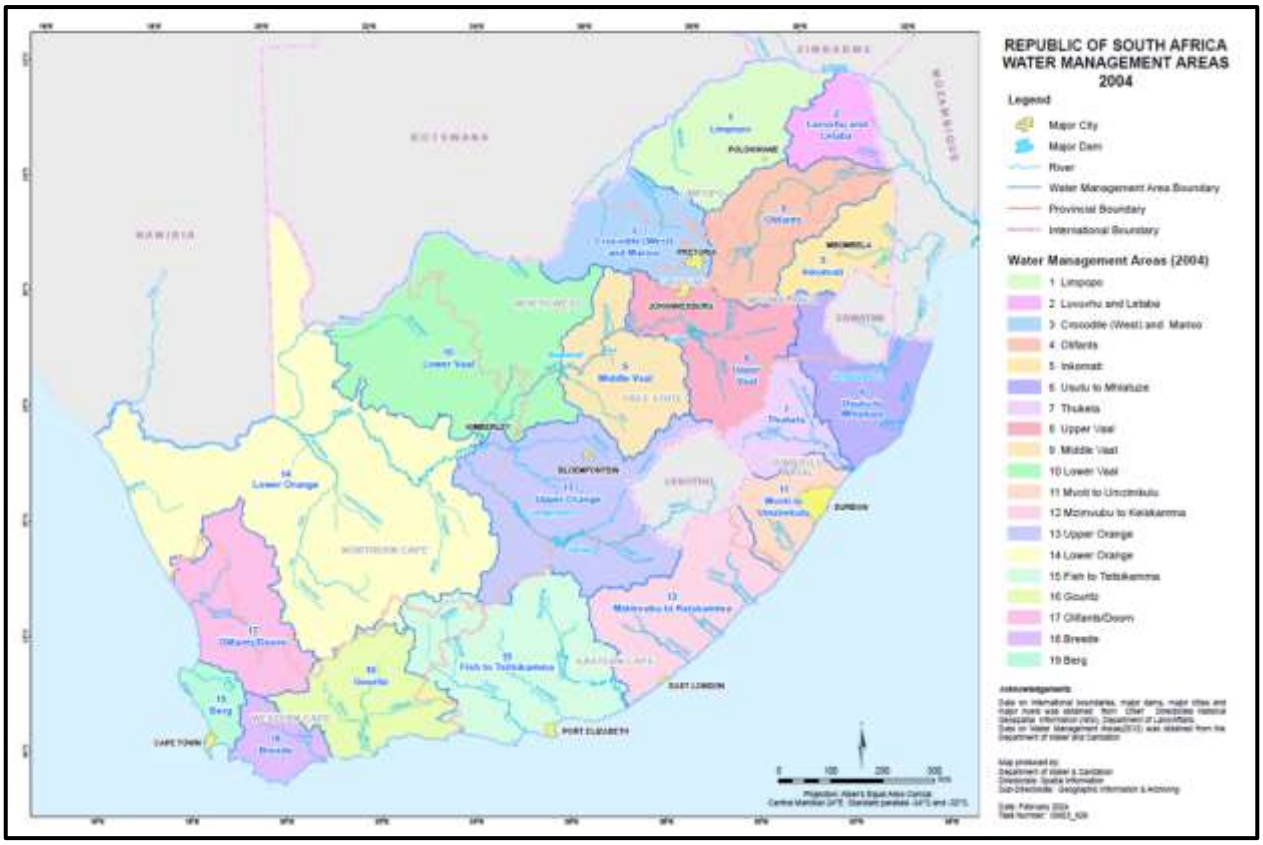

FIGURE 10: The Water Management Areas of South Africa in 2004 [DWAF, 2004b:94].

Although stratified sampling can present certain limitations, such as the need for comprehensive population data to create appropriate strata [Kalton, 1983:19] or the risks associated with over-stratification [Tipton, 2014:5-7] when the sample size is too small for the number of strata, these concerns were minimal in this study's context (see **Section 1.4.3.2**). The sample population was confined to only the Regulator and selected water utility entities. Furthermore, the stratification was limited to WMAs that were aggregated to provide a national overview.

The survey aimed to engage a sample size comprising **at least one representative from each DWAF regional office and for each WMA**, as well as to invite **knowledgeable** representatives from a selected number of water utility entities and DWAF's Head Office. The mobilised sample size (**Annexure D**), along with the survey results, is discussed in **Section 4.4**. Additionally,

DWAF regional office respondents could consult their colleagues for further input and knowledge, suggesting that the actual sample size likely exceeded the recorded sample size.

2.3.2.3 Survey design

Survey formats typically vary depending on the research and survey objectives, the specific characteristics of the target population and the resources available. They range from *"self-administered"* surveys, which can be completed online or via paper, to *"interviewer-administered"* surveys, conducted either by telephone or face-to-face and even to *"mixed-mode"* surveys that combine various methods [De Leeuw & Hox, 2018:45-48].

The survey questions were grounded in the need to discern the extent of eutrophication management issues within each WMA across the country and to gather information on water resources impacted by these issues from a local management perspective. They sought to assess the perceived severity of the eutrophication issues, current monitoring and reporting practices and level of expertise among DWAF and water utility entity staff. Additionally, the questions aimed to identify the need for further information or training, evaluate satisfaction with existing policy and strategy approaches, and determine the willingness of regional institutions to engage in developing revised management policies and strategies. Furthermore, they invited feedback and detailed information about specific eutrophication problems, their causes and the management actions implemented. **Overall, the survey questionnaire aimed to gather comprehensive insights to inform improved governance policy and strategy related to eutrophication.**

The survey was executed using a mixed-mode approach. Survey questionnaires were first distributed through email, and this initial phase was followed by a telephone campaign to enhance the response rate. The following eight questions (**TABLE 1**), along with their corresponding **rating scales or fixed response options**, were included in the survey questionnaire:

TABLE 1: Survey questions and their corresponding rating scales/ fixed response options.

SURVEY QUESTION		RATING SCALE/ FIXED RESPONSE OPTION
Question 1:	*"Based on the complaints received by you from water users and communities, how do you rate eutrophication as a water resource problem in your management area?"*	E=Extreme; M=Medium; L=Low; 0=No problem
Question 2:	*"Is routine eutrophication monitoring and reporting carried out by your office?"*	Y=Yes; N=No; N/A=Not applicable
Question 3:	*"Do you feel that your staff is fully conversant with the topic of eutrophication and its management?"*	Y=Yes; N=No; N/A=Not applicable
Question 4:	*"Would your staff like to receive more information or training on eutrophication and its management?"*	Y=Yes; N=No

SURVEY QUESTION		RATING SCALE/ FIXED RESPONSE OPTION
Question 5:	*"Do you think that the current national policy and strategy[52] for management of eutrophication requires revision?"*	Y=Yes; N=No; ?=Could not provide an opinion
Question 6:	*"Would your region/institution be prepared to participate in the development of a national strategy? This will involve commenting on draft documentation and possibly participating in a workshop."*	Y=Yes; N=No
Question 7:	*"Do you have any comments that you would like the Directorate of Water Quality Management to take note of?"*	Open ended
Question 8:	*"Please indicate where eutrophication problems occur, the level of intensity, the type of problem, the possible causes and the eutrophication management actions, if any, you have put in place."*	Mostly open ended Level ="*persistently*" or "*infrequently*" severe

The questions, thus, presented are a mix of open-ended and close-ended types, which is advantageous in this context. Questions 1 to 6 are primarily close ended, seeking specific information or yes/no responses regarding perceptions of eutrophication, existing practices and willingness to engage in policy and strategy development. These questions efficiently gathered quantifiable data, allowing for a quick assessment of the current state of management policy and strategy needs. On the other hand, Questions 7 and 8 are mostly open-ended, inviting detailed responses and additional insights regarding training needs, respondent feedback and specific local instances of eutrophication. Although not necessary, respondents were encouraged to provide supportive information for their answers to the close-ended questions if they wished. This combination allowed for both breadth and depth in understanding the issue, capturing measurable data and nuanced feedback necessary for comprehensive policy and strategy evaluation and development.

A complete version of the survey questionnaire can be found in **Annexure C**. This annexure provides further details and essential instructions that were included to assist respondents in accurately completing the survey questionnaire. It was estimated that filling out the survey questionnaire should take approximately 20 minutes.

2.3.2.4 Implementation

Prior to the full-scale implementation of the survey, a pilot survey was conducted with a small sample of two DWAF Head Office officials, following the methodology recommended by Van Teijlingen & Hundley (2001:33-34). This was aimed at identifying any potential issues with

[52] The 1991 policy and strategy [DWAF, 1991:1], referred to in the survey questionnaire, was replaced with the 2017 policy and strategy [DWS, 2017c:1; DWS, 2017e:1]. Both these policies and strategies were of a general water quality management nature. The 2017 policy and strategy highlighted the need for the development and implementation of a dedicated eutrophication management policy and strategy, as a matter of urgency.

the survey questionnaires and allowed for necessary adjustments. The adjustments predominantly focused on the addition of supplementary instructions for answering the questions.

Ethical considerations, including obtaining informed consent, ensuring anonymity, preserving confidentiality and providing an opt-out option, when applicable, were taken into account as outlined by Israel & Hay (2006:56-59). In this survey, respondent identities (**Annexure D**) were deliberately linked to their responses. This decision was made to maintain accountability, ensure the reliability of the data, facilitate effective analysis and allow for subsequent follow-up or clarification if required.

Various distribution channels, such as email invitations, online survey platforms, social media, telephonic interviews and postal mail, are available for disseminating surveys questionnaires, as noted by Vehovar & Manfreda (2017:170-172). For this study, the finalised survey questionnaires were initially distributed via email, offering a four-week response period. This method quickly and cost-effectively reached the desired audience, allowing respondents to complete the survey at their convenience. A four-week response period was deemed appropriate, providing recipients ample time amid other commitments, potentially increasing response rates.

To address potential non-response bias and increase response rates, a follow-up telephonic campaign was conducted within two months of the initial distribution. Combining these methods over a well-paced timeline proved effective in survey administration, balancing efficiency, cost and response quality. Comprehensive responses were received from eight of the nine DWAF regional offices for 17 of the 19 WMAs, as well as from DWAF's Head Office and the invited water utility entities.

2.3.2.5 Data and information analysis

The data and information collected from respondents' replies were analysed according to the rating scales and fixed response options provided in **TABLE 1**, in three distinct batches:

- ***"Batch One"***
  - This batch encompassed Survey Questions 1 to 6 (**Annexure C**) with fixed-choice responses;
  - It focused on rating the severity of eutrophication problems, the effectiveness of eutrophication monitoring, the capability to manage eutrophication and the need for eutrophication governance policies and strategies; and
  - All responses could be attributed to individual WMAs or DWAF Head Office.

- ***"Batch Two"***
  - This batch included written narratives supporting the answers to Survey Questions 2, 4, 5 and 7 (**Annexure C**);
  - It provided additional context for the responses analysed in *"Batch One"*; and
  - While written responses to Survey Question 2 could be linked to specific WMAs, those for Survey Questions 4, 5 and 7 could not be.
- ***"Batch Three"***
  - This batch focused on Survey Question 8 (**Annexure C**), addressing the causes of eutrophication and potential solutions;
  - Responses were analysed under four themes: (1) the severity of the problem, (2) identification of immediate causes, (3) identification of underlying causes, and (4) identification of solutions;
  - All responses could be attributed to individual WMAs or DWAF Head Office; and
  - Inputs from DWAF Head Office were utilised to enhance the data received for each WMA.

Survey Questions 1, 2, 3, 4, 5, 6 and 8 were statistically analysed to explore how data values are distributed and clustered across the response options and WMAs. Microsoft Office 365's Excel™ and Word™ was utilised to facilitate this analysis, drawing on methods endorsed by McGrath (2014:30-33) and Briney (2015:22-24). Data were inserted into Excel and summarised in Word tables specifically developed for the analyses (see **Annexure E**). Minimal data cleaning was required, allowing valuable insights to be extracted. The analysis results were displayed as histograms and pie charts, showing distribution percentages and counts per response option and across WMAs. **Chapter 4** presents a comprehensive analysis of the data and information, focusing specifically on the status of eutrophication and its management in South Africa.

2.3.2.6 Interpretation of findings and reporting of results

The survey results were captured in a series of Excel™ and Word™ tables, annexed in **Annexure E**. The information in the Excel™ tables were presented as histograms and pie charts, showing distribution percentages and counts per response option and across WMAs. The narratives in the Word™ tables provided additional context, supporting respondents' replies and their interpretation. The survey findings were integrated into **Section 4.4**, which contains the analysis and interpretation of individual Survey Questions, along with descriptive graphs. Insights from the national survey were utilised in the DPSIR Framework in **Section 4.5** and informed policy and strategy development in **Chapter 5** and **Chapter 6**, respectively. A comprehensive summary of the overarching study findings is included in **Chapter 7**.

2.3.3 Stakeholder engagement

Stakeholder engagement[53] is a crucial tool for gathering insights from interested and affected parties, thereby facilitating better decision-making and quality outputs [Cash, *et al.*, 2003:8088]. It plays a significant role in enhancing the understanding of complex issues and in identifying evolving trends and potential challenges [Reed, 2008:2424]. For this research, the stakeholder engagement approach combined a detailed method description with the best practices in stakeholder engagement processes [Cash, *et al.*, 2003:8089; Reed, 2008:2423-2426]. This includes detailing the **objectives** of the stakeholder engagement, **identifying** stakeholders, **designing** the engagement approach, **implementation**, **analysing** data and information, **interpreting** findings and **integrating results** into research outputs, as outlined in **Sections 2.3.3.1** and **2.3.3.5**, below.

2.3.3.1 Objective

Stakeholder engagement objectives are essential for guiding the engagement process, from identifying stakeholders to designing, executing, analysing, synthesising engagement data and communicating findings [Reed, 2008:2421]. In the context of this research, the DWS strategically utilised stakeholder engagement to ensure broad-based input and buy-in for its Eutrophication Management Strategy. During the parallel execution of this research, stakeholder engagement was not an end in itself but a means to enhance the research outputs by serving as a valuable reference source. Specifically, the aim was to ***"garner valuable insights into eutrophication and its governance within South Africa, thereby enhancing the research outputs, including aiding the development of relevant policy and strategies"***.

2.3.3.2 Stakeholder identification and engagement design

The DWS adopted a tiered stakeholder engagement structure which also benefited this study. This structure comprised several committees with varied responsibilities, including technical guidance, administration, project management, regional input, strategic oversight, peer review and public input. A diverse group of stakeholders was selected for their relevance to eutrophication management, considering their expertise, involvement in activities affecting nutrient loading and the need for a holistic approach across various sectors [DWS, 2023b:41]. Nominees represented a range of functions within the DWS, other government departments, Catchment Management Agencies (CMAs), water boards, municipalities, the Council for Scientific

[53] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

and Industrial Research (CSIR), industry, the WRC, academic institutions, Non-Governmental Organisations (NGOs), civil society and specialists knowledgeable on eutrophication. Engagement methods included regular meetings and workshops, informal interviews and requests for written input [DWS, 2023b:41].

2.3.3.3 Implementation

With approval from the DWS (**Annexure A**), this research was conducted alongside a departmental initiative, both aimed at improving eutrophication governance in South Africa and mutually benefiting each other. Due to the intertwined nature of the departmental initiative and this subsequent research, this research also benefited from the stakeholder engagement conducted by the Department.

Stakeholders were encouraged to contribute openly, freely and respectfully. Internal stakeholder engagement within DWS, aimed at obtaining input and advice on eutrophication governance, occurred regularly over a three-year period from 2020 to 2022. Additionally, the DWS solicited input from external stakeholders, including practitioners and experts, during three separate occasions over the same period. Furthermore, interested and affected parties were consulted during a public meeting by the DWS near the end of the project. Stakeholder input was recorded by both the DWS and the author.

2.3.3.4 Data and information analysis

Once stakeholder input and feedback were received, a qualitative analysis was conducted to identify key insights, issues or perspectives. Common themes, patterns and areas of agreement or disagreement among stakeholders were also considered [Reed, 2008:2425]. The collected data and information were analysed and incorporation into the results chapters of this research – which focus on the evaluation of eutrophication governance and the development of eutrophication governance policy and strategy – was considered. This approach allowed for a systematic evaluation of the input and the enhancement of the research outputs.

2.3.3.5 Findings and integration of results

All input on eutrophication governance obtained during the DWS-conducted stakeholder engagements was recorded using an issues and response register[54] or notes by the author, along with a series of meeting minutes,[54] to capture decisions and enhance project execution. The

[54] The Register and the meeting minutes are available at: https://www.dws.gov.za/wem/DocumentsSDS.aspx, and formed part of a DWS initiative to develop and implement a eutrophication management strategy for South Africa [DWS, 2023d].

results of these engagements were utilised to enhance the *"evaluation of eutrophication governance in South Africa"* discussed in **Chapter 4**, to shape the other study outputs presented in **Chapter 5** and **Chapter 6**, specifically the policy and strategy, and to inform the study findings detailed in **Chapter 7**.

2.4 EVALUATION OF EUTROPHICATION GOVERNANCE IN SOUTH AFRICA (PHASE 2)

The output of Phase 1, comprising findings from literature research, a nationally conducted survey[55] and stakeholder engagement,[56] served as the foundation for Phase 2. In addition to these initial findings, further value was added through the evaluation of eutrophication governance in South Africa. This evaluation encompassed qualitative forecasting of the evolution of eutrophication governance in South Africa (**Section 2.4.1**) and the design and utilisation of a framework for evaluating eutrophication governance in South Africa (**Section 2.4.2**).

2.4.1 Qualitative forecasting of the evolution of eutrophication governance in South Africa

Qualitative forecasting is a method used to make predictions based on opinion, judgment and subjective factors, rather than quantitative data [Arvan, *et al.*, 2019:237-252; Caniato, *et al.*, 2011:413-424; Meneghini, *et al.*, 2018:68-80; Sanders & Ritzman, 2004:514-529; Zellner, *et al.*, 2021:1-25]. This approach is commonly employed in situations where historical data is scarce, unreliable or does not adequately capture the complexity of topics [Goodwin & Wright, 2004:71; Morgan, 2019:5].

Considering historic advancements, combined with an analysis of the present and extrapolation of past and present knowledge into the future, often aids in developing a deeper understanding of trends and fosters forward-thinking. Qualitative forecasting is particularly useful in scenarios where long-term or strategic planning is undertaken, such as in the case of policy and strategy development [Amer, *et al.*, 2013:25-30; Graf, 2002:12-15; Vecchiato & Roveda, 2010:1535-1537; Vecchiato, 2012:436-447].

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[55] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[56] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

Qualitative forecasting of the evolution of eutrophication governance aims to predict future trends and changes in the approaches, policies and strategies that address the increasing nutrient loading of waterbodies. A comprehensive method description for qualitatively forecasting this evolution has been adopted, informed by seminal works [Abraham & Ledolter, 2009:30-35; Chase, 2013:15-17; Dwyer, *et al.*, 2012:40-45; Muraru, 2015:10-12]. Accordingly, the method description encompasses discussions on the forecasting **objective**, **design**, **implementation**, **analysis**, **interpretation of findings** and **reporting** in **Sections 2.4.1.1** to **2.4.1.4**, below.

2.4.1.1 Objective

Forecasting objectives typically guide the method descriptions, covering elements such as forecasting design, implementation, analysis, interpretation of findings and reporting [Jolliffe & Stephenson, 2012:10-12; Samonas, 2015:15-17]. In this research, the specific forecasting objective was to ***"qualitatively forecast the evolution of eutrophication governance in South Africa"*** aiming to provide additional context and support in seeking intervention solutions.

2.4.1.2 Forecasting design

The qualitative forecast design was premised on acquiring sufficient and quality information, as highlighted by Goodman, *et al.* (2014: 331-334) and Goodwin & Wright (2010:355-368). This information was primarily obtained through literature research (**Section 2.3.1**) on the evolution of eutrophication governance in South Africa. Additionally, a nationally conducted survey[57] on the status of eutrophication and its management (**Section 2.3.2**) and stakeholder engagement[58] (**Section 2.3.3**) provided additional supporting context.

The gathered information was then utilised to develop an understanding of historical, current and future trends, as well as governance structures related to eutrophication, as highlighted by Gray (2013: 111), Mitchell, *et al.* (1997: 876) and Reed (2008: 2429).

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[57] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[58] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

2.4.1.3 Implementation and analysis

The qualitative data and information gathered from literature research, as well as the nationally conducted survey[59] and stakeholder engagement,[58] were analysed to identify patterns and trends, broadly following the approaches outlined by Caniato, *et al.* (2011:413-424) and Miles, *et al.* (1994:108), to provide additional context and support in seeking intervention solutions.

Plausible scenarios, potentially affecting the evolution of eutrophication governance in South Africa, were identified, considering factors such as regulatory changes, technological advancements and public awareness [Van Ginkel, 2012:22-25; Lukhele & Msagati, 2024:10-12; Volkery & Ribeiro, 2009:1198-1207]. Management options to address or mitigate these scenarios were also identified and incorporated into the DPSIR evaluation framework (**Section 2.4.2.3**). Additionally, experts in eutrophication were engaged to provide input, as suggested by Rowe & Wright (2001:125).

2.4.1.4 Interpretation of findings and reporting of results

Based on the analysis, the evolution of eutrophication governance in South Africa was forecasted. This output was used to provide recommendations for adaptive strategies, policies and intervention solutions [Lempert & Groves, 2010:960–974; Eriksson & Weber, 2008:470-472]. Validation of the findings involved peer review and stakeholder engagement to ensure credibility and accuracy, as suggested by Loureiro, *et al.* (2020:388-409) and Goodwin & Wright (2004:387). Findings were presented as clearly, concisely and visually appealing as possible [Bekker & Clark, 2018:5-7; Carter, 2012:15-18], utilising appropriate tables, charts and narratives. The qualitative forecast findings were primarily included in **Chapter 4** and further expounded upon in **Chapter 5** and **Chapter 6**. The overall study findings were summarised in **Chapter 7**.

2.4.2 Design of a framework for the evaluation of eutrophication governance in South Africa

Before presenting the method description for evaluating eutrophication governance in South Africa based on the DPSIR Framework in **Section 2.4.2.3**, it is important to first discuss general concepts related to causal chain analyses in **Section 2.4.2.1** and then explore concepts specific to the DPSIR Framework in **Section 2.4.2.2**.

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[59] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

2.4.2.1 Causal chain analyses

This section explains the concept of **causal chains**, utilised to analyse and understand the relationships between various causal factors contributing to eutrophication, in **Section 2.4.2.1.1**. It discusses how these chains link **causes**, such as nutrient pollution from agricultural runoff (covered in **Section 2.4.2.1.2**), to **effects** like the degradation of water quality (covered in **Section 2.4.2.1.3**). The importance of understanding these links to develop effective **policy and strategy responses** is discussed in **Section 2.4.2.1.4**.

2.4.2.1.1 Causal chains and their analyses

The analysis of causal chains [Pearl, 2009a:101-104], often referred to as **root cause analysis** [Rooney & Van den Heuvel, 2004:46], is closely related to **systems thinking** [Arnold & Wade, 2015:670], **life cycle assessment** [Guinee, *et al.*, 2011:90] and the **D**river-**P**ressure-**S**tate-**I**mpact-**R**esponse (DPSIR) Framework [Kristensen, 2004:1-10]. At its most basic, a causal chain is an ordered sequence of events linking the causes of a problem with its effects. Each link in the causal chain is created by repeatedly answering the question: *"Why?"* [Pearl, 2009b:23-25]. In this cause-and-effect relationship, one or more things happen because of something else. A cause is a catalyst, a motive or an action that brings about a reaction or reactions. In other words – a cause instigates an effect [Rooney & Van den Heuvel, 2004:45-53].

A simple schematic showing the major cause and effect components of a causal chain, is shown in **FIGURE 11**.

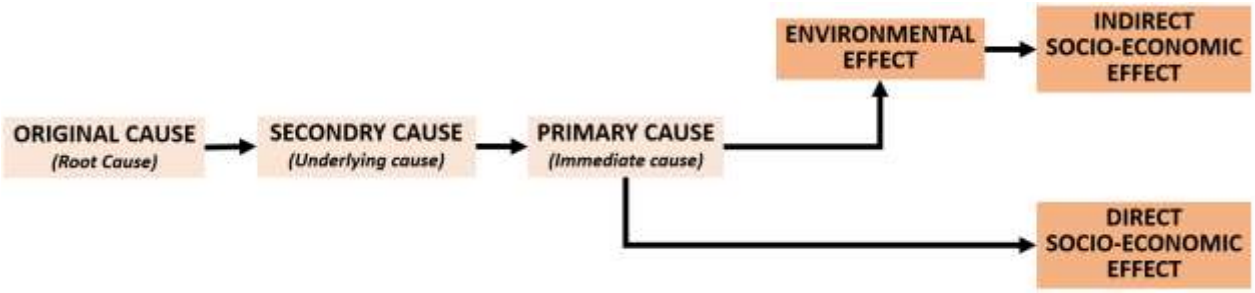

FIGURE 11: The major cause and effect components of a causal chain [adapted from IOC-UNESCO, 2020:69].

A causal factor is deemed the *"original"* or *"root"* cause of a problem if its removal prevents the problem from recurring. Conversely, a causal factor is considered a contributing factor, either an *"underlying"* or *"immediate"* cause, if it influences the outcome of an incident or event without being the *"original"* or *"root"* cause. While removing a causal factor may enhance an outcome, it does not guarantee the prevention of its recurrence [IOC UNESCO, 2020:69; Rooney & Van den Heuvel, 2004:46].

The analysis of causal factors and causal chains constitutes a problem-solving methodology used to identify the root causes of faults or problems [Okes, 2019:23-25]. Causal chain analysis is a form of deductive inference [Pearl, 2000:10-12], requiring an understanding of underlying causal mechanisms to address problems in an informed manner. In addition to its numerous applications, causal chain analysis is widely employed to analyse, better understand and solve various environmental management-related problems [Rooney & Van den Heuvel, 2004:49].

Causal chain analysis can typically be broken down into four steps [Rooney & Van den Heuvel, 2004:46-48], *viz.*:

- Data collection;
- Causal factor charting;
- Original cause identification; and
- Recommendation generation and implementation.

Causal chain analysis is founded on the belief that problems are best solved by focusing on the original causes (*i.e.,* root causes), as opposed to addressing the symptoms [Kristensen, 2004:4]. Typically, causal chain analysis serves as input to remedial processes, guiding corrective actions aimed at preventing problem recurrence. By directing interventions at the original causes, or as close as possible to them, there is a higher likelihood of preventing or minimising the problem's recurrence. It is, however, acknowledged that complete prevention of recurrence through a single corrective action is not always possible [IOC UNESCO, 2020:69].

The causal chain construct is an established concept, endorsed, among others, by the International Organisation for Standardisation (ISO) in their ISO 14001 specification for environmental management systems. This is evident in the introduction of the terms *"environmental aspects"* and *"environmental impacts"* (**FIGURE 12**) [ISO, 2015].

An ***"environmental aspect"*** is defined as *"an element of an organisation's activities, products or services that can interact with the environment"*. Likewise, an ***"environmental impact"*** is the result of an *"environmental aspect"* and is defined as *"any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organisation's activities, products or services"* [ISO, 2015].

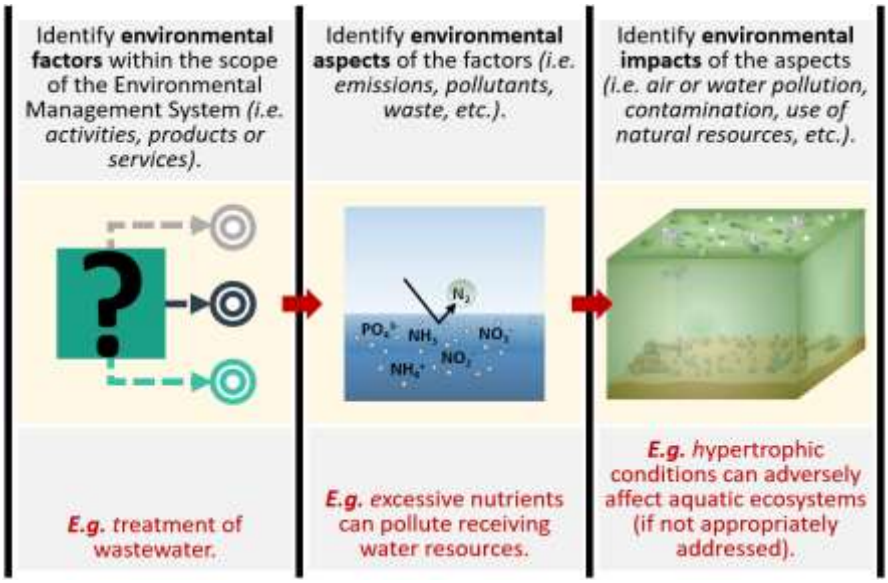

FIGURE 12: ISO 14001 – *"environmental aspects"* and *"environmental impacts"*.

Another variation of the causal chain concept was introduced by the DWS following the promulgation of the NWA (36:1998). This variation employs the terms *"source"* and *"resource"* as part of two approaches known as ***"Source-Directed Control"*** and the implementation of ***"Resource-Directed Measures"*** (**FIGURE 13**). In the context of water resource management, the term *"source"* refers to sources of impacts (comparable to ISO 14001's *"environmental aspects"*), while the term *"resource"* refers to the receiving water environment within which impacts are realised (comparable to ISO 14001's *"environmental impacts"*).

Water quality is inextricably linked with water quantity (typically water flow), in stream and riparian habitat and aquatic biota integrity; all of which are collectively referred to in the NWA (36:1998) as the *"resource quality"*.[60] For water resources to be able to continuously sustain economic growth and social development, the quality (or *"resource quality"*) of such water resources needs to be maintained within certain pre-determined parameters. These parameters, represented by the Management Class (MC), Resource Quality Objectives (RQOs) and Reserve, are part of Resource-Directed Measures (RDMs). This necessitates the implementation of Source-Directed Controls in ways that support RDMs. The relationship between sources of anthropogenic

[60] The NWA (36:1998) defines *"resource quality"* as: *"the quality of all the aspects of a water resource including–*
(a) the quantity, pattern, timing, water level and assurance of instream flow;
(b) the water quality, including the physical, chemical and biological characteristics of the water;
(c) the character and condition of the instream and riparian habitat; and
(d) the characteristics, condition and distribution of the aquatic biota."

pollution and their impacts on receiving water resources is a crucial concept when considering measures for managing eutrophication.

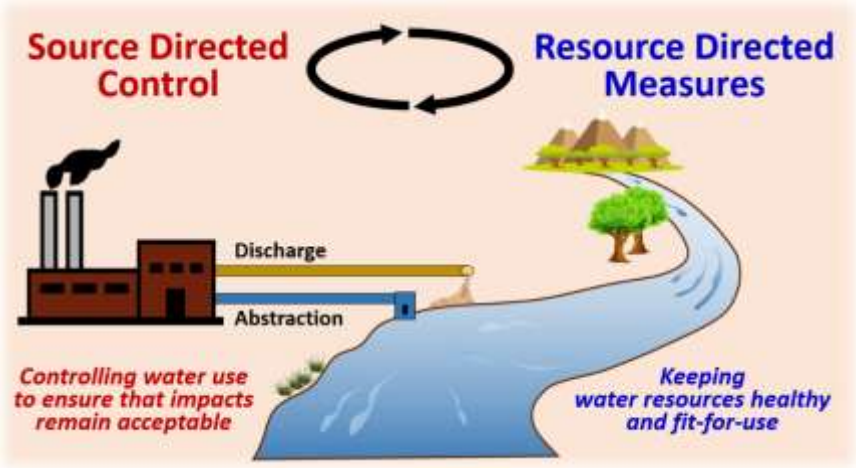

FIGURE 13: Source controls must ensure that downstream water resources support ecological sustainable development.

2.4.2.1.2 Causes

IOC UNESCO (2020:71-74) offers informative descriptions (**TABLE 2**) of the three categories of causes found in typical causal chains, as identified in **FIGURE 11**:

TABLE 2: Description of the categories of causes found in a typical causal chain.

CATEGORIES OF CAUSES	DESCRIPTION
Primary causes Also called *"immediate causes"* or sometimes *"technical causes"*	This category of causes typically involves direct technical and predominantly tangible causes of the problem (*e.g.*, excessive nutrient loading). These causes, mostly of a technical nature, are the most straightforward to quantify, prioritise and geographically locate using maps. Examples of primary causes, include water pollution, changes in biodiversity, habitat degradation and changes in hydrological regimes.
Secondary causes Also called *"underlying causes"*	This category of causes contributes to primary causes and follows on from original causes. They can broadly be defined as (1) underlying resource uses and practices; or (2) their related social and economic causes. **(1) Resource uses and practices link to–** ▶ Land uses (*e.g.,* agriculture); ▶ Water uses (*e.g.,* storage); and ▶ Damaging or unsustainable practices (*e.g.,* the absence of/or outdated wastewater treatment technology). **(2) The social and economic causes link to–** ▶ Increased sectoral development; ▶ Lack of investment, operation and maintenance; ▶ Poor awareness or inadequate education; and ▶ Governance failures (*e.g.,* legislation, regulation, enforcement, etc.).

CATEGORIES OF CAUSES	DESCRIPTION
Original causes Also called *"root causes"*.	This category of causes typically culminates in other effects and is linked to underlying socio-economic or demographic developments, as well as production or consumption practises. Understanding original causes is crucial because (1) some proposed solutions might be unworkable if the original cause of the problem is overwhelming; and (2) actions taken nearer to the original cause are more likely to have a lasting impact on the problem. When considering the degradation of aquatic environments, the original causes are often the most challenging to assess and manage. For example, in the case of eutrophication, the original cause might be a cultural change in diet, such as an increase in meat consumption leading to a market demand for cheap meat and the intensification of animal farming, resulting in higher phosphorus and nitrogen loading. In such scenarios, the sectoral nature of governance is likely to hinder the effective management of eutrophication.

The three categories of causes, described in **TABLE 2**, are not necessarily discrete; it is useful to consider that they often represent component parts of a continuum of following-on causes [IOC UNESCO, 2020:74].

2.4.2.1.3 Effects

IOC UNESCO (2020:66) offers informative descriptions of the types of effects found in a typical causal chain (**TABLE 3**):

TABLE 3: Description of the categories of effects found in a typical causal chain.

CATEGORIES OF EFFECTS	DESCRIPTION
Environmental effects	This category of effects relates to the integrity of ecosystems.
Socio-economic effects	This category of effects relates to changes in the welfare of people, attributable to catchment developmental problems or environmental effects. Socio-economic effects can manifest as direct or indirect effects.

An effect is a condition, occurrence or result generated by one or more causes. These effects (also called impacts) can be direct or indirect results within a causal chain, and they can be either positive or negative. As a general rule – negative effects must be prevented, avoided and minimised, whereas positive effects must be encouraged, maintained and maximised.

FIGURE 14 depicts an example in which eutrophication is the result of escalating phosphorus and nitrate loading (nutrient over-enrichment) of a waterbody. When answering the question, *"What are the consequences of this?"*, an environmental effect might be *"a loss of biodiversity"*. This, for instance, could result in a loss of tourism income and/or a loss of food sources for the riparian community. These consequences represent indirect socio-economic effects of the problem. However, there may also be direct socio-economic effects, such as increased water treatment costs or impaired human health due to polluted potable water. All these effects serve as examples of negative consequences.

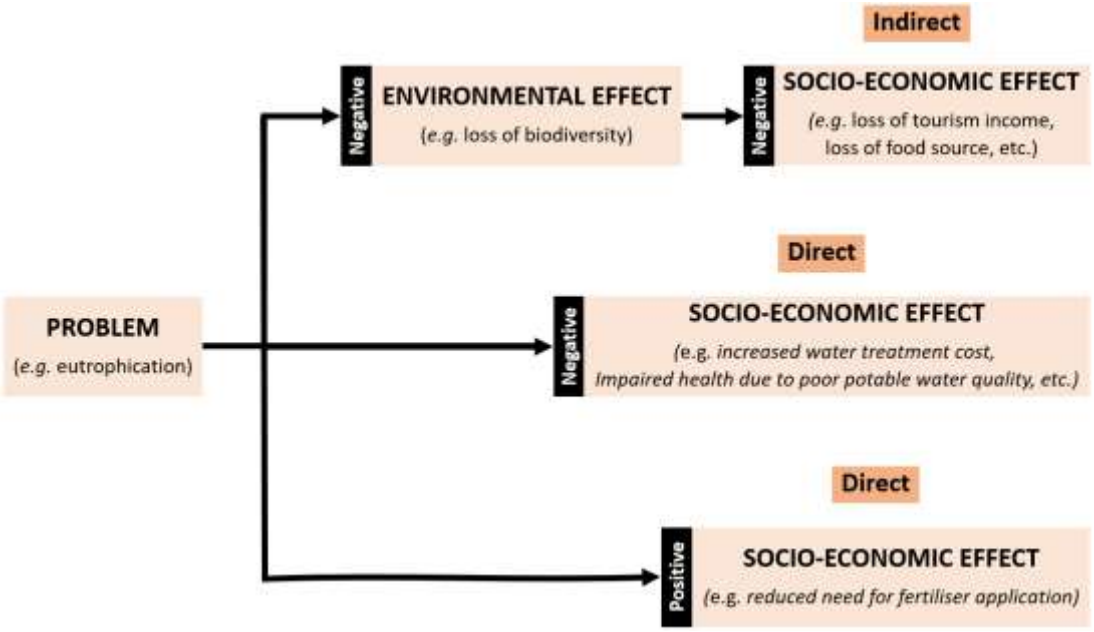

FIGURE 14: Schematic showing the link between problems and effects. [adapted from IOC-UNESCO, 2020:67].

In some cases, a particular problem can lead to positive consequences. For example, as shown in **FIGURE 14**, the use of enriched irrigation water can reduce the need for agricultural fertiliser, representing a positive, albeit perverted, benefit to irrigated agriculture.

In situations where multiple conflicting scenarios must be considered before making management decisions, optioneering instruments, such as Cost-Benefit Analysis (CBA), Life Cycle Assessment (LCA), Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA), Environmental Risk Assessment (ERA), Social Impact Assessment (SIA), etc. should be employed. The golden rule should be that short-term benefits should never outweigh long-term costs.

2.4.2.1.4 The policy response system

Unlike systems thinking, which focuses on the dynamic and complex interactions of the whole system as a structured functional unit, causal chain analysis approaches are typically used linearly to examine causes and effects. However, despite often being presented in a linear format, it is important to recognise that a causal chain is a component of the policy response system [IOC UNESCO, 2020:69-70], which is inherently cyclical (**FIGURE 15**). Nevertheless, causal chain analysis remains a relatively simple, robust and informative process that can be applied in various solution-seeking approaches [Hall, 2006:25-30].

There are essentially two ways of solving problems within the context of a policy response [Larson, *et al.*, 1986:384-398]:

- **Reactively**

  Reactive management involves responding quickly after the problem has occurred by treating its symptoms. This approach is implemented by reactive systems, self-adaptive systems, self-organised systems and complex adaptive systems. The goal is to react promptly and alleviate the effects of the problem as soon as possible.

- **Proactively**

  Proactive management, on the other hand, focuses on preventing problems from occurring. In this case, the emphasis is on the accuracy and precision of the diagnosis, with the objective of addressing the root cause of the problem rather than its effects. Proactive action, such as addressing original or leading causes, is often informed by causal chain analysis.

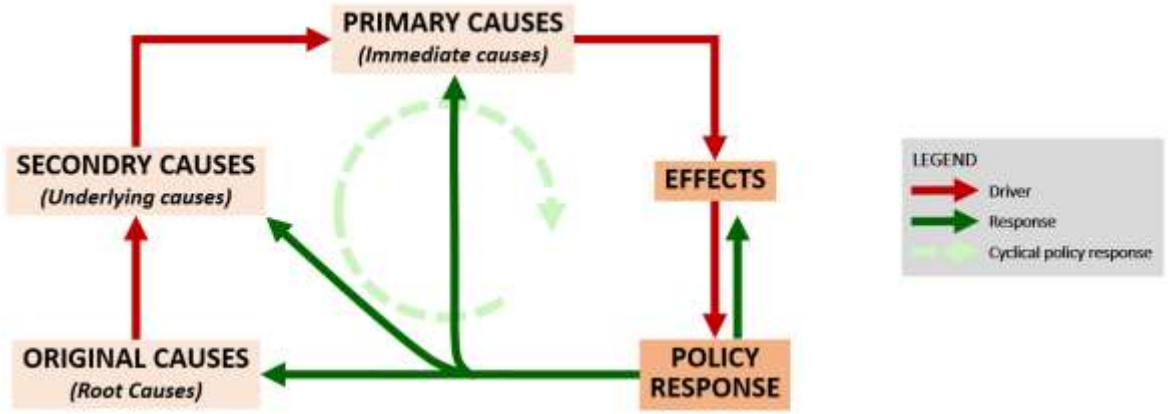

FIGURE 15: The causal chain as a component of the policy response cycle. [adapted from IOC-UNESCO, 2020:70].

Furthermore, to address causes and effects related to eutrophication management, it is essential to develop a thorough understanding of the sectoral governance responsibilities. This involves identifying the sectors to which these responsibilities belong (*e.g.*, agriculture, water and sanitation, the relevant sphere of government, etc.). Unfortunately, these sectors often operate independently, making it challenging to achieve a coordinated intersectoral response. Despite the separation of policymaking and information among sectors, their environmental impacts are interconnected. Therefore, when establishing policy and strategy, considerations of responsibility, accountability and cooperation become crucial components [Larson, *et al.*, 1986:384-400; Rooney & Van den Heuvel, 2004:45-53].

2.4.2.2 The DPSIR Framework

The **D**river-**P**ressure-**S**tate-**I**mpact-**R**esponse (DPSIR) Framework has evolved significantly since its inception. It started as the Stress-Response (S-R) Framework in 1979, developed by Statistics Canada, and then evolved into the Pressure-State-Response (PSR) Framework utilised by the Organisation for Economic Co-operation and Development (OECD) in 1993 for environmental performance evaluation [Gari, *et al.*, 2015:63]. In 1997, the United Nations (UN) Commission on Sustainable Development (CSD) adapted it into the Driving force-State-Response (DSR) Framework [Gari, *et al.*, 2015:64]. Subsequently, in 1995, the European Environment Agency (EEA) refined it further into the DPSIR Framework, as we know it today, making it instrumental in environmental assessments [Smeets & Weterings, 1999:1-19].

The Dobris Report, Europe's first comprehensive environmental assessment published by the EEA in 1995, utilised the DPSIR Framework to evaluate Europe's environmental conditions, focusing on air, water, soil and biodiversity. It identified key environmental problems, analysed trends and offered policy recommendations, highlighting the need for improved governance and sustainable development [EEA, 1995:1]. This report marked a significant milestone in European environmental policy, forming a baseline for subsequent assessments and shaping EU policies [Bongardt, *et al.*, 2008:28].

Over time, variations emerged to address specific critiques, such as the DPSWR Framework, which replaced *"Impact"* with *"Welfare"* to focus on human welfare and DPSER Framework, which emphasised ecosystem services over simple environmental impacts. Researchers have also proposed integrating the DPSIR Framework with other methods, such as combining it with ecosystem-based management approaches or analytic models, to better capture complex socio-ecological dynamics [Gari, *et al.*, 2015:63-77].

While the DPSIR Framework has been applied to assess freshwater resources, such as the Madre Watershed in Brazil, focusing on eutrophication and low oxygen levels [Llantada, *et al.*, 2024:101046], the Framework was/is extensively utilised for marine eutrophication assessments. A well-documented example is its application in addressing nutrient inputs from agriculture and other land-based sources impacting marine ecosystems in the Baltic Sea [HELCOM, 2024].

The DPSIR Framework offers a comprehensive approach for addressing eutrophication governance, making it particularly suited compared to other causal chain frameworks. By integrating both ecological and socio-economic aspects, it establishes clear connections from root causes (*"Drivers"*) to societal and environmental responses. This holistic perspective ensures that interventions, policies and strategies are informed by a thorough understanding of the entire system – from human activities leading to nutrient loading (*"Pressures"*) to ecological changes like algal blooms (*"State"*) and their impacts on ecosystem services and human well-being.

Crucially, it guides policy and strategy developers in identifying effective management interventions (*"Responses"*) that can be monitored and adjusted over time, thus serving as an adaptive tool for sustainable eutrophication control and governance.

Illustrated in **FIGURE 16**, the DPSIR Framework amalgamates causal chain analysis with policy and strategy response thinking, offering a structured methodology to describe environmental problems by establishing relationships between anthropogenic activities, the environment and potential solutions. As described by Smeets & Weterings (1999:7) and Kristensen (2004:3), the framework outlines a chain of causal links, where *"driving forces"* lead to *"pressures"* that alter the *"state"* of bio-physicochemical conditions, causing *"impacts"* on ecosystem goods, services and the environment, which necessitate appropriate policy, strategy and political *"responses"*.

A distinctive feature of the DPSIR Framework is its ability to link problems to potential solutions, making them particularly valuable in policy and strategy development [Smeets & Weterings, 1999:1-19]. The utility of the DPSIR Framework, specifically in investigating policy and strategy solutions to address anthropogenic eutrophication challenges, will be tested and demonstrated in Chapter 5 and Chapter 6, respectively.

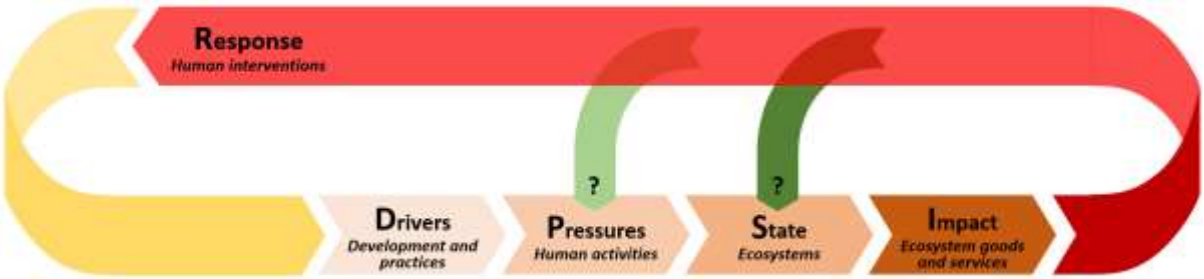

FIGURE 16: The Driver-Pressure-State-Impact-Response Framework [Kristensen, 2004:1].

TABLE 4 offers concise practical descriptions of the individual causal links that constitute the DPSIR Framework:

TABLE 4: The chain of causal links within the DPSIR Framework.

CAUSAL LINKS	DESCRIPTION
D **Drivers** *(or Driving forces)*	*"Drivers"* in the context of the DPSIR Framework pertain to socio-economic or demographic developments, as well as production or consumption practices, that instigate *"pressures"* on the environment [Martins, *et al.*, 2012:273–281]. Examples encompass fundamental elements such as food, water, shelter, health, security and culture.
P **Pressures**	*"Pressures"* within the DPSIR Framework refer to anthropogenic activities or consequences that may exert intentional or unintentional *"pressures"* on the environment. The nature and intensity of these *"pressures"* depend on the type and level of technology involved and can vary across geographic areas and spatial scales. These *"pressures"* are the consequences of *"driving forces"*, ultimately influencing the *"state"* of the environment [Martins, *et al.*, 2012:273–281]. Human activities that exert *"pressure"*, include: ▶ Land use changes; ▶ Resource consumption; ▶ Release of substances, such as effluent; and ▶ Physical damage through direct contact uses.
S **State** *(or State change)*	*"State"* within the DPSIR Framework refers to the condition of both abiotic and biotic components of ecosystems. In other words, the *"pressure"* exerted by humans may result in intentional or unintentional changes in the *"state"* of the physical, chemical or biological conditions of ecosystems, potentially leading to further *"impacts"* on the environment [Martins, *et al.*, 2012:273–281]. The *"state"* is described in terms of– ▶ physical variables, *i.e.,* the quantity and quality of physical phenomena, such as temperature or light availability; ▶ chemical variables, *i.e.,* the quantity and quality of chemicals, such as phosphorus or nitrogen levels; ▶ biological variables, *i.e.,* the condition of the ecosystem, habitat, species, community or genetic levels, such as biodiversity.
I **Impacts**	*"Impacts"* in the context of the DPSIR Framework denote the effects that alterations to the condition of both abiotic and biotic components of ecosystems have on habitats, biota, ecosystem goods and services, ultimately influencing society. Ecosystem goods and services encompass functions or processes that either directly or indirectly benefit human well-being or have the potential to do so in the future. These include: ▶ The provisioning of water, food, etc.; ▶ The regulation of water quality, air quality or disease; ▶ Cultural benefits, including aesthetic or recreational value; and ▶ Indirect supporting processes crucial for ecosystem maintenance. Addressing negative *"impacts"* requires control, management and/or mitigation through appropriate *"responses"* [Martins, *et al.*, 2012:273–281].
R **Responses**	*"Responses"* within the DPSIR Framework refer to societal measures aimed at preventing, minimising or mitigating negative *"impacts"* by influencing the "*drivers"*, *"pressures"* and *"state"*. These measures encompass actions taken by individuals or groups, both within society and government, to address changes in the environment. The objectives include– ▶ controlling *"drivers"* or *"pressures"* through prevention, regulation or mitigation; ▶ directly maintaining or restoring the *"state"* of the environment; or ▶ deliberately choosing to *"do nothing"*. Decision-making processes occur at a variety of scales, from individuals to local management to national and transboundary governance [Martins, *et al.*, 2012:273–281].

2.4.2.3 Evaluation, based on the DPSIR Framework, of eutrophication governance in South Africa

The DPSIR Framework rational was utilised to unpack the eutrophication challenges being experienced in South Africa and to identify possible governance solutions. A comprehensive method description [Hering, *et al.*, 2010:4007-4019; Kristensen & Hansen, 2017:45-62; OECD, 2012:35-43; Rooney & Van den Heuvel, 2004:45-53] for the development and application of the causal chain analysis framework to evaluate eutrophication governance in South Africa was adopted. As such, the method description includes discussions on the framework's **objective**, **design**, **implementation**, **analysis**, **interpretation of findings** and **reporting** in **Sections 2.4.2.3.1** to **2.4.2.3.4**, detailed below.

2.4.2.3.1 Objective

The objectives of causal chain analyses typically serve as guides for causal chain analysis method descriptions, encompassing aspects such as design, implementation, analysis, interpretation of findings and reporting [Hering, *et al.*, 2010:4007-4019; Kristensen & Hansen, 2017:45-62; Remler & Van Ryzin, 2021:215-217]. In the context of this study, the specific objective of the DPSIR causal chain analysis framework was to ***"evaluate the cause-and-effect relationships associated with eutrophication governance in South Africa"***, with the aim of identifying appropriate intervention responses.

2.4.2.3.2 Framework design

The design of the causal chain analysis framework for evaluating eutrophication governance in South Africa is based on the DPSIR Framework, as described in **Section 2.4.2.2**, above. The definitions for *"drivers"*, *"pressures"*, *"state"*, *"impacts"* and *"responses"* follow those adapted from Martins, *et al.* (2012:273–281), as summarised in **TABLE 4**. Throughout the framework design process, and subsequent population of the framework tables, the central focus was to facilitate the identification of appropriate intervention responses that would support the formulation of eutrophication governance policies and the establishment of effective strategies to address South Africa's eutrophication challenges.

2.4.2.3.3 Implementation and analysis

The causal chain analysis framework for evaluating eutrophication governance in South Africa was populated with data and information primarily obtained through literature research (**Section 2.3.1**), *inter alia* on key challenges associated with eutrophication in South Africa and the evolution of eutrophication governance in the country. Additionally, a nationally conducted

survey[61] on the status of eutrophication and its management (**Section 2.3.2**) and stakeholder engagement[62] (**Section 2.3.3**) contributed to the comprehensive dataset of information.

Causal factors and solutions, whether classified as *"drivers"*, *"pressures"*, *"state"*, *"impacts"* or *"responses"*, were considered and recorded together in a brainstorming fashion. An iterative approach was employed to identify these causal factors, beginning with a core team of 12 junior and experienced DWS officials. This was followed by iterations through various project committees, public participation involving 151 interested and affected parties and finally, peer review by six specialists in the field of eutrophication. Collectively, these stakeholders represented different government departments and spheres of government, water utility entities, non-governmental organisations, the private sector, the research community and civil society, with expertise in both natural and social sciences. The framework table for evaluating eutrophication governance in South Africa, guided by the definitions summarised in **TABLE 4**, provided structure to the causal chain analysis.

"Drivers" contributing to human-induced eutrophication, such as urbanisation, intensive agricultural practices and poor local government performance in treating wastewater, were identified, specifically considering the South African scenario, and transferred to the framework table.

The investigation then shifted to investigating how the identified drivers exert anthropogenic ***"pressures"*** on the environment, considering the nature of nutrient inputs (*e.g.*, phosphorus or nitrogen) into receiving water resources. Pressures considered included water and land uses, such as habitat disturbance, atmospheric deposition and point effluent discharges. These pressures were subsequently transferred to the framework table.

The analysis, next, focused on evaluating the current ***"state"*** of ecosystems affected by the identified pressures, utilising appropriate data and information. This included considering relevant water quality parameters, such as indicators of algal blooms, dissolved oxygen levels and other relevant factors. Comparisons of the current state to historical data, focussing on selected water quality parameters, were conducted to support the identification of trends and changes. The implications for the states of ecosystems were subsequently transferred to the framework table.

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[61] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[62] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

The ecological, economic and, ultimately, social ***"impacts"*** resulting from changes to the state of ecosystems were investigated. Both short- and long-term effects on biodiversity, aquatic life, fitness-for-use of receiving water resources, recreational activities and potential economic losses, amongst others, were considered. These impacts were subsequently transferred to the framework table.

Existing policy, strategy and other intervention ***"responses"***, aiming to prevent or mitigate the effects of human-induced eutrophication, were investigated. The effectiveness of these policies, strategies and intervention responses in addressing the identified drivers and pressures was considered, encompassing local, regional and international responses. These responses were, finally, also transferred to the framework table.

2.4.2.3.4 Interpretation of findings and reporting of results

Based on the established causal chain analysis framework for eutrophication governance in South Africa, the relationships, feedback loops and interactions among the individual driver, pressure, state, impact and response elements were investigated. The analysis of the eutrophication governance related causal chains led to recommendations for the effective management and prevention of human-induced eutrophication. Identified gaps in knowledge, data, policy and strategy interventions were addressed and appropriate intervention responses were identified for further developed, aiming to tackle anthropogenic eutrophication in South Africa.

Causal chain analysis findings were primarily included in **Chapter 4** and further expounded upon in **Chapter 5** and **Chapter 6**. The overall study findings were summarised in **Chapter 7**.

2.5 DEVELOPMENT OF APPROPRIATE INTERVENTION RESPONSES, AND POLICY (PHASE 3) AND STRATEGY (PHASE 4) COMPILATION

The output of Phase 2, comprising recommended intervention responses for improved eutrophication governance, served as the foundation for Phases 3 and 4, specifically prompting the development of eutrophication governance policy and strategy. A comprehensive method description for eutrophication governance policy and strategy development was adopted [Bryson, 2011:81; Hill & Jones, 2012:117; Kameoka, *et al.*, 2004:581-585; Presidency, 2020:11; Weible & Sabatier, 2018:17]. This method description includes discussions on the **objective**, **policy and strategy design**, **development**, **roll-out**, **maintenance**, **interpretation of findings** and **reporting of results**, covered in **Sections 2.5.1** to **2.5.5** below.

2.5.1 Objective

The general practice of utilising policy to define ground rules, delineate intent and specify desired outcomes, coupled with strategy to map out overarching implementation approaches to realise policy objectives, applies. This method description's objective was to ***"formulate a eutrophication governance policy, aiming to review and suggest policy objectives for eutrophication governance and nutrient reduction"***. Additionally, the objective also was to ***"propose concomitant eutrophication governance strategies that pursues approaches to implement the objectives of the eutrophication governance policy over time"***.

2.5.2 Policy and strategy design

The development of eutrophication governance policy and strategy [DWS, 2023b:39] focused on water resources, which include surface water such as rivers or springs, natural channels with regular or intermittent water flow, wetlands, lakes or dams into which or from which water flows and, where relevant, their bed and banks. It also includes estuaries and aquifers but excludes coastal marine waters.

The decision was to establish a national policy and strategy, emphasising approaches to eutrophication governance with discretionary universal application across South Africa. Consequently, the focus did not centre on specific problem catchments, although the intention remains to apply the eutrophication governance policy and strategy across catchments in the country [DWS, 2023b:38].

As such, the eutrophication governance policy and strategy for South Africa [DWS, 2023b:38] must–

- apply nationally (*i.e.*, to the country as a whole);
- address issues of anthropogenic nutrient loading, predominantly phosphorus and nitrogen related, which may result in the following adverse effects if left unattended:
  - Lead to excessive nutrient enrichment in water resources (*i.e.,* surface and/or groundwater resources);
  - Impair the resource quality of the country's water resources;
  - Give rise to water quality and nuisance concerns (negatively affecting property value, impairing fitness-for-use and restricting potential utility);
  - Cause eutrophication of surface water resources, and eventually the marine environment;
  - Pose a risk to ecologically sustainable development; and
  - Ultimately, have undesirable social and economic consequences.

The management measures in the eutrophication governance policy and strategy [DWS, 2023b:39] should–

- Focus on regulating and controlling land-based anthropogenic sources of nutrient loading;
- Establish resource water quality planning and management measures to balance the needs for water use with the necessity to protect water resources; and
- Outline remedial measures, whether focused on water resource remediation or targeting the remediation of nutrient pollution sources of impacts, that must be implemented reactively to control nutrient loading.

Furthermore, the eutrophication governance policy and strategy [DWS, 2023b:39] must provide a framework for managing anthropogenic eutrophication at various scales, including the source-specific, local, sub-catchment (up to WMA), national and transboundary/international levels.

2.5.3 Development

Data and information gathering played a crucial role in initiating the policy and strategy development process [Presidency, 2020:6]. This process began with comprehensive literature research (**Section 2.3.1**) to deepen understanding of eutrophication and its governance, including an evaluation of key challenges and a forecast of its evolution in South Africa (**Section 2.4.1**).

Alongside the literature review, a nationally conducted survey[63] on the status of eutrophication and its management (**Section 2.3.2**) and stakeholder engagement[64] (**Section 2.3.3**) were employed to enhance the quality of data and information. To develop a critical understanding of eutrophication governance and identify appropriate intervention solutions for policy and strategy development, a causal chain analysis was conducted using the DPSIR Framework (**Section 2.4.2**).

This approach facilitated the establishment of a visionary framework to address South Africa's eutrophication challenges [DWS, 2023b:64]. A comprehensive framework outlining a vision, mission, goals and objectives was created to guide management efforts. Various intervention options were identified, including Source-Directed Controls, regulation of point effluent discharges, RDMs to ensure fitness-for-use and wetland rehabilitation. Strategic actions were

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[63] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

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delineated across short-term, medium-term and long-term horizons, each with designated governance responsibilities assigned.

A comprehensive eutrophication governance policy and strategy were developed based on the evaluation of potential impacts associated with eutrophication and the assessment of suitable intervention options. It was important to establish policies and strategies that are adaptable to evolving scientific understanding and socio-economic conditions.

2.5.4 Roll-out and maintenance

Policy and strategy finalisation, implementation and maintenance are inherent parts of the policy life cycle but are excluded from the research scope (see **FIGURE 3** on **page 9**). Before rolling out policies and strategies, it is crucial to analyse their potential impacts, costs, benefits, risks and alignment with national priorities [Presidency, 2020:5].

Collaboration among relevant stakeholders is essential for effective implementation. Monitoring and evaluation mechanisms should be established to track progress and assess intervention effectiveness. Continuous engagement with stakeholders is necessary to address emerging challenges and adapt policies and strategies as needed [Conde, *et al.*, 2005:49; Kusters, *et al.*, 2018:173].

Ongoing research and knowledge exchange should support eutrophication governance efforts. Continuous monitoring, data collection and sharing best practices will improve responses to eutrophication [Drohan, *et al.*, 2019:10-13].

While the DWS is the custodian of the country's water resources, the eutrophication governance policy and strategy target all three spheres of government (*i.e.*, local, provincial and national government). Integrated management of eutrophication requires collaboration among shared river basin organisations, non-governmental organisations, the private sector, the research community and civil society.

The DWS is gradually adapting its water resource management approach to review and develop necessary policies and strategies, implement existing ones and focus on more strategic planning. This includes providing regulatory oversight, institutional support and enhancing cooperative governance within the water sector [DWS, 2023b:39].

2.5.5 Interpretation of findings and reporting of results

The intervention responses identified in the causal chain analysis framework (**Section 2.4.2**) were further interpreted and used to formulate eutrophication governance policy and strategy. These were presented clearly, concisely and visually appealing [Bekker & Clark, 2018:5-7;

Carter, 2012:15-18], utilising appropriate tables, charts and narratives in **Chapter 5** and **Chapter 6**, respectively. Overall study findings were summarised in **Chapter 7**.

2.6 CONCLUSION

Chapter 2 introduced a phased research methodology consisting of four discrete but linked phases. Each of these phases consist of several method descriptions that were discussed in this chapter. The individual method descriptions under each of these phases are:

- **Collection of data and information (Phase 1):**
  - Literature research;
  - Nationally conducted survey;[65] and
  - Stakeholder engagement.[66]
- **Evaluation of eutrophication governance in South Africa (Phase 2):**
  - Qualitative forecasting of the evolution of eutrophication governance in South Africa; and
  - Design of a framework for the evaluation of eutrophication governance in South Africa.
- **Development of appropriate intervention responses, and policy (Phase 3) and strategy (Phase 4) compilation:**
  - Policy formulation; and
  - Strategy establishment

The research methodology was underpinned by a philosophical and theoretical foundation.

The execution of the research methodology yielded the following results. **Chapter 3** will present a literature review of existing literature to deepen our understanding of eutrophication and its governance. Following this, **Chapter 4** will provide the results of an in-depth evaluation of eutrophication governance in South Africa. Subsequently, **Chapter 5** will propose a country-level eutrophication governance policy, while **Chapter 6** will outline a eutrophication governance strategy for South Africa.

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[65] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[66] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

THE RESEARCH CONTEXT OF CHAPTER 3

Chapter 3 contains the principal area of shared foundational material between the thesis and the EMSSA [DWS, 2023b]. Sections 3.2 - 3.9 correspond substantially with scientific and conceptual material in Part 1, Chapter 2 (*Defining the subject*) of the EMSSA, while Section 3.11 corresponds substantially with Part 1, Chapter 4 (*Policy, strategy and law context*). These sections contain identical, closely corresponding and adapted text, tables and technical descriptions.

The corresponding EMSSA material also benefited from the wider DWS review and stakeholder consultation process. K. Makanda and S. Mnyango, as Researchers, assisted with sourcing literature and relevant source material. W. Mosefowa, as Co-Author, contributed input, principally on pollution source control and related regulatory matters, while other DWS reviewers, specialists and stakeholders provided technical and contextual inputs that assisted in refining aspects of the scientific, policy, legislative and regulatory context. These contributions are recorded in the *Issues and Response Register* [DWS, 2023c] and the *Document Change Log* [DWS, 2023e].

The shared material was developed within the integrated research process as the common scientific, conceptual, policy and legal foundation required by both outputs. Consistent descriptions were retained where the same established scientific concepts, technical discussions, terminology or statutory provisions served the same function in both outputs. The common material therefore provides the same technical baseline for the two different outputs.

Within the doctoral thesis, however, Chapter 3 serves a distinct academic function. It provides the literature foundation for the subsequent evaluation of eutrophication governance and links that foundation to the wider scholarly research process. It also includes material and academic contextualisation that extend beyond the corresponding EMSSA discussion, including the explicit distinction between management and governance in Section 3.10 and its role in framing the subsequent governance evaluation.

CHAPTER 3 LITERATURE REVIEW

3.1 INTRODUCTION

The inclusion of **FIGURE 17** positions the reader within the high-level thesis structure, while **FIGURE 18** provides a visual representation of the section content within Chapter 3 (this chapter). **Chapter 3** provides a literature review of existing literature to deepen our understanding of eutrophication and its governance.

FIGURE 17: High-level thesis structure (Y*ou have arrived at Chapter 3*).

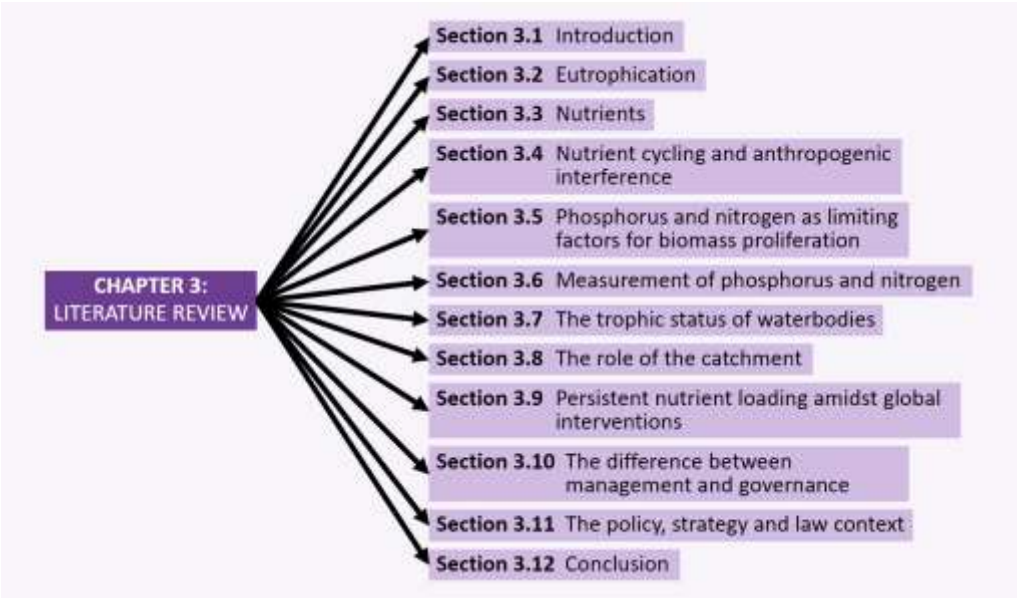

FIGURE 18: Section topics covered in Chapter 3.

3.2 EUTROPHICATION

"Eutrophication" is an ecological term used to describe the process by which a waterbody becomes enriched with plant nutrients [Walmsley, 2000:4]. During this process, the waterbody accumulates organic matter (both living and decaying) and progressively changes its character from that of a deep waterbody to that of a wetland, and ultimately to that of a terrestrial system. Eutrophication is primarily associated with the natural aging of lakes [Holdren, *et al.*, 2001:191]. Under natural conditions this process (**FIGURE 19**) takes place over tens of thousands of years. However, over the last ±100 years, human influences have greatly accelerated the rate of enrichment, thereby shortening the lifespan of waterbodies.

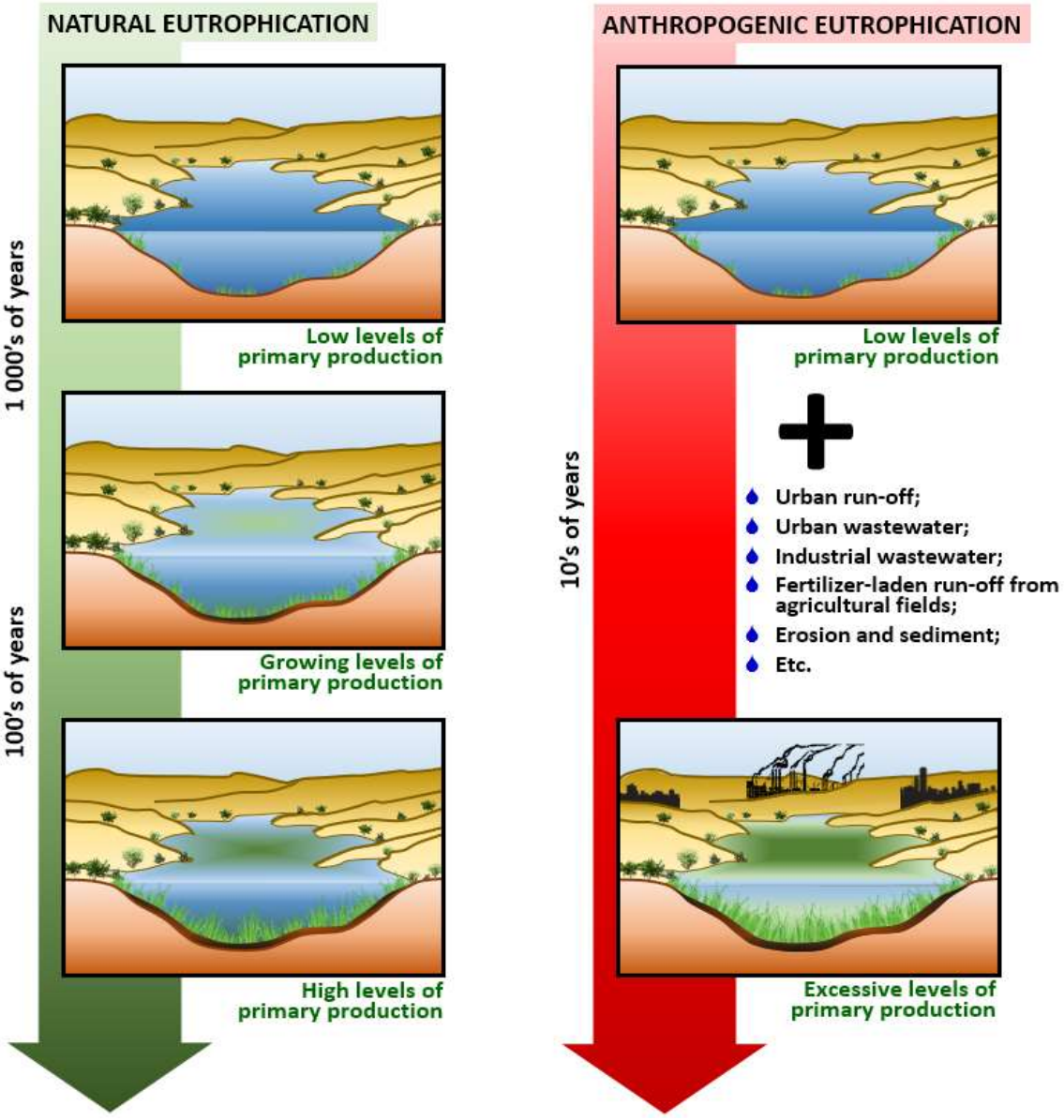

FIGURE 19: Illustration of *"natural"* and *"anthropogenic"* eutrophication [Holdren, *et al.*, 2001:42].

Importantly, two types of eutrophication can be distinguished [Walmsley, 2000:4; Walmsley, 2003:10], *viz.*:

- ***Naturally occurring eutrophication*** depends on the geology and natural features of a catchment. It is not reversible and continues *ad infinitum*, albeit at a slow rate; and
- ***Human-induced eutrophication*** is linked to anthropogenic activities and is sometimes referred to as *"cultural eutrophication"* due to its association with human (social and economic) activities. It may also be termed *"excessive eutrophication"* as it occurs at levels above the natural baseline, accelerating the aging of waterbodies. Although it is reversible, reversing anthropogenic eutrophication comes at a cost.

Stewart & Rohlich (1967) and Vollenweider (1968), as per Walmsley (2000:4), state that anthropogenic eutrophication was first recognised as a problematic environmental phenomenon when scientists were able to associate adverse conditions in waterbodies with increased nutrient enrichment from human activities. The process of eutrophication also became linked to a wide array of water resource problems [Dunst, *et al.*, 1974:2]. This association led to many definitions of the term, contributing to a somewhat confused understanding of its meaning. One of the most widely accepted definitions of eutrophication is provided by the Organisation for Economic Cooperation and Development, as captured by DWAF (2002:2-3), which describes the process as: ***"... the nutrient enrichment of waters which results in the stimulation of an array of symptomatic changes, including increased production of algae and aquatic macrophytes, deterioration of water quality and other undesirable effects that interfere with water users"***.

By controlling the anthropogenic triggers of excessive nutrient enrichment, eutrophication can be managed. In contrast to anthropogenic eutrophication, natural eutrophication cannot be readily managed, though, in some instances, it may be possible to influence naturally occurring eutrophication with management measures, such as stream-flow manipulation.

Some perceive nutrient enrichment as having far-reaching implications beyond water quality problems associated with water resources. This is due to the extensive impact of anthropogenic nutrient-containing materials on continental air, terrestrial and aquatic ecosystems. Nutrient enrichment can thus be understood to influence sustainable natural resource use (*i.e.*, the utilisation of material sources of nutrients), nutrient flow through ecosystems and have multiple impacts on air, land and water [EPA, 2000a:3-8; EPA, 2000b:(1)1-3; EPA, 2001:(1)5-7; EPA, 2008:(1)3].

In contrast to eutrophication, oligotrophication is often referred to as *"eutrophication in reverse"* and denotes the process of nutrient depletion and reducing levels of primary production. Oligotrophication can result from various factors, including the removal of primary nutrient inputs, such as the decommissioning of WwTWs, inter-basin transfers, vegetation clearance and

removal, the channelisation and drainage of wetlands and streams and processes like acidification or liming of waterbodies and soils [Stockner, *et al.*, 2000:7].

3.3 NUTRIENTS

In the previous discussion general references were made to nutrient loading as the cause of both natural and anthropogenic eutrophication, to introduce the concept. Next, it is essential to clarify the relative importance of the individual nutrient elements in this process.

Living organisms require approximately 40 different nutrient elements, which naturally occur, collectively in both the Earth's crust, *i.e.* the lithosphere, and in the atmosphere, to sustain growth and reproduction. These essential nutrient elements are usually considered in two groups [Harper, 1992:29], *viz.*:

- ***Macronutrients*** (or major elements), such as calcium (Ca), magnesium (Mg), potassium (K), carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), sulphur (S), iron (Fe), as well as silica (Si), used in cell frustules by diatoms and a few other algal species. These nutrient elements are the most important of the macronutrients, and are required in larger quantities; and
- ***Micronutrients*** (or trace elements), such as copper (Cu), cobalt (Co), molybdenum (Mo), manganese (Mn), zinc (Zn), boron (Br), vanadium (Va), chlorine (Cl), selenium (Se) and vitamin complexes. These are the most important of the micronutrients and are required in smaller quantities.

The most important nutrient element, carbon, is usually considered separately from the others, because it is the energy locked into the chemical bonds between carbon atoms and those with oxygen and hydrogen atoms, which is the basis of the photosynthetic conversion of solar energy into living tissue [Post, *et al.*, 1990:317]. Additionally, oxygen and hydrogen are freely available in water under most circumstances [Miller, 1998:185-186].

Out of all the nutrient elements derived from the lithosphere and present in plant tissue, phosphorus and selenium are those whose proportional abundance is lower in the lithosphere than in plant tissue [Harper, 1992:30]. Phosphorus, thus, is a prime candidate for a macronutrient that would potentially limit primary production. Selenium, followed by zinc, molybdenum and manganese are potentially likely to be limiting micronutrients [Atlas & Bartha, 1987:167-180, 275-276, 316].

Out of all the nutrient elements derived from the atmosphere or hydrosphere, such as carbon, nitrogen, oxygen and hydrogen – nitrogen is regarded as a prime contender to potentially limit

primary production. This is due to nitrogen's prevalent gaseous form, nitrogen gas (N_2), making up the lion's share of nitrogen on the planet. Nitrogen gas (N_2) cannot be assimilated directly by most plants. In contrast, carbon is unlikely to be limiting because of its prevalent gaseous form, carbon dioxide gas (CO_2), being water-soluble and bioavailable under most circumstances [Harper, 1992:61].

Anthropogenic eutrophication and the construction of dams have led to decreased downstream silicate availability and silicate availability for input to estuaries and oceans [Ittekkot, *et al.*, 2000:776-782]. Furthermore, phosphorus and nitrogen are recycled more rapidly in the water column than silicon. With increased eutrophication in receiving rivers, estuaries and coastal areas, higher P:Si and N:Si ratios are expected [Egge & Aksnes, 1992:281]. Officer & Ryther (1980:83-90) note that phytoplankton communities can generally be divided into two basic categories: those dominated by diatoms, dependent on silicate presence, and those dominated by flagellates (or non-diatomaceous forms), typically not dependent on silicate. It is conceivable that P:Si and N:Si ratios influence the composition of phytoplankton communities, with low ratios (*i.e.*, high silicon availability) generally associated with diatom dominance. Additionally, flagellate communities are often linked to the undesirable effects of anthropogenic eutrophication, while diatom communities are not [Officer & Ryther, 1980:89]. The presence and composition of diatom communities are indicative of past and present aquatic health conditions and are useful indicators of resource quality.

3.4 NUTRIENT CYCLING AND ANTHROPOGENIC INTERFERENCE

Cycling of the limiting nutrients, phosphorus and nitrogen, is discussed next:

3.4.1 Phosphorus

On land, over thousands of years, phosphorus gradually becomes less available to plants as it slowly leaches into runoff and eventually reaches the marine environment. Human activities, such as mining and the utilisation of phosphorus minerals, including phosphorus fertiliser, detergents and the export of food from farms to cities, have induced significant alterations to the global biogeochemical phosphorus cycle. In this process, phosphorus is lost, among other ways, as effluent in urban areas. While phosphorus does enter the atmosphere in minute amounts when dust dissolves in rainwater and seaspray, the majority remains on land within rock and soil minerals. Phosphates exhibit swift movement through plants and animals. Nonetheless, the processes facilitating phosphorus transfer through soil or oceans are notably slow, rendering the phosphorus cycle one of the slowest biogeochemical cycles overall. The global biogeochemical

phosphorus cycle, illustrated in **FIGURE 20**, encompasses five major processes [Atlas & Bartha, 1987:350-352; Miller, 1998:117-119], *viz.*:

- ***Tectonic uplift***, leading to exposure of phosphorus-bearing rocks, such as apatite, to surface weathering;
- ***Geological cycling*** induced by physical erosion, as well as chemical and biological weathering of phosphorus-bearing rocks. This is further intensified by anthropogenic activities like mining, exposing dissolved and particulate phosphorus in soils and water resources;
- ***Cycling through terrestrial organisms***, causing sedimentation of particulate phosphorus (*e.g.,* phosphorus associated with organic matter and oxide/ carbonate minerals), eventually leading to burial in soils on land;
- ***Riverine and subsurface transportation*** of phosphorus to receiving lakes and runoff to the ocean; and
- ***Cycling through aquatic organisms***, causing the sedimentation of particulate phosphorus (*e.g.*, phosphorus associated with organic matter and oxide/carbonate minerals), ultimately leading to burial in sediments in freshwater resources and the marine environment.

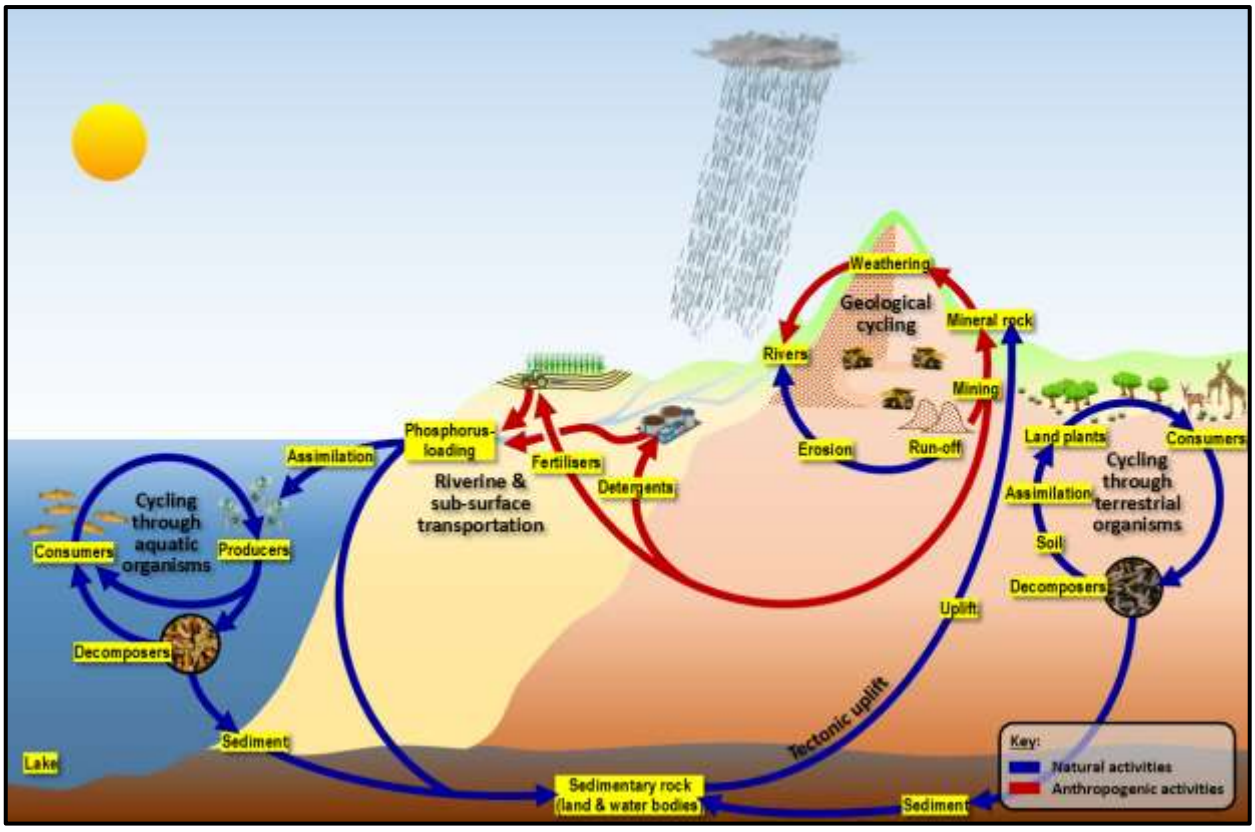

FIGURE 20: The bio-geochemical phosphorus cycle.

Elemental phosphorus is highly reactive and does not naturally occur in the environment. In natural water, phosphorus exists as orthophosphates, polyphosphates, metaphosphates,

pyrophosphates and organic phosphates, either dissolved or bound to particulate material. Among these, the orthophosphate species H_2PO_4 and HPO_4^{-2} are the only soluble inorganic phosphorus forms directly utilisable by aquatic biota. Soluble Reactive Phosphorus (SRP), or orthophosphate (PO_4^{3-}), is generally considered the most immediately available form of phosphorus [DWAF, 1996:(7)95; Walmsley, 2000:7].

In eutrophic lakes and under anaerobic conditions, there is a noticeable rise in soluble phosphorus (orthophosphate) content in the lower hypolimnion. This occurs due to the loss of the oxidised microzone, between sediments and the water phase, resulting in the release of phosphate and ferrous iron into the water [Wetzel, 2001:242-250]. Conversely, various processes, including mineralisation; adsorption onto suspended material or sediment; desorption under aerobic conditions; assimilation by plants; and precipitation with calcium or iron under aerobic conditions to form relatively insoluble compounds that precipitate out of the water, are all processes that influence the concentration of available phosphorus in fresh and marine waters [Paytan & McLaughlin, 2007:563-576; Walmsley, 2000:7; Wetzel, 2001:244].

3.4.2 Nitrogen

The Earth's atmosphere is primarily composed of atmospheric nitrogen, constituting approximately 78% of the total, making it the most abundant nitrogen source. Nitrogen exists in various forms in surface waters, including ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), urea (CH_4N_2O) and diatomic nitrogen gas (N_2). All freshwater algae can assimilate the first four forms, but nitrogen gas can only be utilised by specific species of blue-green algae and bacteria (*e.g.,* cyanobacteria such as *Anabaena* species) [Brock & Madigan, 1988:628-630].

The nitrogen cycle plays a crucial role in determining the availability of nitrogen, both in terms of timing and quantity, in surface waters [Walmsley, 2000:7]. Human activities, such as fossil fuel combustion, the use of artificial nitrogen fertilisers and the release of nitrogen in wastewater, have significantly altered the global nitrogen cycle. This human modification of the global biogeochemical nitrogen cycle can have adverse effects on ecosystems and human health.

FIGURE 21 illustrates the biogeochemical nitrogen cycle, depicting the processes through which nitrogen is converted into various chemical forms as it circulates among the atmosphere, terrestrial and marine ecosystems.

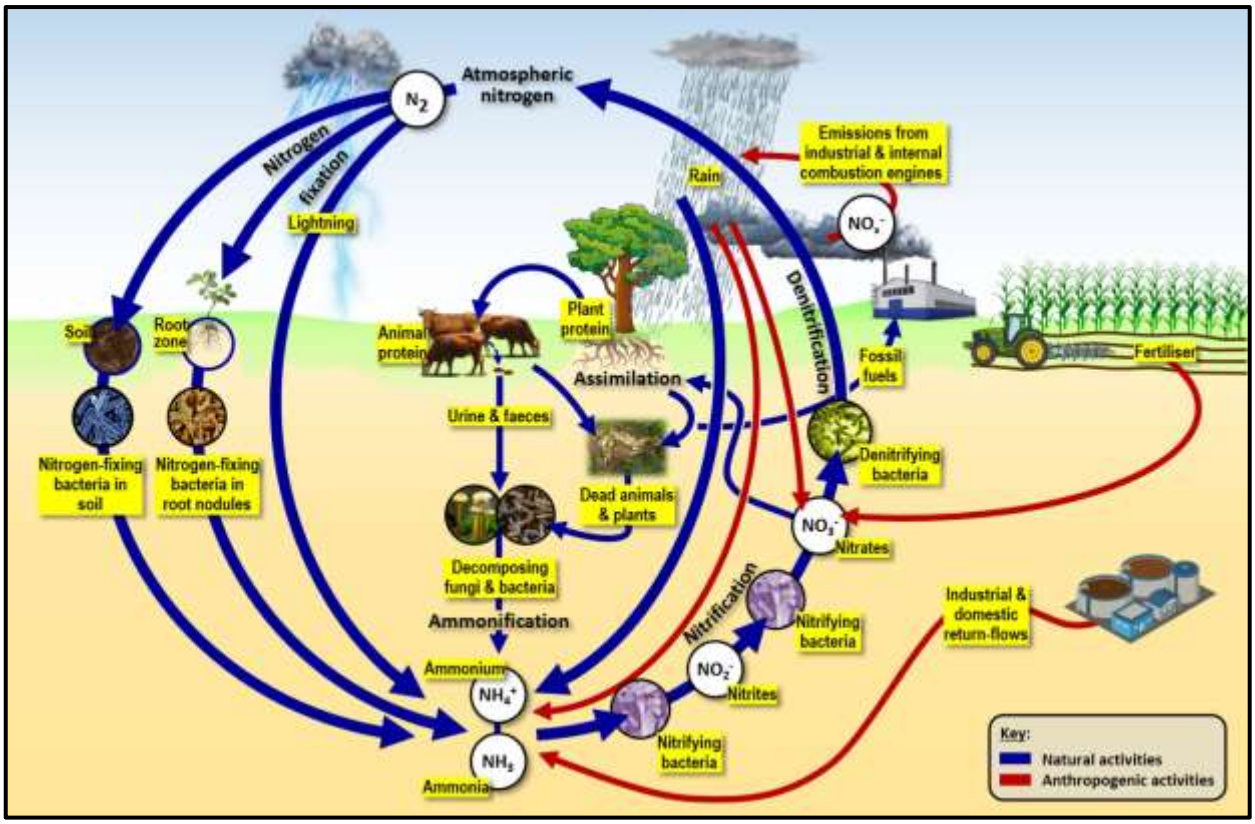

FIGURE 21: The bio-geochemical nitrogen cycle.

The biogeochemical nitrogen cycle, as outlined by various sources [Atlas & Bartha, 1987:333-342; Brock & Madigan, 1988:628-630; Davis, *et al.*, 1980:43; Miller, 1998:115-117], includes the following key processes:

- ***Nitrogen fixation:*** This involves the conversion of nitrogen gas (N_2) into nitrites (NO_2^-) and nitrates (NO_3^-) through atmospheric, industrial and biological processes. Atmospheric nitrogen must be *"fixed"* into a usable form before plants can assimilate it. While lightning strikes contribute significantly, the majority of fixation is carried out by free-living or symbiotic bacteria, known as diazotrophs and certain heterocyst-containing filamentous cyanobacteria;
- ***Assimilation:*** Plants absorb nitrates (NO_3^-) or ammonium (NH_4^+) from the soil or sediment through the cell walls of their root hairs. Nitrate (NO_3^-) is initially reduced to nitrite ions (NO_2^-) and then to ammonium ions (NH_4^+), which are incorporated into amino acids, nucleic acids and chlorophyll. Some plants can directly assimilate nitrogen gas (N_2) in the form of ammonium ions (NH_4^+) from root nodules;
- ***Ammonification or mineralisation:*** This process occurs when a plant or animal dies, or when an animal expels waste. Bacteria or fungi convert the initial organic nitrogen within the remains back into ammonium (NH_4^+);
- ***Nitrification:*** This involves the conversion of ammonium (NH_4^+) to nitrate (NO_3^-), primarily by soil-living and other nitrifying bacteria. Initial oxidation of ammonium (NH_4^+) is performed by

bacteria, like the *Nitrosomonas* species, converting free ammonia (NH_3) to nitrites (NO_2^-). Other bacterial species, such as *Nitrobacter*, oxidise nitrites (NO_2^-) into nitrates (NO_3^-). Under aerobic conditions, certain cyanobacterial species, like *Anabaena* (one of the filamentous species with heterocysts) and soil bacteria, like *Azotobacter* and *Clostridium*, contribute to nitrification, converting N_2 in the epilimnion of impoundments to compounds that are readily available for uptake. It is important for the free ammonia (NH_3) to be converted to nitrites (NO_2^-) or nitrates (NO_3^-), because free ammonia (NH_3) gas is toxic to plants; and

- ***Denitrification:*** Nitrates (NO_3^-) are reduced back into nitrogen gas (N_2), completing the biogeochemical nitrogen cycle. Bacterial species such as *Pseudomonas* and *Paracoccus* perform denitrification under anaerobic conditions, such as in waterlogged soils. These facultative anaerobic bacteria can also thrive in aerobic conditions.

3.5 PHOSPHORUS AND NITROGEN AS LIMITING FACTORS FOR BIOMASS PROLIFERATION

The rate and extent of aquatic plant growth depend on the concentration and ratios of nutrients present in the water. Typically, plant growth is restricted by the concentration of the nutrient that is present in the least amount relative to the growth requirements of the plant [Walmsley, 2000:6]. This principle is known as Liebig's Law of the Minimum or the Limiting Nutrient Concept [de Baar, 1994:347-386]. It forms the basis for the management of eutrophication [Smith, *et al.*, 1999:179-196].

The overall composition of aquatic plant tissue is C106; H263; O110; N16; and P, resulting in a C:N:P w(weight):w:w ratio of 41:7:1. The optimal ambient N:P weight ratio for algal growth in surface waters typically falls in the range of 8:1 to 12:1. Due to the dynamics of nutrient supply and demand in nature, it has been observed that phosphorus and nitrogen are the most commonly limiting nutrients in freshwater systems. Elevated levels of either of these two nutrients in a waterbody increase the risk, both in terms of extent and frequency, of experiencing eutrophication problems. Therefore, **the control of phosphorus and nitrogen inputs into the aquatic environment is considered essential for the effective management of catchment eutrophication issues.** While other nutrients may play a role as limiting factors, their significance is usually limited to specific circumstances [Walmsley, 2000:6].

In freshwater systems, phosphorus typically serves as the limiting nutrient, while in marine waters, nitrogen is often the limiting factor. This distinction arises from centuries of phosphorus input via surface runoff from land and the increased sequestration of iron (Fe) by sulphide (S^{2-}) in high sulphate (SO_4^{2-}) containing marine waters. This elevated sulphide concentration reduces the

availability of iron for the precipitation of phosphate (PO_4^{3-}) in marine waters compared to freshwater systems.

In the oxidative hydrolysis of iron and the concurrent precipitation of phosphate, a minimum of two iron (Fe) atoms is required to precipitate one phosphate (PO_4^{3-}) molecule (*i.e.,* Fe:P = 2). However, in anoxic marine waters, dissolved Fe:P < 2 predominates, while most freshwater lakes exhibit Fe:P > 2. This distinction allows almost complete phosphate sequestration upon oxygenation in freshwater systems [Blomqvist, *et al.*, 2004:2236].

Additionally, water stratification is a natural occurrence in freshwater systems and more saline environments, driven by temperature or salinity gradients that result in different density properties. In freshwater, stratification is especially prevalent during summer periods due to rising temperatures. In estuarine and coastal marine waters, it becomes particularly pronounced when less dense freshwater from rivers encounters the heavier, denser saline seawater.

Limited vertical mixing between these stratified layers hinders the supply of oxygen from surface waters to the more saline bottom waters, leading to hypoxic conditions and the formation of *"dead zones"*. The development of these dead zones is exacerbated by excessive nutrient loading – with nitrogen (often the limiting nutrient in seawater) playing a crucial role [Pers. coms. Thornton, 2021]. Consequent primary production results in an accumulation of particulate organic matter, fostering microbial activity and further depleting dissolved oxygen in hypolimnetic waters. Under such circumstances, a crucial management measure for eutrophication is to limit nitrogen in effluents, as emphasised by Kemp, *et al*. (2009:2986-2990).

3.6 MEASUREMENT OF PHOSPHORUS AND NITROGEN

To assess the levels of phosphorus and nitrogen in effluents, runoff from land areas or water resources, and to determine compliance with WDSs or in-water resource water quality objectives, various parameters can be analysed and assessed.

The measurement of algal biomass, typically conducted by analysing the concentration of Chlorophyll-α in surface water resources, offers a direct indication of primary production. Although the percentage of Chlorophyll-α may vary between species or during the lifecycle of a species, it also provides an indirect indication of phosphorus (P) and nitrogen (N) levels in the water resources.

To assess phosphorus levels in wastewater and water resources, routine analyses of Total Phosphorus (TP) and orthophosphate are commonly conducted. These analyses serve various purposes, as outlined in **TABLE 5** [Pers. coms. Louw, 2022]:

TABLE 5: Assessment of phosphorus levels in water and wastewater		
PARAMETER	**DESCRIPTION**	**PURPOSE**
Total Phosphorus (TP)	All phosphorus (P) found in a water sample, whether dissolved or in the form of condensed phosphates.	Commonly analysed when sampling wastewater and water resources to indicate the total potentially available phosphorus.
Orthophosphate (PO_4^{3-})	Form of water-soluble P produced by natural processes or through human-influenced sources, like untreated sewage, and that is readily bioavailable.	Commonly analysed when sampling water resources to indicate the nutrient status of natural raw water.

To assess nitrogen levels in wastewater and water resources, the most relevant substances include ammonium nitrogen, organic nitrogen, nitrate nitrogen (NO_3) and nitrite nitrogen (NO_2). The analysis and/or assessment of these substances, depending on the purpose, are outlined in **TABLE 6** [Pers. coms. Louw, 2022]**:**

TABLE 6: Assessment of nitrogen levels in water and wastewater		
PARAMETER	**DESCRIPTION**	**PURPOSE**
Total Kjeldahl Nitrogen (TKN)	= Total Organic Nitrogen + Ammonium (NH_4^+)	Typically analysed when sampling wastewater that is associated with biological treatment processes.
Total Nitrogen (TN)	= TKN + Nitrate (NO_3^-) + Nitrite (NO_2^-)	Commonly analysed when sampling wastewater and water resources to indicate the total potentially available nitrogen.
Total Organic Nitrogen (TON)	= TKN - NH_4^+	Organic nitrogen is generally of concern more as Biological Oxygen Demand (BOD) than as a source of nitrogen.
Total ammonia	= NH_3 + NH_4^+	Provides an indication of the aerobic and anaerobic decomposition of organic material.
Free un-ionised ammonia (NH_3)	= Total ammonia - NH_4^+	Provides an indication of ammonia toxicity (which is pH and temperature dependant) that for instance affects the aquatic ecology.
Dissolved Inorganic Nitrogen (DIN)	= (NO_3^- + NO_2^-) + NH_3	Commonly analysed when sampling water resources to indicate the nutrient status of raw water.

3.7 THE TROPHIC STATUS OF WATERBODIES

Trophic status refers to the degree of nutrient enrichment in surface water resources and the amount of primary productivity that can be sustained. It is essential to note that the trophic status of water resources is influenced by multiple abiotic, biotic, physico-chemical and biological factors (**FIGURE 22**) that impact nutrient concentrations within the water resource.

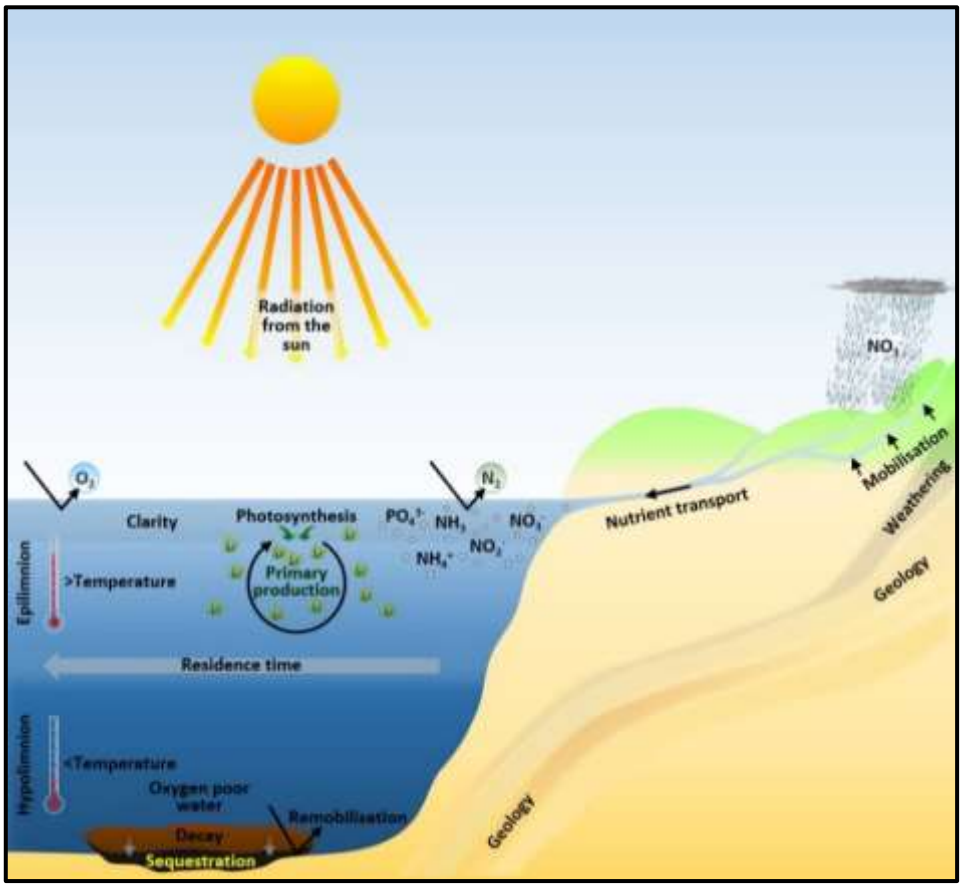

FIGURE 22: Natural factors that affect the trophic status of water resources.

Natural factors [Carlson & Simpson, 1996:1] that influence the trophic status of waterbodies, include:

- ***Atmospheric precipitation:*** Rainfall, hail, snow, etc., containing soluble nutrients (predominantly nitrates) promote primary production;
- ***Properties of geology and soils:*** These contribute to high natural background levels of phosphorus and nitrogen from mineral sources, promoting primary production;
- ***Geohydrological and hydropedological characteristics:*** Enable nutrient transport through the soil profile to promote primary production;
- ***Hydrology:*** Causes flushing or concentration of nutrients in aquatic ecosystems. Well-flushed systems generally tolerate higher nutrient inputs;
- ***Residence time and hydraulics:*** Affect cell growth and primary production;
- ***Ecological infrastructure:*** Features like wetlands provide natural attenuation and water quality improvement functions;
- ***Water chemistry:*** Primarily the concentrations of limiting nutrients (phosphorus or nitrogen) affecting primary production;

- ***Remobilisation of nutrients from bottom sediments:*** Often exacerbates and/or prolongs eutrophication problems. Release rates differ for phosphorus and nitrogen;
- ***Availability of sunlight:*** Affects plant growth. Abundance of sunlight supports primary production;
- ***Inorganic turbidity:*** Reduces water clarity and light penetration, affecting available light for plant growth. Turbid systems can tolerate higher nutrient levels;
- ***Changing temperature regimes:*** Affect stratification of the water column and algal growth patterns;
- ***Seasonal variation:*** Causes responses of algae and aquatic macrophytes to available nutrients to vary with the time of year;
- ***Morphology of the waterbody:*** Influences eutrophication impacts through both depth and shape. Deep waterbodies can tolerate higher nutrient inputs; and
- ***Primary production***: Affects the growth of algae and macrophytes.

Interestingly, while turbidity affects the penetration of sunlight, it does not necessarily influence total algal growth. Robarts and Zohary (1992:238) demonstrated that the euphotic zone of the Hartbeespoort Dam becomes compressed under turbid conditions, reducing from what would have been 6.4 m in a clear water reservoir to 0.6 m. However, primary production remains at levels consistent with the nutrient status of the particular waterbody.

The presence of nutrients is a common factor that plays a role in most of the natural influences on eutrophication discussed above. This phenomenon supports the focus of eutrophication management on the said two nutrients that are limiting to primary production in water resources, and play a key role in causing anthropogenic eutrophication [de Baar, 1994:347-386; Carlson & Simpson, 1996:2; Walmsley, 2000:14].

The causes and effects of eutrophication are very complex and vary for different aquatic systems. However, some general trends in lakes becoming eutrophic can be identified. The relationships among phosphorus input, primary production (usually phytoplankton biomass), density of benthos, submerged macrophytes, dissolved hypolimnetic oxygen, biological diversity and trophic status are conceptually illustrated in **FIGURE 23** below.

The observation that the trophic status of water resources is affected by multiple abiotic, biotic, physicochemical and biological factors highlights the importance of adapting eutrophication management to the conditions in individual ecosystems.

A Trophic State Index (TSI) is a classification system designed to rate waterbodies based on the amount of biological productivity they sustain. Although the term *"trophic index"* is commonly applied to lakes, any surface waterbody may be indexed. Trophic classification makes it possible

to describe waterbodies in terms of the primary production continuum, predict system behaviour, judge fitness-for-use and assign perceived utility [Fosberg & Ryding, 1980:189-207].

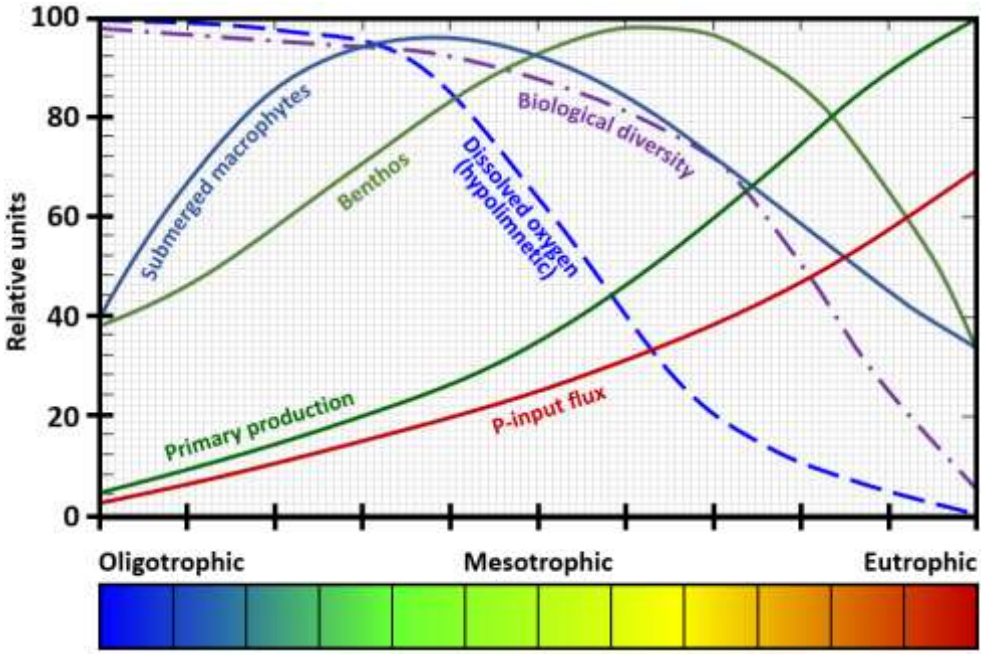

FIGURE 23: Conceptualisation of freshwater eutrophication [adapted from Roos, 2009:6 and Correll 1998:262].

Unfortunately, the biological structure of most waterbodies does not respond in a linear fashion to nutrient additions. For instance, algal biomass is usually concentrated in the benthos of fast-flowing, gravel or cobble bed streams (*i.e.*, periphyton dominated) and measured as benthic Chl-α per unit area of stream substrate. In contrast, in slow-moving, sediment-depositing rivers and lakes (*i.e.*, plankton dominated), algal biomass is suspended in the water column and measured as sestonic Chl-α per unit water volume [EPA, 2000a:26].

Toerien, *et al.* (1975:21-23) emphasised the importance of classifying South Africa's water resources according to their trophic status for eutrophication management purposes. Carlson (1977:361), followed by Fosberg & Ryding (1980:189-207), Walmsley (2000:45) and endorsed by DWAF (2002:(2)5), proposed the following definitions to describe the degrees of nutrient enrichment and the degrees of primary production that it can sustain:

- ***Oligotrophic*** denotes the presence of low levels of nutrients, the least amount of biological productivity and *"good"* water quality;
- ***Mesotrophic*** indicates intermediate levels of nutrients, moderate levels of biological productivity and *"fair"* water quality;
- ***Eutrophic*** signifies high levels of nutrients, high levels of biological productivity and *"poor"* water quality; and

- ***Hypertrophic*** represents excessive levels of nutrients, excessive levels of biological productivity, plant production being governed mostly by physical factors and water qualities ranging between *"poor"* and *"unacceptable"*. The water quality problems in hypertrophic waterbodies are almost continuous.

Vollenweider and Kerekes (1980:26-36) employed a statistical approach to quantify probability ranges for several variables within each trophic designation, generating bell-shaped curves per trophic class for each variable. The resulting overlap emphasised that waterbodies with the same concentrations may fall into more than one trophic class [EPA, 2000b:(2)12]. **FIGURE 24** depicts the primary production continuum for TP in lakes [OECD, 1982:78-82].

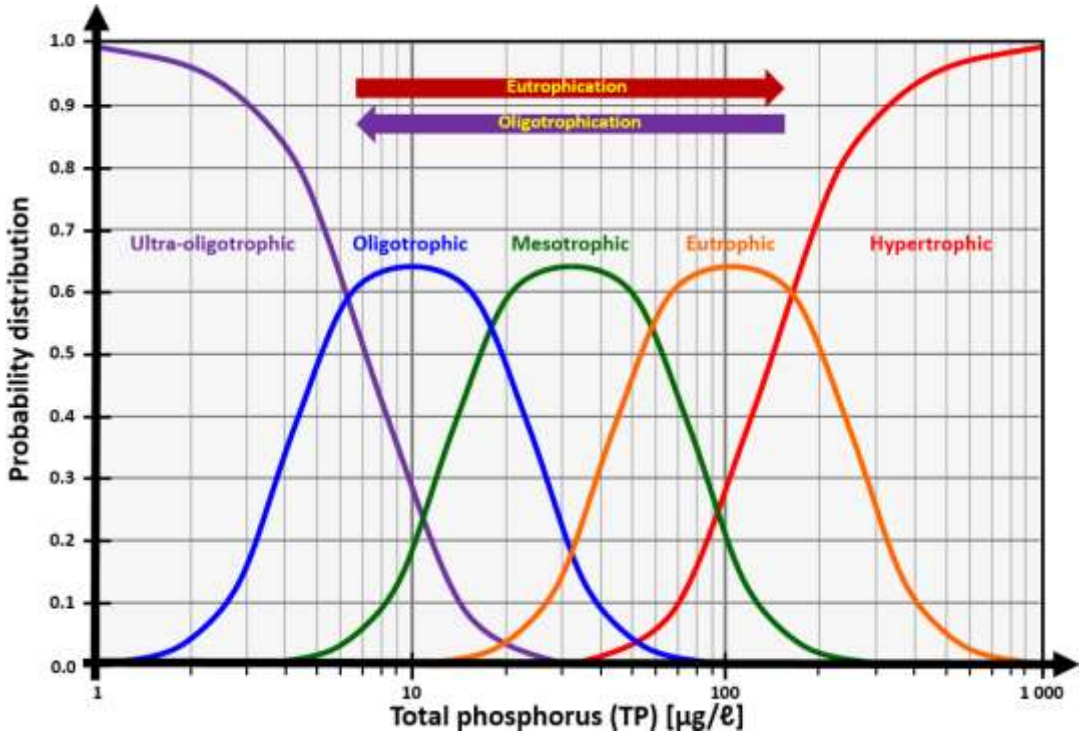

FIGURE 24: The primary production continuum [adapted from OECD, 1982:83].

While probabilistic curves are useful for characterising waterbodies in terms of the relationships between selected parameters and trophic status, their utility as a basis for developing a general TSI is limited. This limitation arises due to the substantial number of parameters that must be measured and the assumption that specific waterbody types exist [Carlson & Simpson, 1996:9]. **TABLE 7** provides examples of key physical, chemical and biological parameters along with their expected changes in response to increasing eutrophication. Initially, biological activity is expected to increase with rising eutrophication. However, beyond a certain point, increasing biological stress is likely to be incurred as eutrophication continues to increase.

Multi-parameter indices are cumbersome, and the linear relationship assumed between the parameters in some of these indices does not hold [Carlson, 1977:361]. Conversely, indices

based on a single criterion have the potential to be both unambiguous and sensitive to change. However, there is currently no consensus on what the single criterion of trophic status should be, and it is doubtful that an index based on a single parameter would achieve widespread acceptance. The ideal TSI should combine the strengths of both approaches, preserving the expression of diverse aspects of trophic state found in multi-parameter indices, yet maintaining the simplicity of a single-parameter index. This can be achieved if the commonly used trophic criteria are interrelated.

TABLE 7: Trophic criteria and their responses to increased eutrophication [67] [Rast, *et al.*, 1989:19].

PHYSICAL	CHEMICAL	BIOLOGICAL [68]
Transparency (Secchi transparency) ↓	Nutrient concentrations ↑	Algal bloom frequency ↑
Suspended Solids ↑	Chlorophyll-α ↑	Algal species diversity ↓
Electrical conductivity (EC) ↑	Dissolved solids ↑	Phytoplankton biomass ↑
	Hypolimnetic oxygen deficit ↑	Littoral vegetation [69] ↑
	Epilimnetic oxygen supersaturation ↑	Zooplankton ↑
		Fish [70] ↑
		Bottom fauna [71] ↑
		Bottom fauna diversity ↓
		Primary production ↑

In 1977, Carlson developed the TSI, which is both simple in terms of the limited number of parameters considered and appreciative of the multidimensional nature of the *"trophic status"* concept. This is achieved by considering the interrelatedness of selected parameters and other factors influencing biological activity. According to Carlson (1977:361), waterbodies are rated on a scale from zero to one hundred, with each major division (10, 20, 30, etc.) representing a doubling in algal biomass. The index number can be calculated from several parameters, including Secchi disk transparency,[72] chlorophyll-α and TP concentrations (**TABLE 8**). The TSI serves as a valuable tool in the management of surface water resources and is a valid scientific tool for investigations requiring an objective assessment of trophic status.

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[67] ↑ signifies that the value of the parameter generally increases with the degree of eutrophication; whereas ↓ signifies that the value generally decreases with the degree of eutrophication.

[68] Biological criteria have important qualitative (*e.g.,* species) changes as well as quantitative (*e.g.,* biomass) changes, as the degree of eutrophication increases.

[69] Aquatic plants in shallow, nearshore areas may decrease in the presence of high densities of phytoplankton.

[70] May be decreased in numbers and species in bottom waters (hypolimnion) beyond a certain degree of eutrophication, because of hypolimnetic oxygen depletion, *i.e.,* the initial increase may be reversed under hypertrophic conditions.

[71] Bottom fauna may be decreased in numbers and species in high concentrations of hydrogen sulphide (H_2S), methane (CH_4) or carbon dioxide (CO_2), or low concentrations of oxygen (O_2) in hypolimnetic waters.

[72] Parameters, such as clarity and transparency, should be used with circumspect in cases where dissolved organic compounds (*e.g.,* tannins) or suspended solids are present in significant amounts, as such results may be misleading — giving the impression that the waterbody is more biologically productive than it actually is.

TABLE 8: Trophic State Index (TSI) and associated parameters for waterbodies [Carlson, 1977:365; Carlson & Simpson, 1996:3].				
TROPHIC STATE INDEX (TSI)	**SECCHI DISK [m]**	**TP [µg/ℓ]**	**CHL-A [µg/ℓ]**	**Trophic Class**
0	64	0.75	0.04	*"Oligotrophic"*
10	32	1.5	0.12	
20	16	3	0.34	
30	8	6	0.94	
40	4	12	2.6	*"Mesotrophic"*
50	2	24	6.4	*"Eutrophic"*
60	1	48	20	
70	0.5	96	56	*"Hypertrophic"*
80	0.25	192	154	
90	0.12	384	427	
100	0.062	768	1183	

The trophic state of waterbodies affects its use and perceived utility (**FIGURE 25**).

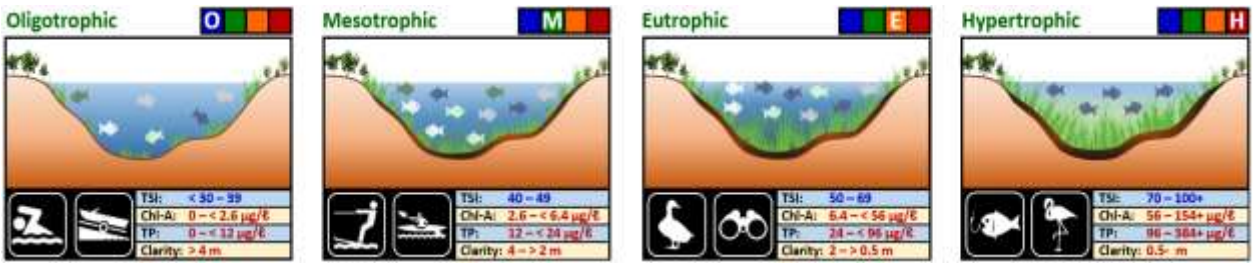

FIGURE 25: The trophic state of waterbodies affects their use and perceived utility [adapted from Carlson, 1977:361 and Fosberg & Ryding, 1980:189-207].

TSI = Trophic State Index; Chl-α = Chlorophyll-α; TP = Total Phosphorus;
Clarity = Secchi Depth; O = Oligotrophic; M = Mesotrophic; E = Eutrophic; H = Hypertrophic

TABLE 9 summarises the perceived utility of waterbodies across different trophic classes:

TABLE 9: Trophic classes and their associated perceived utility [Fosberg & Ryding, 1980:189-207].	
TROPHIC STATE INDEX (TSI) *	**UTILITY OF THE WATERBODY**
< 30	Such waterbodies are good for water sports and good sources for drinking water. These waterbodies exhibit clear water with good visibility but may potentially not provide the necessary nutrients and algae to maintain a healthy environment for fish and wildlife.
between **30 to 45**	Such waterbodies have an adequate amount of nutrients, which supports a fair number of algae, aquatic plants, birds, fish, insects and other wildlife.
between **46 to 70**	Such waterbodies have a greater amount of nutrients, which can support an abundance of algae, aquatic plants, birds, fish, insects and other wildlife.
between **71 to 100**	Such waterbodies have the highest levels of nutrients and have the potential to support the highest levels of biological productivity (*e.g.,* an abundance of algae, aquatic plants, birds, fish, insects and other wildlife.) These waterbodies, however, have the greatest potential for widely ranging dissolved oxygen conditions, which can have a detrimental effect on biological diversity, and natural plants and animals.

***** As per the TSI set out in **TABLE 8**.

Van Ginkel, *et al.* (2000b:871-878) uses the criteria, noted in **TABLE 10** below, for the concentrations of phosphorus (as TP); and planktonic algae and cyanobacteria (as chlorophyll-α), to classify the trophic status of impoundments in South Africa [DWAF, 2002:(2)5]:

TABLE 10: South African classification of trophic status according to Total Phosphorus (TP) and chlorophyll-α (Chl-α) concentrations in lakes [DWAF, 2002:(2)5].

VARIABLE	UNIT	OLIGOTROPHIC	MESOTROPHIC	EUTROPHIC	HYPERTROPHIC
Mean annual Chl-α	µg/ℓ	0 < **Chl-α** ≤ 10	10 < **Chl-α** ≤ 20	20 < **Chl-α** ≤ 30	**Chl-α** > 30
% of time Chl-α > 30 µg/ℓ	%	**%Chl-α** = 0	0 < **%Chl-α** ≤ 8	8 < **%Chl-α** ≤ 50	**%Chl-α** > 50
Mean annual TP	mg/ℓ	**TP** ≤ 0.015	0.015 < **TP** ≤ 0.047	0.047 < **TP** ≤ 0.130	**TP** > 0.130

Applying the trophic status classification criteria from **TABLE 10** to 393 South African impoundments, the results for the 2019/2020 hydrological year show that 37.7% of the reservoirs were classified as hypertrophic, 28.2% as eutrophic, 21.9% as mesotrophic and 12.2% as oligotrophic (**FIGURE 26)**. Additionally, **FIGURE 26** indicates a consistent deterioration in the trophic status of these impoundments for the 2019/2020 hydrological year compared to the 2016/2017 hydrological year [DWS, 2024].

The TSI presented in **TABLE 10**, developed for the National Eutrophication Monitoring Programme (NEMP), was specifically established for impoundments. When applying this TSI to rivers and streams, caution is advised, as adaptation may be necessary prior to its application to such water resources. While TSIs for rivers and streams may be available internationally, they will need to be adjusted to suit South African conditions, considering the aridity of the country.

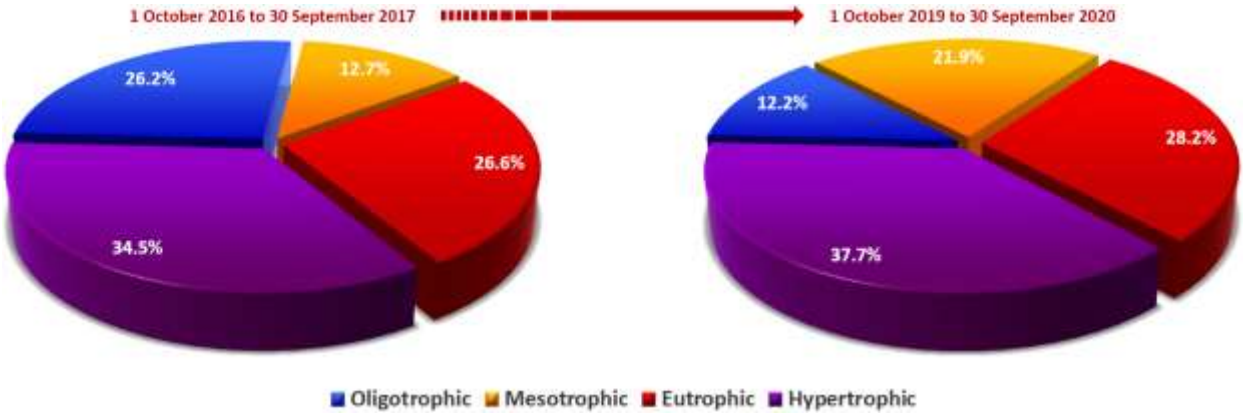

FIGURE 26: Comparison of the trophic status of 393 South African impoundments for the 2016/2017 and 2019/2020 hydrological years [Data obtained from NEWIS, 2021].

3.8 THE ROLE OF THE CATCHMENT

It is often said: *"A waterbody is a reflection of its catchment!"* [Holdren, *et al.*, 2001:13]. A river or lake is not an isolated body of water but part of a larger system that includes the surrounding land draining into such waterbodies. The geographical area from which rain and surface water drain toward a common receiving water resource is called a basin, drainage region, watershed or catchment. In addition to the natural factors affecting the trophic status of waterbodies (mentioned in **Section 3.7**), anthropogenic activities within a waterbody's catchment have a significant effect on the amount of nutrients entering the waterbody and, therefore, on primary productivity [EPA, 2000b:(2)4]. This constitutes the principal reason why appropriate nutrient standards and management objectives are required to control human activities and manage eutrophication in catchments.

The nutrient concentration of a natural waterbody is primarily influenced by the nutrient content of precipitation, the rate of weathering of geologic formations and the dissolution of natural minerals from soils in the catchment. If the underlying geology is mostly granitic, the rates of weathering will be slow, resulting in both low productivity of terrestrial vegetation and low concentrations of nutrients in the runoff from the catchment. On the other hand, if the underlying bedrock is sedimentary, the weathering rates will be higher, leading to increased fertility of the soil and higher nutrient content in the runoff water as well [EPA, 2000b:(2)4].

Human activity has at least three effects on the nutrient load input to waterbodies:

- It disturbs the overlying vegetation, exposing the soil to increased weathering and erosion [EPA, 2000b:(2)4];
- It adds easily erodible nutrient-containing material, such as fertilisers and human and animal waste, into the catchment [EPA, 2000b:(2)4]; and
- It increases the area of impervious surfaces and compacts soils making them less pervious and leading to increased runoff that acts as conveyance mechanism for sediments and nutrients. In high rainfall areas, nutrient transport can be *"supply-limited"* (little or no nutrient rich material is available to be transported) and in low rainfall areas, the nutrient transport can be *"transport-limited"* (the water volume or runoff is insufficient to result in the transport of available nutrient rich materials) [Pers. coms. Thornton, 2021].

As the biological surface of an undisturbed catchment is disrupted or converted to impervious surfaces, and as people move into the catchment, it can be expected that there will be an increased runoff of soil and nutrients. The degree of disturbance, relative to the size of the waterbody, will affect the impact of the disturbance. For instance, building a summer cottage

would not have the same impact on a lake as clear-cutting natural vegetation or dense urban development [EPA, 2000b:(2)4].

Sometimes the term *"assimilative capacity"* is used to imply that the waterbody has a certain capacity to absorb the impact of disturbance. In a eutrophication context, this concept, although comforting, probably has little basis in fact. Impact, until demonstrated otherwise, is probably better thought of as a continuous response to nutrient increases (**FIGURE 27**). The degree of change will depend on other factors, for example the size of the waterbody or any of the other factors mentioned in **Section 3.7**, and the change may not immediately or even ever be detectable to humans or their monitoring instruments. However, whether detected or not, changes do occur. It is for this reason that catchment disturbance is a sensitive early warning of waterbody change. Clearly, biological impact within the waterbody will be directly related to the increased amount of nutrient loading, and that impact will occur, whether or not it is detected [EPA, 2000b:(2)4].

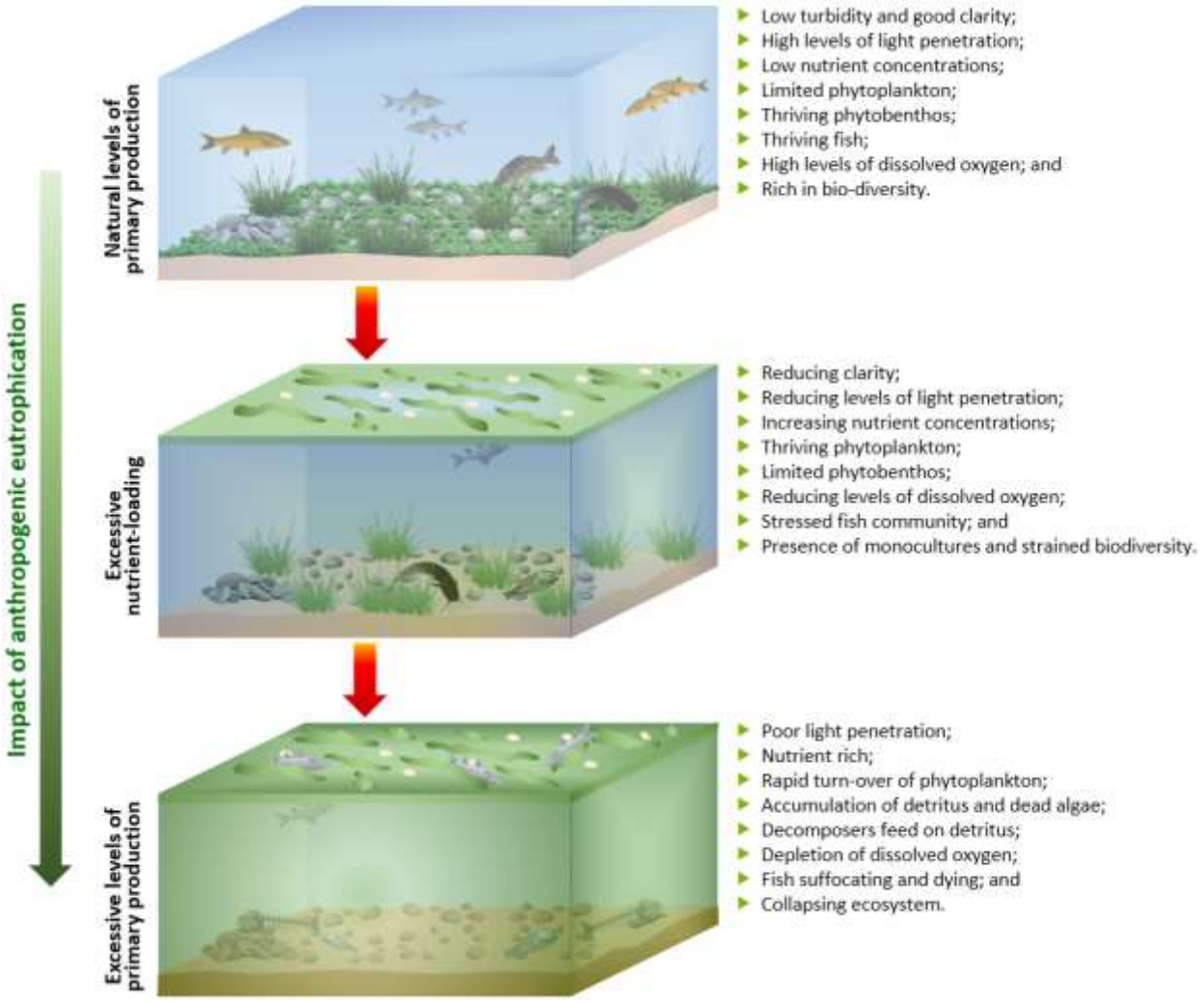

FIGURE 27: The effects of eutrophication on aquatic ecology and biological diversity.

Prevailing weather conditions in catchments also affect nutrient regimes and eutrophication in streams, rivers and impoundments. Additionally, South African impoundments, even in the hypolimnetic layer, seldom reach temperatures below 9°C. The potential for bacterial activity increases significantly at temperatures exceeding 10°C and increases exponentially with every 1°C increase above 10°C. This can have a serious impact on the anaerobic conditions, especially in hypertrophic impoundments, where anaerobic areas push through the thermocline and thus recycle nutrients to the epilimnetic waters during summer algal and cyanobacterial blooms [Pers. coms. Van Ginkel, 2022].

Human population growth and associated economic activities are the main driving forces behind eutrophication problems. Humans use numerous products and resources which contain phosphorus and nitrogen, converting them into elemental compounds (or, available phosphorus and nitrogen) and ultimately releasing them through various pathways into the aquatic environment [Walmsley, 2000:9-11]. **FIGURE 28** illustrates the linkages between human activity and eutrophication.

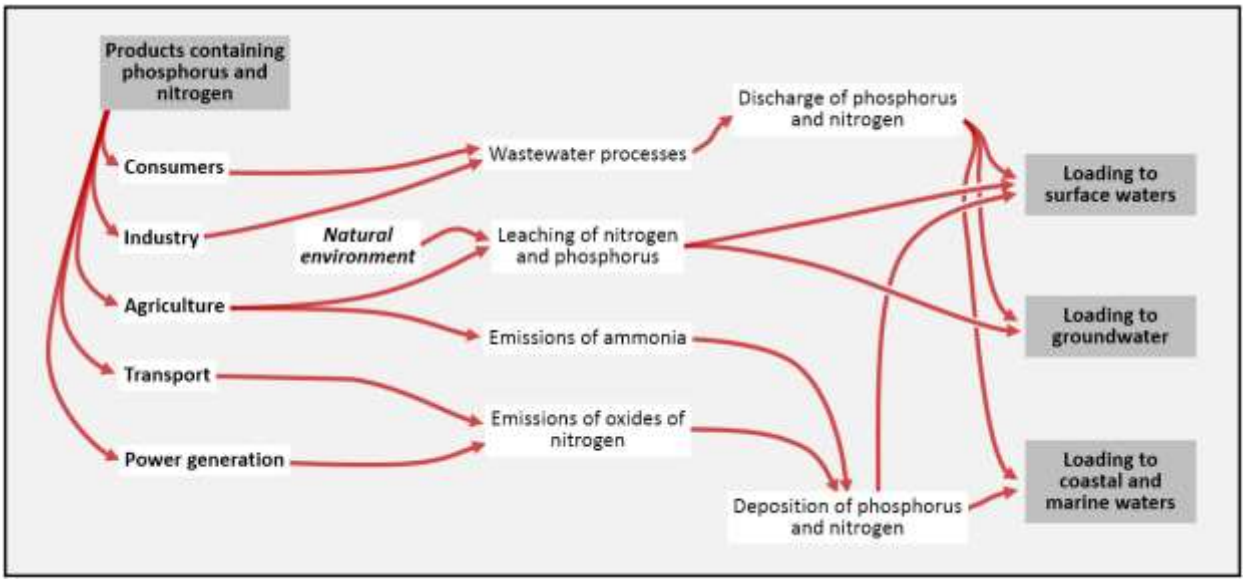

FIGURE 28: The routes by which nutrients from various sources enter waterbodies [Walmsley, 2000:10].

According to Kronvang, *et al.*, (1995:167-177), there are two path-ways in which nutrients are introduced to the aquatic environment, *viz.* as point and diffuse (non-point) sources of nutrients (**FIGURE 29**):

- ***Point sources of pollution*** are directly discharged into receiving water resources at discrete locations, such as through pipes and ditches from WwTWs, industrial sites and confined intensive livestock operations. The most severe water quality impacts from point source

pollution typically occur during summer or dry periods when river flows are low and the capacity for dilution is reduced. Additionally, impacts can be significant during storm events when uncontrolled sewer overflows occur more frequently; and

- ***Diffuse (non-point) sources of pollution*** are indirectly discharged to receiving surface water and groundwater resources, via surface flow, subsurface flow (leaching) and atmospheric deposition during periods of rainfall and irrigation. Soil properties, such as the soil pH, and iron, aluminium and calcium contents, affect the mobility of nutrients, such as phosphorus, through soils. The most severe water quality impacts from diffuse source pollution occur during storm periods, particularly after a dry spell, when rainfall induces hillslope hydrological processes and runoff of pollutants from the land surface.

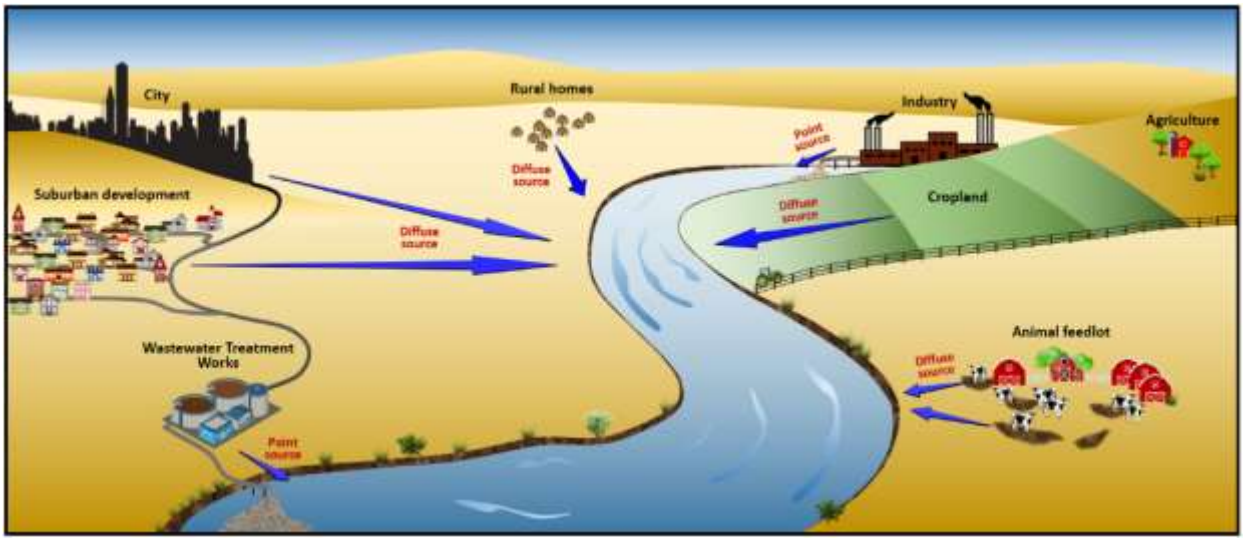

FIGURE 29: Point and diffuse sources of nutrients in a catchment context [Rossouw & Forster, 2008:7].

Models are useful for forward planning, comparing scenarios on a catchment basis and proactively recommending and implementing appropriate management interventions to prevent and address the effects of eutrophication [Álvarez, *et al.*, 2017:1-11]. Unlike salts and other conservative pollutants, nutrients act in a non-conservative manner (**FIGURE 30**). This is because nutrients, such as phosphorus and nitrogen, naturally change concentration. Some react chemically, resulting in different salts. At times, oxygen is removed from the water to release hydrogen gas, which is more volatile and escapes. Oxygen content, whether depleted or in excess, in water is the cause of many changes. For example, ammonia is oxidised to nitrites, which, in turn, are oxidised to nitrates. Nitrates cannot be eliminated except by chemical replacement, absorption or biochemical processes, as is currently done in some wastewater treatment processes. Simple mass balance modelling, therefore, is often not helpful [Zhang, *et al.*, 2019:3-5; Cai, *et al.*, 2020:5-7].

The term *"mass balance modelling"* assumes that a substance, such as phosphorus, cannot simply appear or disappear from a reservoir; **it must come from somewhere and go somewhere**. The phosphorus entering the reservoir must either exit through some outflow, sediment to the bottom, be incorporated into biomass or persist in the waterbody in either dissolved or particulate forms. It is this remaining phosphorus in the water that is of interest because it represents the amount available for primary production [Dabrowski, *et al.*, 2017:208-217; Phillips, *et al.*, 2013:506–527].

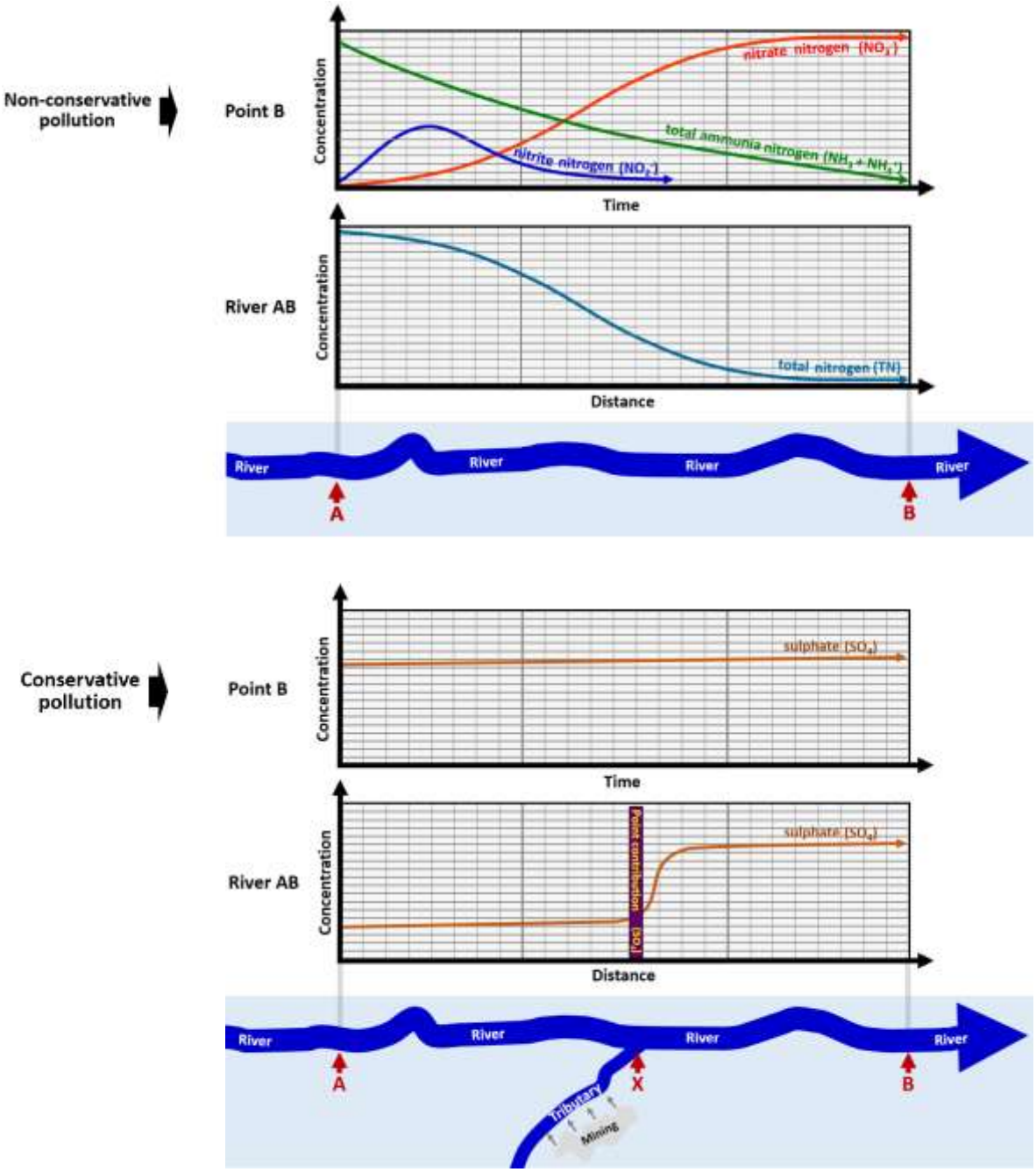

FIGURE 30: A theoretical comparison between non-conservative and conservative water pollution, comparing nitrogen and sulphate trends on *concentration-over-time*, and *concentration-over-distance* graphs.

Thornton, *et al.* (2013:298) outline eutrophication as a complex or *"wicked problem"* (see **TABLE 11**) facing society.

TABLE 11: The characteristics of a *"wicked problem"*.

According to Thornton (2013:299), the characteristics of a *"wicked problem"* include:	
(1)	The absence of a singular solution that universally resolves a wicked problem;
(2)	An indefinite endpoint when implementing solutions, indicating the complexity and ongoing nature of addressing such problems;
(3)	The lack of simple true or false answers, underscoring the complexity and nuance inherent in wicked problems;
(4)	A partial understanding of the potential outcomes of interventions, making it challenging to predict the effects of attempts to solve these problems;
(5)	The uniqueness of each solution and its outcomes, highlighting the customised approach required for each wicked problem;
(6)	An unlimited array of approaches to address a wicked problem, indicating the necessity for creative and diverse strategies;
(7)	The distinct nature of every wicked problem, emphasising their individual characteristics and challenges;
(8)	Each wicked problem being indicative of another underlying issue, suggesting a layered and interconnected nature of such problems;
(9)	The variability of outcomes when applying the same intervention to similar problems in different contexts, highlighting the influence of context on effectiveness; and
(10)	The assertion that "the planner has no right to be wrong", underscoring the high stakes and demands placed on those attempting to address wicked problems.

Therefore, eutrophication cannot be resolved solely with engineering solutions, such as applying suitable wastewater treatment technologies. Implementing a blanket approach to eutrophication governance nationwide would overlook the complexities of this issue. Complex problems, like eutrophication, may have multiple resolutions [Thornton, *et al.*, 2013:299] depending on various factors. A national approach to eutrophication governance should include catchment-focused water resource planning combined with local action.

3.9 PERSISTENT NUTRIENT LOADING AMIDST GLOBAL INTERVENTIONS

Despite several interventions, eutrophication persists as a global problem. Here are some important reasons and gaps as to why global eutrophication management interventions and governance arrangements may be failing:

- **Data and research limitations:** A lack of comprehensive data on nutrient sources, transport and impacts across various ecosystems hinders the development of targeted and effective management strategies [Conley, *et al.*, 2009:1014-1015].

- **Symptom-focused interventions:** Many intervention efforts tend to address immediate symptoms like algal blooms or hyacinth outbreaks rather than tackling the underlying causes, such as nutrient input from agricultural runoff and wastewater [Smith & Schindler, 2009:201-207]. The outbreak of water lettuce (*Pistia stratiotes*) in the Vaal River in 2023, which severely affected the Vaal Barrage Reservoir (**FIGURE 31**), serves as a pertinent example. Here, the focus was on an approach that included physical removal, biological control and chemical application, rather than addressing the introduction pathways or the sources of nutrients that sustain its proliferation [Evans, 2024].

FIGURE 31: To address the ever-growing issue of invasive water lettuce in the Vaal River, Rand Water has adopted an integrated approach that includes physical removal, biological control and chemical application. Photo sourced: © Daily Maverick, 15 February 2024.

It is important to emphasise long-term water quality planning to mitigate and prevent eutrophication, rather than continuously addressing crises with a short-term perspective. However, it is acknowledged that a balanced approach incorporating both reactive and proactive eutrophication management measures is necessary [Perry & Vanderklein, 2009:10-12].

- **Lack of management integration:** Eutrophication management often lacks an integrated approach that considers the interconnectedness of land use, water management and ecological health. This fragmentation can lead to inconsistent policies, strategies and practices. [Álvarez, *et al.*, 2017:4-6; Rabalais, *et al.*, 2009:1528-1537]. Improvements in eutrophication management can be achieved through effective coordination, appropriate institutional arrangements, cooperative planning and synergistic approaches. These efforts should involve basin states, relevant government departments, various levels of government and diverse sectors, alongside active engagement with the private sector and civil society [DWS, 2017e:1-4].
- **Public awareness and education gaps:** Public understanding of the causes and impacts of eutrophication is often limited. Increased education and awareness are necessary to foster community participation in mitigation efforts [Paerl & Paul, 2012:1349-1363]. Many individuals remain unaware of how their actions contribute to nutrient pollution or how eutrophication affects water quality, biodiversity and the economy. Strengthening community engagement and education is crucial to fostering the behavioural changes needed to support larger policy and structural interventions [Xaba, 2022:214-217].
- **Political will and governance are critical:** Eutrophication management requires stringent policy enforcement and long-term commitment, which can be difficult to achieve. Legislation may exist to regulate nutrient discharges, but without effective enforcement and accountability mechanisms, these laws do little to deter non-compliance [Turpie, *et al.*, 2017:27-43].
- **Insufficient enforcement and poor regulations:** Even when regulations are in place, enforcement can be weak due to limited resources, lack of political will and inadequate monitoring and compliance mechanisms [Carpenter, *et al.*, 1998:559-568]. Cooperative governance should not hinder the effective regulation and management of eutrophication; rather, it should enhance environmental protection and support ecologically sustainable development [Wang, *et al.*, 2006:580-582]. Additionally, it's crucial that regulatory requirements are integrated with the needs of receiving water users. Uniform regulatory requirements may not always be suitable for ensuring downstream fitness-for-use in all instances [Welsh, *et al.*, 2013:81-102].
- **Scalability of intervention across different contexts:** Another gap is in the scalability and adaptation of successful interventions across different ecosystems and socio-economic contexts. Solutions that are effective in one region may not be applicable in another due to differences in topography, climate, land use or governance structures. For instance, riparian buffer zones may work well in temperate zones but could be less effective in arid regions where water flow dynamics differ [Carpenter, *et al.*, 1998:559-568]. A one-size-fits-all strategic and operational approach will therefore not be effective in managing eutrophication [Macrae, *et al.*, 2021:529-541].

- **Mismatch between short and long-term policy imperatives:** The mismatch between short-term and long-term policy objectives further complicates effective intervention. Efforts to address eutrophication may focus on immediate reduction targets, neglecting the need for sustainable practices that prevent recurrence over the long term. Sustained commitment, funding and adaptive management are required to ensure that efforts do not fall short in the face of evolving challenges [Sharpley, *et al.*, 2014:1308-1322].
- **Growing economic and social pressures:** The need for agricultural productivity and economic growth often overshadows environmental concerns, leading to the continued use of fertilisers and practices that contribute to nutrient loading [Pretty, *et al.*, 2010:219-236]. It should be acknowledged, however, that commercial agriculture tends to apply fertilisers at optimal rates to save costs and minimise losses to the environment, whereas the cumulative impacts from smaller operators may be greater [Chien, *et al.*, 2009:270-272]. Additionally, escalating population growth and urbanisation trends significantly contribute to increasing pressure on rivers and the surrounding environment [Ayeni, 2017:69-83].
- **Misalignment of economic incentives:** Current incentive-based regulation often does not incentivise sustainable practices or adequately penalise pollution that exacerbates eutrophication, creating barriers to the adoption of more environmentally friendly solutions [Sharpley, *et al.*, 2014:1308-1326].
- **Inadequate infrastructure:** Aging or inadequate wastewater treatment infrastructure continues to pose a global challenge, as many systems are not equipped to effectively remove nutrients before discharging effluents into waterbodies [Larsen, *et al.*, 2016:930-932]. In South Africa, the increasing instances of fruitless, wasteful, irregular and unauthorised expenditure of public funds are considered serious contributing factors to this issue [Muller & Erasmus, 2020:47-62].
- **Governance and policy disconnect:** There is often a gap between policy development and practical implementation, compounded by jurisdictional overlaps and insufficient international cooperation [Galloway, *et al.*, 2008:889-892].
- **Climate change interactions:** Climate change is expected to exacerbate eutrophication through increased precipitation and temperature changes, yet many strategies do not adequately integrate climate resilience and adaptation [Jeppesen, *et al.*, 2009:187-196].

To move forward, it is crucial to adopt a comprehensive and coordinated eutrophication governance approach that prioritises long-term planning and sustainability over short-term fixes. This can be achieved by enhancing data collection and research efforts, integrating water and land use management, increasing public education and engagement and ensuring strong political commitment and effective enforcement of existing regulations. Additionally, adaptive eutrophication management strategies should be developed to remain flexible in the face of

evolving challenges, such as population growth, climate change and economic pressures. By fostering collaboration across governmental, private and community sectors, more holistic and effective framework for addressing eutrophication and safeguarding our water resources can be created for future generations.

3.10 THE DIFFERENCE BETWEEN MANAGEMENT AND GOVERNANCE

The terms *"management"* and *"governance"* are often used interchangeably in eutrophication-related discussions. However, it is essential to differentiate between these two broad terms in order to establish a sound basis for study execution. Succinct explanations for these terms are provided in **Sections 3.10.1** and **3.10.2**, respectively:

3.10.1 Management

Management is fundamentally concerned with the intricacies of daily operations. It emphasises the importance of implementing purposeful actions and decisions to achieve set goals and objectives [Linton & Brooks, 2011:606-618; Mintzberg, 1989:7-24; Pahl-Wastl, 2007:49-62]. In the context of eutrophication management, this involves implementing targeted measures, such as operational policies and strategies, to limit excessive nutrient loading, mitigate the effects of anthropogenic eutrophication and ensure fitness-for-use of affected water resources. Typically, these measures operate within an established management framework that prioritises informed decision-making, learning through practical experience and iterative continuous improvement [Conley, *et al.*, 2009:1014-1015; DWS, 2023b:112; Moen & Norman, 2009:1-10; Smith & Schindler, 2009:201-207].

A significant difference between eutrophication management and governance lies in their scope and scale [Fourie, 2020:14]. Eutrophication management tends to be local and specific, targeting eutrophication in specific waterbodies or catchment areas that contribute to eutrophication. While eutrophication management can involve activities at various geographical settings, including WMAs and transboundary cooperation, the establishment and maintenance of governance structures, systems and frameworks fall beyond the scope and scale of eutrophication management [Omann & Larson, 2012:84-95; Smith & Schindler, 2009:201-207; Tricker, 2015:30-53].

3.10.2 Governance

In contrast to managing eutrophication, eutrophication governance operates at a broader systemic scale, encompassing legislative and institutional frameworks, regulatory mechanisms, executive policies, high-level strategic arrangements and cross-sectoral cooperation spanning

various jurisdictions and sectors to address eutrophication on a more extensive scale [Dodds, *et al.*, 2009:12-19; Omann & Larson, 2012:84-95; Rodgers & Hall, 2003:1-49].

Eutrophication governance can be described as the political, social, economic and administrative systems directing and controlling institutions and organisations to manage eutrophication across different societal levels. It focuses on the structure and processes of decision-making, accountability, control and behaviour within these entities, influencing goal setting, risk management and performance optimisation [adapted from DWAF, 2006f:2].

Effective water governance relies on predictability, inclusivity, representation, accountability, efficiency, effectiveness, social equity and justice. It necessitates transparent policymaking, a competent bureaucracy and active civil engagement [DWAF, 2006f:2].

Given this, eutrophication management is likely to reference and attempt to influence eutrophication governance arrangements. Understanding eutrophication governance, therefore, is crucial before adjusting existing eutrophication management rules and approaches or introducing new ones [Folke, *et al.*, 2005:447-449; Graham, *et al.*, 2003:1-9].

Cooperative governance, as outlined in Chapter 3 of the Constitution (108:1996), is designed to promote inter-governmental relations and ensure that all spheres of government collaborate in the national interest [RSA, 1996:Ch.3]. Organs of state are required to work together in a coordinated and cooperative manner to achieve the objectives of the Constitution, including ecologically sustainable development and service delivery [Malan, 2005:226-243; Mokoena, 2020:35-58].

However, this framework does not exempt organs of state and municipalities from compliance with other legal requirements, emphasising accountability, the rule of law, separation of powers, uniformity and compliance. Cooperative governance, thus, is about ensuring that all levels of government work together within the bounds of the law to achieve the Constitutional objectives, not about providing exemptions from legal obligations [CoG, 2019:12; Municipality of Amalgamated v. Republic of South Africa, 2021].

While crucial, cooperative governance is just one aspect of the broader concept of governance, which involves civil society and the private sector [DWAF, 2006f:2].[73] This holistic approach is crucial in the context of eutrophication, as national, provincial and local government enact legislation with wide-ranging impacts on water resources and potentially the trophic status of

[73] Collaboration with the private sector and civil society is addressed in **Section 6.5.3**: Collaboration and management participation.

receiving waterbodies [Dodds, *et al.*, 2009:12-19; Omann & Larson, 2012:84-95; Tricker, 2015:30-58].

3.11 THE POLICY, STRATEGY AND LAW CONTEXT

The purpose of the ensuing discussion is to highlight the most prominent policy, strategy and legislative elements giving direction to eutrophication governance in South Africa. To this end, linkages are pursued with the international sustainable development agenda (**Section 3.11.1**); key pieces of national legislation, with respect to applicable law principles (**Section 3.11.2**); selected executive strategies (**Section 3.11.3**); and the Integrated Water Quality Management (IWQM) Policy and Strategy for South Africa (2017) (**Section 3.11.4**).

3.11.1 The international sustainable development agenda

The concept of sustainable development formed the basis of the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992. The summit marked the first international attempt to draw up action plans and strategies for moving towards a more sustainable pattern of development. Agenda 21 was one of the key outputs of UNCED, and Chapter 18 of this agenda identifies freshwater resources as an essential component of the Earth's hydrosphere and an indispensable part of all terrestrial ecosystems [UNCED, 1992:166-185].

Sustainable development was proposed as the solution to the problems of environmental degradation discussed by the Brundtland Commission in their preceding 1987 report – Our Common Future [Brundtland, 1987]. According to Brundtland (1987:Ch.2), *"sustainable development"* is: ***"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"***. This interpretation of sustainable development has been adopted in the Bill of Rights in the Constitution of democratic South Africa and forms a central theme in all our environmental legislation and policies.

The Natural Step Framework, colloquially known as The Natural Step (TNS) Funnel (**FIGURE 32**), provides a conceptual model for easy reference and discussion of the concepts of sustainable- and unsustainable development. The TNS Funnel is based on four system conditions, also known as the principles of sustainability (**TABLE 12**), that must be met for sustainability to be reached and maintained [Nathan, 2018:129].

In September 2000, the historic Millennium Declaration was signed, committing countries to achieve a set of eight measurable goals known as the Millennium Development Goals (MDGs). One of these goals, Target 7c, aimed to halve the population without sustainable access to water

and basic sanitation before 2015 [UN, 2015a:58]. Subsequently, the World Summit on Sustainable Development (WSSD) took place in Johannesburg in 2002, assessing progress since the initial Rio Summit. The Johannesburg Summit resulted in three key outcomes: a political declaration, the Johannesburg Plan of Implementation and various partnership initiatives. Notable commitments included those related to sustainable consumption and production, water and sanitation, and energy [WSSD, 2002:14-23]. Building on this momentum, the Rio^{+20} conference (UNCED) in Rio de Janeiro in June 2012 initiated the development of a new set of 17 Sustainable Development Goals (SDGs) to carry forward the progress generated by the MDGs beyond 2015. This new global development framework, called Agenda 2030, aims to address a broader spectrum of challenges [UN, 2015b:7].

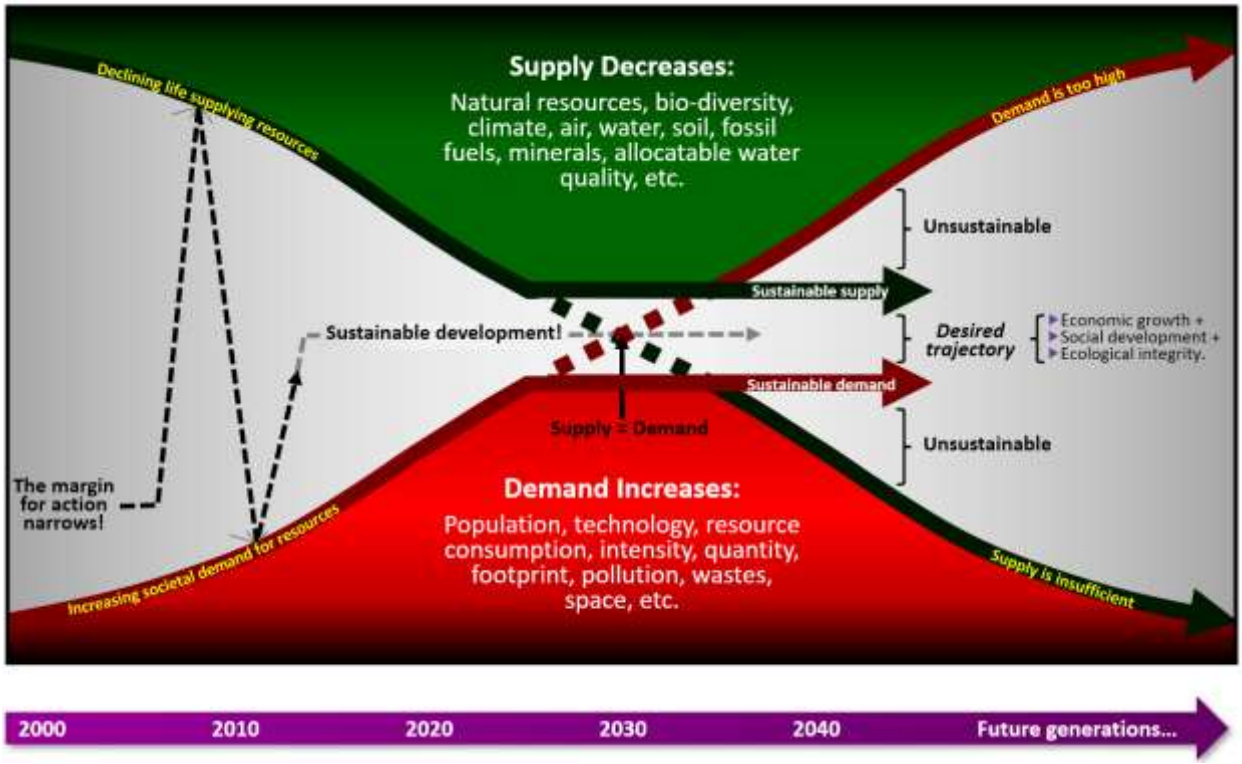

FIGURE 32: Natural Step Funnel demonstrating converging global supply and demand [adapted from Nathan, 2018:130].

TABLE 12: The four principles of sustainability [Robèrt, 2002:6], related to eutrophication.	
IN A SUSTAINABLE SOCIETY –	
Principle 1	***… nature is not subjected to systematically increasing concentrations of substances extracted from the Earth's crust;***
	Explanation: Ecosystem functions and processes are altered when society mines and disperses materials at a faster rate than they are being redeposited back into the Earth's crust. (Examples of these materials are phosphorus, coal and metals, such as lead.)

IN A SUSTAINABLE SOCIETY –	
Principle 2	***… nature is not subjected to systematically increasing concentrations of substances produced by society;***
	Explanation: Ecosystem functions and processes are altered when society produces substances faster than they can be broken down by natural processes, if they can be broken down at all (for example, a build-up of nutrients in the environment causing eutrophication).
Principle 3	***… nature is not subjected to systematically increasing degradation by physical means; and***
	Explanation: Ecosystem functions and processes are altered when society extracts resources at a faster rate than they are replenished (for example, overharvesting trees or fish), or by other forms of ecosystem manipulation (for example, causing soil erosion or paving over fertile land).
Principle 4	***… human needs are being met worldwide.***
	Explanation: By considering the first three principles of sustainability, within which human life-supporting structures and functions are being altered, three basic principles for maintaining essential ecological processes have been defined. Principle 4 recognises that social and economic dynamics fundamentally drive the actions that lead to ecosystem changes. Principle 4, therefore, focuses on the socio-economic dimension in terms of the importance of meeting human needs worldwide as an integral and essential part of sustainability.

The SDG programme, endorsed by Heads of State (including by South Africa), serves as a reporting platform to measure the sustainability of countries, prompt action in cases of poor performance or deteriorating trends, bolster local accountability and enable global comparisons. SDG 6 specifically focuses on clean water and sanitation, ensuring the availability and sustainable management of water and sanitation for all. SDG 6 is detailed through six SDG targets and two additional supporting SDG targets. Among these, four SDG targets specifically relate to eutrophication management (**TABLE 13)**. A series of twelve indicators, some global, some domesticated and other additional indicators,[74] were proposed to collectively measure progress against the said four SDG targets:

TABLE 13: SDG 6 targets and indicators, with direct relevance to eutrophication management.

SDG 6:	**Ensure availability and sustainable management of water and sanitation for all.**
SDG TARGET 6.2:	**SANITATION AND HYGIENE**
By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.	
Indicator 6.2.1:	Proportion of population using safely managed sanitation services, including a handwashing facility with soap and water.
SDG TARGET 6.3:	**WATER QUALITY AND WASTEWATER**
By 2030, improve water quality by reducing pollution, eliminating dumping and minimising release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.	
Indicator 6.3.1D:	Proportion of water containing waste lawfully discharged.

[74] The annotation: *"D"* for *"Domestic"* and *"A"* for *"Additional"*, as per UN convention, is used to identify the indicators in **TABLE 13**. In cases where neither *"D"* nor *"A"* is denoted, the global indicator wording was retained, as proposed by the UN, and has been adopted without change for South Africa.

Indicator 6.3.2D:	Proportion of bodies of water that complies with water quality objectives.
Indicator 6.3.3A:	Proportion of water containing waste recycled or reused.
Indicator 6.3.4A:	Proportion of waste lawfully disposed of.
Indicator 6.3.5A:	Proportion of waste recycled or reused.
SDG TARGET 6.5:	**WATER RESOURCES MANAGEMENT**
By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.	
Indicator 6.5.1:	Degree of integrated water resources management implementation (0 - 100).
Indicator 6.5.2:	Proportion of transboundary basin area with an operational arrangement for water cooperation.
SDG TARGET 6.6:	**WATER-RELATED ECOSYSTEMS**
By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.	
Indicator 6.6.1D(1):	Change in the spatial extent of water-related ecosystems over time, including wetlands, reservoirs, lakes and estuaries as a percentage of total land area.
Indicator 6.6.1D(2):	Number of systems affected by high trophic and turbidity states.
Indicator 6.6.1D(3):	Change in the national discharge of rivers and estuaries over time.
Indicator 6.6.1A(1):	Change in the ecological condition of rivers, estuaries, lakes and wetlands.

Importantly, it has been observed that water pollution affects each of the other 16 SDGs, underscoring the inter-relatedness and importance of water resources that are fit-for-use in sustainable development. Enhanced synergy between the SDG programme, specifically the SDG targets and indicators summarised in **TABLE 13**, and the management of eutrophication must be encouraged – particularly in relation to the following:

- Reporting on the safe management of faecal waste along the entire sanitation value chain, from containment to final treatment and disposal;
- Reporting on compliance to phosphorus and nitrogen WDSs;
- Reporting on water resource quality, with respect to phosphorus and nitrogen loading;
- Reporting on the application of wastewater recycling and reuse strategies;
- Reporting on the degree of integration of water resource management efforts; and
- Reporting on the status of ecological systems affected by phosphorus and nitrogen loading.

3.11.2 Key pieces of national legislation

3.11.2.1 Constitution of the Republic of South Africa, 1996 (Act No.108 of 1996)

The Bill of Rights contained in the Constitution of the Republic of South Africa, 1996 (Act No. 108 of 1996)[75] applies to all law, binding the legislature, executive, judiciary and all organs of state.

[75] Hereafter referred to as the Constitution (108:1996) or the Constitution.

Section 24 (**TABLE 14**) in the Bill of Rights places a duty on the state to implement reasonable legislative and other measures to protect water resources and ensure that they are not harmful to anyone's health and well-being. In this context, *"other measures"* include the roll-out and implementation of a eutrophication governance strategy to protect water resources and ensure they are not harmful to anyone's health and well-being.

TABLE 14: Constitution of the Republic of South Africa, 1996 (Act No. 108 of 1996): Bill of Rights: Implications for water resources

ENVIRONMENT **Section 24 addresses the *"environment"* in its broad context, considering the ecology, social and economic dimensions.**	**WATER RESOURCES** **Section 24 paraphrased to address the *"freshwater environment"*, as a subset of the *"environment"*, considering the ecology, social and economic dimensions.**
Everyone has the right-	**Everyone has the right-**
(a) to an **environment** that is not harmful to their health or well-being and	**(a)** to **water resources** that are not harmful to their health or well-being and
(b) to have the **environment** protected, for the benefit of present and future generations, through reasonable legislative and other measures that-	**(b)** to have **water resources** protected, for the benefit of present and future generations, through reasonable legislative and other measures that-
(i) prevent pollution and ecological degradation;	**(i)** prevent pollution and ecological degradation;
(ii) promote **conservation**; and	**(ii)** **conserve water**; and
(iii) secure ecologically sustainable development and use of **natural resources** while promoting justifiable economic and social development.	**(iii)** secure ecologically sustainable development and use of **water resources** while promoting justifiable economic and social development.

Additionally, Section 27 in the Bill of Rights places a duty on the state to take reasonable legislative and other measures, within its available resources, to achieve the progressive realisation of providing sufficient water to everyone. While the right to basic sanitation is not explicitly stated in the Constitution, it could be derived from the right to a clean environment (Section 24), read together with the right of access to clean water (Section 27). Once again, it is inferred that *"other measures"* include the roll-out and implementation of a eutrophication governance strategy to ensure the fitness-for-use of receiving water resources, including effective sanitation services.

Many other constitutional rights in the Bill of Rights overlap with, and support the rights to clean water resources, water supply and sanitation services. These include the rights to equality (Section 9), dignity (Section 10), access to information (Section 32) and just administrative action (Section 33) [Algotsson, *et al.*, 2009:2].

The rolling-out and implementation of the eutrophication governance policy and strategy for South Africa should undoubtedly promote these constitutional rights. It must protect water resources against the effects of eutrophication, thereby contributing to securing ecologically

sustainable development and the use of water resources while promoting justifiable economic and social development.

3.11.2.2 National Environmental Management Act, 1998 (Act No.107 of 1998)

According to Glazewski (2005), environmental law encompasses the following three distinct but interrelated areas of general focus:

- Land-use planning and development;
- Resource conservation and utilisation; and
- Waste management and pollution control.

Overseeing these three focus areas affects eutrophication governance. The National Environmental Management Act, 1998 (Act No. 107 of 1998)[76] is a framework act and, therefore, provides overarching mechanisms, principles and procedures that inform– (1) other acts, particularly the Specific Environmental Management Acts (SEMAs) of which the NWA (36:1998) is part; and (2) subordinate or subsidiary regulations. Additionally, the statutory mechanisms, principles and procedures established by NEMA (107:1998) would also apply to subsequent environmental policy and strategy being established, including eutrophication governance policies and strategies for South Africa.

NEMA (107:1998) defines *"sustainable development"* as *"the integration of social, economic and environmental factors into planning, implementation and decision-making so as to ensure that development serves present and future generations"*. NEMA (107:1998), further, provides that sustainable development requires the consideration of all relevant factors including-

- that the disturbance of ecosystems and loss of biological diversity are avoided, or, where they cannot be altogether avoided, are minimised and remedied;
- that pollution and degradation of the environment are avoided, or, where they cannot be altogether avoided, are minimised and remedied;
- that the disturbance of landscapes and sites that constitute the nation's cultural heritage is avoided, or where it cannot be altogether avoided, is minimised and remedied;
- that waste is avoided, or, where it cannot be altogether avoided, minimised and re-used or recycled where possible and otherwise disposed of in a responsible manner;
- that the use and exploitation of non-renewable natural resources is responsible and equitable, and considers the consequences of the depletion of the resource;

[76] Hereafter referred to as the NEMA (107:1998).

- that the development, use and exploitation of renewable resources and the ecosystems of which they are part do not exceed the levels beyond which their integrity is jeopardised;
- that a risk-averse and cautious approach is applied, which considers the limits of current knowledge about the consequences of decisions and actions; and
- that negative impacts on the environment and on people's environmental rights be anticipated and prevented, and where they cannot be altogether prevented, are minimised and remedied.

NEMA (107:1998) further sets out several supporting national environmental management principles. These principles also have relevance to eutrophication governance and serve as guidelines that any organ of state must apply in any function or when taking any decision concerning the protection of the environment.

In addition, NEMA (107:1998) calls for *"co-operative environmental governance"*, a phrase derived from the constitutional mandate [RSA, 1996:Ch.3]. According to this mandate, all spheres and organs of government are obliged to coordinate their actions by establishing principles to be considered in all decision-making processes affecting the environment.

NEMA (107:1998) plays a crucial role in providing for co-operative environmental governance by establishing principles for decision-making on matters affecting the environment. Additionally, it establishes institutions that will promote co-operative governance and procedures for coordinating environmental functions exercised by organs of state.

Key environmental regulatory authorities include:

- Department of Agriculture, Land Reform and Rural Development (DALRRD);
- Department of Forestry, Fisheries and the Environment (DFFE);
- Department of Mineral Resources and Energy (DMRE); and
- Department of Water and Sanitation (DWS).

All spheres of government and all organs of state must cooperate, consult, and support one another on matters involving or affecting the environment, including those related to eutrophication. **Cooperative environmental governance must promote the right to an environment that is not harmful and may not be used as a mechanism to evade accountability.**[77]

[77] Refer to **POLICY STATEMENT 11**: Eutrophication management responsibility and accountability.

3.11.2.3 National Water Act, 1998 (Act No.36 of 1998) and Water Services Act, 1997 (Act No.108 of 1997)

The National Water Act, 1998 (Act No. 36 of 1998),[78] along with the Water Services Act, 1997 (Act No. 108 of 1997),[79] promotes sustainability and equity as central guiding principles in managing water resources and services. The NWA (36:1998) specifically addresses integrated water resource management, encompassing the protection, use, development, conservation, management and control of water resources. It focuses on promoting efficient, sustainable and beneficial water use in the public interest, facilitating social and economic development, protecting aquatic ecosystems and their biodiversity, and reducing and preventing pollution and degradation of water resources. On the other hand, the WSA (108:1997) contains provisions for basic water supply and sanitation services.

Water law in South Africa is based on *28 fundamental principles and objectives*, as approved by Cabinet in November 1996 [DWAF, 1997:34]. Eutrophication governance policies and strategies should conform to these fundamental principles and objectives, particularly the 13 that are of foremost relevance to eutrophication governance. Accordingly, eutrophication governance policies and strategies must–

- acknowledge that eutrophication management is nested within the broader concept of catchment management *[links to Principle 5 and finds expression in the NWA (36:1998) inter alia in Chapter 2]*;
- strive to contribute towards long-term ecologically sustainable social and economic development [*links to Principles 7 and 9 and finds expression in the NWA (36:1998) inter alia in Chapters 3 and 4*];
- contribute towards water resource use, development, management and control that is in the public interest, sustainable, equitable and efficient, while also honouring relevant international obligations *[links to Principle 13 and finds expression in the NWA (36:1998) inter alia in Chapter 2 and 4]*;
- where desirable, promote wastewater reuse and recycling [*links to principle 14 and finds expression in the NWA (36:1998) inter alia in Chapter 4*];
- acknowledge interrelatedness between eutrophication and water quantity, *i.e.*, water flow, level and pattern *[links to Principle 15 and finds expression in the NWA (36:1998) inter alia in Sections 13]*;

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[78] Hereafter referred to as the NWA (36:1998).

[79] Hereafter referred to as the WSA (108:1997).

- employ financial incentive systems, such as the Waste Discharge Charge System (WDCS), to limit and prevent excessive primary production in receiving water resources *[links to Principle 16 and finds expression in the NWA (36:1998) inter alia in Chapter 5]*;
- consider land use management and management cooperation, as a means of limiting and preventing anthropogenic eutrophication *[links to Principle 18 and finds expression in the NWA (36:1998) inter alia in Sections 12 and 26(1)(g)]*;
- promote effective water use authorisation [*links to Principle 19 and finds expression in the NWA (36:1998) inter alia in Chapter 4*];
- acknowledge the roles of disaster management in limiting danger to life and property [*links to Principle 21 and finds expression in the NWA (36:1998) inter alia in Chapter 14*];
- enable role-players and other stakeholders to participate [*links to Principle 23 and finds expression throughout the NWA (36:1998)*]; and
- ensure that water services are provided in a manner consistent with the goals of water resource management [*links to Principles 25 and 27 and finds expression in the NWA (36:1998) inter alia in Chapter 2 and in the WSA (108:1997) inter alia in Chapter 3*].

The water law provisions, as outlined above alongside the implications of the *13 fundamental principles and objectives* most relevant to eutrophication governance, are further contextualised in **Section 4.3.2.1**. Additional supporting context is elaborated upon in **Annexure F**.

3.11.3 Selected executive strategies, plans and frameworks

3.11.3.1 National Water Resource Strategy and National Water and Sanitation Master Plan

The National Water Resources Strategy (NWRS) is a statutory document established under the NWA (36:1998), binding all authorities and institutions that exercise powers or perform duties under the Act. It outlines the strategic imperatives for water management at regional or catchment levels within specified WMAs. The National Water and Sanitation Master Plan (NW&S MP) functions as the implementation mechanism for the NWRS, detailing priority budget allocations up to 2030 and beyond for the entire water sector [DWS, 2018c:(2)1]. Together, the NWRS and NW&S MP constitute the primary framework for water management across all sectors, aligning with national government's development objectives [NPC, 2012:62].

The Eutrophication Governance Strategy for South Africa and the NWRS-NW&S MP duo have a reciprocal relationship. The eutrophication governance strategy provides detailed insights for the NWRS-NW&S MP on managing eutrophication effectively, while the NWRS-NW&S MP offers a broader strategic perspective on integrated water resource management priorities to inform eutrophication management.

3.11.3.2 National Development Plan (2030) and National Water Security Framework

The National Development Plan (NDP), finalised in 2012, articulates the vision of development for the country, highlighting key milestones and targets across several sectors. The relationship between the NDP and eutrophication governance in South Africa is rooted in the broader context of water resource management and environmental sustainability. The NDP emphasises the importance of maintaining and improving water quality, given that South Africa is a water-scarce country. Eutrophication directly impacts water quality, leading to detrimental effects on aquatic ecosystems. The NDP outlines strategies to address water pollution and implement better governance frameworks, including the development of regional water and wastewater utilities to ensure effective water management [DWS, 2018b:11].

Furthermore, the NDP highlights the need for comprehensive water resource management programs that include the development of irrigation systems and urban water schemes, which are crucial for mitigating eutrophication. These plans align with eutrophication governance by advocating for improved wastewater management and efficiency in water use, particularly in the urban and agricultural sectors. The Plan also stresses the importance of a national water conservation program aimed at reducing pollution and preserving the quality of water resources.

In addition to these governance frameworks, the NDP calls for stronger environmental management systems that promote sustainable practices. The Plan suggests implementing an environmental management framework that addresses serious environmental and social impacts. This includes mitigating the effects of industrial and agricultural activities that contribute to eutrophication, ensuring that these sectors follow sustainable practices and comply with environmental standards.

The National Water Security Framework (NWSF) for South Africa integrates key principles, scope, and recommendations drawn from the NDP and the work of the National Planning Commission (NPC), which oversees NDP implementation. Aligned with the UN Water definition of water security [UN WATER, 2013], which emphasises safeguarding sustainable access to adequate quantities of acceptable-quality water for livelihoods, well-being and socio-economic development, the NWSF supports Jepson *et al.* (2017)'s perspective that water security is about enhancing human capabilities regarding water rather than merely securing it. This aligns with the NDP's vision of improving living standards, reducing poverty and inequality, and restoring the dignity of South Africans. The NWSF aims to ensure national water security by considering all significant current water uses, as shown in **FIGURE 33**. By focusing on national priorities, underpinned by a thriving economy [Nepfumbada & Seetal, 2020:4], the NWSF seeks to address the broader goals outlined in the NDP.

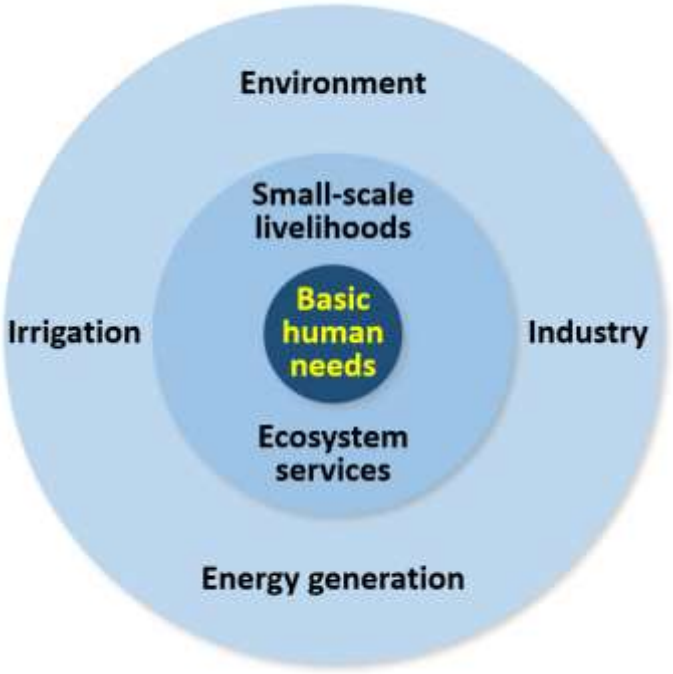

FIGURE 33: Important socio-economic water uses requiring water security [Nepfumbada & Seetal, 2020:4].

The escalating incidents of over-enrichment of water resources pose a threat to all seven socio-economic water uses illustrated in **FIGURE 33**. Consequently, this jeopardises a thriving South African economy. Therefore, eutrophication governance policies and strategies for South Africa must align with the sentiments of the NWSF, emphasising the necessity for a deliberate and concerted effort to ensure water security for the current and future socio-economic development needs of South Africa.

3.11.4 The Integrated Water Quality Management Policy and Strategy for South Africa (2017)

As of 2017, the Integrated Water Quality Management (IWQM) Policy and Strategy constitutes the apex policy and strategy for water quality management in South Africa, as depicted in **FIGURE 34**.

The IWQM Policy [DWS, 2017d:4] aims to–

- provide a coherent, consolidated, current and inclusive approach to water quality management;
- align water quality management policy with current legislation and overarching policy, addressing matters not adequately covered in existing policies;
- guide the further development of legislative and regulatory instruments;
- inform the water resource management function;

- address key operational aspects, such as adopting an integrated approach, broadening finance mechanisms, and enhancing knowledge and information in water quality management execution;
- offer guidance on sustainable water use, particularly concerning water quality management; and finally
- provide the necessary framework for the development of related policies and strategies, such as the eutrophication governance policy and strategy for South Africa, as a sub-strategy.

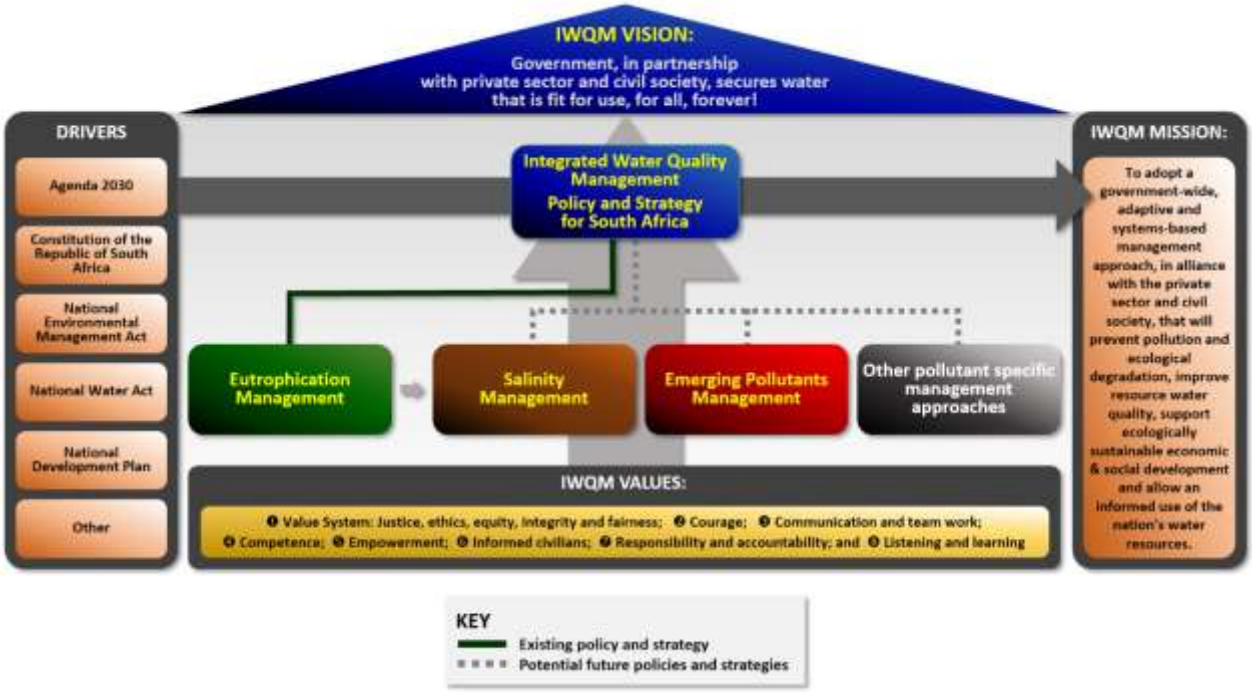

FIGURE 34: Relationship between the Integrated Water Quality Management (IWQM) Policy and Strategy for South Africa and the eutrophication governance policy and strategy for South Africa.

The IWQM Strategy outlines essential short, medium and long-term actions to help achieve the goals of the IWQM Policy, aiming to halt and reverse the decline in water resource quality [DWS, 2017f:3]. It recognises eutrophication as a priority issue requiring urgent intervention [DWS, 2017e:9] and incorporates the following Strategic Objectives (SOs) related to managing eutrophication [DWS, 2017e:43]:

- Harmonising policies and strategies impacting IWQM (SO1a);
- Ensuring effective support for IWQM by the NWA (36:1998) and/or the WSA (108:1997) (SO2a);
- Ensuring effective support for IWQM by other legislation (SO2b);
- Establishing and maintaining partnerships/stewardships (SO4a);
- Implementing targeted and strengthened compliance monitoring and enforcement of key polluting sectors (SO6b); and

- Realising sustained capacity for Government/CMA/sector to effectively manage and support IWQM through improved education and training (SO11b).

The IWQM Policy and Strategy for South Africa (2017) provides a comprehensive framework to tackle water quality challenges through a coherent and inclusive approach. It seeks to align policy with existing legislation, guide the development of regulatory instruments and offer operational guidance for sustainable water use, especially in managing water quality. This policy and strategy emphasise the importance of coordinated efforts across government sectors and stakeholders to address water quality degradation and ensure the sustainable management of South Africa's water resources.

3.12 CONCLUSION

The literature reviewed in **Chapter 3** provides an overview of eutrophication, nutrient cycling and their governance in South Africa. Eutrophication, driven by excessive nutrient loading from human activities, primarily phosphorus and nitrogen, remains a critical environmental issue. These nutrients, while essential for biological productivity, cause significant ecological disturbances and degrade water quality when present in elevated concentrations.

This chapter emphasised the dual nature of eutrophication – both natural and anthropogenic – and the need for governance structures to manage human-induced nutrient pollution. Phosphorus and nitrogen were highlighted as limiting factors for biomass proliferation, necessitating close monitoring. The use of TSIs for classifying waterbodies underscored the need for effective catchment management to limit nutrient overloading.

The chapter also examined international and national governance frameworks, particularly South Africa’s IWQM Policy and Strategy. This policy and strategy align South Africa’s eutrophication management with other strategic requirements.

Catchment-based management is crucial for mitigating nutrient pollution by considering local hydrological conditions. However, persistent nutrient pollution, despite interventions, highlights the need for ongoing improvements in governance and management.

Overall, **Chapter 3** served as a prelude to developing a critical understanding of eutrophication governance in South Africa. It set the stage for forthcoming discussions, emphasising the need for a multi-faceted approach to governance. The challenges identified will inform the development of robust policy and strategy aimed at addressing the environmental and socio-economic impacts of nutrient pollution on the country’s water resources.

THE RESEARCH CONTEXT OF CHAPTER 4

Chapter 4 represents the principal analytical and evaluative stage of the doctoral research. Material generated during this evaluation was also reflected in and informed Part 1 of the EMSSA [DWS, 2023b]. In particular, the six key challenges evaluated in Section 4.2 correspond with the challenge discussion in Part 1, Chapter 1 of the EMSSA, while aspects of the historical, current and prospective governance analysis in Section 4.3 correspond with Part 1, Chapter 5 (*Evolution of eutrophication management in South Africa*). Selected wording and factual descriptions are therefore common to both outputs. The causal chain and DPSIR work in Section 4.5 also informs the problem declaration and policy and strategy responses presented in the EMSSA.

The thesis develops this analytical work considerably beyond the requirements of the applied government policy and strategy output. It contains detailed evaluations of individual governance challenges, a fuller examination and forecasting of governance evolution, detailed analysis of the national survey in Section 4.4, causal chain and DPSIR analyses in Section 4.5, and integration of stakeholder evidence in Section 4.6. The EMSSA condenses relevant findings from this larger analytical body into the context, problem definition and response framework required to support national policy and strategy. The shared material, therefore, represents selected outputs of the broader analytical work undertaken through the integrated research process.

CHAPTER 4 EVALUATION OF EUTROPHICATION GOVERNANCE IN SOUTH AFRICA

4.1 INTRODUCTION

FIGURE 35 positions the reader in terms of the high-level thesis structure, whereas **FIGURE 36** depicts the section content of Chapter 4 (this chapter).

FIGURE 35: High-level thesis structure (Y*ou have arrived at Chapter 4*).

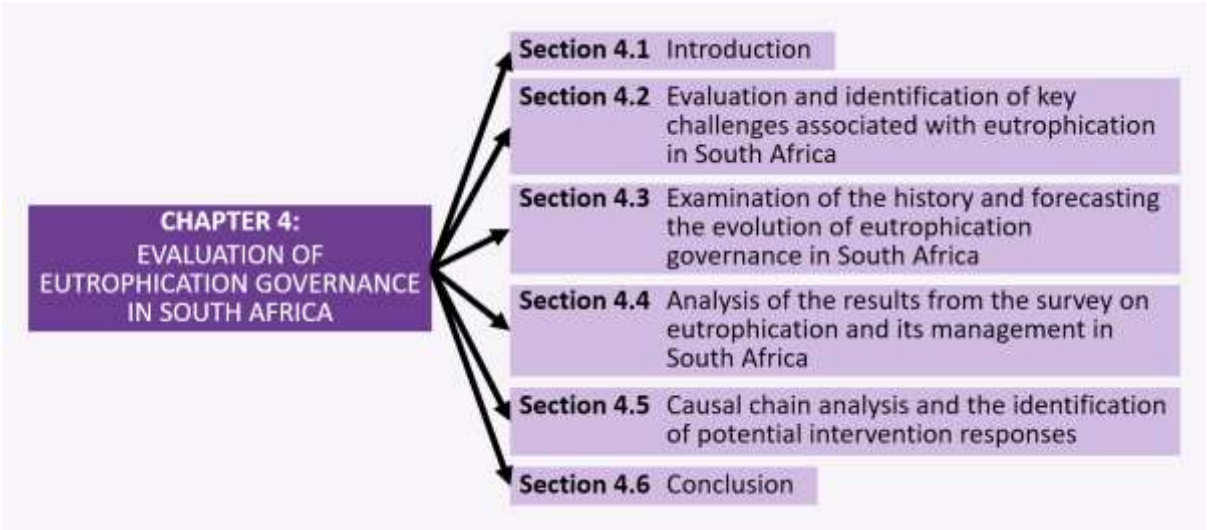

FIGURE 36: Section topics covered in Chapter 4.

Chapter 4 marks the beginning of three consecutive *"results chapters"* (**FIGURE 37**), delving into the outcomes following the execution of the research methodology delineated in **Chapter 2**.

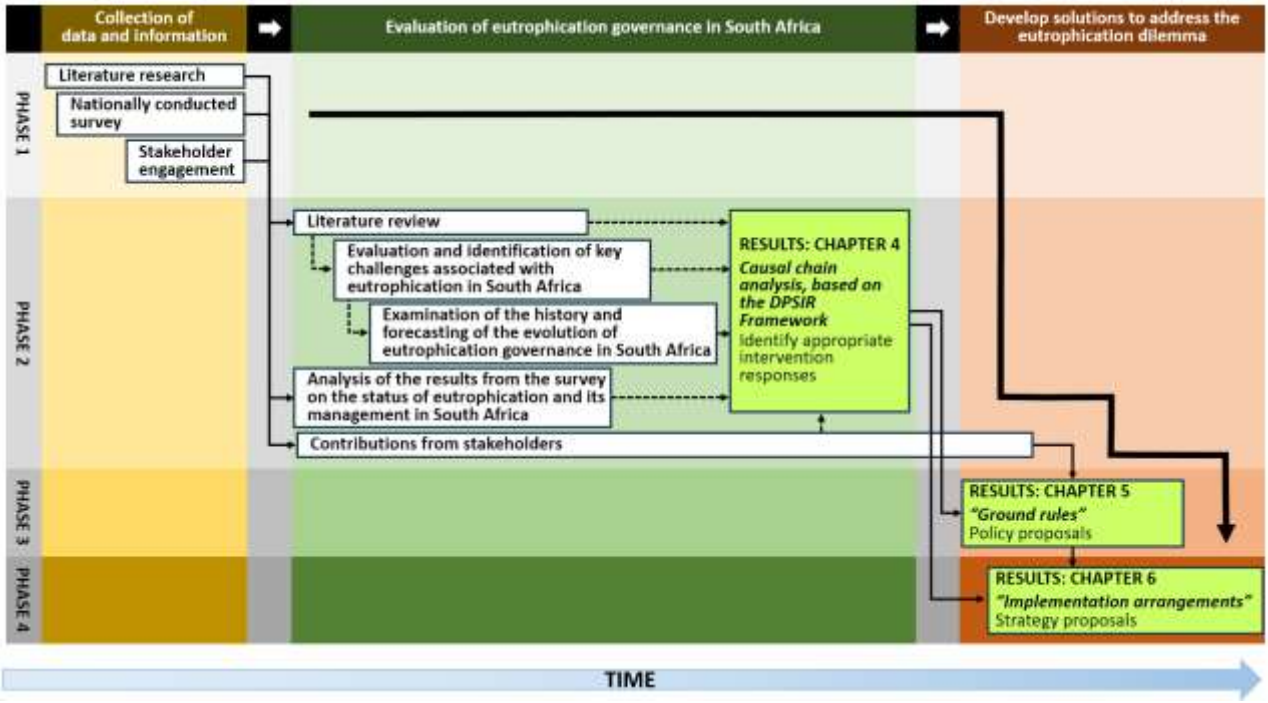

FIGURE 37: Sequential execution of the research methodology, linked to outcomes.

To develop a critical understanding of eutrophication governance in South Africa, it was necessary to establish a solid foundation of appropriate intelligence on the topic. For this reason, considerable effort was made to collect sufficient data and information on eutrophication and its governance from several sources (**FIGURE 38**), employing the method descriptions outlined in **Section 2.3**.

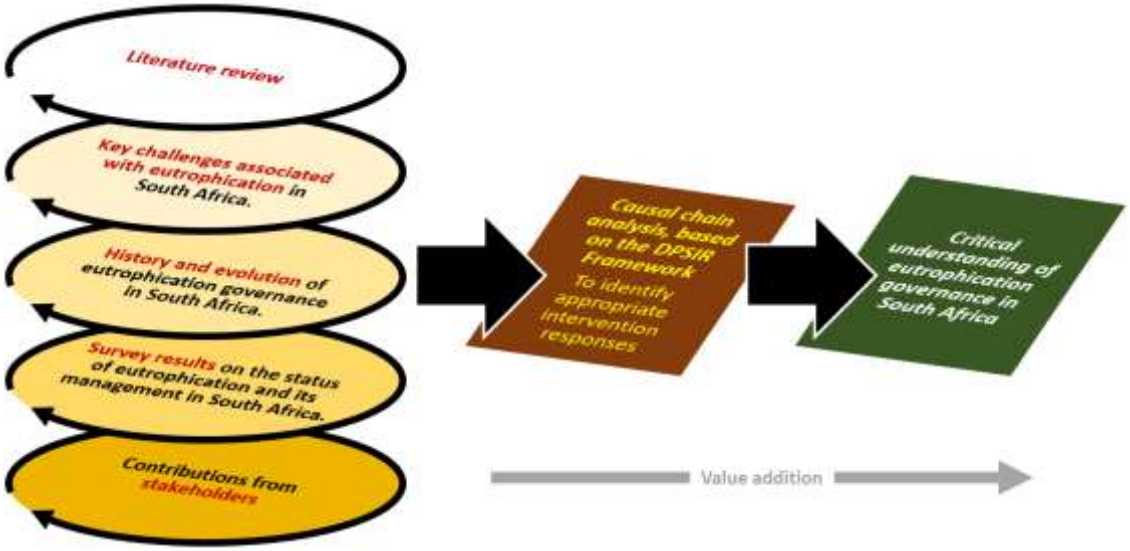

FIGURE 38: Towards a critical understanding of eutrophication governance in South Africa.

This data and information was then carefully evaluated from multiple perspectives, employing the method descriptions outlined in **Sections 2.3** and **2.4**, aiding informed research synthesis, decision-making and recommendations. A key function of the diverse data and information sources was to facilitate informed causal chain analysis, which helped establish a deeper understanding of eutrophication governance in South Africa (**FIGURE 38**). By analysing the data and information from different angles and converting it into governance intelligence, comprehension of the causes, nature and effects of anthropogenic eutrophication could be enhanced.

As such, **Chapter 4** includes the following:

- An evaluation and identification of key challenges associated with eutrophication in South Africa (**Section 4.2**);
- An examination of the evolutionary aspects of eutrophication governance and forecast of probable future regulatory adjustments (**Section 4.3**);
- A detailed analysis of results from a nationally conducted survey[80] on the status of eutrophication and its management (**Section 4.4**);
- A thorough examination of causal relationships, utilising the DPSIR Framework, to address root causes of failure and to propose intervention solutions (**Section 4.5**); and
- Stakeholder engagement,[81] which played an important role in enhancing research outputs (**Section 4.6**).

The primary focus throughout these sections is on aligning eutrophication-related problems with appropriate intervention responses. This effort will ultimately culminate in proposals for eutrophication governance policy in **Chapter 5** and strategy in **Chapter 6** for South Africa.

4.2 EVALUATION AND IDENTIFICATION OF KEY CHALLENGES ASSOCIATED WITH EUTROPHICATION IN SOUTH AFRICA

South Africa itself boasts some of the most highly enriched surface waters in the world [Ashton, *et al.*, 1985:1-2; Van Ginkel, *et al.*, 2000b:871-872]. A contemporary analysis of eutrophication in South Africa revealed that between 41% and 76% of the raw water stored in the

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[80] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[81] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

major national impoundments was either eutrophic or hypertrophic [Harding, 2015:1]. When coupled with the fact that the NWRS ranks eutrophication as the highest concern among thirteen tiers of water quality issues, including salination and Acid Mine Drainage (AMD) [DWS, 2023a:60], this finding becomes particularly concerning for a semi-arid country where impounded water largely underpins the quality of socio-ecological and economic existence [Harding, 2015:1].

Eutrophication challenges in South Africa[82] are exacerbated by– (1) i**nsufficient wastewater infrastructure maintenance and investment**; (2) **deteriorating ecological infrastructure**; (3) **recurrent droughts, driven by climatic variation, and an inescapable need for water resource development**; (4) **inequities in access to safe sanitation, against the backdrop of a growing population**; (5) **water use regulation that is not consistently and adequately protecting water resources against eutrophication**; and (6) **a lack of skilled water scientists and engineers** [DWS, 2018a:46; DWS, 2018b:5; DWS, 2018c:(2)1]. Poor water quality is already having significant impacts on economic growth and the well-being of South Africans [DWS, 2017c:5].

4.2.1 Insufficient wastewater infrastructure maintenance and investment

One of the most frequently quoted opening statements on water issues in South Africa typically emphasises that *"… South Africa is a water-scarce country with severely limited water resources ..."*. What is less commonly mentioned is that wastewater return flows constitute a significant component of the country's water budget and that discharges of water containing waste are mandated to be returned to surface water resources for indirect reuse further downstream [Harding, 2017:31].

The significance of well-functioning municipal wastewater infrastructure lies in its role as the last barrier and final interface between untreated urban wastewater and healthy aquatic ecosystems; other receiving water users that optimally contribute to economic growth; and the health of the country's population [Mitchell, *et al.*, 2014:1]. While poor wastewater handling is a leading cause of nutrient over-enrichment, this factor in eutrophication is also intertwined with other water quality challenges such as microbial pollution and associated health risks; elevated Chemical Oxygen Demand (COD); and others that impact wastewater reuse and recycling strategies. Studies indicate that up to 70%, and sometimes even more, of the water abstracted by cities returns as polluted effluent [SA Commission of Enquiry into Water Matters, 1970]. Municipal urban wastewater return-flow profiles include residential, commercial, business and industrial users, as

[82] Key challenges associated with eutrophication in South Africa were identified through an examination of data and information from relevant literature, in accordance with the method description outlined in **Section 2.3.1**.

well as schools, hospitals, sports and recreation facilities, parks and government institutions, implying that poor urban wastewater handling affects society at multiple levels.

South Africa possesses an extensive network of collection and sewer network systems, pumping stations and WwTWs. Collectively, these systems are designed to ensure that the quality of waterborne urban wastewater complies with authorised levels before being discharged, reused or recycled. However, a significant concern is evident, as approximately 56% of the over 1 150 municipal WwTWs in the country are in poor or critical condition, and urgently require rehabilitation [DWS, 2018b:2]. Moreover, some facilities previously serving households have become inadequate due to various factors, including poor facilities operation, infrastructure operated above its design capacity (**FIGURE 39)**, vandalism, ageing infrastructure and insufficient maintenance (**FIGURE 40**). Other challenges include poorly constructed and operated on-site sanitation systems, as well as ventilated improved pit latrines (VIP) pits and septic tanks not being emptied regularly. Compliance with Green Drop requirements, assessed in 2021 as part of the 2022 Green Drop Assessment,[83] was generally very poor. Out of a total of 850 WwTWs, 828 were unable to achieve Green Drop Certification [DWS, 2022:15].

FIGURE 39: Streams of poorly treated and untreated sewage and industrial wastewater, exacerbating the effects of anthropogenic eutrophication, have become an all too familiar face in many parts of the country. Photos: © P. Venter.

[83] The Green Drop Certification Programme has been relaunched by the Department of Water and Sanitation with a full Green Drop audit conducted in 2021/22.

South Africa stands out as one of the most unequal countries globally, grappling with extraordinarily high levels of unemployment and poverty [DWS, 2018b:79]. Sixty-three percent of households earn less than R 38 000 per annum, placing them at indigent level. This reality results in a high level of grant dependency, with corresponding impacts on affordability and the viability of services. Notably, 77% of rural households fall into the indigent category, exempt from paying for basic municipal services. The percentage of individuals benefiting from social grants steadily rose from 12.7% in 2003 to 29.7% in 2016 [DWS, 2018b:79] and surged to 39,4% in 2023 [Stats SA, 2023:23], imposing a growing burden on already limited government financial resources for financing the operation and maintenance of municipal WwTWs. In addition to these challenges, effective administrative and management practices face hindrance due to systemic corruption associated with many municipalities in South Africa [Muller & Erasmus, 2020:12].

FIGURE 40: Vandalism, ageing infrastructure and insufficient maintenance of sewage infrastructure cause water pollution, which contributes to eutrophic conditions in receiving water resources.
Main photo: © P. Venter; Insert photo: © J.J. van Wyk.

This situation has led to a lack of proper operation and maintenance of both *"regulated"* WwTWs and *"unregulated"* sanitation services, such as on-site sanitation systems, in most municipalities. The frequent discharge or leakage of sub-standard return flows or untreated sewage into the environment is a common occurrence that significantly contributes to nutrient loading of water resources, thereby exacerbating the prevalence of eutrophication. Consistent operation and maintenance of wastewater infrastructure, along with the adoption of good practices, are essential for upholding principles of health, dignity and the protection of water resources. This, in turn, contributes to an improved quality of life for all in South Africa.

4.2.2 Deteriorating ecological infrastructure

The fundamental hydrological unit for water resource quality management is the catchment, emphasising the unity of the water cycle and the interdependence of its elements. Elements, such as evaporation, clouds and precipitation are intricately linked to groundwater, rivers, lakes, wetlands and the sea [DWAF, 1997:35]. Each catchment heavily relies on extensive ecological infrastructure to maintain healthy functioning aquatic ecosystems and to provide essential services, often referred to as *"nature-based solutions"*. Ecological infrastructure encompasses mountain catchment areas, streams, rivers, subsurface water movement, floodplains, lakes, wetlands, estuaries, coastal dunes, the marine environment, as well as beds and banks of water resources, nodes and corridors of natural habitat. Together, these elements form a network of interconnected structural elements in the landscape [SANBI, 2014:3].

The ecological infrastructure in catchments provides valuable services, including freshwater for domestic, industrial, agricultural and recreational use; support for ecotourism; soil formation; provisioning of medicine and food, including fish and wild foods; hydropower generation; regulation of climate variability; reduction of flood and drought risks; air purification; crop pollination; pest and disease control; waste decomposition and detoxification; and functions related to water quality improvement, such as nutrient cycling and dispersal. This ecological infrastructure serves as the nature-based equivalent of built or hard infrastructure, playing an equally crucial role in providing services, ensuring water security and underpinning socio-economic development. Despite the invaluable *"free services"* derived from ecological infrastructure, few authorities or utilities list catchments as assets on their books and landowners are not typically rewarded for good management practices that result in downstream user benefits [WRC, 2014:14].

A healthy aquatic ecosystem remains intact in its physical, chemical and biological components, along with their interrelationships, demonstrating resilience to withstand changes and stressors. Signs of a healthy aquatic ecosystem include the absence of abnormal growth or decline of native species, non-persistence of elevated concentrations of contaminants (exemplified by excessive orthophosphate, as shown in **FIGURE 41**)[84] and the avoidance of drastic anthropogenic changes to its landscape or ecological processes [Baron & Poff, 2004:52-55].

[84] The Reserve, as per IUA 3/ RU 3.1/ EWR 3 in Drainage Region A21J [GN 1388, 2017], that has application to the Hartbeespoort Dam was used. On average, 15 water samples per month were collected near the dam wall for statistical analysis. The samples taken at depths ranging from the surface up to 5 metres were all treated equally and were regarded as representative of the water quality of the dam, *i.e.,* the assumption is that the dam acts as a completely mixed body of water for the purpose of representing the data on the graph.

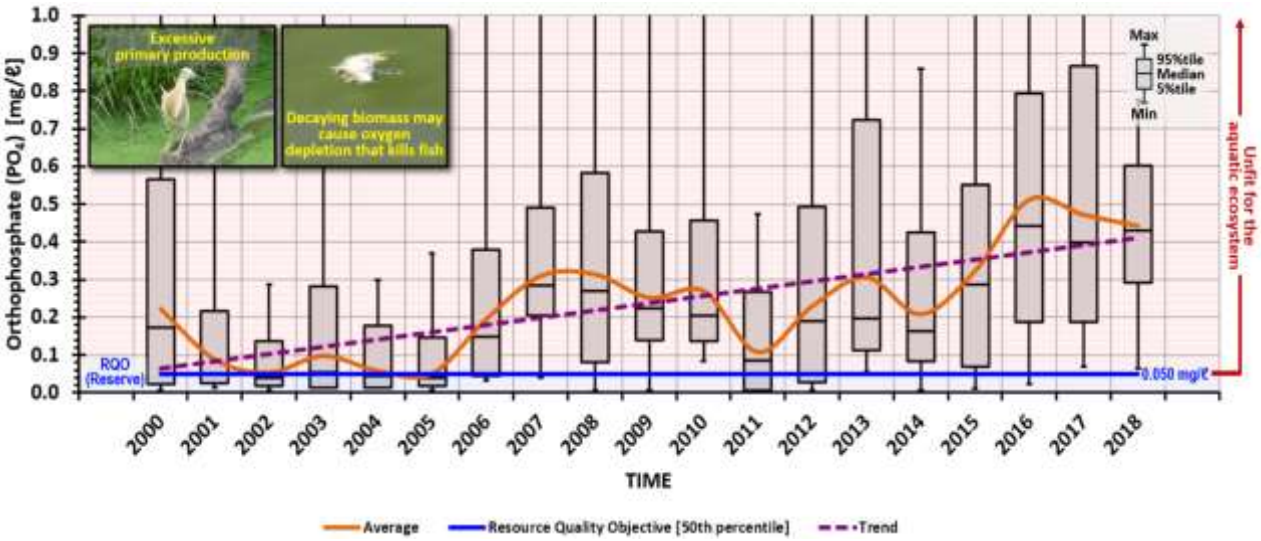

FIGURE 41: Aquatic ecology is the water user most sensitive to orthophosphate levels. The graph indicates that the Reserve, established to protect the Hartbeespoort Dam's ecology, is frequently being exceeded. Insert photos: (Left) © P. Venter; (Right) © J.J. van Wyk.

Unfortunately, socio-economic development and growth often come with adverse impacts on ecosystem health and ecological infrastructure. Human-induced effects exacerbate nutrient loading and eutrophication. As shown in **FIGURE 42**,[85] increasing trends in nitrogen loading and primary production are observed across the six large South African dams that were analysed. The reasons for the slight improvement in phosphorus loading are unclear, but it might be related to the introduction of phosphate-free detergents in South Africa a few years ago [DWS, 2015b:3]. Notably, an average annual phosphorus load of ~600 tons and a nitrogen load of ~2,000 tons are evident across these dams.

Eutrophication, recognised as a persistent environmental hazard in aquatic ecosystems, leads to a series of deteriorations in water quality and poses risks to biotic components. These risks, as outlined by various sources [Baron & Poff, 2004:52-58; Chamier, *et al.*, 2012:345-356; Clark, *et al.*, 2017:1-24; Kazmi, *et al.*, 2022:852; Padedda, *et al.*, 2017:21-33], include:

- Increased occurrences of floating and rooted aquatic macrophytes;
- Loss of native plant species, replaced by alien plant species, affecting water quality through reduced dilution capacity, altered nutrient cycling and increased occurrences of soil erosion;
- Increased occurrences and intensity of nuisance algal blooms;

[85] Loads were calculated for the Hartbeespoort, Roodeplaat, Bloemhof, Vaal, Vanderkloof and Sterkfontein Dams. The first three dams are known to experience elevated trophic conditions compared to the latter three. For the load calculations, it was assumed that the epilimnions of these dams act as completely mixed systems. Monthly load estimates were determined using average concentrations from surface water quality samples taken at the dam walls, combined with daily total dam outflow volumes.

- Growing dominance of cyanobacteria, including toxic species;
- Impact on drinking water quality, affecting taste and odour due to the presence of pollutants like Geosmin and 2-methylisoborneol (2-MIB), which are challenging to remove during water treatment and increase water treatment costs;
- Undesirable aesthetic conditions, such as discolouration, increased turbidity, foaming and presence of odours;
- Severe shading and light attenuation caused by macro algae and phytoplankton blooms, hindering photosynthetic processes in benthic plants and leading to benthic habitat stress and destruction;
- Loss of benthic diversity, affecting and stressing bottom-feeding fish and other animals;
- Increased occurrences of deoxygenation in reservoir bottom waters, resulting in elevated levels of hydrogen sulphide, heavy metals and nutrients;
- Decomposition of organic matter leading to an oversupply of CO_2, enhancing water acidification;
- Harmful effects on aquatic animals, including fish gill clogging, poisoning by toxin secretion, localised anoxia affecting subsistence and sports fishing;
- Increased fish and invertebrate mortality;
- Changes of ecological community structure and loss of biological diversity; and
- Mortality of domestic and wild animals drinking hypertrophic waters containing toxins.

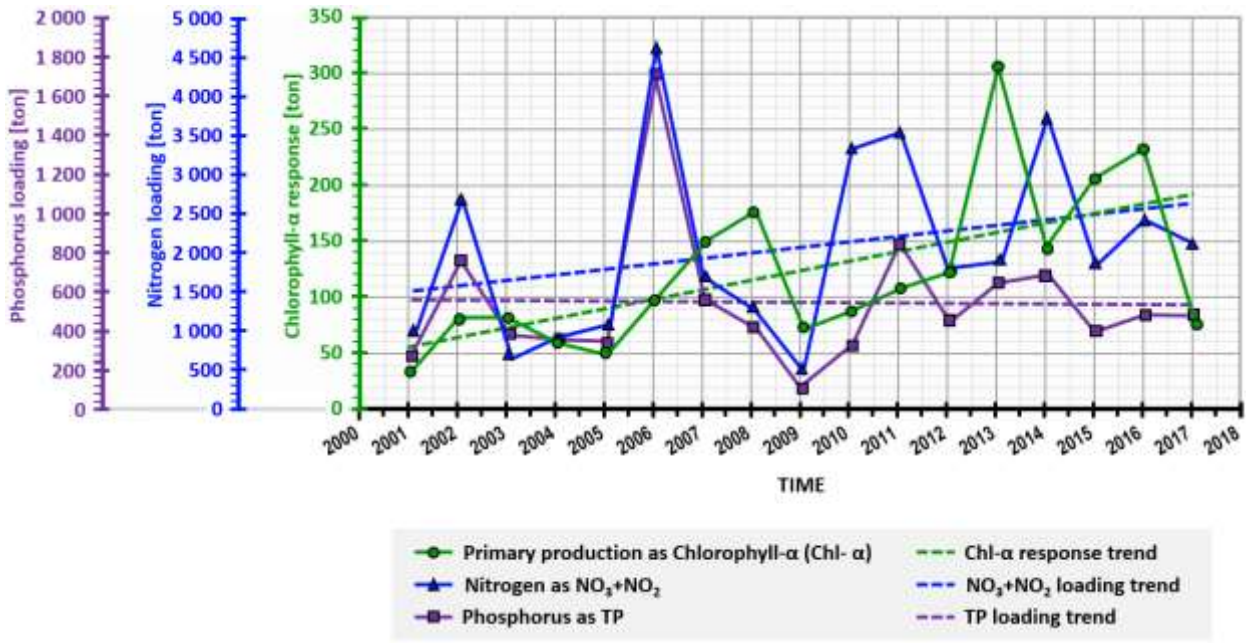

FIGURE 42: Aggregated annual phosphorus and nitrogen loading of, and primary production in six large South African dams.

The White Paper on a National Water Policy for South Africa (1997) states: *"The sustainable use of water resources means that, even where the immediate demands for development are very high, society must find different development approaches which ensure that the use of water resources does not destroy their ability to recover"* [DWAF, 1997:13]. Protecting our ecological infrastructure is not optional but obligatory.

4.2.3 Recurrent droughts (driven by climatic variation) and an inescapable need for water resource development

Large parts of South Africa experience relatively low rainfall and water resources, particularly surface water systems, are highly developed through numerous large dams across the country [DWS, 2018b:19]. Dams can be viewed as a *"necessary evil"* that, along with other water supply interventions, play a crucial role in ensuring continued water security in the country [DWA, 1986:6.45; Venter, 1971:29]. However, the damming of surface water resources significantly modifies the ecological functioning of river systems. In particular, dams sequester nutrient elements and, hence, reduce downstream transfer of nutrients to floodplains, wetlands, lakes and the coastal marine environment. Additionally, impoundments influence regional nutrient limitation patterns, food web dynamics and trophic conditions, often resulting in the presence of hypertrophic conditions in reservoirs [Maavara, *et al.*, 2015:15603–15608].

The Hartbeespoort Dam, for instance, was constructed in 1923, about 35 kilometres north-west of Johannesburg and 20 kilometres west of Pretoria. It first overflowed in March 1925 [De Beer, 1975:405]. Originally built for irrigation purposes, it is currently also utilised for domestic, recreational and industrial purposes. However, since the late 1950s, the dam has been experiencing problems with nuisance algae and floating water plants [Pers. coms. Silberbauer, 2022]. Impacts stemming from the upstream urban zones are increasingly affecting the resource quality of the Hartbeespoort Dam. **FIGURE 43** demonstrates how trophic conditions are compromising the suitability of the Hartbeespoort Dam for recreational purposes. These deteriorating conditions also adversely affect the regional economy and property values in the area surrounding the dam [Botha, 2015:45-47; Mitchell, *et al.*, 2016:7-9].

Drought conditions in South Africa, driven by climate variation, are expected to have a major impact on the country, with resulting consequences for ecosystems, people and the economy. Water is the primary medium through which the impact of climate change is anticipated [DWS, 2013:75]. Climate change is anticipated to result in shifts in rainfall patterns, changes in storm intensities and increased extremes of floods and droughts. Higher solar radiation intensities, rising ambient air temperatures and elevated evaporation rates are also expected. Consequently, these factors will affect soil moisture and runoff, leading to increased water demand in some areas and alterations in water availability. Moreover, changes in water quality

conditions, such as the water temperature of aquatic systems and increased climate variability, are projected [DWS, 2015a:22]. Additionally, climate change is likely to worsen the trophic status of water resources by impacting both internal and external nutrient loadings. This effect is linked to **elevated ambient temperatures**, **shifting precipitation patterns**, **varying solar radiation intensity** and **changing wind speeds** [Nazari-Sharabian, *et al.*, 2018:3668].

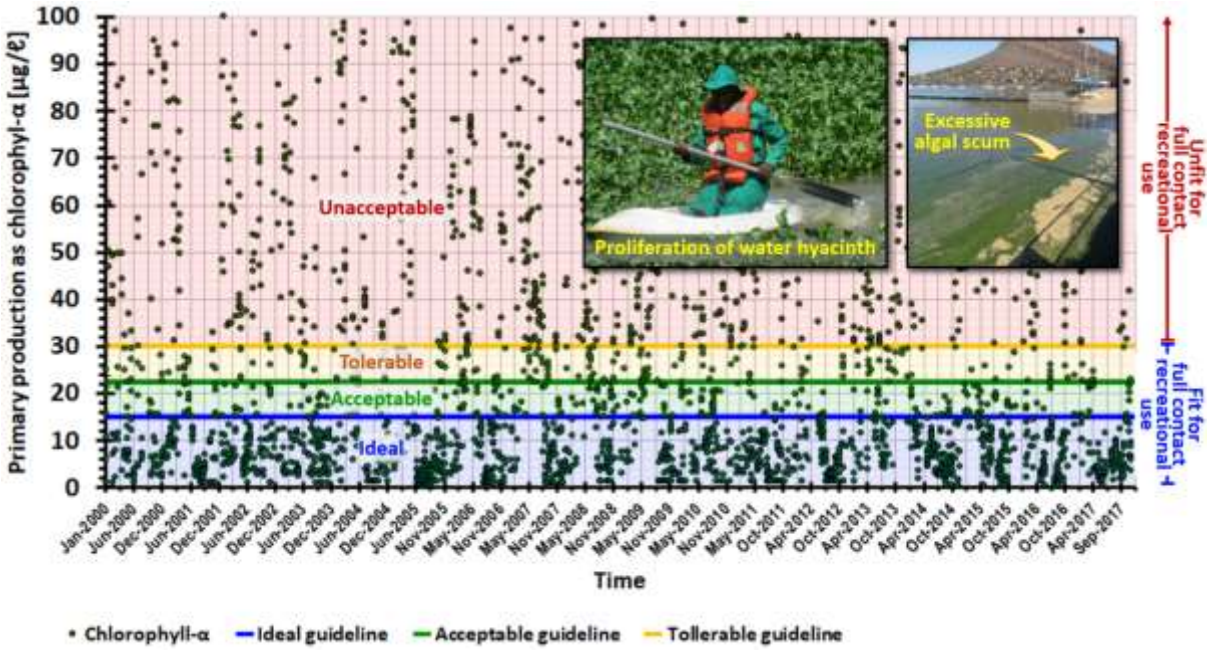

FIGURE 43: Excessive primary production in the epilimnion, measured as chlorophyll-α concentrations per single sample, has an adverse effect on recreational water use in the Hartbeespoort Dam. Insert photos: © P. Venter.

Warmer **water temperatures**, resulting from heat exchange between a warmer ambient atmosphere and the water column, influence the chemical and physical properties of water. For instance, as water temperatures rise, pH decreases, salinity decreases, the solubility of solids increases and the solubility of gases, such as oxygen, decreases. Additionally, diffusion rates increase and the rates of biochemical processes initially rise. When water temperature and nutrient concentrations increase, primary production is stimulated, leading to eutrophic conditions and algal blooms [Mooij, *et al.*, 2007:584-442]. This effect is particularly pronounced within stratified reservoirs that act as nutrient traps [Schmutz & Sendzimir, 2018:114].

As temperatures rise, precipitation is not expected to change uniformly. In areas with projected **higher precipitation**, there is a possibility of intense precipitation events that may cause increased erosion, resuspension of sediments and mobilisation of diffuse sources of pollution. This, in turn, can result in higher concentrations of sediments and nutrients ending up in receiving water resources [Vogel, *et al.*, 1999:148-156; Whitehead, *et al.*, 2009:105]. In areas with projected **lower precipitation**, it is possible that lower minimum flows, coupled with higher rates

of evaporation and evapotranspiration, will occur. This could lead to reduced dilution capacity in receiving water resources. Consequently, increased concentrations of contaminants may cause deoxygenation by lowering dissolved oxygen (DO) concentrations and increasing biological oxygen demand (BOD). The risk of eutrophication, especially in water resources with limited re-aeration capacity, is consequently increased. Therefore, under climate change conditions and due to the alteration of regional precipitation patterns, water resources can be expected to be exposed to increased nutrient loading, ultimately leading to elevated primary production and hypertrophic conditions [Whitehead, *et al.*, 2009:106].

Global warming and solar radiation share mutual connections. Solar radiation, as a crucial source of energy, plays a vital role in driving photosynthesis in most ecosystems and is essential for the growth of phytoplankton and other aquatic plants. When phytoplankton and aquatic plants are deprived of sufficient sunlight, they begin to consume oxygen, leading to the depletion of dissolved oxygen (DO) in the water column. Under anaerobic conditions, phosphorus released from sediments can contribute to eutrophication. Additionally, the distribution of algae is dependent on the intensity of solar radiation received at different depths, resulting in increased algae growth up to a maximum growth rate [Craig, *et al.*, 2014:434-441].

Climate change may also impact **wind patterns**, leading to direct and indirect effects on the trophic status of water resources. Direct effects of wind include blowing surface algae to shores, forming thick algal mats and altering environmental conditions. Indirectly, wind induces mixing in the water column, enhancing the blending of nutrients and accelerating the release of nutrients from sediments. Furthermore, as air temperatures rise, wind mixes the warmer upper layers of water with the colder lower layers, expediting the solubility, diffusion and transformation of pollutants. Changes in wind action may also increase or decrease the occurrence of inversion in stratified layers within water columns, resulting in oxygen deprivation near the water surface. Conversely, intense and high-speed winds can restrict the formation of algal blooms by dissipating them and weakening their aggregation [George, *et al.*, 2007:1647-1666].

Poor trophic conditions in water resources are likely to be exacerbated by climate change. The protection of our invaluable water resources in a changing climate poses a significant challenge for policymakers today and deserves considerable attention for the sake of future generations. However, three important questions related to eutrophication in a changing climate, as identified by Nazari-Sharabian, *et al.* (2018, 3668-3672), remain to be addressed:

- Which are the critical **climate change factors that most affect eutrophication** in freshwater ecosystems?

- How can we **effectively differentiate the impact of climate change from that of anthropogenic activities on eutrophication** and understand the associated feedback mechanisms?
- What are the **best and most feasible adaptation measures for dealing with the effects of climate change on eutrophication**?

Eutrophication strategies are primarily aimed at managing nutrient loading within catchments. In contrast, addressing the broad and systemic impacts of climate change requires global-scale resolutions. At this juncture, climate adaptation strategies become essential. These strategies are designed to adjust human and natural systems in response to real or anticipated climatic changes and their effects, which can, in turn, influence eutrophication.

4.2.4 Inequities in relation to access to safe sanitation (against the backdrop of a growing population)

The provision of safe sanitation is essential for sustainable and healthy communities. It is crucial for protecting water resources and promoting social and economic benefits aligned with national development goals [NPC, 2012:62], as well as for upholding the human rights of all people living in South Africa [RSA, 1996:Ch.2].

While population growth averages 1.2% per annum, it varies from negative to positive across communities. The growth in the number of households, however, is much higher, currently standing at around 3% per annum nationwide. This surge is primarily attributed to migration, mainly urbanisation. Urbanisation is driving an increasing demand for sanitation provision, as many rural residents relocate to urban centres in search of job opportunities and improved services. The demand for sanitation provision is further fuelled by the government's dedicated housing programme, which, among other things, leads to the subdivision of previously large households. Additionally, despite only 33% of the population currently residing in rural areas, they account for 81% of the national count of settlements. This is due to their often small and scattered nature, posing spatial challenges in providing comprehensive sanitation services to all [DWS, 2018b:79; Stats SA, 2016:68].

Baseline figures on access to reliable sanitation services are regularly surveyed by Statistics South Africa through the national census and their general household surveys. Since 1994, and particularly after 2001, an estimated 5.15 million households have been provided with safe and acceptable sanitation facilities [Schreiner & Hassan, 2011:75]. Despite the National Sanitation Policy (2016) advocating for sanitation services that are less reliant on water, approximately 66% of sanitation services consist of flush toilets today, channelling nutrient-rich return-flow water towards receiving water resources [DWS, 2016c:2]. By 2023, approximately 97% of the population had access to safe sanitation services, mainly consisting of flush toilets and pit latrines

(**FIGURE 44**). Given the poor track record of wastewater treatment by many municipalities, this situation has significant potential to contribute to the nutrient loading of surface and groundwater resources.

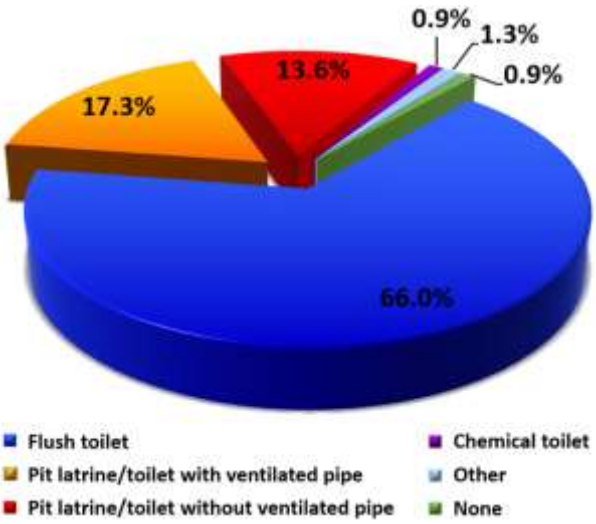

FIGURE 44: Access to sanitation in South Africa, 2023 [Stats SA, 2023:37].

The sanitation backlog in 1994 was estimated at 4 million households, and as of April 2017, it was still estimated that there were 3.96 million unserved households [DWS, 2018b:86]. The South African population grew from approximately 40 million in 1994 to 62 million, as recorded in the 2022 Census [Stats SA, 2024:10]. Progress in reducing the backlog has been hampered by substantial population growth, with households becoming smaller, growing at a faster rate than the population [DWS, 2018a:2]. The sanitation crisis in South Africa poses a threat to the health and well-being of the poor and vulnerable, contributes to the eutrophication of water resources and hinders the country's economic growth.

4.2.5 Water use regulation that is not consistently and adequately protecting South Africa's water resources against anthropogenic eutrophication

In the Republic of South Africa (RSA), government is constituted of national, provincial and local spheres. These spheres of government are distinctive, interdependent and interrelated [RSA, 1996:S.40(1)].

The Constitution (108:1996) designates the executive authority to provide water and sanitation services to local government [RSA, 1996:S.156(1)(a)]. According to the WSA (108:1997), Water Services Authorities (WSAs), which are the relevant municipalities, are accountable for ensuring access to water and sanitation services in their areas of jurisdiction [RSA, 1997:S.11]. It is expected that WSAs, through Water Services Providers (WSPs), ensure access to safe water and dignified sanitation services.

The lawfulness of discharging water containing waste, such as municipal wastewater, is essentially determined by whether such a discharge is permissible under the NWA (36:1998), and whether it complies with applicable authorisation requirements, including the relevant WDSs [RSA, 1998a:S.22(1)]. These discharges should be conducted in accordance with the conditions stipulated in:

- The Municipal Approval (in the case of Schedule 1 water use);
- An authorisation issued within a 24-month period prior to 30 September 1998 (in the case of an Existing Lawful Water Use);
- Any General Authorisation (GA);
- Any water use license in question; or
- An alternative authorisation, if dispensing with the requirement for a license to be issued under the NWA (36:1998).

One of the primary contributors to excessive nutrient enrichment in the country's water resources is inadequate municipal wastewater handling [Harding, 2017:31; Mudaly & van der Laan, 2020:17]. The socio-economic impacts of poor water quality in natural resources can be severe, making the authorisation of municipal water uses and the enforcement of water use authorisation conditions essential.

While the Constitution (108:1996) calls on all spheres of government and all organs of state within each sphere to cooperate with one another in mutual trust and good faith by fostering friendly relations, assisting and supporting one another, and avoiding legal proceedings against one another [RSA, 1996: S.41(1)(h)], it also grants citizens specific rights. These include the right to access sufficient water, an environment not harmful to health and well-being and the protection of the environment from degradation [RSA, 1996:S.27 and 24]. Although the right to basic sanitation is not explicitly stated in the Constitution, it could be derived from the right to a clean environment, read together with the right of access to clean water. The rights to water supply and sanitation services overlap with, and are supported by many other constitutional rights in the Bill of Rights. These include the rights to equality, dignity, access to information and just administrative action [Algotsson, *et al.*, 2009:2].

The NWA (36:1998), in Section 3(1), designates the authority to act as the trustee of the nation's water resources to National Government, acting through the Minister of Water and Sanitation. This is to ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner for the benefit of all persons. Part of the purpose of the NWA (36:1998) is to prevent and reduce pollution and degradation of water resources [RSA, 1998a:S.2(h)]. Any person who unlawfully and intentionally or negligently commits any act or omission that pollutes or is likely to pollute a water resource is guilty of an offence

[RSA, 1998a:S.151(1)(i)]. The Act further compels responsible authorities to give effect to any determination of a class of a water resource and the associated RQOs [RSA, 1998a:S.15] to ensure that South Africa's water resources remain fit for use and continue to support ecologically sustainable development.

While legislation should be applied justly and consistently to both private and public water users, the Constitution (108:1996) mandates national and provincial governments to support and strengthen municipalities' capacity to manage their own affairs [RSA, 1996:S.154(1)]. However, this support should not enable municipalities to contravene environmental legislation and avoid accountability, especially post-compliance monitoring and enforcement by DWS.

A notable degree of dysfunction exists in many municipalities due to a range of institutional, technical and/or management incapacity, along with financial and political reasons [DWS, 2017a:85]. The fact that up to 828 WwTWs (**FIGURE 45**) could not achieve Green Drop certification in 2021, reflects the poor condition of municipalities in South Africa [DWS, 2022:15]. There is an urgent need to address issues of accountability, coordination and leadership, poor cooperative governance and inadequate cross-regulatory interfacing with the DWS, as well as the appropriate actions to be put in place where WSAs show consistent failure in the delivery of universal and reliable water services.

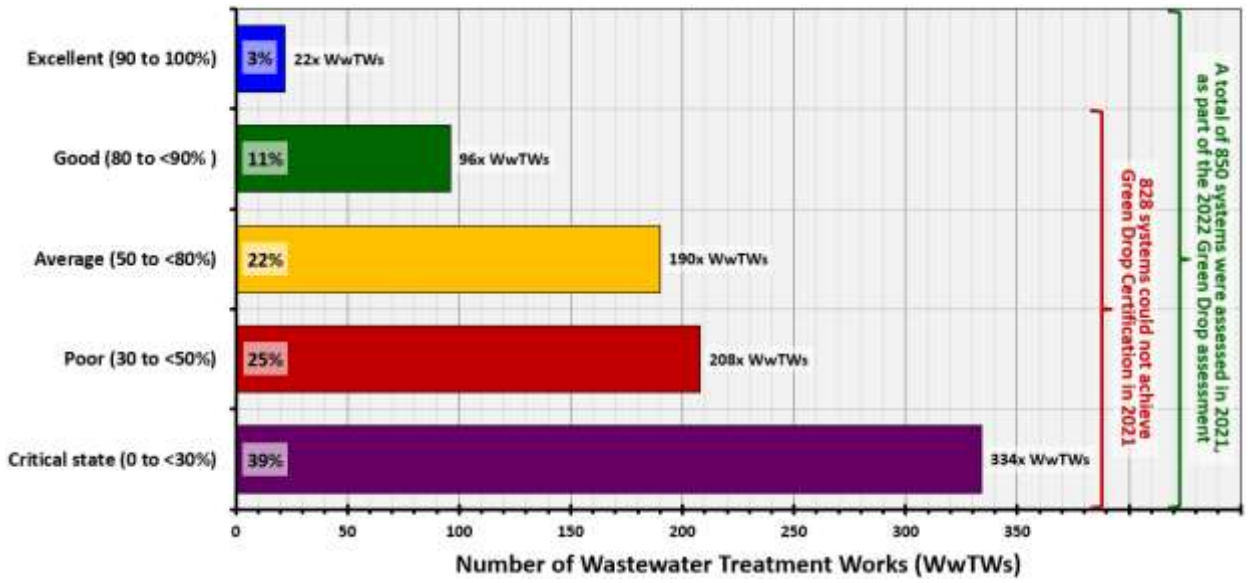

FIGURE 45: Wastewater treatment works that have been awarded different Green Drop scores, ranging from *"excellent"* to *"critical state"* [DWS, 2022:15].

Challenges with the authorisation of water use, that have significant impacts on aquatic ecosystems and other receiving water users, include the following:

- The prevalence of water uses that are not permissible under the NWA (36:1998);

- Incidences of poor authorisation administration;
- Lack of regulatory integration and poor cooperation amongst relevant authorities;
- Periodic backlogs with the issuing of water use authorisations;
- Poor quality of some water use authorisations (*e.g.*, authorisation conditions that do not appropriately integrate with water resource requirements) and ELU with water use authorisations that contain inadequate or outdated conditions; and
- Poor compliance with water use authorisation conditions, often coupled with insufficient compliance monitoring and/or inadequate enforcement.

Annexure B provides a summary of some eutrophication-related pollutant parameters, associated water user concentration requirements and the effects on human and aquatic ecosystem health, as well as other water users, should such pollutants be present at unacceptable high levels in receiving water resources.

4.2.6 Lack of skilled water scientists and engineers

Skilled water scientists and engineers are critical for solving complex eutrophication governance issues, such as developing infrastructure solutions, decision-making and forward planning to develop interventions that seamlessly integrate with receiving water resource requirements. Their expertise benefits both the public and private sectors, facilitating environmental compliance, innovation and the resolution of technical challenge.

In the public sector, entities like the DWS, local government and other water institutions require these professionals to manage the water value chain effectively, while the private sector relies on them for compliance and the development of solutions. The water sector's inter-sectoral nature necessitates collaboration between several sectors, including agriculture, health, education, forestry, aquaculture, industry, mining, etc., across multiple disciplines including policy, construction and ecological protection [DWS, 2018b:155].

In 2015, the WRC reported that selected public water institutions had significant capacity and skills gaps ranging from 44% to 92% and 36% to 60%, respectively [Vienings, *et al.*, 2015:220]. In a self-rating exercise conducted by staff members to assess available skills in the DWS, a rating of 71% was recorded [Win-SA, 2015:9]. The vacancies in technical departments of water institutions analysed, averaged at 24% [Vienings, *et al.*, 2015:222]. Additionally, local government, particularly the 144 municipalities designated as WSAs, faced challenges, with over 50% lacking technical capacity and 33% considered dysfunctional [DWS, 2018b:79]. This is concerning, especially considering legal requirements stipulating that the process control function at WwTWs must be performed by skilled personnel [GN R.813, 2013; GN R.2834, 1985].

It is crucial to expand the definition of skills and capacity building beyond individual capability (**FIGURE 46**) to include organisational capacity and an enabling environment [Morgan, 1998:3]. Individual capacity, the foundational element, involves an individual's ability to set and achieve objectives using their skills and knowledge. This underpins organisational capacity, which encompasses factors influencing an organisation's performance. Lastly, environmental capacity includes the conditions necessary for demonstrating capacities at both individual and organisational levels [JICA Task Force on aid approaches, 2004:16].

FIGURE 46: Levels of capacity [adapted from UNDP, 1998, as quoted by Matachi, 2006:4].

Despite a doubling of Civil Engineering graduates over five years, water institutions still experience a shortage of skilled scientists and engineers, exacerbated by inadequate organisational capacity and environmental support [Van Baalen, *et al.*, 2015:13].

Eutrophication management capacity has declined nationwide due transformation and human resource turnover within institutions, leading to the limited availability of knowledge and experience. Few capacity-building projects have targeted the rehabilitation of aquatic systems, causing regression in addressing eutrophication [Walmsley, 2000:40]. A progressive water sector needs skilled individuals supported by a positive organisational culture and an enabling environment that adheres to *"Batho Pele"* principles.[86] Without intervention, poor service delivery trends in many water institutions are likely to continue, including procrastination and growing

[86] *"Batho Pele"* is Sotho-Tswana for *"People First"*. The Batho Pele White Paper is national government's White Paper for Transforming Public Service Delivery [DPSA, 1997].

incidences of fruitless, wasteful, irregular and unauthorised expenditure of public funds [Muller & Erasmus, 2020:47-62].

4.3 EXAMINATION OF THE HISTORY AND FORECASTING THE EVOLUTION OF EUTROPHICATION GOVERNANCE IN SOUTH AFRICA

Considering historical advancements, analysing the present and extrapolating past and present knowledge to the future can often enhance our understanding of trends and stimulate forward-thinking.[87] The following discussions explore the evolution of eutrophication governance, reflecting on past and present thinking and identifying current positions. Understanding this evolution, along with its weaknesses, will help propose improved strategies for addressing problem areas. This will aid in developing progressive policies (**Chapter 5**) and appropriate implementation approaches (**Chapter 6**) to tackle current trends of nutrient over-enrichment and limit excessive anthropogenic eutrophication in the future.

4.3.1 Past paradigm

The past paradigm is characterised by the growing awareness of the effects caused by nutrient-laden wastewater and waste. During this period, pollution control slowly emerged, initially taking various forms. It faced challenges in gaining universal acceptance, struggling to find traction as the primary approach to combat pollution and being initially restricted to areas of unacceptable impact. However, it later gained momentum as the generally accepted approach to deal with pollution caused by nutrient-laden wastewater and waste. The past paradigm concludes with the realisation that pollution control approaches had to be replaced with a water quality management approach, emphasising the need for water resource requirements to be linked with end-of-pipe effluent control.

4.3.1.1 The period prior to the industrial age

In the early years, measures closely resembling eutrophication management worldwide, if at all, were limited to general waste and wastewater handling practices. Although municipal water supply and sanitation date back as far as 600 BC to ancient Rome [Havlíček & Morcinek, 2016:39], the adoption of inventions such as the water closet in Elizabethan times (second half of the 16th Century) was limited to only a very few households [Wall, 2018:1].

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[87] An examination of the evolutionary aspects of eutrophication governance, along with forecasts of potential regulatory adjustments, was conducted. This process involved researching relevant literature, using the method described in **Section 2.3.1**, and conducting qualitative forecasting, using the method described in **Section 2.4.1**.

The first recorded proclamation in South Africa addressing water pollution and wastewater handling dates to 10 April 1655. On this day, the Dutch Administration in the Cape of Good Hope issued a *"placaat"* (a public notice) that prohibited pollution of selected streams draining the slopes of Table Mountain [Thompson, 2016:34]. According to the public notice, fines would be imposed on individuals washing in or dumping refuse into the streams that supplied freshwater through *"grachts"* (canals) to the downstream settlements [Wall, 2018:3]. However, during those days, water quality received limited attention, with the bulk of the focus on consumptive water use and related matters.

4.3.1.2 The 19th Century

From the late 18th Century onwards, the pace of change in South Africa accelerated rapidly in response to profound social and institutional shifts, coupled with significant medical, scientific and technological advances. The discovery of diamonds in 1867 near Hopetown [Atherstone, 1869:552-553] and gold in 1886 on the Witwatersrand [Richardson & Van Helten, 1984:319], transformed South Africa from a predominantly agricultural society into the world's largest producer of gold and one of the largest producers of diamonds.

However, much of 19th Century South Africa, particularly in rural areas, experienced slow change. The dispersed population of just over 5 million people at the turn of the 19th Century [Beinart, 2001:1-3] meant that waste disposal could occur with minimal risk of harm to others. Consequently, there was little to no need for regulations regarding anthropogenic eutrophication causes [Wall, 2018:6].

4.3.1.3 The 20th Century up to 1956

With the advent of the 20th Century, urban centres and mining towns, notably Johannesburg and its sister gold mining towns, experienced rapid expansion. The establishment of the first engineered schemes in the early 1900s aimed to transport water from more distant sources to meet the growing needs of urban centres [Wall, 2018:5], leading to increased return flows.

The initial legislative efforts related to water quality management appeared in the Public Health Act of the Union of South Africa, 1919 (Act No. 36 of 1919).[88] This act prohibited local authorities from discharging effluents into natural watercourses, regardless of quality. The legislation also granted the Minister of Health the authority to set standards for purified effluent, although these powers were never exercised [Wall, 2018:6]. Furthermore, in 1951, the South African Bureau for

[88] Hereafter, referred to as the Union Health Act (36:1919).

Standards (SABS) published guidelines for effluent discharge into streams, though these were more advisory with no mandatory enforcement [Osborn, 1988:141].

The first municipal WwTWs in South Africa, operating with what would now be considered extremely small and primitive technology, were commissioned in Bloemfontein (November 1904) and Wynberg (January 1905), followed by Pietermaritzburg in 1908 [Osborn, 1988:139]. In these early cases, the improved effluent was irrigated over adjacent land. In most other urban centres, if wastewater was collected at all, it was often irrigated on land in an untreated state [Wall, 2018:6].

4.3.1.4 The period following 1956 up to 1994

By 1956, it was becoming evident that reconciling water supply with growing demands would pose increasingly challenging. The reuse of growing volumes of wastewater emerged as a key strategy for managing the country's scarce water resources. The Water Act, 1956 (Act No. 54 of 1956),[89] marked a pivotal shift in how wastewater was perceived. It essentially reversed the prohibition on effluent discharge into natural watercourses, a restriction previously enforced under the Union Health Act (36:1919) [DWAF, 1991:2]. The 1956 Act mandated that effluent must be treated to acceptable standards before being returned to the watercourse from which the water was originally obtained.

As time progressed, riverine ecosystems underwent systematic modifications on increasingly large scales. By the turn of the 20th century, a growing population of just over 44 million people [Stats SA, 2003:6] heightened the demands for food production and wastewater management. The progressive industrialisation and establishment of infrastructure programmes necessitated the construction of large dams for water security purposes. These factors collectively contributed to the growing prevalence of anthropogenic eutrophication in surface water resources in the period following 1956.

The linkage between aquatic plant growth, nutrients and human activities leading to eutrophication was recognised as a threat to South African surface waters almost seven decades ago, with the first impacts becoming apparent in the 1950s and reaching problematic levels in the 1960s [Van Ginkel, 2011:693; Walmsley & Butty, 1980:6; Zohary, *et al.*, 1988:1-5]. In 1962, the then Department of Water Affairs[90] (DWA) published *the Regional Standards for Industrial Effluent*, specifying a series of uniform WDSs. This was the first rendition of what are today known as the *General and Special Standards for the purification of Wastewater or Effluent*. Importantly,

[89] Hereafter, referred to as the WA (54:1956).

[90] Currently the Department of Water and Sanitation (DWS).

the notice included a Special Standard for phosphorus of 2 mg/ℓ orthophosphate [GN R.553, 1962].

Eutrophication monitoring in South Africa commenced in the early 1970s, mostly being done as *ad hoc* monitoring surveys and research projects supported by the WRC up to about 1985 [Toerien, *et al.*, 1975:1]. Also worth mentioning is that James L. Barnard, a South African, during this time, pioneered Biological Nutrient Removal (BNR) to solve the city of Johannesburg's phosphorus and nitrogen challenges. Today, he is recognised internationally for developing the BARNDENPHO and Phoredox Processes, which constitute the basis for all biological and nutrient removal process configurations in use [Nicholls, *et al.*, 1986:13-18].

In 1980, according to Taylor, *et al.* (1984) as referenced by Walmsley (2000:38), a revised Special Standard for phosphorus, based on best available wastewater technology, was published with a limit of 1 mg/ℓ orthophosphate [GN R.1567, 1980]. In 1984, this Special Standard for phosphorus of 1mg/ℓ orthophosphate was included in the *General and Special Standards for the purification of Wastewater or Effluent* [GN R.991, 1984] (see **TABLE 15**).

TABLE 15: General and Special Standards for the purification of Wastewater or Effluent: Selected constituents, relevant to excessive primary production.

CONSTITUENT	GENERAL STANDARD for less sensitive catchments	SPECIAL STANDARD for more sensitive catchments
Chemical Oxygen Demand *(after applying chloride correction)*	≤75 mg/ℓ	≤30 mg/ℓ
Suspended solids	≤25 mg/ℓ	≤10 mg/ℓ
Nitrogen as free and saline ammonia (NH_3)	≤10 mg/ℓ	≤1 mg/ℓ
Nitrogen as nitrates (NO_3^-)	-	≤1.5 mg/ℓ
Phosphorus as orthophosphate (PO_4^{3-})	-	≤1 mg/ℓ

These Special Standards for phosphorus were made applicable in specific catchment areas by means of specifying them in schedules in the relevant regulations, *viz.* 73 catchment areas, as listed in GN R.533 (1962); and 7 catchment areas, as listed in both GN R.1567 (1980) and GN R.991 (1984).

Pretorius (1983) and Toerien (1984) both criticised the decision to include a blanket (uniform) phosphorus standard of 1 mg/ℓ orthophosphate for all sensitive catchments on the grounds that the differences in phosphorus-receiving capacity of impoundments was ignored and that in some catchments the contributions from diffuse sources was so high that removal of point sources would have negligible effects on the trophic status of impoundments [Grobler & Silberbauer, 1985:69].

Later legislative amendments, notably the Water Amendment Act, 1984 (Act No. 96 of 1984), broadened water pollution control. Industrial effluent, and sources other than effluent, *e.g.,* water

which arises as a by-product from industrial and mining activities and seepage or stormwater runoff from a site, were made subject to pollution control regulations. The State was also given powers to prevent pollution before it takes place [DWAF, 1991:2].

The disposal of land-derived wastewater to the marine environment of South Africa was governed under Section 21(1) of the WA (54:1956), which required that such wastewater had to be treated in accordance with the requirements as prescribed by the Minister, in this case the *General and Special Standards for the purification of Wastewater or Effluent* [GN R.991, 1984], and that the treated wastewater must be returned to the sources of abstraction. Since these standards had not been developed with sea outfalls in mind, wastewater discharges to estuaries, surf zones and the offshore marine environment were mostly exempted from meeting the prescribed standards, as well as from being returned to the sources of abstraction [DWAF, 2004a:(1)1].

In 1985, the DWA initiated the first eutrophication-focused monitoring programme, *i.e.,* the Trophic Status Project (TSP), which covered the 7 sensitive catchments, as listed in GN R.1567 (1980) and GN R.991 (1984), respectively. The TSP would lay a solid foundation for the NEMP, to be designed and implemented years later, in that it highlighted the extent of the problem at a national scale in sensitive catchments, and also provided a database to be used during the design of the NEMP [DWAF, 2002:(3)15].

In 1991, the then DWAF,[91] adopted its new water quality management policy, entitled *Water Quality Management Polices and Strategies in the Republic of South Africa*, concluding an era of pollution control and entering an era typified by the Receiving Water Quality Objectives Approach [DWAF, 1991:12]. With the adoption of this approach, water quality management would henceforth focus on cumulative impacts on water resources, rather than on individual point sources of pollution [DWS, 2017c:11]. Full implementation of this approach in the absence of supporting legislation, *i.e.,* until the promulgation of the NWA (36:1998) in 1998, however, would prove to be difficult.

4.3.2 Current paradigm

The current paradigm starts with the new democratic dispensation for South Africa that saw the dawn of a new constitution, establishing human rights to– an environment that is not harmful; and sufficient water supply. In the current paradigm, the foundation for IWQM had been laid with the promulgation of new environmental and water legislation. Water quality management would be characterised by a concept to integrate water quality management efforts in the context of

[91] Currently the Department of Water and Sanitation (DWS).

ecologically sustainable development and attempts to operationalise the Receiving Water Quality Objectives Approach.

4.3.2.1 The years leading up to present-day eutrophication governance, 1994 to 1998

The evolution of supporting legislation and policy for water quality management over time, along with some implications for eutrophication governance, is summarised in **FIGURE 47**.

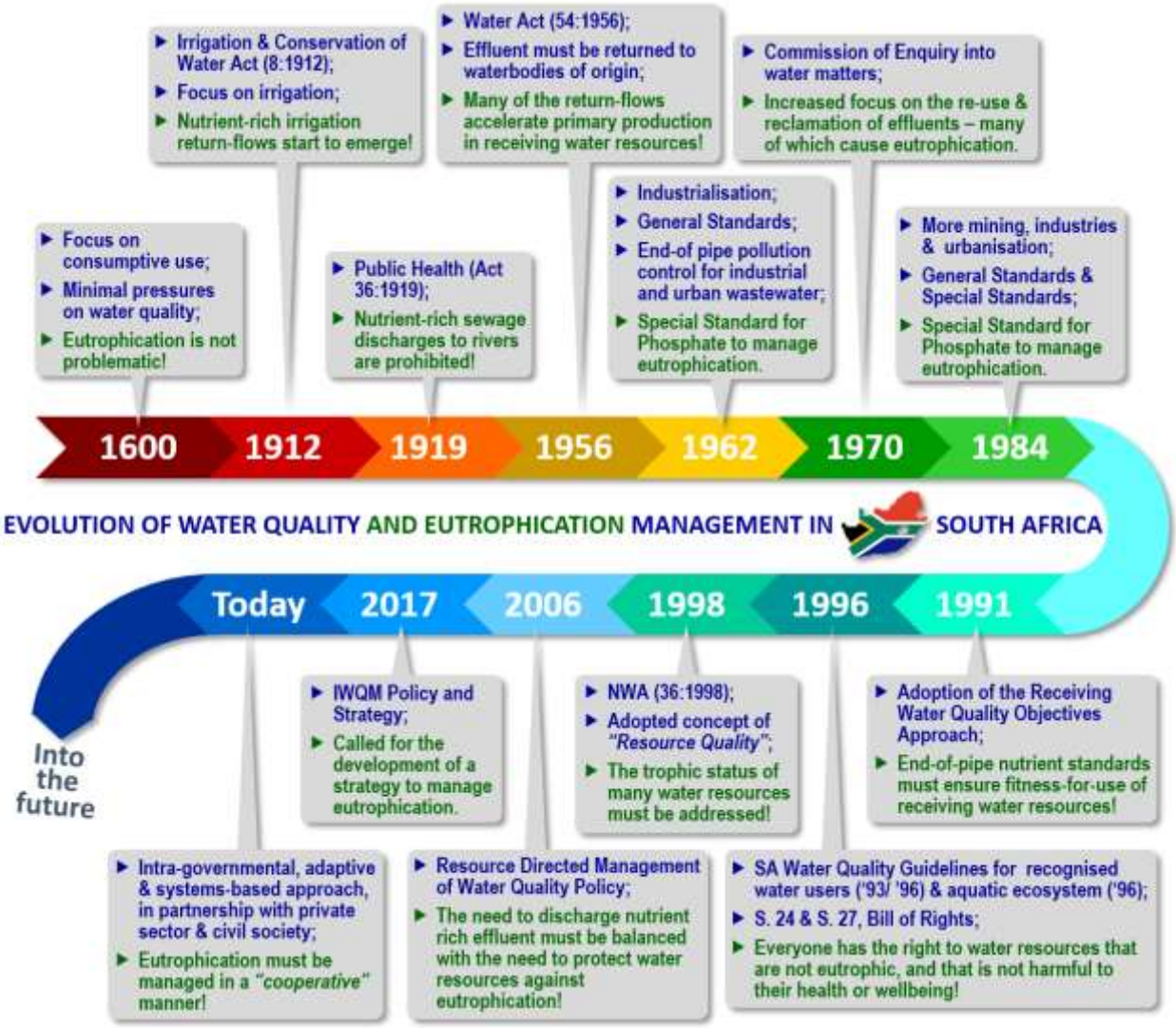

FIGURE 47: The evolution of eutrophication management in South Africa up to the current period.

The year 1994 marked a pivotal moment in South Africa's history. The interim Constitution of the Republic of South Africa, 1993 (Act No. 200 of 1993), along with the new Constitution (Act 108 of 1996) — especially Sections 24 regarding *"an environment that is not harmful..."* and 27 on *"access to sufficient water"* — necessitated a revision of the national water policy and legislation. Subsequent white papers, namely the Water Supply and Sanitation Policy (1994) and the National

Water Policy for South Africa (1997), laid the groundwork for the enactment of the WSA (108:1997) and the NWA (36:1998) on the 27th of November 1997 and the 20th of August 1998, respectively. The latter act came as a replacement for the WA (54:1956). These statutes, [92] taken together, concentrate primarily on the freshwater value chain, encapsulated by the phrase *"from resource to source to resource"*. [93]

Henceforth, all water is considered part of a common good, held in public trust on behalf of all persons by the Minister of Water and Sanitation [DWAF, 1997:14; RSA, 1998a:S.3]. Therefore, the DWS is mandated, among other things, to protect water resources and water users, meet the basic human needs of present and future generations, promote equitable access to water and manage the water quality of all water resources while supporting ecologically sustainable development.

The NWA (36:1998) furthermore recognises that water quality is intricately linked with water quantity, typically water flow, in stream and riparian habitats, as well as to aquatic biota integrity. All these aspects are collectively referred to in the Act as *"resource quality"*. To ensure that water resources can continuously support economic growth and social development, the quality (or *"resource quality"*) of such water resources needs to be maintained within certain predetermined parameters. These water resource parameters, or statutory RDMs, are represented by the MC, RQOs and the Reserve.

The NWA (36:1998) also makes provision for Source-Directed Controls (SDCs) to manage sources of negative impacts on resource quality, with the goal of ensuring compliance with the determined RDMs. SDCs encompass measures such as water use registration, authorisation, directives, prosecution and economic incentives such as levies and fees. This approach acknowledges the necessity for upstream water use and development while emphasising the importance of downstream protection for aquatic ecosystems and meeting water quality requirements for users.

The NEMP gained momentum and was implemented in 2002. In 2003, the Strategic Framework for Water Services was published to serve as an umbrella framework for the water services sector. This framework established overall goals and outlined institutional and operational frameworks necessary for achieving its objectives. In 2006, the Resource-Directed Management of Water Quality Policy and Strategy series was published to provide substance to resource water quality

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[92] **Annexure F** provides a synopsis of important provisions in these two acts and their roles in eutrophication management.
Annexure G is included in support of **Annexure F** and focuses on provisions for the making of regulations and the prescribing of compulsory national standards which can be employed to enhance the efficacy of eutrophication management.

[93] Until the promulgation of the National Environmental Management: Integrated Coastal Management Act, 2008 (Act No. 24 of 2008), more than forty South African sea outfalls had been formalised through authorisations issued in terms of the (previous) WA (54:1956) and the (current) NWA (36:1998) [Oelofse, et al., 2007].

management. The publication of the IWQM Policy and Strategy in 2017 introduced a new integrated approach to water quality management across key government departments and the sector. The IWQM Policy and Strategy serve as umbrella policies and strategies for water quality management, including eutrophication management, in South Africa.

4.3.2.2 Contemporary eutrophication governance

While excessive nutrient loading of water resources stems from both point and diffuse sources of water pollution, current eutrophication management measures predominantly concentrate on regulating point sources of nutrient loading. The freshwater value chain, encompassing upstream supply operations, consumptive water uses and downstream discharge of wastewater return flows (some with high nutrient content), provides a practical basis for conceptualising present-day point source-focused eutrophication management (**FIGURE 48**). The subsequent discussion assesses whether the statement *"No chain is stronger than its weakest link"* also holds true for the water value chain, particularly considering the escalating anthropogenic eutrophication observed in numerous receiving water resources.

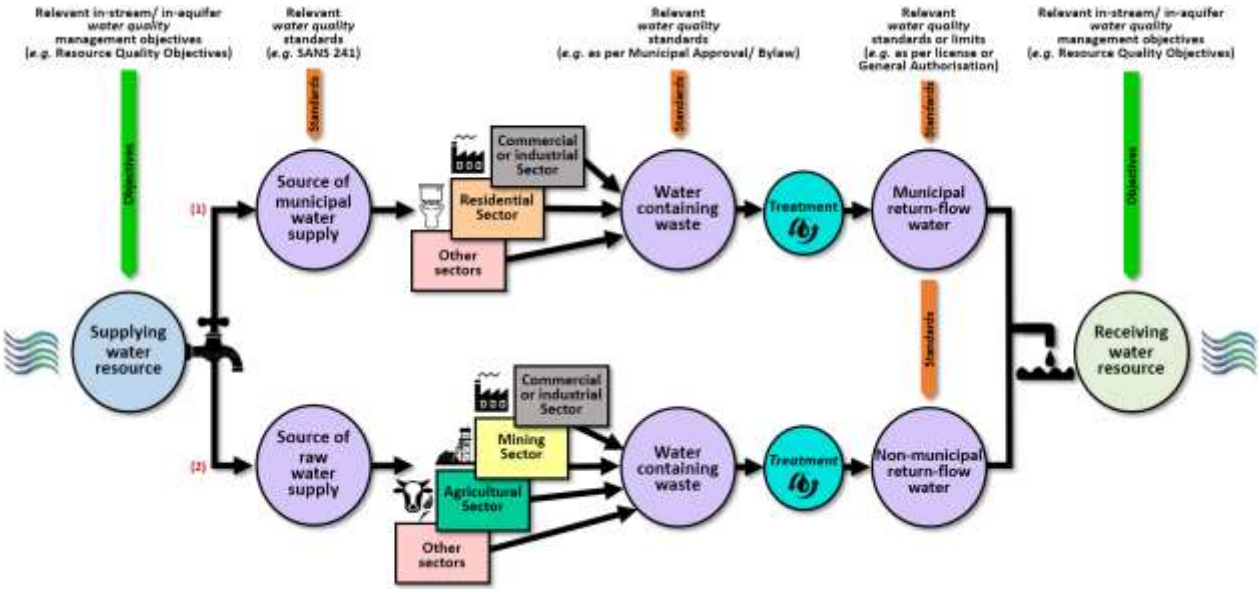

FIGURE 48: The freshwater value chain: *"From resource to source to resource"*.

The freshwater value chain is structured with a two-leg configuration: (1) a municipal supply and return-flow leg; and (2) a raw water supply and return-flow leg. Regulatory responsibilities are divided between these two legs, with WSAs, usually municipalities, holding regulatory responsibility over leg (1) and the DWS overseeing leg (2), which often leads to challenges in cooperative governance. WSAs are mandated to register the qualifications of operators of WwTWs. Until recently, DWS, particularly from an effluent perspective, focused solely on the final end-of-pipe discharge quality of the wastewater return flows from both legs. Consequently,

DWS has limited insight into the volumes and qualities of feed water received by WSAs at municipal WwTWs from their client sectors. t is widely known that the municipal supply and return-flow leg of the freshwater value chain is currently the weakest link in South Africa's efforts to curb the trajectory of eutrophication.

In contemporary eutrophication governance, numerous provisions in the NWA (36:1998) are available to the Regulator to enhance eutrophication management and water resource protection. However, some of these provisions are not fully utilised. Important provisions include:

- The WDCS, which could facilitate the limitation and prevention of nutrient loading by applying the Polluter-Pays Principle [NWA, 1998, S.56];
- The establishment of Catchment Management Strategies (CMSs), incorporating eutrophication-specific interventions tailored for each WMA and sub-catchment to address specific eutrophication management needs [NWA, 1998, S.8];
- Regulations to govern the design, construction, installation, operation and maintenance of WwTWs, owned by both the private and public sectors [NWA, 1998, S.26(1)(e)]. These regulations can improve the current situation regarding municipal WwTWs by addressing poor maintenance, timely upgrading and the utilisation of works over their design capacity;
- Regulations with conditions to control or prohibit any activity, aiming to protect water resources, as well as instream or riparian habitats, from the effects of excessive nutrient loading [NWA, 1998, S.26(1)(g)];
- Regulations prescribing waste standards, specifying the quantity, quality (concentrations of nutrients) and temperature of wastewater and waste that may be discharged or deposited into a water resource [NWA, 1998, S.26(1)(h)]; and
- Regulations requiring monitoring and analysis of waste discharged or deposited into a water resource, with prescribed methods for such monitoring and analysis [NWA, 1998, S.26(1)(j)]. The data and information obtained should be uploaded onto the DWS's Integrated Regulatory Information System (IRiS) or a suitable alternative system for efficient data interrogation.

While the NWA (36:1998) has introduced various statutory RDMs [NWA, 1998, S.15] to ensure the fitness-for-use of receiving water resources, operationalising the Receiving Water Quality Objectives Approach has proven to be challenging. It is crucial that receiving water quality requirements for nutrient reduction be integrated with water use authorisations to address the effects of anthropogenic eutrophication.

In many cases, there is room for better integration within certain provisions of the WSA (108:1997). For instance, integration with Municipal Approvals of water use [WSA, 1997, S.7(2)], water services development planning and the establishment of

Water Services Development Plans (WSDPs) [WSA, 1997, S.16] and information management [WSA, 1997, S.67] can be improved.

The National Environmental Management: Integrated Coastal Management Act, 2008 (Act No. 24 of 2008),[94] would ultimately assume full regulatory responsibility for marine water quality management. The regulation of anthropogenic causes of marine eutrophication emanating from coastal areas may potentially present further integration challenges. However, the regulation of inland anthropogenic activities, which, through river runoff, impact excessively on the trophic status of estuarine, and eventually coastal marine waters, remains under the NWA (36:1998). The addition of the NEM ICMA (24:2008) would, thus, fully extend the management of eutrophication to address the entire water value chain – *"from freshwater resource to source of water to marine water resource"*, albeit that the regulation of inland and coastal marine waters would be administered by two different government departments [DEA, 2014:1-3].

4.3.3 Future paradigm

Ten *"megatrends"* pertinent to the future governance of eutrophication have been identified (**TABLE 16**).

TABLE 16: Identification of *"megatrends"* that are likely to influence eutrophication governance in future.

***"MEGATRENDS"* AND THEIR POTENTIAL IMPLICATIONS FOR EUTROPHICATION GOVERNANCE**
(1) Population growth, urbanisation and land use change: The increasing concentration of populations in urban areas contributes to changes in land use, resulting in higher nutrient runoff from these areas and impacting eutrophication [Booth, *et al.*, 2004:1351]. Consequently, urban planning and sustainable development strategies will play a crucial role in managing this trend.
(2) Agricultural intensification: Growing populations and intensified agriculture contribute to higher nutrient loading in waterbodies [Carpenter, *et al.*, 1998:559-568]. Best management practices will play a crucial role in managing this trend.
(3) Technological innovation and advancements: Advances in monitoring, data analytics and commercial production technologies offer new tools to enhance our understanding and mitigation of excessive eutrophication. Integrated sensor networks, remote sensing and precision agriculture technologies can optimise nutrient management and minimise runoff [Randall, *et al.*, 2016:389-409].
(4) Innovations and advancements in wastewater treatment: Advances in wastewater treatment technologies contribute to reducing nutrient discharges [Yang, *et al.*, 2014:2207-2256].
(5) Shifting consumer preferences and behaviours: Increasing consumer awareness of environmental issues can stimulate demand for sustainable production practices, precipitating changes in food production and supply chains. These shifts carry significant implications for the governance of eutrophication [Plieninger, *et al.*, 2013:207-219].

[94] Hereafter, referred to as the NEM ICMA (24:2008).

"MEGATRENDS" AND THEIR POTENTIAL IMPLICATIONS FOR EUTROPHICATION GOVERNANCE
(6) Public awareness and engagement: Heightened public awareness and engagement are likely to exert influence on policy decisions and foster the adoption of sustainable practices [Plieninger, *et al.*, 2013:118-129].
(7) Ecosystem-based approaches: Implementing ecosystem-based approaches in environmental management enhances resilience to eutrophication [Corvalan, *et al.*, 2005:2].
(8) Policy and governance frameworks: Policies and governance frameworks tend to persistently focus more holistically on pertinent matters and continuously aim to promote better management integration [Lafferty & Hovden, 2003:5-7]. Consequently, changes in policies and governance structures play a crucial role in the effective management of eutrophication.
(9) Climate change and extreme weather events: Changes in temperature, precipitation patterns and extreme weather events can impact nutrient cycling and runoff, altering eutrophication dynamics in waterbodies [Schindler, *et al.*, 2008:11254-11258]. Adaptation strategies and resilience planning will be essential to address these impacts.
(10) Globalisation: The interconnectedness of economies and international trade can prompt changes in production practices and land use, impacting nutrient pollution and eutrophication on a global scale. Therefore, international cooperation and agreements play a critical role in addressing these issues [Khan & Mohammad, 2014:1-15].

In the shorter term, the future paradigm is likely to be characterised by a consolidation of water quality management efforts, aiming to fully utilise and refine all available legal and policy instruments. In the longer term, the future paradigm must yield innovative solutions and approaches to effectively tackle anthropogenic eutrophication, which is likely to be influenced by several megatrends, ensuring ecologically sustainable development for future generations.

FIGURE 49 illustrates multiple projected adjustments to eutrophication governance in South Africa deemed crucial for the future. These modifications are driven by the increasing eutrophication trends witnessed and anticipated to intensify in future. The pace of eutrophication governance evolution relies heavily on the efficacy of proposed interventions aimed at curtailing nutrient influx into water resources. Speeding up or slowing down these trajectories inevitably carries cost implications, impacting both water users and the entities implementing these strategies.

The implementation of interventions necessitates diligent monitoring to evaluate their efficacy and make essential adjustments as needed. The quest for identifying novel and improved approaches to eutrophication governance must commence with the complete enactment of existing legislative and policy measures before striving for enhancements. Moving forward, participative management will be essential as anthropogenic eutrophication impacts everyone, and reversing its effects demands a collaborative approach involving all stakeholders.

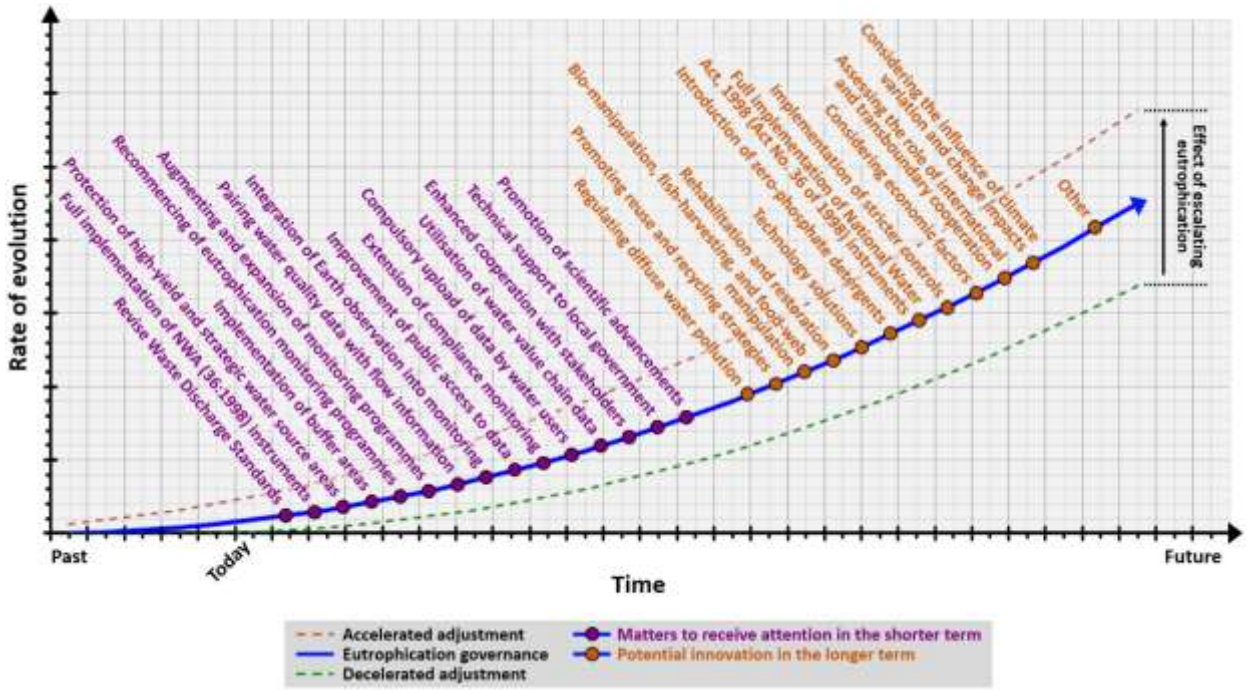

FIGURE 49: Anticipated adjustments in eutrophication governance responding to future needs.

The discussions following in **Sections 4.3.3.1** and **4.3.3.2** below will delve deeper into the expected adjustments to eutrophication governance, as illustrated in **FIGURE 49**.

4.3.3.1 Matters to receive attention in the shorter term

Van Niekerk (2000:12) observed widespread non-compliance among WwTWs to the phosphorus standard of 1 mg/ℓ orthophosphate. Conversely, Harding (2017:43) argued that the phosphorus benchmark of 1 mg/ℓ orthophosphate might be overly permissive in certain situations. Together, these observations highlight **critical considerations regarding the deployment of appropriate WDSs** that necessitate urgent attention in the near future, *viz.*:

- ***Room for improved management integration:*** Integrated approaches that consider the interconnectedness of water sources, land use and ecosystem health are likely to become more prominent. This requires collaboration and coordination among several stakeholders involved in water management;
- ***Development and implementation of feasible WDSs:*** Establishing standards that are practical and achievable for different wastewater dischargers, taking into account the diversity of sources and conditions;
- ***Operationalisation of the Receiving Water Quality Objectives Approach:*** Implementing an approach that considers the specific water quality objectives for receiving waterbodies. Harding (2008:3) proposed an approach involving the calculation of Total Maximum Daily

Loads (TMDLs) for dams. Establishing TMDLs can link waste discharges to the receiving water assimilation capacity, providing a structured approach to manage nutrient loading;

- ***Role and feasibility of technology:*** Assessing the role and feasibility of technology in treating nutrient-laden wastewater to improve the trophic conditions in receiving water resources. Implementing the Best Practicable Environmental Option (BPEO) ensures that the most effective and sustainable technology is employed;
- ***Legal compliance:*** Ensuring that all water uses are lawful and, where necessary, valid water use authorisations are in place. This requires regulatory oversight and a transparent process for obtaining water use authorisations;
- ***Intensification of compliance monitoring and enforcement:*** Strengthening efforts to monitor and enforce compliance with WDSs and other conditions in authorisations. This includes acting against unlawful and non-complying water uses to prevent adverse impacts on water quality; and
- ***Responsibility of water users:*** Water users must take due responsibility to limit their contributions to excessive eutrophication (duty of care). In cases where users fail to do so, regulatory authorities should intervene to ensure adherence to WDSs.

Addressing these points collectively can contribute to more effective eutrophication management and the protection of water quality in diverse ecosystems. **Additionally, future actions in the short term** should also address priorities such as:

- **Full implementation of NWA (36:1998) and its instruments:** Ensure the comprehensive implementation of all instruments and mechanisms provided in the NWA (36:1998) to facilitate effective eutrophication management;
- ***Protection of high-yield and strategic water source areas:*** Safeguard areas that contribute significantly to water resources and implement measures to protect related ecological infrastructure, enhancing water quality improvement functions;
- ***Implementation of buffer areas:*** Establish buffer zones to shield water resources against diffuse sources of nutrient-laden pollution, preventing excessive nutrient runoff reaching water resources;
- ***Recommencing of eutrophication monitoring programmes:*** Ensure that national and regional eutrophication monitoring programmes are fully operational, providing valuable data for effective management;
- ***Augmenting and expansion of monitoring programmes:*** If feasible, enhance national and regional eutrophication monitoring programmes with volumetric, nutrient and chlorophyll α-related data obtained from monitoring raw feed water. Ensure electronic

availability of abstraction-related data through an appropriate information management system;

- ***Pairing water quality data with flow information:*** Combine resource water quality data and information with water resource flow data to comprehensively assess nutrient loading;
- ***Integration of Earth observation into monitoring:*** Utilise satellite Earth observation (remote sensing) to monitor cyanobacterial blooms and eutrophication in medium- and large-sized freshwater bodies. Incorporate chlorophyll-α (Chl-α) estimates from satellite imagery into the Water Management System (WMS) of the DWS [Matthews & Bernard, 2015:1];
- ***Improvement of public access to data:*** Enhance the availability and accessibility of resource quality data for the public to increase awareness of eutrophication. Consider promoting new technology solutions, such as the CyanoLakes™ cellular telephone application;
- ***Extension of compliance monitoring:*** Expand compliance monitoring to include volumetric effluent data and information, in addition to water quality data, allowing for a comprehensive assessment of nutrient loading from WwTWs;
- ***Compulsory upload of data by water users:*** Make it mandatory and easy for water users to upload both volumetric and water quality data and information on IRiS (or an approved alternative system) instead of relying solely on hard copy submissions, as required by some water use authorisations;
- ***Utilisation of water value chain data:*** Use water quality and volumetric data from earlier stages in the water services value chain to provide additional intelligence to the DWS, aiding in nationwide improvement of municipal WwTWs' performance;
- ***Enhanced cooperation with stakeholders:*** Strengthen collaboration with government, private sector and civil society role-players to increase awareness and drive demand for sustainable practices and conservation efforts;
- ***Technical support to local government:*** Provide technical support to local government where necessary, ensuring municipalities have appropriate bylaws to manage eutrophication causes early in the water value chain and facilitate monitoring of water quality and volume; and
- ***Promotion of scientific advancements:*** Encourage and promote scientific advancements that may lead to the discovery of new methods for nutrient removal, restoration of degraded ecosystems and the adoption of sustainable land use practices.

4.3.3.2 Potential innovation in the longer term

In the longer term, efforts can shift towards attaining more innovative and progressive solutions to address eutrophication problems.[95] These may include the following:

- ***Regulating diffuse water pollution:*** Particularly addressing land care and land-use management as a major source of nutrient loading, requiring innovative arrangements and approaches;
- ***Promoting reuse and recycling strategies:*** Emphasising mechanisms to promote reuse and recycling of wastewater return flows to reduce demand and minimise contributions to nutrient loading of receiving water resources;
- ***Bio-manipulation, fish-harvesting and food-web manipulation:*** Exploring these strategies to address the symptoms of eutrophication;
- ***Rehabilitation and restoration:*** Implementing bio-remediation initiatives and supporting projects like the Harties Metsi-a Me/ Hartbeespoort Dam Biological Remediation Project in affected water resources;
- ***Technology solutions:*** Exploring the use of advanced sensors, satellite monitoring, data analytics, Solar Powered Reservoir Circulators[96], etc.;
- ***Introduction of zero-phosphate detergents:*** Pursuing the introduction of zero-phosphate detergents in South Africa, coupled with consumer education. While these detergents may not foam as well as phosphate-containing ones, promoting their use can contribute to reducing nutrient inputs into water resources. Additionally, it is important to consider potential consequences, such as the use of alternative, possibly more harmful chemicals to compensate for reduced foaming [Pers. coms. Thornton, 2021];
- ***Implementation of stricter controls:*** In anticipation of worsening trophic conditions in the country's impoundments, it may be necessary to implement stricter controls on nutrient discharges, agricultural practices and wastewater treatment;
- ***Considering economic factors:*** The costs and benefits of different management strategies, as well as economic incentives for sustainable practices, can shape the direction of policy and strategy development and implementation;
- ***Assessing the role of international and transboundary cooperation:*** Shared waterbodies and transboundary pollution may require collaborative efforts between countries to develop and implement effective management strategies; and

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[95] Interventions need sufficient funding and support for scientific monitoring of the outcomes over a long period – several years or even decades.

[96] Solar Powered Reservoir Circulators, (Solar-Bees), are floating solar-powered reservoir long-distance circulation pump systems. These systems can accelerate biological and solar processes that clean up water. However, careful consideration is needed in their acquisition and application to ensure effectiveness and prevent potential counterproductive impacts on water quality.

- ***Considering the influence of climate variation and change impacts:*** Changes in temperature, precipitation patterns and extreme weather events can affect nutrient cycling and the dynamics of eutrophication, requiring adaptive management strategies.

These innovative solutions should be considered in a holistic manner, with attention to their potential synergies and trade-offs to achieve effective and sustainable eutrophication management. Public awareness and education play a crucial role in implementing such intervention responses successfully.

4.4 ANALYSIS OF THE SURVEY ON THE STATUS OF EUTROPHICATION AND ITS MANAGEMENT IN SOUTH AFRICA

The nationally conducted survey[97] on the status of eutrophication and its management in South Africa involved distributing questionnaires to **each of the nine DWAF regional offices**, **DWAF Head Office** and **selected water utility entities**. Respondents were chosen based on their proficiency and knowledge of eutrophication. All respondents listed in **Annexure D** were senior and highly experienced officials, with many holding positions in middle management or serving as specialised scientists within their respective offices or organisations, thereby enhancing confidence in the responses at WMA level.

Nominated DWAF regional office officials had intimate knowledge of the catchments within their areas of responsibility. Representing their regional offices, they also had access to the DWAF's operational resources, including the ability to draw on their colleagues' expertise. As representatives of the DWAF regional offices, the views of these nominees carried the collective weight of their offices.

The goal was to receive at least one completed survey questionnaire per DWAF regional office and per WMA (see **TABLE 17**). Across 17 of the 19 WMAs – with exceptions for WMAs 1 (Limpopo) and 14 (Lower Orange) – each received between one and four replies per WMA. Sixteen DWAF regional office officials[98] responded on behalf of 8 of the 9 DWAF regional offices, with no reply received from the Polokwane Regional Office.

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[97] The survey was executed, as per the method description outlined in **Section 2.3.2**. A copy of the survey questionnaire is annexed, as **Annexure C**. The survey, carried out by the DWAF during 2002 and 2003, was a component of a departmental initiative targeting eutrophication control [Walmsley, 2003]. The findings from this survey supplied crucial insights that proved to be invaluable to this study. The survey results were complemented with recent information (see Sections 4.2 and 4.3).

[98] Note that one of the DWAF regional office official represented three different WMAs, namely WMAs 6, 7 and 11.

TABLE 17: Mobilised survey sample size.					
SAMPLE STRATIFICATION				**RESPONSES**	
DWAF Head Office				3	
Water Management Areas (WMAs)	**DWAF regional office / survey questionnaires received**		**Survey questionnaires received from water utility entities**	**Total number of survey questionnaires received**	
(1) Limpopo	–	0	0	0	← *No response*
(2) Luvuvhu-Letaba	–	0	**1**	**1**	
(3) Crocodile-Marico	*Northwest*	**2**	**2**	**4**	
(4) Olifants (middle to lower)	*Mpumalanga*	**1**	0	**1**	
(5) Inkomati	*Mpumalanga*	**1**	0	**1**	
(6) Usutu to Mhlatuze	*KwaZulu-Natal*	**2***	0	**2**	
(7) Thukela	*KwaZulu-Natal*	**1***	0	**1**	
(8) Upper Vaal	*Gauteng*	**1**	0	**1**	
(9) Middle Vaal		**0**	**2**	**2**	
(10) Lower Vaal	*Northern Cape*	**2**	0	**2**	
(11) Mvoti to Umzimkulu	*KwaZulu-Natal*	**1***	**1**	**2**	
(12) Mzimvubu to Keiskamma	*Eastern Cape*	**1**	0	**1**	
(13) Upper Orange	*Free State*	**2**	**1**	**3**	
(14) Lower Orange	–	0	0	0	← *No response*
(15) Fish to Tsitsikamma	*Eastern Cape*	**1**	0	**1**	
(16) Gouritz	–	0	**1**	**1**	
(17) Olifants/Doorn	*Western Cape*	**1**	0	**1**	
(18) Breede	*Western Cape*	**1**	**1**	**2**	
(19) Berg	*Western Cape*	**1**	0	**1**	
Grand total		**18**	**9**	3 + 27 = 30	
		27			

* One DWS regional office official represented 3x WMAs, replying on three separate survey questionnaires.

Considering the mobilised survey sample size and the responses received, the geographic coverage of the nationally conducted survey on the status of eutrophication and its management in South Africa can be summarised as shown in **TABLE 18**.

TABLE 18: Response spread.		
SPREAD DESCRIPTION	**WATER MANAGEMENT AREAS (WMAs)**	**DWS REGIONAL OFFICE AREAS**
Covered by the survey	17	8
Total number	19	9
Percentage coverage	**89.47%**	**88.88%**

The geographic coverage associated with the response spread was approximately 89% for both WMAs and DWAF regional offices. Although the mobilised coverage fell short of the objective of having a minimum of one response per DWAF regional office and per WMA, the overall ±89%

coverage is considered sufficient to provide a comprehensive nationwide perspective suitable to satisfy the survey's objective, namely: ***gaining insights on the status of eutrophication and its management to support policy and strategy development in South Africa***. A total of 28 participants responded with 30 responses. One of the DWAF regional office officials represented three different WMAs, namely WMAs 6, 7 and 11.

The responses to Survey Questions 1 through 8 (found in **Annexure E**) are summarised in **Sections 4.4.1** to **4.4.2**, below.

References to *"n"*, in the insert *national perspective pie diagrams*, reflect the number of respondents representing their constituencies who answered in a specific way. While the number of responses that were converted to percentages is limited, it is important to note that responses from individual DWAF regional offices represented entire regions or parts thereof. Expressing these results as percentages was necessary, as it helped provide an overview of the status and management of eutrophication in South Africa. Furthermore, the subsequent analyses and discussions aim to identify challenges in managing eutrophication, used to explore potential solutions. **As the objective was not to conduct a comprehensive catchment assessment or to examine eutrophication prevalence in WMAs in extensive detail, the limited number of responses per individual WMA was not considered a critical flaw.**

4.4.1 Question 1: *"Based on the complaints received by you from water users and communities, how do you rate eutrophication as a water resource problem in your management area?"*

The 28 participants in the survey submitted a total of 26 responses to Survey Question 1, suggesting that two responses were not received, attributable potentially to various reasons. Responses to this question were received for 17 out of 19 WMAs, equating to approximately 89% coverage of all WMAs for that question.

FIGURE 50 shows that eutrophication was identified as a significant and widespread water quality issue in only two WMAs, namely, the Crocodile/Marico and Berg. In contrast, it was perceived as a minor concern in five WMAs, and this perception may extend to two additional WMAs. In ten WMAs, eutrophication was viewed as a concern of moderate severity.

However, it is important to consider these findings in light of the responses to Survey Question 8. These responses revealed that, despite eutrophication being regarded as a moderate to minor concern at the broader WMA level, nearly all WMAs experienced localised areas with severe eutrophication problems. Eutrophication governance policies and strategies should aim to *"align"* with the 35% of WMAs nationwide where eutrophication was considered a minimal or non-issue for water quality.

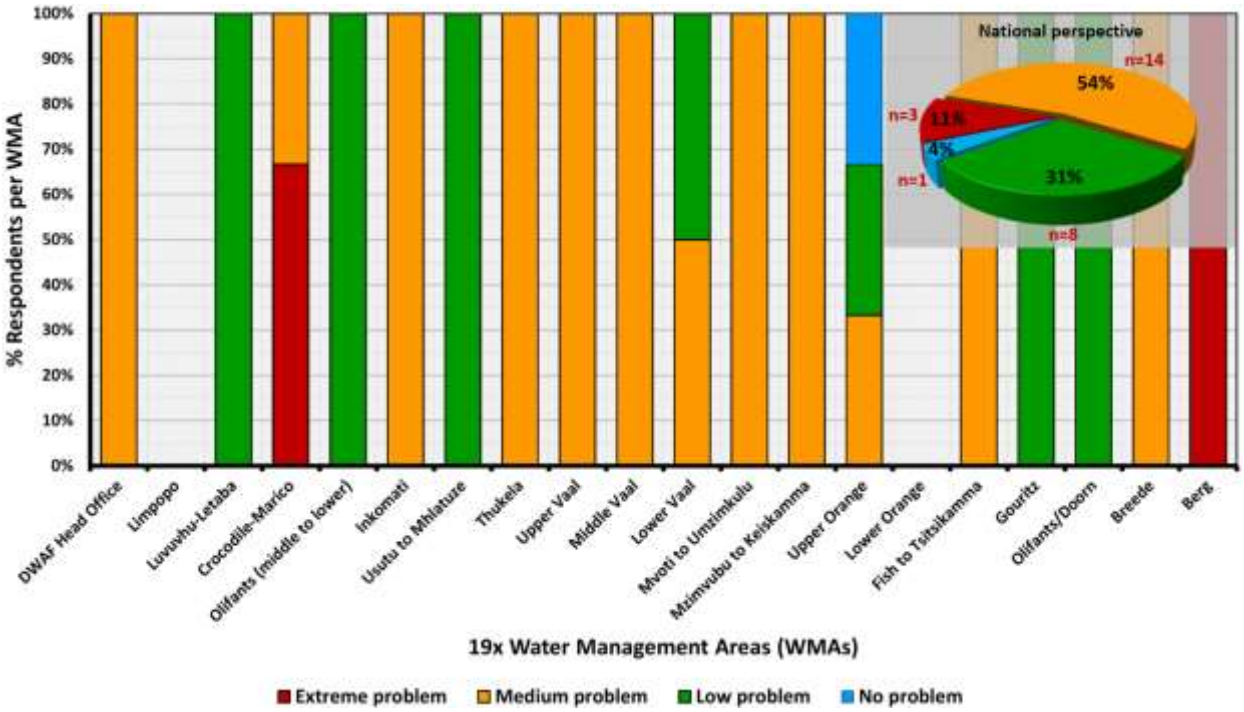

FIGURE 50: Question 1: *"... how do you rate eutrophication as a water resource problem?"*

4.4.2 Question 2: *"Is routine eutrophication monitoring and reporting carried out by your office?"*

Among the 28 participants who took part, a total of 27 responses were provided to Survey Question 2, indicating that one reply to the specific question was not received. Responses to Survey Question 2 were received for 17 out of 19 WMAs, equating to approximately 89% coverage of all WMAs.

Certain WMAs exhibited well-developed eutrophication monitoring programmes within their catchments, including the Crocodile/Marico (*e.g.,* Hartbeespoort Dam), Upper Vaal (*e.g.,* Vaal Dam and Vaal Barrage), Mvoti to Umzimkulu (*e.g.,* Umgeni), Mzimvubu to Keiskamma (*e.g.,* Mzimvubu) and Upper Orange (*e.g.,* Orange River mainstem). However, this comprehensive monitoring was not consistently implemented across all WMAs, as indicated in **FIGURE 51**. In fact, there was a lack of adequate monitoring in some systems that are known to experience eutrophication problems. The data, showing that 55% of WMAs were considered to lack monitoring programmes, when compared with responses identifying affected waterbodies from Survey Question 8, underscores the uneven distribution of monitoring efforts. Establishing an effective monitoring programme is crucial for a national initiative aimed at curbing the problem of excessive eutrophication.

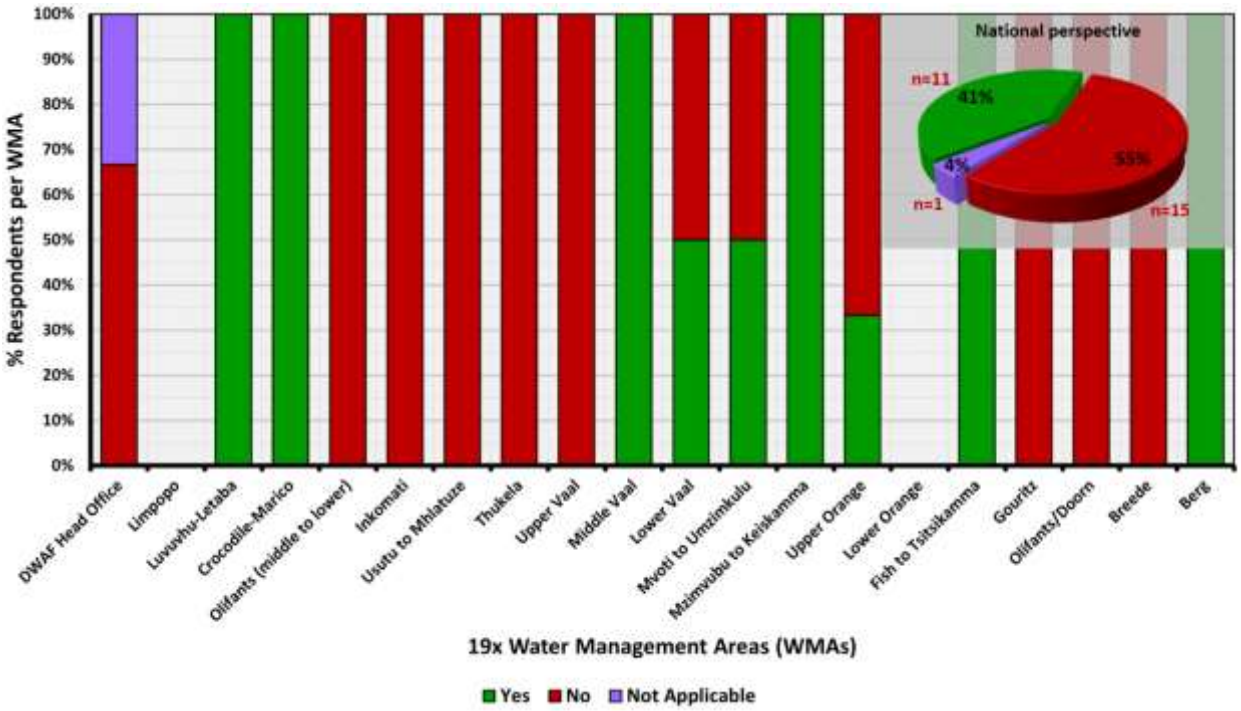

FIGURE 51: Question 2: *"Is routine eutrophication monitoring and reporting carried out by your office?"*

4.4.3 Question 3: *"Do you feel that your staff are fully conversant with the topic of eutrophication and its management?"*

Among the 28 participants who took part, a total of 27 responses were provided to Survey Question 3. This suggests that one reply to the specific question was not received. Responses to Survey Question 3 were received for 16 out of 19 WMAs, equating to approximately 84% coverage of all WMAs.

It was concerning to discover that 63% of the DWAF regional offices and institutions, that were consulted, have indicated that all their staff are not fully knowledgeable about the topic of eutrophication, as illustrated in **FIGURE 52**. Notably, regional offices such as the Western Cape and Gauteng Regional Offices seem to have personnel who are familiar with the topic, while other regional offices reported deficiencies in the knowledge of some personnel. On a positive note, the participating water utility entities appeared to be aware of the problem and have the necessary knowledge to address it.

A progressive water sector requires skilled individuals empowered by a conducive organisational culture and an enabling external environment that supports excellence. Without the necessary capacity, poor service delivery trends are likely to continue.

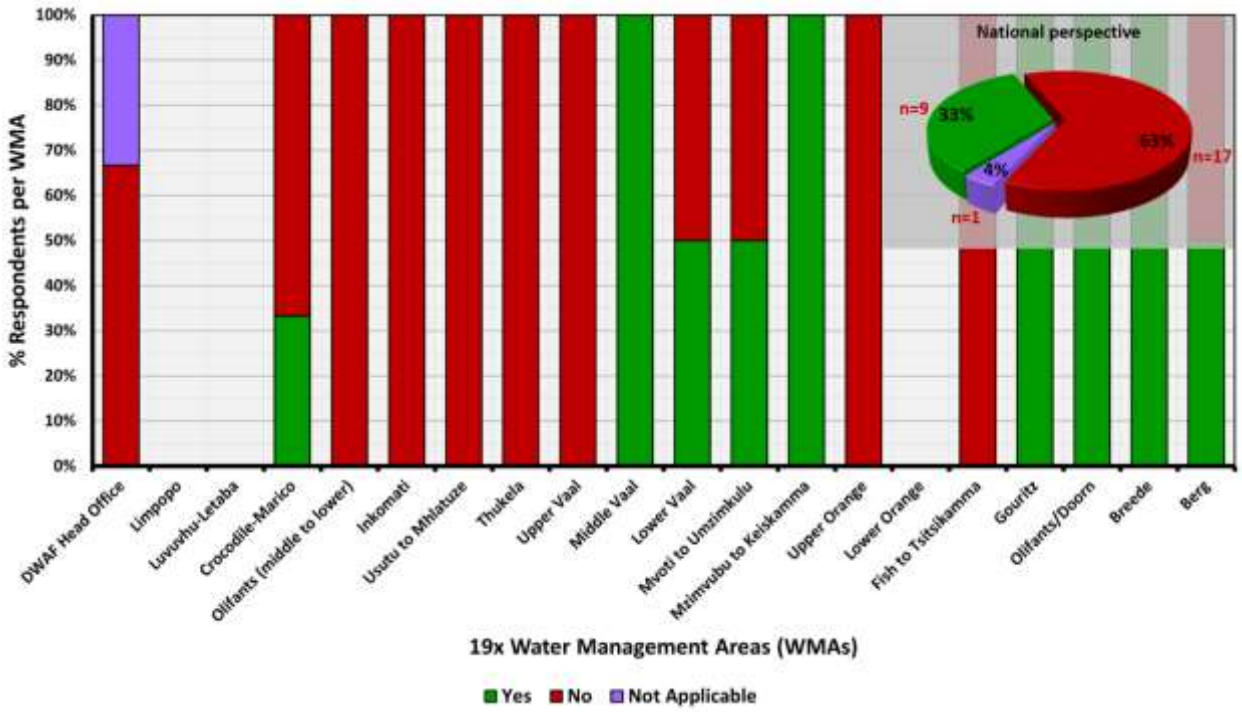

FIGURE 52: **Question 3:** ***"Do you feel that your staff are fully conversant with the topic of eutrophication and its management?"***

4.4.4 Question 4: *"Would your staff like to receive more information or training on eutrophication and its management?"*

Among the 28 participants who took part, a total of 26 responses were provided to Survey Question 4. This suggests that two replies to the specific question were not received. Responses to Survey Question 4 were received for 16 out of 19 WMAs, equating to approximately 84% coverage of all WMAs.

Ninety-two percent of the DWAF regional offices and consulted institutions expressed an interest in receiving additional information on the topic of eutrophication and in obtaining further training to enhance their skills and knowledge, as depicted in **FIGURE 53**. The feedback and requests covered a wide array of topics, including management information, prevention strategies (especially in diffuse nutrient source reduction), mitigating the impacts of eutrophication such as algae bloom minimisation, understanding the reversibility or mitigation of anthropogenic eutrophication, identifying causes and addressing specific environmental and catchment concerns related to waterbodies such as Hartbeespoort Dam. Additionally, there was a strong interest in available resources and cost implications, management of aquatic weeds and algae, training for new officers due to high staff turnover, short and long-term management strategies for eutrophication, general overviews, monitoring implementation, biomonitoring, water quality monitoring, interpretation of water chemistry data, toxicity testing, combatting algae proliferation, techniques for detecting and testing for eutrophication and reducing nutrients as a means to

control eutrophication. There were also inquiries related to the negative effects of different algae species, removal strategies and the implementation of management options in line with cooperative governance principles. This comprehensive feedback clearly demonstrates the enthusiastic interest and substantial range of needs related to addressing and understanding eutrophication.

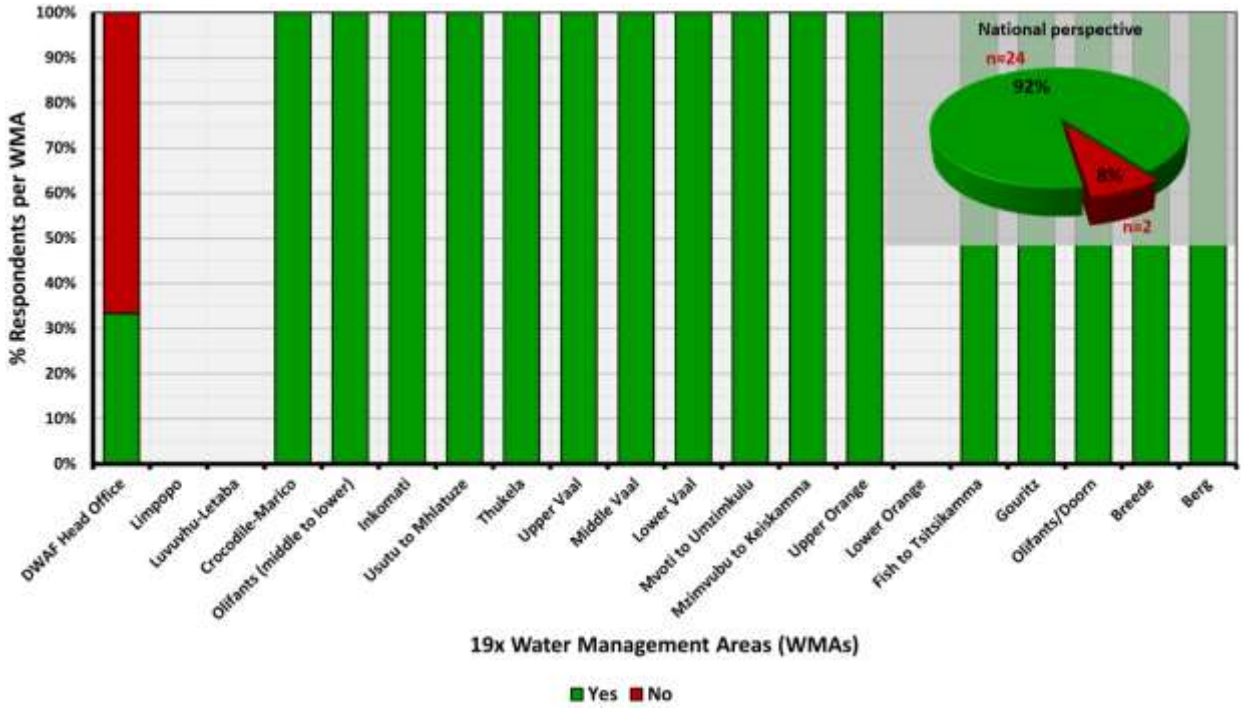

FIGURE 53: Question 4: *"Would your staff like to receive more information or training on eutrophication and its management?"*

4.4.5 Question 5: *"Do you think that the current national policy & strategy for management of eutrophication requires revision?"*

Among the 28 participants, a total of 22 responses were provided to Survey Question 5, indicating that six replies were not received. Responses to this question were received for 16 out of 19 WMAs, equating to approximately 84% coverage of all WMAs. The geographic coverage per WMA is deemed sufficient for drawing conclusions with reasonable confidence about the status and management of eutrophication in South Africa.

The survey results presented in **FIGURE 54** seem to mirror the operational mode of the DWAF, where the Head Office is primarily responsible for developing policies and strategies, while the regional offices carry out their implementation. This likely accounts for the 27% of respondents from WMAs who were hesitant to provide an opinion. When combined with the 55% who indicated that revising policy and strategy is crucial, it becomes evident that most respondents believe there is a strong need for a dedicated eutrophication governance policy and/or strategy.

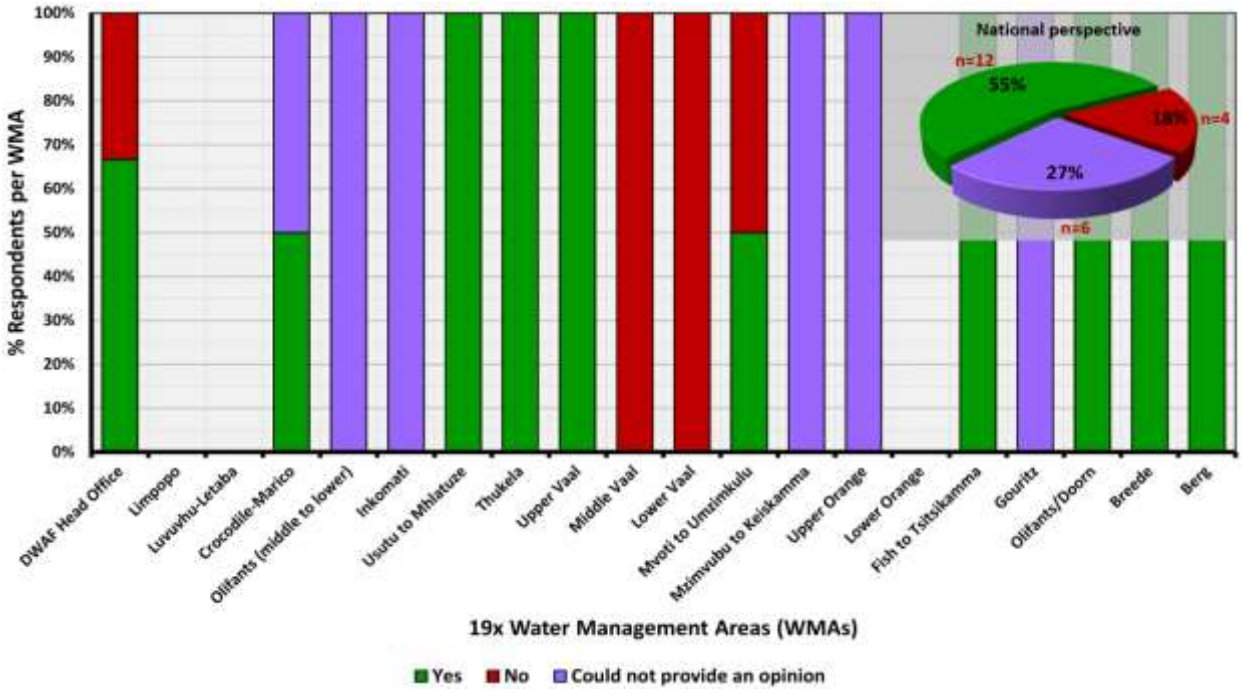

FIGURE 54: **Question 5:** ***"Do you think that the current national policy & strategy for management of eutrophication requires revision?"***

4.4.6 Question 6: *"Would your region/institution be prepared to participate in developing a national strategy?"*

Among the 28 participants who took part, a total of 26 responses were provided to Survey Question 6. This suggests that two replies to the specific question were not received. Responses to Survey Question 6 were received for 16 out of 19 WMAs, equating to approximately 84% coverage of all WMAs.

The majority of officials, accounting for 92% as shown in **FIGURE 55**, from the DWAF and the institutions consulted were willing to partake in a future initiative to develop a dedicated policy and strategy for managing eutrophication.

4.4.1 Question 7: *"Do you have any comments that you would like the DWAF to take note of?"*

The comments provided include a range of concerns and recommendations intended for communication to the DWAF, addressing multifaceted aspects of water quality management. Notably, there was an emphasis on the need to strategically position the proposed eutrophication policy and/or strategy within the evolving hierarchy of Water Quality Management policies and strategies, and to ensure its integration with other policies and strategies. The urgency of public awareness campaigns and the demand for more accessible information on sustainable water resource management also surfaced as critical concerns.

Furthermore, specific regional office issues such as the serious eutrophication problem in the Crocodile-Marico region were highlighted, with requests for support and commitment from both internal and external stakeholders. Staff turnover emerged as a major challenge, with a call for the creation of a career path within water quality management to ensure continuity and expertise. Notably, the necessity for comprehensive and progressive training for staff was emphasised, moving away from superficial, short-term training and recognising the need for broader knowledge encompassing water treatment processes, ecological understanding and early warning signs for issues such as algal blooms and chemical quality problems.

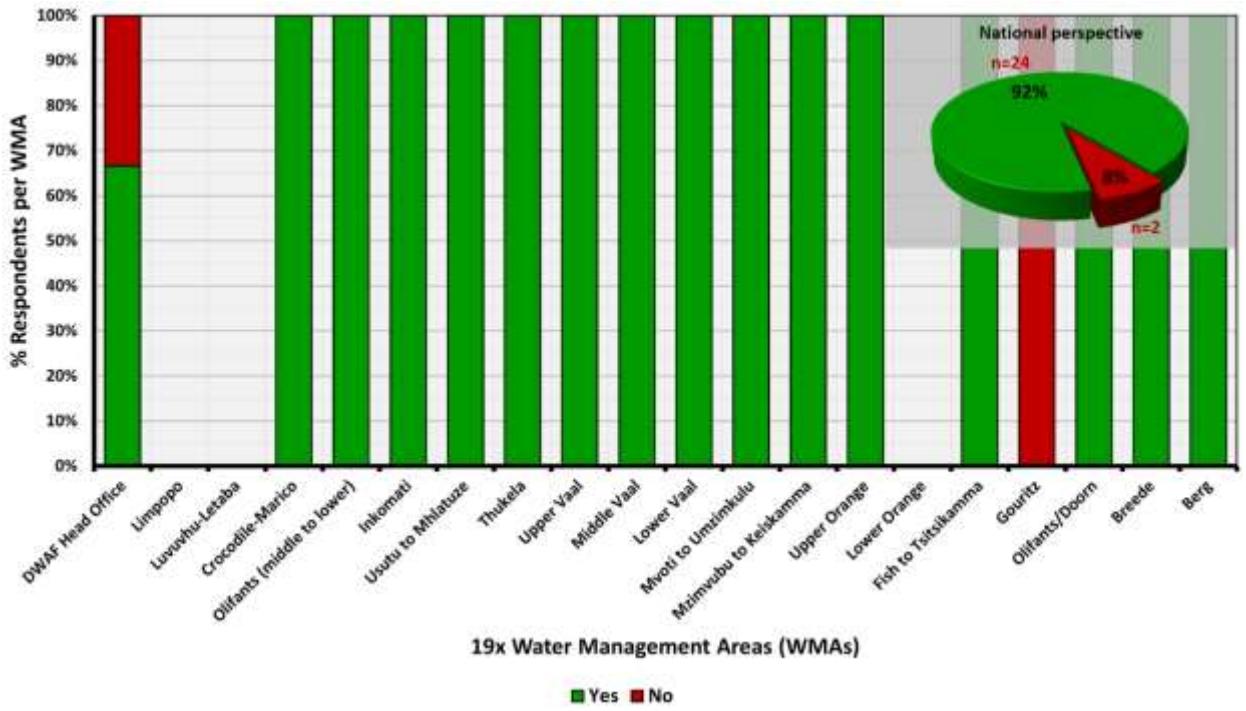

FIGURE 55: Question 6: *"Would your region/institution be prepared to participate in developing a national strategy?"*

Moreover, the comments address the broader system of water management, highlighting the interconnectedness of issues like effluent control, integration between governmental tiers and the importance of proactive eutrophication monitoring across WMAs. These perspectives underscored a holistic approach to water management, emphasising that eutrophication cannot exist in isolation and necessitated coordinated, comprehensive strategies embedded within broader water resource governance frameworks.

4.4.2 Question 8: "*… please indicate where eutrophication problems occur, (8.1) the level of intensity, (8.2) the type of problems (immediate causes) and (8.3) the possible underlying causes. (8.4) Where severe eutrophication problems occur, provide details of any eutrophication management actions that have been implemented.*"

A total of 84 water resource systems with severe eutrophication challenges have been identified by the 28 respondents across the country (**FIGURE 56**). Responses to Survey Question 8 were received for 17 out of 19 WMAs, equating to approximately 89% coverage of all WMAs.

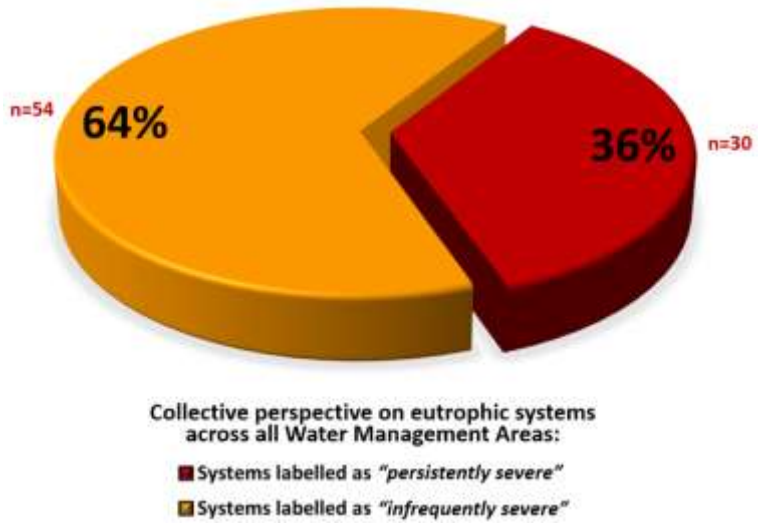

FIGURE 56 Question 8.1: Respondents were asked to use the scale description *"persistently severe"* or *"infrequently severe"* to label eutrophic systems in their Water Management Areas.

As depicted in the figure, more than a third of these water resource systems show severe eutrophication challenges year-round, while nearly two-thirds experience severe eutrophication during specific parts of the year. This emphasises the likelihood of seasonality significantly affecting primary production in the water column. Understanding the seasonal variations in eutrophication enables the development of specific strategies for managing and mitigating these challenges. It is imperative to consider the implications of climate variation and unpredictability in the management of eutrophication.

In **FIGURE 57**, influencing factors early in the eutrophication causal chain are highlighted. According to respondents, the presence of algae was identified as the most significant contributor to catchment eutrophication problems, at 37%. Following closely, water chemistry accounted for 29%, with aquatic weeds at 27%, and biodiversity and habitat impairment at 7% noted as the second, third and fourth biggest contributors to catchment eutrophication problems, respectively. Importantly, anthropogenic nutrient loading of water systems induces excessive primary production, leading to biodiversity and habitat destruction. Therefore, it is crucial to consider

measures for controlling anthropogenic nutrient loading as a means of effectively managing eutrophication.

Participants were then asked to indicate the primary cause of eutrophication, selecting from options including sewage effluent discharges, agricultural practices or other practices, or a combination of these factors.

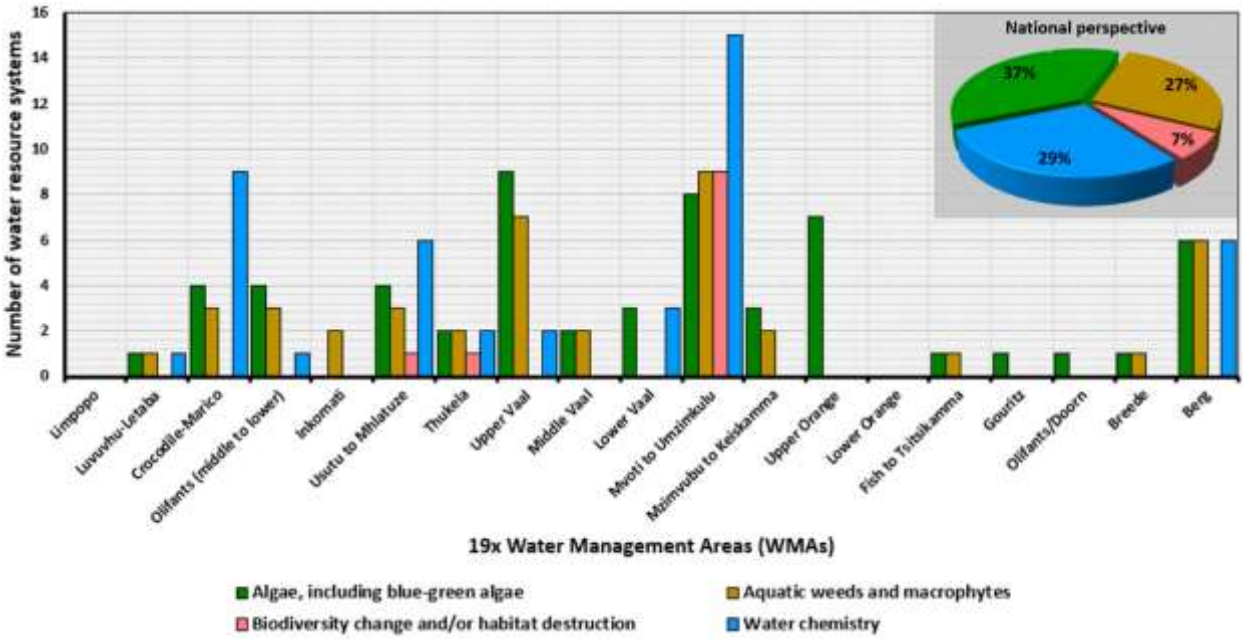

FIGURE 57: Question 8.2: Respondents were asked to identify the *"immediate causes"* of eutrophication in Water Management Areas.

FIGURE 58 suggests that the primary cause of eutrophication is the discharge of treated wastewater and domestic effluents into watercourses. Respondents indicated that form these listed causes, wastewater treatment constituted 52% of the primary causes. Additionally, agricultural practices, at 29%, are noted as a contributing factor, releasing nutrients from both point and non-point sources, while drainage from densely populated areas in highly urbanised WMAs, at 15%, was emphasised as a significant concern. Other non-specified upstream causes came in at 4%.

It is clear that a combination of institutional, technical and management incapacity, as well as financial and political reasons, have contributed to dysfunction within many South African municipalities [DWS, 2017a:85]. The aging infrastructure, insufficient maintenance and lack of investment in wastewater treatment facilities have indeed been significant challenges [DWS, 2022:14]. Moreover, systemic corruption associated with many municipalities has hindered effective administrative and management practices [Muller & Erasmus, 2020:63]. These factors combined, have resulted in the inability of many South African municipalities to effectively

handle sewage water. Leaking sewage reticulation infrastructure and the direct discharge of poorly or untreated sewage into public streams lead to environmental and public health concerns, violating our constitutional right to an environment that is not harmful to health or well-being. Addressing these issues will require comprehensive efforts to improve infrastructure, address systemic corruption and enhance administrative capacity within these municipalities.

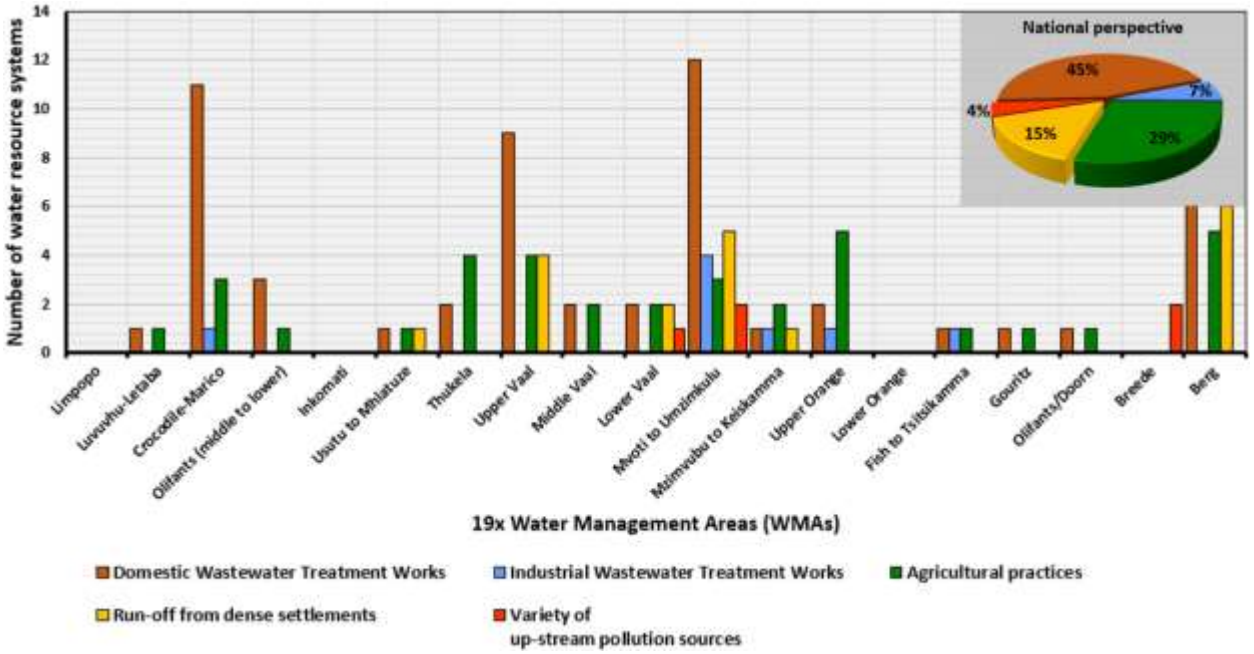

FIGURE 58: Question 8.3: Respondents were asked to identify the *"underlying causes"* of eutrophication in Water Management Areas.

Based on the responses, it is apparent that, beyond measures regulating the discharge of treated sewage into water courses, there is a dearth of comprehensive, integrated eutrophication management programmes practiced across South Africa. The country continues to implement long-established policies, strategies and regulations, such as the 1mg/ℓ orthophosphate regulation and uniform WDSs, without adopting or executing new approaches, despite the evolution of eutrophication challenges and their varied sources.

In **FIGURE 59**, 29% of respondents emphasised regulatory and enforcement interventions as the most prominent, followed by catchment management at 19%, stakeholder and participatory approaches at 11%, and physical water plant removal at 8%. Bioremediation and nature-based solutions were noted at 6%, while cooperative governance and technical support, as well as water quality monitoring, were each indicated at 2%. Notably, 22% of respondents cited *"no action"* as the second most prevalent response. These findings raise concerns about the effectiveness of current intervention responses, indicating an urgent need for a comprehensive overhaul considering the responses to Survey Questions 8.

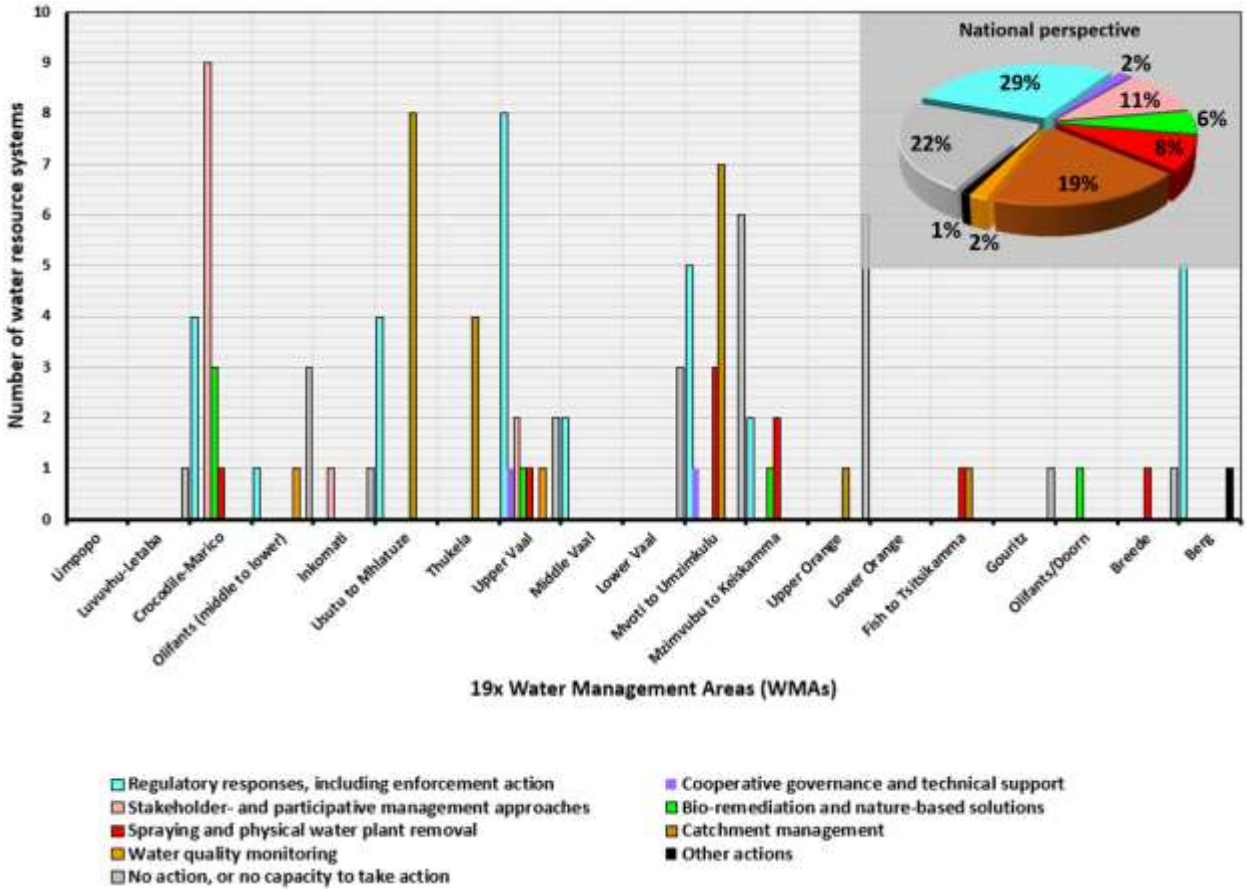

FIGURE 59: Question 8.4: Respondents were asked to identify actions taken to address eutrophication in their Water Management Areas.

The survey results in **Section 4.4** outlined causes, effects and possible interventions. By applying the DPSIR Framework to these results, **Section 4.5** can design interventions that address root causes and pressures more effectively. These insights support the creation of effective eutrophication governance policies and strategies.

4.5 CAUSAL CHAIN ANALYSIS AND THE IDENTIFICATION OF POTENTIAL INTERVENTION RESPONSES

The evaluation of eutrophication governance in South Africa has been a multifaceted process that, thus far, involved:

- A thorough review of existing literature on the theme of *"eutrophication governance"*, which provided a robust foundation for study execution (**Chapter 3**);
- The evaluation and identification of key challenges associated with eutrophication, highlighting the most prominent eutrophication-related problems that the country grapples with (**Section 4.2**);

- An examination of the historical context and forecasting of the evolution of eutrophication governance, as a means to project likely future management policy and regulatory requirements (**Section 4.3**);
- An analysis of survey results[99] relating to the status of eutrophication and its management to solicit geographically representative regulatory and other input (**Section 4.4**); and
- Active engagement with stakeholders[100] to enhance study insights and validate outputs (**Section 4.6**).

In addition to providing valuable context in the search for solutions to anthropogenic eutrophication, **Sections 4.2**, **4.3** and **4.4** also revealed or confirmed a number of causes, effects and potential intervention responses. These are summarised in **Section 4.5.1**, below.

4.5.1 Condensed summaries of causes, effects and intervention responses, distilled from detailed discussions in preceding sections

It should be noted that **Sections 4.2**, **4.3** and **4.4** were compiled from different perspectives, and that the emphasis on *"causes and effects"* versus potential *"intervention responses"* varied. To reconcile this, a causal chain analysis, based on the DPSIR Framework, will be presented in **Section 4.5.2**, comprehensively detailing all identified causal linkages and chains. Stakeholder engagement has informed the contents of **Sections 4.2**, **4.3** and **4.4**.[101] The causes, effects and intervention responses discussed in these sections have been identified and are captured in **TABLE 19**, **TABLE 20** and **TABLE 21**, respectively. These tables will serve as the foundation for the causal chain analysis detailed in **Section 4.5.2**.

TABLE 19: Summary of causes, effects and potential intervention responses identified in *"Section 4.2: Evaluation and identification of key challenges associated with eutrophication* in South Africa*".*

Section 4.2.1: Insufficient wastewater infrastructure maintenance
Causes and effects: ● Insufficient wastewater infrastructure maintenance and investment; ● return flows constitute a significant component of the country's water budget; ● poor wastewater handling; ● over-enrichment is often intertwined with other water quality challenges such as microbial pollution; ● infrastructure operated above its design capacity; ● vandalism; ● ageing infrastructure; ● poorly constructed and operated on-site sanitation systems; ● unemployment and poverty; ● high level of grant dependency; ● compromised affordability and viability of services; ● growing burden on already limited government financial resources; ● systemic corruption associated with many municipalities; and ● frequent discharge or leakage of sub-standard return flows and untreated sewage.
Potential intervention responses: ● None mentioned.

[99] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[100] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

[101] The *Issues and Response Register* is available at: https://www.dws.gov.za/RDM/DocumentsSDS.aspx and formed part of a DWS initiative to develop and implement a eutrophication management strategy for South Africa [DWS, 2023b:1].

Section 4.2.2 Deteriorating ecological infrastructure

Causes and effects: ● Increased occurrences of floating and rooted aquatic macrophytes; ● loss of native plant species; ● native plant species replaced by alien plant species; ● replacement with alien plant species affects water quality through reduced dilution capacity; ● replacement with alien plant species alters nutrient cycling; ● replacement with alien plant species increases occurrences of soil erosion; ● increased occurrences and intensity of nuisance algal blooms; ● growing dominance of cyanobacteria, including toxic species; ● impacts on drinking water quality, affecting taste and odour due to the presence of pollutants like Geosmin and 2-methylisoborneol (2-MIB), which are challenging to remove during water treatment and increase water treatment costs; ● undesirable aesthetic conditions, such as discolouration, increased turbidity, foaming and presence of odours; ● severe shading and light attenuation caused by macro algae and phytoplankton blooms, hindering photosynthetic processes in benthic plants, leading to benthic habitat stress and destruction; ● loss of benthic diversity, affecting and stressing bottom-feeding fish and other animals; ● increased occurrences of deoxygenation in reservoir bottom waters, resulting in elevated levels of hydrogen sulphide, heavy metals and nutrients; ● decomposition of organic matter leading to an oversupply of CO_2, enhancing water acidification; ● harmful effects on aquatic animals, including fish gill clogging, poisoning by toxin secretion, localised anoxia affecting subsistence and sports fishing; ● increased fish and invertebrate mortality; ● changes of ecological community structure and loss of biological diversity; and ● mortality of domestic and wild animals drinking hypertrophic waters containing toxins.

Potential intervention responses: ● None mentioned.

Section 4.2.3: Recurrent droughts (driven by climatic variation) and an inescapable need for water resource development

Causes and effects: ● The damming of surface water resources significantly modifies the ecological functioning of river systems; ● dams sequester nutrient elements and reduce downstream transfer of nutrients to floodplains, wetlands, lakes and the coastal marine environment; ● impoundments influence regional nutrient limitation patterns, food web dynamics and trophic conditions, often resulting in the presence of hypertrophic conditions in reservoirs; ● poor trophic conditions in dams affect fitness-for-use, and impact regional economies and property values in the vicinity of such dams; ● climate change is expected to bring about changing rainfall patterns; ● altered storm intensities; ● extremes of floods and droughts; ● higher solar radiation intensities; ● increased ambient air temperatures; ● rising evaporation rates; ● changes in soil moisture and runoff; ● higher demands for water in some areas; ● alterations in water availability; ● climate change is expected to lead to changing water quality conditions, including the water temperature; ● increased climate variability; and ● climate change amplifies deteriorating trophic conditions in water resources by affecting internal and external nutrient loadings.

Potential intervention responses: ● Adaptation strategies designed to adjust human and natural systems in response to real or anticipated climatic changes and their effects, which can, in turn, influence eutrophication.

Section 4.2.4: Inequities in relation to access to safe sanitation (against the backdrop of a growing population)

Causes and effects: ● The South African population has increased significantly; ● urbanisation is driving an increasing demand for sanitation provision; ● progress in reducing the sanitation backlog has been hampered further by households becoming smaller and the number of households growing at a faster rate than the population; and ● the small and scattered nature of rural populations poses spatial challenges in providing comprehensive sanitation services to all.

Potential intervention responses: ● None mentioned.

Section 4.2.5: Water use regulation that is not consistently and adequately protecting South Africa's water resources against anthropogenic eutrophication
Causes and effects: ● Many discharges of water containing waste are not permissible in terms of the NWA (36:1998); ● or do not comply with applicable authorisation requirements, such as relevant WDSs; ● contributary factors include incidences of poor authorisation administration; ● lack of regulatory integration and poor cooperation amongst relevant authorities; ● periodic backlogs with the issuing of water use authorisations; ● poor quality of some water use authorisations (*e.g.*, authorisation conditions that do not appropriately integrate with water resource requirements); ● Existing Lawful water Uses with water use authorisations that contain inadequate or outdated conditions; and ● poor compliance with water use authorisation conditions, often coupled with insufficient compliance monitoring and/or inadequate enforcement. **Potential intervention responses:** ● None mentioned.
Section 4.2.6: Lack of skilled water scientists and engineers
Causes and effects: ● Eutrophication management capacity has diminished throughout the country due to staffing transformation and human resource turnover within institutions. **Potential intervention responses:** ● None mentioned.

TABLE 20: Summary of causes, effects and potential intervention responses identified in ***"Section 4.3: Examination of the history and forecasting the evolution of eutrophication governance in South Africa"***.
Causes and effects: ● Population growth, ● urbanisation and associated land use change; ● agricultural intensification; ● shifting consumer preferences and behaviour; and ● climate change and extreme weather events. **Potential intervention responses:** ● Technological innovation and advancements; ● technology solutions; ● innovations and advancements in wastewater treatment; ● public awareness and engagement; ● ecosystem-based approaches; ● policy and governance frameworks; ● globalisation, interconnectedness of economies and international trade; ● improved management integration; ● implementation of feasible WDSs; ● operationalisation of the Receiving Water Quality Objectives Approach; ● legal compliance; ● intensification of compliance monitoring and enforcement; ● responsibility of water users; ● full implementation of all NWA (36:1998) instruments; ● protection of high-yield and strategic water source areas; ● implementation of buffer areas; ● recommencing of eutrophication monitoring programmes; ● augmenting and expansion of monitoring programmes; ● pairing water quality data with flow information; ● integration of Earth observation into monitoring; ● improvement of public access to data; ● extension of compliance monitoring; ● compulsory upload of data by water users; ● utilisation of water value chain data; ● enhanced cooperation with stakeholders; ● technical support to local government; ● promotion of scientific advancements; ● regulating diffuse water pollution; ● promoting reuse and recycling strategies; ● bio-manipulation, fish-harvesting, and food-web manipulation; ● rehabilitation and restoration; ● introduction of zero-phosphate detergents; ● implementation of stricter controls; ● economic incentives for sustainable practices; ● assessing the role of international and transboundary cooperation; and ● considering the influence of climate variation and change impacts.

TABLE 21: Summary of causes, effects and potential intervention responses identified in *"Section 4.4: Analysis of the survey on the status of eutrophication and its management in South Africa"*.
Causes and effects: ● Effects of different species of algae; ● increasing staff workload; ● staff capacity shortages; ● eutrophication is a severe problem in many water resources; ● abundance of algae, including blue-green algae; ● proliferation of aquatic weeds and macrophytes; ● biodiversity change and/or habitat destruction; ● problematic water chemistry; ● poorly functioning domestic and industrial WwTWs; ● poor agricultural practices; ● run-off from dense settlements ; and ● variety of upstream pollution sources.
Potential intervention responses: ● Diffuse nutrient source reduction; ● algae bloom minimisation; ● reversing of anthropogenic eutrophication; ● algae and water plant removal; ● mitigation; ● water quality status monitoring; ● river health monitoring; ● biomonitoring; ● toxicity testing; ● environmental and catchment management; ● management of local authority infrastructure; ● reduction of nutrient input; ● nutrient budgets for reservoirs; ● nutrients reduction as a principal means of controlling and managing eutrophication; ● training new officers are important; ● holistic progressive training; ● allocation of resources, including human capital and budget; ● interpretation of water chemistry data; ● how do one test for eutrophication; ● policy is needed to specify Government's intent with respect to eutrophication governance; ● communication of policy is essential; ● legislation review and improved enforcement; ● extend the Special Phosphate Standard to other areas, especially near impoundments; ● link eutrophication related algae with aquatic ecosystem health/ fish kills; ● point source pollution management instruments are lacking; ● integration of proposed policy within the broader policy environment is important; ● public awareness campaigns; ● use of action groups; ● use of catchment management forums; ● use of case studies to test and research potential solutions; ● maintain contact with local authorities; ● maintain contact with academic institutions; ● understand water treatment processes; ● solutions and management measures should have been implemented 10 years earlier; ● more attention to early warning systems; ● the control of runoff from informal settlements must receive attention; ● eutrophication prevention and minimisation are priority considerations; ● biological response monitoring systems are imperative to assess the real impact of poor water chemistry; ● need a legal leg to stand on with respect to sewerage works that overflow and that are over capacity; ● information management is important; ● regulatory responses, including enforcement action; ● cooperative governance and technical support; ● stakeholder- and participative management approaches; ● bio remediation and nature-based solutions; and ● spraying.

4.5.2 Causal chain analysis, in respect of eutrophication in South Africa, utilising the DIPSIR Framework

The evaluation of eutrophication governance in South Africa, as presented in **Chapter 4**, reaches its apex with a causal chain analysis in **Section 4.5.2**. Employing the DPSIR Framework, this analysis offers a systematic approach[102] to deciphering and tackling the eutrophication challenges within the South African context. **TABLE 22**, which is presented next, illustrates the completed DPSIR Framework. Its development was informed by the condensed summaries in **Section 4.5.1** and contributions from stakeholder engagement.[103] Through meticulous analysis, cause and effect chains, along with intervention responses, were consolidated and refined, to remove duplicates and synthesised to present a comprehensive causal chain analysis. The analysis aims to develop a critical understanding of eutrophication governance in the country, bolstering the development of effective eutrophication governance policies and strategies to follow in **Chapter 5** and **Chapter 6**, respectively.

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[102] The causal chain analysis, employing the DPSIR Framework, was carried out in line with the method description outlined in **Section 2.4.2**.

[103] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

TABLE 22: An analysis of anthropogenic nutrient enrichment and the effects of eutrophication in South Africa, based on the DPSIR Framework.

(1) DRIVER ⇨	(2) PRESSURE ⇨	(3) STATE ⇨	(4) IMPACT ⇨	(5) RESPONSE ↺
i.e., the socio-economic or demographic developments, OR production or consumption practices that trigger *"pressures"*.	*i.e.,* the anthropogenic activities or consequences that disturb the *"state"* of ecosystems.	*i.e.,* the physical, chemical or biological condition of ecosystems that causes *"impacts"* on the environment.	*i.e.,* effects on habitats, biota, ecosystem goods and services and ultimately society that require control, management and/or mitigation, through appropriate responses.	*i.e.,* the societal measures aimed at preventing, minimising or mitigating negative *"impacts"* by feeding back to the *"drivers"*, *"pressures"* and *"state"*.[104]
(1.1) Mining: ▶ Opencast mines to supply demands for minerals; and ▶ Underground mining operations to supply demands for minerals.	▶ Blasting; ▶ Exposing of phosphorus-bearing rock; and ▶ Disturbance of habitat and soil layers.	▶ Soil properties, such as pH, affects P availability. Under some condition a high soil pH can increase P mobility and availability, whereas, acid precipitation can reduce P mobility, holding P back until the pH rises again; ▶ Water properties, such as pH, temperature and O_2 affect the $NH_3 \leftrightarrow NH_4^+$ equilibrium. Free un-ionised ammonia (NH_3) is toxic to aquatic organisms and predominates when the pH and water temperatures are high, or when O_2 levels are low (*i.e.,* low O_2 levels inhibit nitrification).	▶ Shading leads to benthic habitat destruction; ▶ Fish and other aquatic animals become stressed, and are susceptible to parasites; ▶ Aquatic animals are subjected to bacterial infections; ▶ Excessive algal blooms are harmful to, and lead to injury of aquatic animals, such as the clogging of fish's gills, poisoning by toxin releases and localised anoxia that effects subsistence and sports fishing;	**(5.1) IMPLICATIONS FOR POLICY FORMULATION:** **(5.1.1) Chief imperatives:** ▶ Limit anthropogenic nutrient loading; ▶ Reduce excessive primary production; ▶ Protect aquatic ecosystems and their biological diversity; ▶ Secure water resources that are fit-for-use; and ▶ Support ecologically sustainable development and justifiable socio-economic growth.
(1.2) Industry: ▶ Industrialisation and industrial expansion; ▶ More industrial waste and wastewater; and ▶ Growing potential for air pollution.	▶ Discharge of substandard wastewater; ▶ Atmospheric emissions of NH_3 and NO_2 affecting the nutrient content of precipitation; ▶ Atmospheric emissions of NO_2 and SO_2 generating acid precipitation; and ▶ Habitat disturbance.			

[104] After examining the identified responses, they were grouped according to their nature, *i.e.* (5.1) those that typically support policy formulation vs (5.2) those that typically support strategy establishment. The policy supporting responses were again subdivided into the following sub-groups: (5.1.1) *"chief imperatives"*; and (5.1.2) *"complementing imperatives"*. The strategy supporting responses were subdivided according to the following sub-groups: (5.2.1) *"core approaches"* (as *"source"*, *"resource"* or *"remediation"* directed management); (5.2.2) *"operational approaches"* (as per the Plan-Do-Check-Act cycle [Moen & Norman, 2009:1-10]); and (5.2.3) *"supporting approaches"*.

(1) DRIVER ⇨	(2) PRESSURE ⇨	(3) STATE ⇨	(4) IMPACT ⇨	(5) RESPONSE ↺
(1.3) Agriculture: ▶ Increased dry-land and irrigated crop production to maintain food security; ▶ More dairies and intensive animal feeding units needed to maintain food security; ▶ Expanding aquaculture to provide alternative sources of protein to maintain food security; ▶ The intensification of farming practices to maintain favourable economies of scale and to remain profitable; ▶ A lack of capacity hindering effective farm advisory services; and ▶ Lack of capacity with respect to on-farm best management practices.	▶ Poor fertilising practices and over-fertilising causing fertiliser-laden diffuse runoff from agricultural fields; ▶ Prevalence of erosion, mobilising sediments on which chemical elements are adsorbed; ▶ Over-irrigation to satisfy leaching requirements; ▶ Feedlot waste disposal and wastewater discharged; ▶ Habitat disturbance; ▶ Organic waste, food leftovers and excreta associated with aquaculture; ▶ Inadequate farm advisory and extension services; and ▶ Poor farming practices.	Factors, such as alkaline drainage, thus, may have an aggravating influence; ▶ Elevated P; ▶ Elevated N, also in groundwater resources that feed surface water resources; ▶ Climate change is expected to lead to changing water quality conditions (including the water temperature); ▶ Climate change amplifies deteriorating trophic conditions in water resources by affecting internal and external nutrient loadings; ▶ Elevated Chl-α; ▶ Occurrences and intensity of nuisance algal blooms; ▶ Occurrences of floating and rooted aquatic macrophytes; ▶ Invasive plant species replace native plant species; ▶ Loss of native plant species; ▶ Replacement with alien plant species alters nutrient cycling; ▶ Dominance of cyanobacteria and the occurrence of toxic cyanobacteria; ▶ Undesirable aesthetic conditions (*viz.* discolouration, increased	▶ Changes of ecological community structure and loss of biological diversity; ▶ The proliferation of alien invasive plant species affects resource water quality through reduced dilution capacity and altered nutrient cycling; ▶ Replacement with alien plant species increases occurrences of soil erosion; ▶ Undesirable aesthetic conditions, such as discolouration, increased turbidity and foaming; ▶ Increased occurrences of taste and odour problems in final drinking water; ▶ Increased water treatment costs to run water treatment works (WTWs) to remove odours, tastes, toxins, etc.; ▶ Toxic levels of free ammonia (NH_3) may kill fish and other aquatic organisms; ▶ Inorganic chemicals, such as ammonia, nitrites, hydrogen sulphide, etc. that induce the formation of harmful substances, such as nitrosamines, suspected of being mutagenic during the production of potable water;	**(5.1.2) Complementing imperatives:** ▶ Resource eutrophication governance (with money, people, etc); ▶ Promote research; ▶ Promote management cooperation; ▶ Promote transparency; and ▶ Facilitate capacity building and the empowerment of role-players. **(5.2) IMPLICATIONS FOR STRATEGY ESTABLISHMENT:** **(5.2.1) Core approaches:** **(5.2.1.1) Source-directed management:** ▶ Improved regulation; ▶ Operationalising of the Receiving Water Quality Objectives Approach; and ▶ Integration across sectors. **(5.2.1.2) Resource-directed management:** ▶ Determine RDMs; and ▶ Improved regulation.
(1.4) Tourism: ▶ Seasonal trends peaking during holiday periods; and ▶ Increased demands for water services during holiday peak seasons.	▶ Fluctuating and increased waste and wastewater production; and ▶ Fluctuating and increasing pressure on urban wastewater handling.			
(1.5) Human settlement areas: ▶ Expansion of paved areas and generation of more stormwater.	▶ Nutrient-laden diffuse runoff from built-up areas; and ▶ Habitat disturbance.			

(1) DRIVER ⇨	(2) PRESSURE ⇨	(3) STATE ⇨	(4) IMPACT ⇨	(5) RESPONSE ↺
(1.6) Other land uses: ▶ Establishment of more golf courses.	▶ Fertiliser and nutrient-laden diffuse runoff from golf courses; and ▶ Habitat disturbance.	turbidity and loss of clarity, foaming, presence of odours, etc.); ▶ Impoundments sequester nutrients; ▶ Sequestration of nutrients in the sediment; ▶ Increased occurrences of floating and rooted aquatic macrophytes; ▶ Severe shading and light attenuation caused by excessive macrophyte growth, blooms of macro-algae and phytoplankton, and the presence of debris hinder the photosynthetic processes in benthic plants; ▶ Elevated COD; ▶ Oxygen depletion, especially in the deeper layers of water resources during the end of summer; ▶ Loss of benthic diversity affects and lead to stressed bottom-feeding fish and other animals; ▶ The decomposition of organic matter leads to an oversupply of CO_2, which, in turn, also enhances water acidification; ▶ Increased occurrences of elevated levels of hydrogen	▶ The sequestration of nutrients in impoundments reduces the downstream transfer of nutrients to floodplains, wetlands, lakes and the coastal marine environment; ▶ Impoundments influence regional nutrient limitation patterns, food web dynamics and trophic conditions, often resulting in the presence of hypertrophic conditions in reservoirs; ▶ The destruction of habitat and ecological infrastructure, such as wetlands, may liberate and reintroduce previously sequestered pollutants back into receiving water resources; ▶ Increased occurrence of human health problems (*i.e.,* gastroenteritis, skin irritations, etc.); ▶ Increased incidence of Bilharzia, due to increased habitat, which may be associated with the proliferation of aquatic plants and macrophytes; ▶ Increased interference with recreational activities (*i.e.,* boating, fishing, swimming, etc.);	**(5.2.1.3) Remediation-directed management:** ▶ Develop and implement a Remediation Strategy to address cases of legacy nutrient pollution; and ▶ Improved regulation. **(5.2.2) Operational approaches:** **(5.2.2.1) Plan stage:** ▶ Holistic water resource system and catchment planning; ▶ Structured planning to ensure that WwTWs are timeously upgraded to not exceed design capacities; ▶ Validation and verification (V&V) of all water uses with a water quality impact potential; and ▶ Waste load accounting to be introduced as a planning instrument. **(5.2.2.2) Do stage:** ▶ Integration of authorisation conditions with water resource requirements;
(1.7) Local government performance: ▶ Capacity and skills shortages; ▶ Growing and deteriorating industrial wastewater handling, feeding municipal sewer network systems; ▶ Deteriorating urban wastewater handling; and ▶ Poor waste management.	▶ Inadequate operation and maintenance of off-site and on-site sanitation systems; ▶ Theft and vandalism of wastewater infrastructure; ▶ Discharge or loss of untreated and/or substandard wastewater; ▶ Poor waste practices; and ▶ Inadequate investment in wastewater infrastructure.			
(1.8) Poverty and criminality: ▶ Increasing unemployment; ▶ High levels of grant dependency; ▶ Increasing vandalising, recycling and selling-off of scrap metal and other components of water services infrastructure; ▶ Systemic corruption, associated with many municipalities; ▶ Growing burden on limited government resources; and ▶ Declining affordability of social infrastructure.	▶ Washing in streams and rivers; ▶ Inappropriate onsite sanitation and bush-toileting; ▶ Theft and destruction of sanitation services infrastructure; ▶ Overflowing utility access holes caused by sewer system blockages and sabotage; and ▶ Discharge of untreated and/or substandard urban wastewater.			

(1) DRIVER ⇨	(2) PRESSURE ⇨	(3) STATE ⇨	(4) IMPACT ⇨	(5) RESPONSE ↺
(1.9) Administrative and political instability: ▶ Increasing staff workload; ▶ Shortages of resources, including financial and human capital; ▶ Fading institutional capacity in many government departments and agencies; ▶ Failing corporate management and governance; ▶ Systemic corruption; ▶ Escalating collapse of local government; ▶ More frequent service delivery protests; and ▶ Shrinking availability of funds or capital (capex) and operational expenditure (opex).	▶ Exceeding the design capacity of WwTWs; ▶ Destruction of water resource and services infrastructure; ▶ Failing operation and maintenance of water resource and services infrastructure; ▶ Discharge of untreated and/or substandard urban wastewater; ▶ Variety of upstream pollution sources; and ▶ Operating rules for the water resource infrastructure that promote enrichment.	sulphide and heavy metals in deoxygenated hypolimnia; ▶ Increased fish and invertebrate stress; ▶ Over-enrichment is often intertwined with other pollution challenges, such as microbial pollution; ▶ Undue exposure to pathogens that are present and associated with faeces; and ▶ Diminishing state of ecological infrastructure.	▶ Increasing risk to human health affecting traditional ceremonies and rituals performed in rivers and wetlands; ▶ Struggling tourism due to foul odour and turbidity issues, skin irritations, etc.; ▶ Loss of property values; ▶ Interference with irrigation and livestock agriculture (*i.e.,* clogging of irrigation nozzles and livestock mortalities); ▶ Mortality of domestic and wild animals, drinking hypertrophic waters that contain toxins; ▶ Reduced income from agriculture, tourism and other effected sectors;	▶ Increased reuse and recycling of waste and water containing waste; ▶ Revision of nutrient discharge standards; ▶ Ensure that all water uses with a potential to contribute towards eutrophication are permissible, compliant and lawful; ▶ Improved water use authorisation and administration; ▶ Improved regulation; ▶ Enforcement of conservation agriculture; ▶ Enforcement of buffer zones and other best management practices; and ▶ Implementation of the WDCS.

(1) DRIVER ⇨	(2) PRESSURE ⇨	(3) STATE ⇨	(4) IMPACT ⇨	(5) RESPONSE ↺
(1.10) Population dynamics: ▶ Depopulation of rural areas; ▶ Constant stream of foreign nationals in search of a better future moving to South Africa; ▶ Significant population growth; ▶ Increasing urbanisation; ▶ Increasing development; ▶ Progress in reducing the sanitation backlog has been hampered by households becoming smaller**;** ▶ Small and scattered nature of rural populations poses spatial challenges to comprehensive sanitation services provision to all; ▶ Replacement of ecological infrastructure with grey infrastructure; ▶ Growing demands for potable water and water resource development; ▶ Demand for western style foods and fast foods, *e.g.,* growing consumption of meats; ▶ Use of phosphate-free detergents; ▶ Escalating unemployment; and ▶ Inadequate levels of education or less skilled and aspiring employees being absorbed.	▶ Return flows becoming an increasingly important component of the country's water budget; ▶ Habitat disturbance; ▶ Increased urban waste and wastewater production; ▶ The nutrient-loading character of wastewater is changing; ▶ Pressure on urban wastewater handling; ▶ Negative effect on the affordability of rural water services infrastructure, affecting operation and maintenance; ▶ Altered flow and water quality regimes associated with the establishment of impoundments and related infrastructure; ▶ Lack of skilled water scientists and engineers; and ▶ Inadequately capacitated water institutions.		▶ Impaired social development; and ▶ Economic loss.	**(5.2.2.3) Check stage:** ▶ Improved monitoring programmes and reporting for local and national government; ▶ Regular and targeted compliance monitoring; and ▶ Appropriate information management systems are in place. **(5.2.2.4) Act stage:** ▶ Effective enforcement of big and regular offenders; ▶ Rehabilitation and restoration of ecological infrastructure; ▶ Rehabilitation of hard infrastructure; and ▶ Adequate maintenance of water resource and services infrastructure. **(5.2.3) Supporting approaches:** ▶ Skills development training and capacity building; ▶ Appointment of employees, who possess appropriate skills levels, in technical positions; ▶ Research and technology development; ▶ Creation of an informed, supportive and responsible public;

(1) DRIVER ⇨	(2) PRESSURE ⇨	(3) STATE ⇨	(4) IMPACT ⇨	(5) RESPONSE ↺
(1.11) Climate variability and change: ▶ Extended dry spells; ▶ High solar radiation intensities; ▶ Increased ambient air temperatures; ▶ Extended hot spells; ▶ Changing evaporation rates; ▶ Changing rainfall patterns; ▶ Changes in soil moisture and runoff; ▶ Extremes of floods and droughts; ▶ Alterations in water availability; ▶ Higher demands for water in some areas; ▶ Increasing demands for water resource development; ▶ Extreme wind action; ▶ Altered storm intensities; and ▶ Potentially changing climatic conditions.	▶ Changing water temperatures; ▶ Altered dilution capacity of water resources; ▶ Increasing levels of erosion; ▶ Altered flow and water quality regimes associated with the establishment of impoundments and related infrastructure; ▶ More frequent mixing of stratified layers and inversion of epilimnion and hypolimnion may lead to more regular recycling of nutrients from the anaerobic hypolimnion; and ▶ Exacerbated poor trophic conditions.			▶ Behavioural change communication programmes to facilitate behavioural change and a sense of responsibility in communities aimed at limiting and preventing excessive nutrient loading; and ▶ Management participation, cooperative governance and technical support.

4.5.1 Observations with respect to causal chain analyses utilising the DPSIR Framework

The preceding causal chain analysis underscores the intricate and multifaceted nature of eutrophication as an environmental concern, shaped by a wide array of contributing causal factors. For example, agricultural practices, urban settlements, industrial operations, climate patterns, mining activities, governance challenges, population trends, socio-economic issues, tourism, human settlement areas and natural hydrological processes all significantly contribute to the nutrient loads in waterbodies. These factors serve as crucial drivers of eutrophication in South Africa, as detailed in (**TABLE 22**). Moreover, the pervasive impacts of eutrophication ripple across recreational activities, human health, agriculture, the economy and environment, forming a complex web of causal relationships, as depicted in **FIGURE 60**.

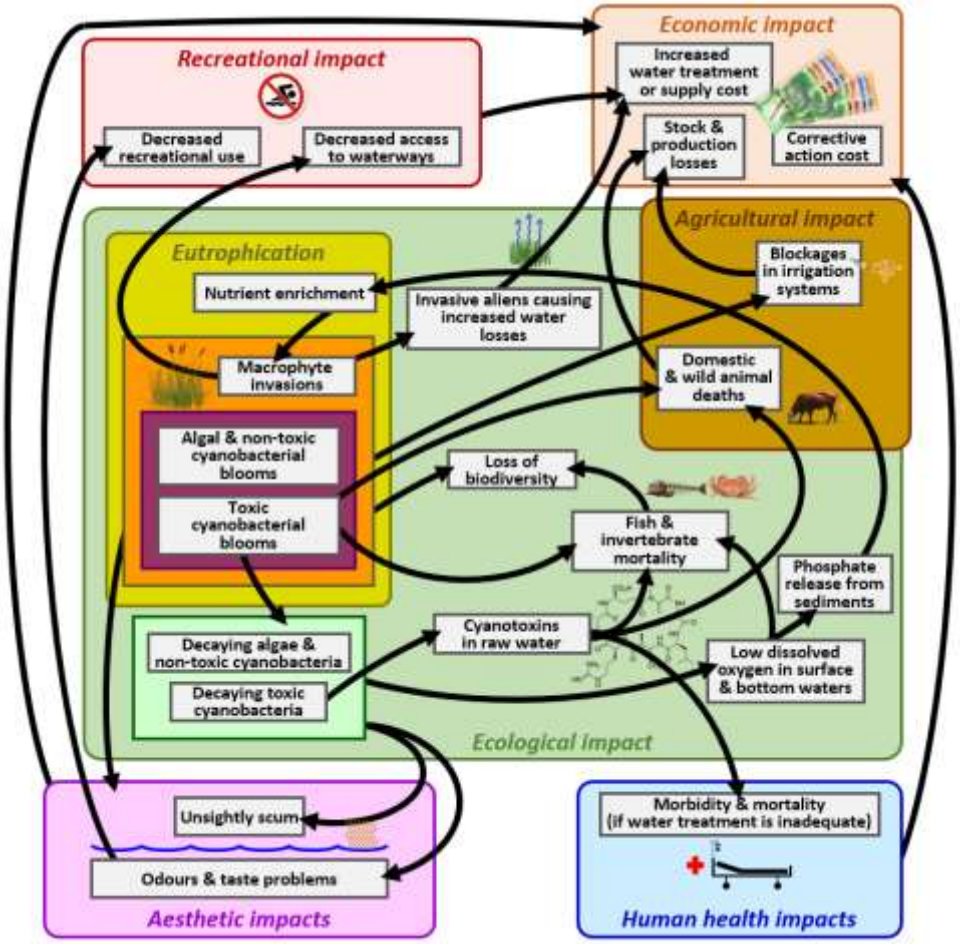

FIGURE 60: A causal *"web"* illustrating the complex interconnection of some causal factors, associated with eutrophication [adapted from DWAF, 2002:(2)7].

While establishing a linear connection between *"drivers"* and *"pressures"* for eutrophication proved to be relatively easy, the process became too complex when attempting to establish a

similar linear relationship between these factors and the resulting *"state"*, *"impacts"* and *"responses"*. It is important to note that the drivers and pressures outlined in **TABLE 22** do not linearly relate to the recorded state, impacts and responses. Despite this complexity, the usefulness of the DPSIR Framework remains intact, as the causal chain analysis aimed to identify appropriate intervention responses designed to address the underlying causal factors, with a preference for targeting the root causes of failure.

The root causes of excessive nutrient loading in South Africa have been identified across various sectors (**TABLE 23**), revealing a complex network of societal drivers and associated anthropogenic pressures:

TABLE 23: Inventory of root causes of excessive nutrient loading in South Africa.
(1) Mining: *This sector contributes through–* ▶ blasting and exposing phosphorus-bearing rock; and ▶ disturbing habitat and soil layers.
(2) Industry: *Industrial activities lead to eutrophication by–* ▶ discharging substandard wastewater; ▶ emitting NH3 and NO2, altering the nutrient content of precipitation; ▶ emitting NO_2 and SO_2, generating acid precipitation; and ▶ disturbing habitats.
(3) Agriculture: *This sector impacts through practices such as–* ▶ poor and excessive fertilising practices leading to nutrient-rich runoff; ▶ erosion mobilising sediments that carry chemical elements; ▶ over-irrigation and leaching requirements; ▶ disposal of feedlot waste and wastewater; ▶ habitat disturbance; ▶ organic waste, leftovers and aquaculture excreta; ▶ inadequate advisory and extension services; and ▶ other poor farming practices.
(4) Tourism: *The tourism sector adds pressure through–* ▶ variable and increased waste and wastewater production; and ▶ increased strain on urban wastewater systems.
(5) Human settlements: *Urban areas contribute via–* ▶ nutrient-rich runoff from built-up areas; and ▶ habitat disturbance.
(6) Other land uses: *Activities such as–* ▶ fertiliser and nutrient rich runoff from golf courses; and ▶ habitat disturbance.
(7) Local government: *The effectiveness of governance impacts eutrophication through–* ▶ inadequate sanitation system maintenance; ▶ theft and vandalism of wastewater infrastructure; ▶ discharge of untreated or substandard wastewater; ▶ poor waste management practices; and ▶ insufficient investment in wastewater infrastructure.

(8) Poverty and criminality: *Contribute through–*

- ▶ washing in streams and rivers;
- ▶ improper sanitation practices and bush-toileting;
- ▶ theft and destruction of sanitation infrastructure;
- ▶ overflowing utility access holes due to blockages; and
- ▶ discharge of substandard urban wastewater.

(9) Administrative and political instability: *Affects eutrophication via–*

- ▶ overloading of wastewater treatment facilities;
- ▶ destruction and ineffectual maintenance of water services infrastructure;
- ▶ discharge of poor-quality wastewater; and
- ▶ upstream pollution and enrichment-promoting operating rules.

(10) Population dynamics: *Impact eutrophication through–*

- ▶ return flows becoming an increasingly important component of the country's water budget;
- ▶ habitat disturbance;
- ▶ increased urban waste and wastewater;
- ▶ shifts in wastewater nutrient profiles;
- ▶ strain on urban wastewater management;
- ▶ challenges in rural water services affordability;
- ▶ flow and water quality changes resulting from infrastructure development, such as impoundments; and
- ▶ lack of skilled personnel and inadequately capacitated institutions.

(11) Climate variability and change: *Contributes by–*

- ▶ changing water temperatures;
- ▶ altering the dilution capacity of water resources;
- ▶ increasing levels of erosion;
- ▶ altering flow and water quality regimes associated with the establishment of impoundments and related infrastructure;
- ▶ increasing the frequency of nutrient recycling from the anaerobic hypolimnion through more regular mixing of water layers; and
- ▶ exacerbating poor trophic conditions.

Additionally, **FIGURE 61** [105] depicts a basic theoretical causal chain example illustrating phosphorus loading's impact on receiving water resources, emphasising how the causes of water quality issues, particularly eutrophication, and their ultimate effects are rooted within the socio-economic domain.

Eutrophication problems stem from anthropogenic activities and are often worsened by poor planning, ineffective regulation and management inaction. These issues affect various aspects of water resources and ultimately have a negative impact on local communities. It is clear that the problem starts and ends with human activities, signifying that poorly planned, regulated, managed development and water use are often detrimental to both the environment and society.

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[105] Complex causal relationships are often represented in a tree format, where a specific *"cause"* branches off into one or multiple *"effects"*. In **FIGURE 61**, the numbering system of the cause-and-effect elements reflects this interconnected relationship. For instance, *"Cause 9"* leads to *"Effects 10.1"* through *"10.3"* and any of the *"Effects 10.1"* through *"10.3"* can further lead to *"Effects 11"*. This sequential progression signifies that the effect, following a preceding cause, acts as the cause for the subsequent effect, creating a cohesive causal chain.

Conversely, without human activities, negative environmental and socio-economic impacts would theoretically not occur. This underscores the need for focused interventions to address anthropogenic eutrophication.

FIGURE 61: An example of a possible phosphorus loading causal chain, illustrating how root causes and ultimate effects are both linked to the socio-economic domain.

The integration of climate change considerations has surfaced as a contested topic within the causal chain analyses for eutrophication governance. While climate change is likely to exacerbate eutrophication, directly addressing climate change within the scope of management policies and strategies for anthropogenic eutrophication is not practical. Instead, the focus is shifted towards incorporating elements of climate adaptation into eutrophication governance and management. Climate adaptation seeks to reduce vulnerability and bolsters resilience against the **impacts of climate change**. Effective eutrophication governance policies and strategies should thus consider these adaptation approaches, as they are essential in planning for resilience [Lebu, *et al.*, 2024:12-15; Quevauviller, 2010:3-5; Sadoff & Muller, 2009:22-25; Srivastav, *et al.*, 2021:1234-1240; Whitehead, *et al.*, 2013:4-6]. These strategies may include:

- **Infrastructure resilience:** such as upgrading drainage systems for more substantial rainfall or creating water storage and conservation solutions to combat droughts;
- **Ecosystem-based adaptation:** like restoring and safeguarding wetlands to mitigate storm surges, prevent erosion, sustain water release during low flows and improve water quality;
- **Water resources management:** encompassing the reduction of losses within water supply infrastructure and the promotion of waste and wastewater recycling and reuse;

- **Disaster risk reduction:** techniques to mitigate the effects of floods and other severe weather events;
- **Urban planning:** development of green spaces and ecological buffers in urban areas to lessen nutrient overloading and mitigate the urban heat island effect;
- **Agricultural adaptation:** implementing conservation agriculture practices to improve soil moisture retention and reduce erosion;
- **Health sector resilience:** strengthening the public health infrastructure to respond to a rise in climate-related diseases;
- **Community-based adaptation:** engaging communities in the development and implementation of adaptive measures;
- **Policy and governance:** dovetailing eutrophication governance with climate adaptation policies and programmes; and
- **Economic diversification:** shifting towards renewable energy investments to lessen reliance on climate-sensitive resources like hydroelectric power.

Additionally, the causal chain analysis with the DPSIR Framework also revealed that root causes like administrative and political instability, poverty and criminality are equally challenging to be controlled by eutrophication practitioners. Conversely, activities such as mining, industry, agriculture, tourism, waste and wastewater handling by local government and expanding human settlement areas can be more readily controlled by practitioners in their respective fields. Furthermore, indirect control over societal drivers can be achieved by focusing on their anthropogenic pressures. For example, rather than a general focus on local government, effective wastewater handling can be the focal point.

FIGURE 62 offers a concise one-page overview of the causal relationships identified in TABLE 22 for eutrophication governance in South Africa. To effectively tackle eutrophication, addressing only one aspect within this intricate causal chain will not be adequate. A holistic and integrated approach is essential, which involves a comprehensive understanding of the ecological, social and technological aspects. This underscores the crucial importance of adaptive management, where responses are regularly adjusted through continual assessment of eutrophication's drivers, pressures, states and impacts.

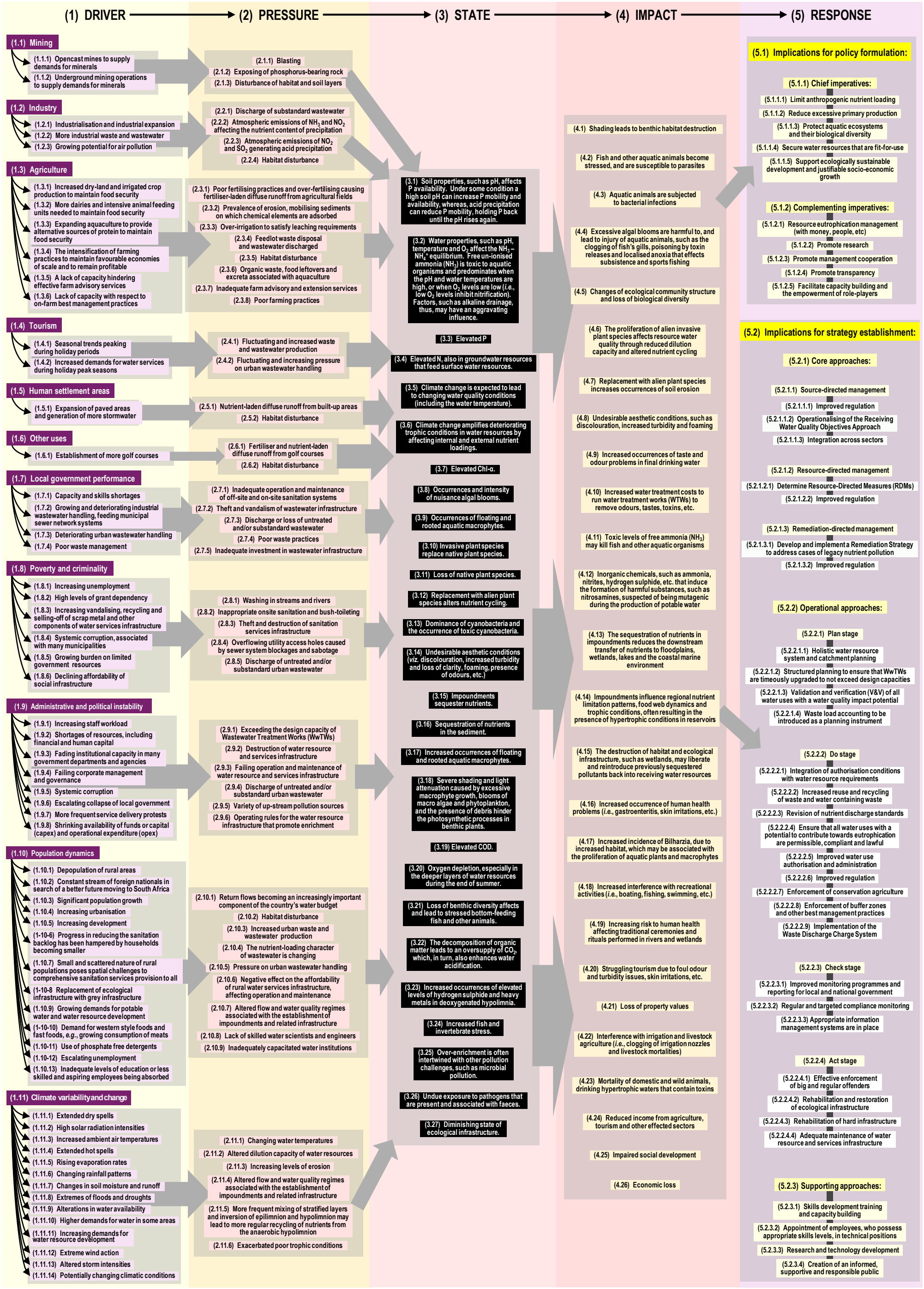

FIGURE 62: DPSIR diagram depicting the causal relationships within eutrophication governance in South Africa.

4.6 STAKEHOLDER ENGAGEMENT

During the parallel execution of this research, stakeholder engagement[106] was not an end in itself but a means to enhance the research outputs by serving as a valuable reference source. With approval from the DWS (**Annexure A**), this research was conducted alongside the departmental initiative, both aimed at improving eutrophication governance in South Africa and both mutually benefiting each other. Due to the intertwined nature of the departmental initiative and this subsequent research, this research also benefited from the stakeholder engagement conducted and the tiered stakeholder engagement structure adopted by the Department. This structure comprised several committees with varied responsibilities (see **FIGURE 63**) set up to guide the Department's policy and strategy development initiative at different levels, also benefiting the outputs from this research.

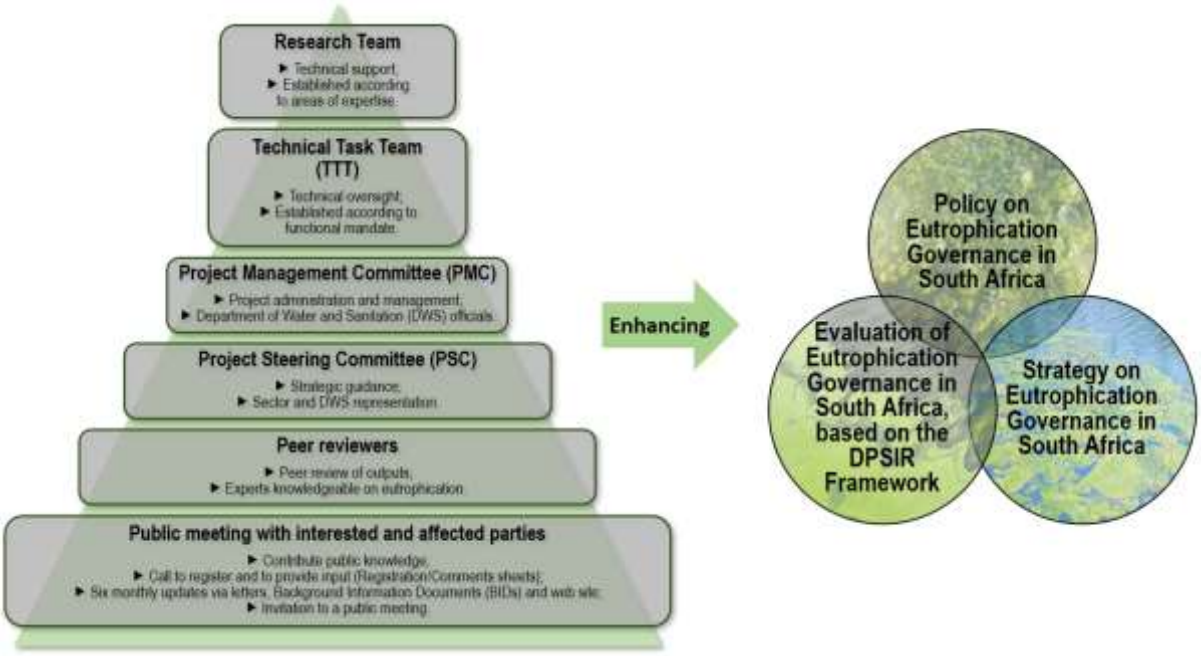

FIGURE 63: DWS stakeholder engagement and enhancement of research outputs [DWS, 2023b:42].

Internal stakeholder engagement within the DWS, aimed at obtaining input and advice on eutrophication governance, took place regularly over a three-year period between 2020 to 2022. Additionally, the DWS solicited input from external stakeholders, including practitioners and

[106] The stakeholder engagement was conducted, as per the method description outlined in **Section 2.3.3**. The engagements took place between 2020 and 2022 as part of a DWS initiative to develop a eutrophication management strategy for South Africa [DWS, 2023b:41]. Inputs gathered during this stakeholder engagement process [DWS, 2023d] were utilised in this study with the approval of the DWS (**Annexure A**), to enhance research outputs.

experts, at three separate occasions on 29 July 2020, 27 July 2021 and 19 August 2022. Furthermore, 151 interested and affected parties were consulted during a hybrid physical and online public engagement on 14 October 2022. Stakeholder input was recorded by both the DWS and the author.

All input on eutrophication governance obtained during the DWS-conducted stakeholder engagements was formally recorded utilising an issues and response register[107] or informal notes by the author, supplemented by a series of meeting minutes[107] to capture decisions and enhance execution. Acceptable stakeholder perspectives and insights were integrated into the research outputs and findings, with corrections and improvements made to the text where relevant. This approach allowed for a systematic evaluation of the input and enhancement of research outputs. The results of these engagements were used to enhance the *"evaluation of eutrophication governance in South Africa"* discussed earlier in this chapter and to shape the study outputs presented in **Chapter 5** and **Chapter 6**, specifically the policy and strategy.

4.7 CONCLUSION

The comprehensive evaluation of eutrophication governance in South Africa, detailed in **Chapter 4**, has illuminated the complex nature of this environmental challenge. It delved into the intricacies of its governance and the breadth of its impact. Drawing on extensive literature, diverse data sets, detailed surveys[108] and stakeholder input,[109] the chapter outlined key challenges, the evolution of governance and potential intervention responses appropriate for the South African context.

At the heart of the evaluation is the identification of eutrophication as a persistent issue in South African waterbodies, with severe implications for ecological integrity, the economy and public health. Critically, it points to inadequate wastewater systems, substandard agricultural practices, in some cases, and multifaceted climatic and socio-economic factors as primary contributors.

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[107] The Register and the meeting minutes are available at: https://www.dws.gov.za/wem/DocumentsSDS.aspx, and formed part of a DWS initiative to develop and implement a eutrophication management strategy for South Africa [DWS, 2023d].

[108] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[109] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

This analysis highlights an overarching need for systematic reforms in eutrophication governance, emphasising the enhancement of infrastructure, policy and strategy development, public education and coordinated action by stakeholders to address the fundamental causes. The urgency for integrated, forward-looking solutions is evident, aiming for policies and strategies that meet contemporary and future needs.

Chapter 4 underscored not only the challenges but also the potential for positive change, as shown by stakeholders' readiness to collaborate on national policies and strategies and their eagerness for more knowledge and training in effective eutrophication management. This reflects a strategic commitment to a robust, multi-pronged approach to alleviate the adverse effects of eutrophication.

In sum, Chapter 4, through the lens of the DPSIR Framework, sharply focusses on the essential role of astute governance in addressing the intricate issue of anthropogenic eutrophication. The path forward demands a united, adaptable, proactive approach, one finely tuned to South Africa's dynamic socio-economic, ecological and climatic landscape. With diligent application of these new insights, there is hope for a future where the problem of anthropogenic eutrophication is not just managed but sustainably reversed.

In the broader context, South Africa's populace of approximately 62 million, spread across more than 28 thousand communities [Stats SA, 2016:68; Stats SA, 2024:10], is entitled to basic rights enshrined in the Constitution through the Bill of Rights. This affirms the democratic values of human dignity, equality and freedom. The maxim ***"Water is life! Sanitation is dignity!"*** encapsulates the role water plays in achieving these democratic values. Hence, eutrophication, which directly contradicts these values by compromising the fitness-for-use of the nation's water resources through poor sanitation and nutrient pollution, is a significant obstacle to overcome.

THE RESEARCH CONTEXT OF CHAPTER 5

Chapter 5 translates the findings of the preceding research, particularly the causal chain and DPSIR evaluation in Chapter 4, into a proposed eutrophication governance policy for South Africa. It, therefore, corresponds closely with Part 2 of the EMSSA, *Eutrophication management policy for South Africa* [DWS, 2023b]. In particular, the visionary perspective in Section 5.3 and the nineteen policy components in Section 5.4 correspond with the visionary perspective and policy intent in Part 2 of the EMSSA. Substantial conceptual and textual correspondence is therefore present, including closely aligned policy formulations.

The development of the corresponding EMSSA policy component also benefited from the contributions of the Co-Author, Researchers, DWS specialists and other stakeholders. W. Mosefowa provided input principally on pollution source control and related regulatory and incentive instruments; K. Makanda and S. Mnyango provided research support during development of the EMSSA, with S. Mnyango additionally supporting stakeholder engagement and coordination; and wider review and consultation assisted in testing and refining the policy intent, individual policy statements and their relationship with the broader water quality management policy framework. These contributions are recorded in the *Issues and Response Register* [DWS, 2023c] and the *Document Change Log* [DWS, 2023e].

The shared material reflects the development of the EMSSA as the applied policy output of the integrated research process. The policy positions, developed through the integrated research process and analysed in the doctoral evaluation, are reflected in the corresponding policy formulations in the national government instrument. The thesis, however, records their fuller scholarly derivation: Section 5.2 explicitly links policy formulation to the causal chain and DPSIR analysis, while the subsequent discussions provide the research reasoning, supporting evidence and academic context underlying the individual policy responses. The EMSSA presents the resulting fourteen technical and five supporting policy statements for application within the national water management context.

CHAPTER 5 TOWARDS A EUTROPHICATION GOVERNANCE POLICY FOR SOUTH AFRICA

5.1 INTRODUCTION

The inclusion of **FIGURE 64** positions the reader within the high-level thesis structure, while **FIGURE 65** provides a visual representation of the section content within Chapter 5 (this chapter).

FIGURE 64: High-level thesis structure (*you have arrived at Chapter 5*).

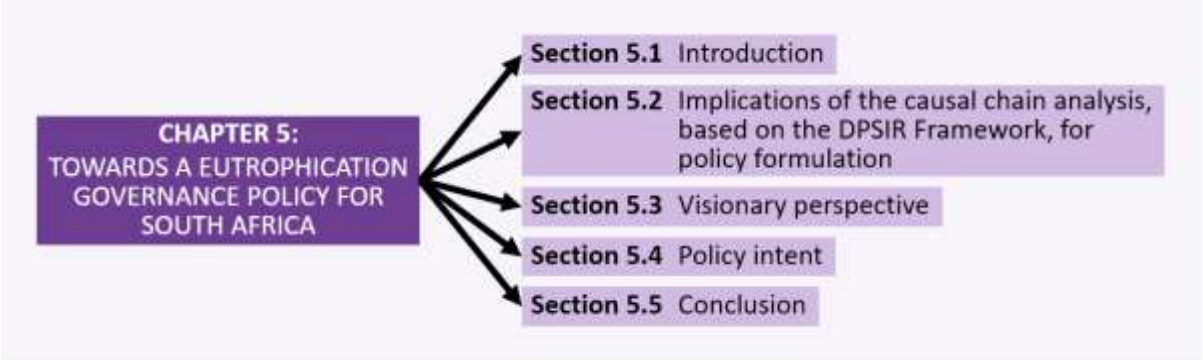

FIGURE 65: Section topics covered in Chapter 5.

Broadly, *"government policy"* serves as a foundational guide, providing intent and reflecting a political mandate by outlining high-level objectives [Presidency, 2020:8].

The completed DPSIR Framework – drawn from- (1) an extensive literature review; (2) an evaluation of key challenges; (3) an examination of governance trends; (4) an evaluation of the nationwide survey;[110] and (5) stakeholder engagement[111] (outlined in the previous chapter) – played a pivotal role in informing and enhancing eutrophication governance policy development in this chapter.

In **Chapter 5**, several concise policy statements most relevant to eutrophication governance in South Africa are identified. Collectively, these statements will serve as an expansion of the overarching IWQM Policy, specifically tailored to address eutrophication governance at a country-level.[112] While some statements closely align with the IWQM Policy, others are supplemental or entirely new.[113] Although the eutrophication governance policy holds its own significance, it will be complemented by a dedicated strategy on eutrophication governance (Chapter 6) to facilitate its implementation.

5.2 IMPLICATIONS OF THE CAUSAL CHAIN ANALYSIS, BASED ON THE DPSIR FRAMEWORK, FOR POLICY FORMULATION

The goal was to address root causes by beginning with societal drivers and then reducing anthropogenic pressures, rather than merely treating symptoms of excessive nutrient loading. However, root causes like climate change, political instability, poverty and criminality are challenging to address directly within the scope of eutrophication governance. Conversely, activities like mining, industry, agriculture, tourism, waste and wastewater management and development planning can be more readily managed or influenced by practitioners in the field of eutrophication management. Indirect influence over societal drivers can often be achieved by focusing on specific human-induced pressures. For example, targeting ineffective wastewater management can serve as a focal point, rather than having a general focus on local government.

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[110] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[111] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

[112] Efforts were made to ensure the development of policies that harmonise with one another. In the rare event of conflicting policy views, the higher-level policy takes precedence.

[113] The National Policy Development Framework (NPDF), as adopted by Cabinet on 2 December 2020, outlines six broad categories of generic policy. Policy directives are one of these categories and represent formal instructions that all affected policy implementers must adhere to. These directives typically contain instructions of a technical nature that do not necessitate adjustments to higher-level policies. Additionally, policy directives may embody significant strategic or policy decisions, communicating changes to the interpretation or application of policies and legislation. They can take various forms, such as prescripts that interpret and clarify legislation regarding procedures, processes and practices that must be followed. The eutrophication Governance policy aligns with the prescripts associated with policy directives [Presidency, 2020:11].

TABLE 24 provides a summary of the societal drivers and anthropogenic pressures, which are the *"original"* causes contributing to eutrophication. This table synthesises information from the populated DPSIR Framework (**TABLE 22**) and was compiled to inform the formulation of eutrophication governance policy statements.

TABLE 24: Potential national policy responses to the societal drivers and anthropogenic pressures that contribute to eutrophication.[114]

DRIVER [115]	PRESSURE [116]	NATIONAL POLICY[117] RESPONSES[118]
▶ Mining; ▶ Industry; ▶ Agriculture; ▶ Tourism; ▶ Human settlement areas; ▶ Other land uses; ▶ Local government; ▶ Poverty and criminality; ▶ Administrative and political instability; ▶ Population dynamics; and ▶ Climate variability and change.	▶ Blasting; ▶ Exposing of phosphorus-bearing rock; ▶ Disturbance of habitat and soil layers. ▶ Discharge of substandard wastewater; ▶ Atmospheric emissions of NH_3 and NO_2 affecting the nutrient content of precipitation; ▶ Atmospheric emissions of NO_2 and SO_2 generating acid precipitation; ▶ Habitat disturbance. ▶ Poor fertilising practices and over-fertilising causing fertiliser-laden diffuse runoff from agricultural fields; ▶ Prevalence of erosion, mobilising sediments on which chemical elements are adsorbed; ▶ Over-irrigation to satisfy leaching requirements; ▶ Feedlot waste disposal and wastewater discharged; ▶ Habitat disturbance; ▶ Organic waste, food leftovers and excreta associated with aquaculture; ▶ Inadequate farm advisory and extension services; ▶ Poor farming practices. ▶ Fluctuating and increased waste and wastewater production; ▶ Fluctuating and increasing pressure on urban wastewater handling. ▶ Nutrient-laden diffuse runoff from built-up areas; ▶ Habitat disturbance. ▶ Fertiliser and nutrient-laden diffuse runoff from golf courses; ▶ Habitat disturbance.	**CHIEF IMPERATIVES:** ▶ Limit anthropogenic nutrient loading; ▶ Reduce excessive primary production; ▶ Protect aquatic ecosystems and their biological diversity; ▶ Secure water resources that are fit-for-use; and ▶ Support ecologically sustainable development and justifiable socio-economic growth. **COMPLEMENTING IMPERATIVES:** ▶ Resource eutrophication governance (with money, people, etc); ▶ Promote research; ▶ Promote management cooperation; ▶ Promote transparency; and ▶ Facilitate capacity building and the empowerment of role-players.

[114] **TABLE 24** is based on **TABLE 22: An analysis of anthropogenic nutrient enrichment and the effects of eutrophication in South Africa, based on the DPSIR Framework.**

[115] Defined as the socio-economic or demographic developments, OR production or consumption practices that trigger *"pressures"*.

[116] Defined as the anthropogenic activities or consequences that disturb the *"state"* of ecosystems.

[117] *"Policy"* is colloquially defined as the ground rules (for eutrophication management).

[118] *"Response"* is defined as the societal measures aimed at preventing, minimising or mitigating negative *"impacts"* by feeding back to the *"drivers"*, *"pressures"* (and *"state"*).

DRIVER [115]	PRESSURE [116]	NATIONAL POLICY[117] RESPONSES[118]
	▶ Inadequate operation and maintenance of offsite and onsite sanitation systems; ▶ Theft and vandalism of wastewater infrastructure; ▶ Discharge or loss of untreated and/or substandard wastewater; ▶ Poor waste practices; ▶ Inadequate investment in wastewater infrastructure. ▶ Washing in streams and in rivers; ▶ Inappropriate onsite sanitation and bush-toileting; ▶ Theft and destruction of sanitation services infrastructure; ▶ Overflowing utility access holes caused by sewer system blockages and sabotage; and ▶ Discharge of untreated and/or substandard urban wastewater. ▶ Exceeding the design capacity of WwTWs; ▶ Destruction of water resource and services infrastructure; ▶ Failing operation and maintenance of water resource and services infrastructure; ▶ Discharge of untreated and/or substandard urban wastewater; ▶ Variety of upstream pollution sources; ▶ Operating rules for the water resource infrastructure that promote enrichment. ▶ Return flows becoming an increasingly important component of the country's water budget; ▶ Habitat disturbance; ▶ Increased urban waste production; ▶ The nutrient-loading character of wastewater is changing; ▶ Pressure on urban wastewater handling; ▶ Negative effect on the affordability of rural water services infrastructure, affecting operation and maintenance; ▶ Altered flow and water quality regimes associated with the establishment of impoundments and related infrastructure; ▶ Lack of skilled water scientists and engineers; ▶ Inadequately capacitated water institutions. ▶ Changing water temperatures; ▶ Altered dilution capacity of water resources; ▶ Increasing levels of erosion; ▶ Altered flow and water quality regimes associated with the establishment of impoundments and related infrastructure; ▶ More frequent mixing of stratified layers and inversion of epilimnion and hypolimnion may lead to more regular recycling of nutrients from the anaerobic hypolimnion; and ▶ Exacerbated poor trophic conditions.	

Policy responses were selected and crafted to address the identified causal factors outlined in **TABLE 24**, with the aim of establishing strong mandates. The policy formulation process was tailored to focus on issues deemed most relevant to managing eutrophication, in order to avoid unnecessary overlap with overarching and other policies. The agreed-upon mandates were categorised into two groups, *viz. "chief"* and *"complementing"* imperatives. These mandates or imperatives were then employed to shape a forward-looking policy perspective and to steer the creation of policy objectives and statements.

5.3 VISIONARY PERSPECTIVE

It is essential that public policy has a clear vision and sets out its ultimate intention [Presidency, 2020:10]. Eutrophication governance in South Africa adheres to the IWQM Vision and Mission [DWS, 2017c:22], which are outlined as follows:

Vision: ***"Government, in partnership with private sector and civil society, secures water that is fit-for-use, for all, for ever."***

Mission: ***"To adopt a government-wide, adaptive and systems-based management approach, in alliance with the private sector and civil society, which will improve resource water quality, prevent pollution and ecological degradation, support ecologically sustainable economic and social development and allow an informed use of the nation's water resources."***

Eutrophication governance holds a crucial and specific role in progressing the vision and mission mentioned above. In South Africa, this role is encapsulated in the distinct goal for eutrophication management:

Goal: ***"To manage eutrophication effectively in order to protect aquatic ecosystems and to secure water resources that are fit-for-use."***

A collage of objectives provides additional context to the goal and informs subsequent policy formulation. This set of objectives is organised into two tiers that relate to eutrophication management. For practical purposes, these are differentiated into a *"primary tier"* of **Chief Objectives** and a *"secondary tier"* of **Complementing Objectives**. Together, these two interrelated tiers of objectives for eutrophication management are designed to contribute towards achieving the IWQM Vision and Mission, as well as the overarching national eutrophication management goal. The specifics of these objectives are outlined below:

The Chief Objectives for eutrophication management are to–

- limit anthropogenic nutrient loading of water resources;
- reduce excessive primary production in surface water resources;
- protect aquatic ecosystems and their biological diversity;
- secure water resources that are fit-for-use on a continuous basis; and
- support ecologically sustainable development and justifiable socio-economic growth.

The Complementing Objectives for eutrophication management are to–

- resource eutrophication management, *inter alia*, by securing funding, providing human capital and equipping responsible parties;
- promote research in relation to management of eutrophication and control of anthropogenic sources of nutrient enrichment;
- promote management cooperation within and between government, private sector and civil society;
- promote transparency through stakeholder consultation, eutrophication-related communication and awareness creation; and
- facilitate capacity building and empowerment of role-players.

TABLE 25 outlines **policy statements** aligning with the objectives essential for eutrophication governance in South Africa. It indicates whether each statement is *"existing",* meaning it is complementary to the IWQM Policy and modified for a eutrophication focus, or *"new",* meaning it serves as additional policy beyond the IWQM Policy.

TABLE 25: List of pertinent policy statements for eutrophication governance in South Africa.

STATEMENT #	POLICY STATEMENT TITLE	STATUS
Policy statements in support of the Chief Objectives for eutrophication management		
POLICY STATEMENT 1	Application of management instruments for environmental compliance in eutrophication management	*New*
POLICY STATEMENT 2	The Mitigation Hierarchy for decision-making on eutrophication	*Existing*
POLICY STATEMENT 3	The Differentiated Approach for the control of excessive nutrient loading	*Existing*
POLICY STATEMENT 4	The application of the Precautionary Principle	*Existing*
POLICY STATEMENT 5	The Receiving Water Quality Objectives Approach applied to eutrophication management	*Existing*
POLICY STATEMENT 6	A life cycle view on nutrient loading	*New*
POLICY STATEMENT 7	Incentive-based regulation	*Existing*
POLICY STATEMENT 8	Nature-based solutions	*New*
POLICY STATEMENT 9	The application of the Best Practicable Environmental Option	*New*
POLICY STATEMENT 10	Holistic eutrophication management	*New*

STATEMENT #	POLICY STATEMENT TITLE	STATUS
POLICY STATEMENT 11	Eutrophication management responsibility and accountability	*New*
POLICY STATEMENT 12	Monitoring	*Existing*
POLICY STATEMENT 13	Information management	*Existing*
POLICY STATEMENT 14	Water resource assessment and planning to inform decision-making	*Existing*
Policy statements in support of the Complementing Objectives for eutrophication management		
POLICY STATEMENT 15	Resourcing of eutrophication management	*New*
POLICY STATEMENT 16	Promotion of eutrophication-related research	*Existing*
POLICY STATEMENT 17	Transparency	*Existing*
POLICY STATEMENT 18	Technical capacity to take eutrophication management action	*Existing*
POLICY STATEMENT 19	Cooperative eutrophication management	*Existing*

FIGURE 66 provides a contextual outline of the eutrophication governance policy.

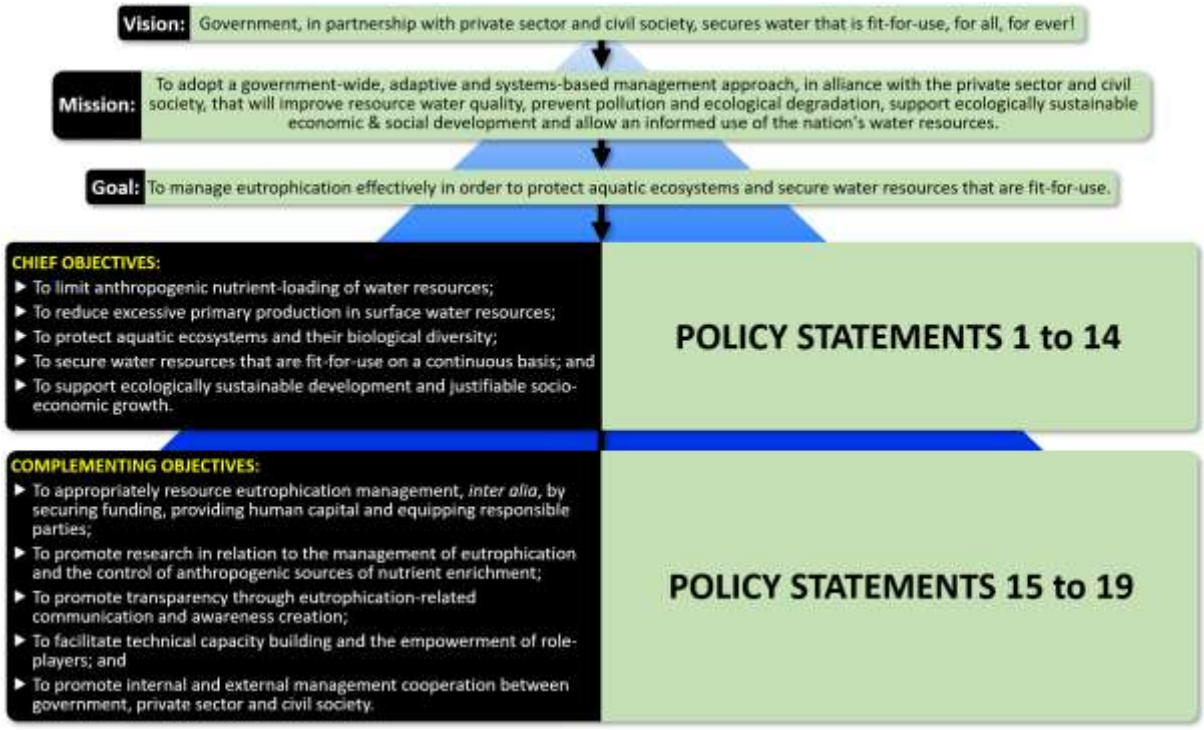

FIGURE 66: Outline of the eutrophication governance policy.

Section 5.4 delves deeper into individual policy statements. Presented in semi-tabular layout, keywords are emphasised on the left, matched by policy narratives and supporting information on the right. Each policy narrative is designed to uncover the core reason behind the policy statement, explain the policy statement's aim and conclude with an assessment of the policy statement's current standing. To enhance comprehension, appropriate figures and tables are included where they add value.

5.4 POLICY INTENT

Recognising that:

(1) Nutrient over-enrichment of water resources from anthropogenic sources poses a significant pollution threat, impacting the integrity of South African aquatic ecosystems and the fitness-for-use of water resource; and

(2) Excessive nutrient loading, stemming from both point and diffuse pollution sources, adversely affects social development and economic prosperity; and

(3) Anthropogenic eutrophication is an escalating concern that poses substantial water quality challenges nationwide, potentially reaching crisis levels without proper national policies and strategies in place to provide a cohesive, structured approach; and

(4) Historical neglect of eutrophication management has led to the depletion of human resources, institutional knowledge, management data and a general comprehension within institutions across the country.

Acknowledging that:

(1) Anthropogenic eutrophication is reversible – there are no quick fixes and long-term, sustainable and lasting solutions are necessary; and

(2) Engineered and technical interventions will not fully solve all eutrophication-related problems – social and economic trade-offs are necessary; and

(3) All water uses should only be allowed in terms of the NWA (36:1998) – the cumulative impact of land and water use activities need to be addressed in a catchment context; and

(4) Eutrophication problems mostly do not occur in isolation from other water quality issues – eutrophication management should be undertaken in the context of IWQM; and

(5) Data and information gaps exist – monitoring, research, reporting and transparency are pre-requisites to effective decision-making and policy implementation; and

(6) Eutrophication management requires government cooperation, vertically, between spheres of government and, horizontally, between government departments; and

(7) Government, private sector and civil society collaboration is essential – the DWS has a lead-role to play with respect to eutrophication management.

Therefore:

(1) As the trustee of the nation's water resources, working in alignment with legislation such as the NWA (36:1998), the WSA (108:1997) and the NEMA (107:1998), alongside cooperation with government, private sector and civil society, **the DWS highlights the following**

nineteen intentions and commitments shaped as policy statements for managing eutrophication on a country-wide basis:

POLICY STATEMENT 1

5.4.1 Application of management instruments for environmental compliance in eutrophication management

Premise

There are four broad universally accepted categories of management instruments for environmental compliance, *viz.*:

- Command-and-control, or regulatory, management instruments;
- Economic, or market-based, management instruments;
- Self-regulatory management instruments; and
- Societal participation management instruments.

Each of these instruments is vital to the management of water quality; specifically, also eutrophication.

Application of the management instruments

To effectively limit anthropogenic eutrophication, both joint and separate applications of the aforementioned management instruments must facilitate the aims of the Mitigation Hierarchy for decision-making on eutrophication, [119] as shown in **FIGURE 67**. To advance eutrophication governance, it is essential to align, improve and strengthen these instruments, ensuring that they are effectively and consistently supported and applied. The availability of suitable data and information[120] is a prerequisite for this process.

Command-and-control, or regulatory, management instruments

Direct regulation of land and water use is crucial for environmental compliance and remains key in managing eutrophication. There is an urgent need to refine command-and-control approaches to effectively address anthropogenic point and diffuse nutrient pollution, ensuring consistent achievement of the eutrophication management goal. Additionally, the constitutional requirement for ecologically sustainable development must be acknowledged. Strengthening cooperative

[119] Refer to **POLICY STATEMENT 2**: The Mitigation Hierarchy for decision-making on eutrophication.
[120] Refer to **POLICY STATEMENT 12**: Monitoring.

regulation[121] – both vertically between spheres of government and horizontally between departments within those spheres – is essential, as multiple regulatory mandates affect eutrophication control. Support is also given to the One Environmental System, which synchronises environmental authorisation processes within a set timeframe.

Examples of command-and-control instruments include environmental authorisations following Environmental Impact Assessments (EIAs), water use authorisations, Environmental Management Programme Reports (EMPRs) compiled by mines, atmospheric emission licensing, waste management licensing and the regulation of land and water use activities. This also involves prohibiting activities to protect water resources or instream or riparian habitats, as well as land use development planning mechanisms and other related regulatory measures.

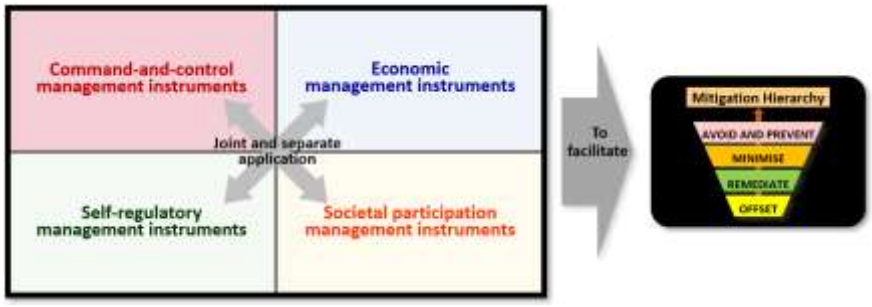

FIGURE 67: The management instruments for environmental compliance in eutrophication management.

Economic, or market-based, management instruments

Economic instruments for eutrophication management complement traditional command-and-control methods and should incentivise positive behavioural change, promote the avoidance, prevention and minimisation of excessive nutrient loading, stimulate innovation and address anthropogenic eutrophication from both point and diffuse pollution sources. They should enhance economic efficiency and generate revenue for eutrophication-related expenditures. External

[121] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

costs of anthropogenic eutrophication should be internalised, where appropriate, by using economic incentives[122] to limit nutrient loading.

Examples of economic instruments include the WDCS.

Self-regulatory management instruments

Self-regulation effectively promotes **corporate responsibility** (choosing production methods, processes and waste streams with minimal impact on water resources) and **corporate accountability**, (ensuring legal compliance with norms and standards). It supports command-and-control approaches and reduces pressure on government resources, particularly in regulatory compliance monitoring and enforcement. Therefore, schemes that encourage responsible self-regulation should be investigated, supported and encouraged.

Examples of self-regulatory instruments include voluntary standards for the certification of production processes, such as Global G.A.P. (Good Agricultural Practice), ISO 14001 [ISO, 2015] and others.

Societal participation management instruments

Partnerships with civil society should complement traditional governmental mechanisms, promoting decentralised and participatory management[123] of eutrophication. These partnerships must be voluntary and based on shared responsibility, complementing rather than replacing government strategies. They should involve multi-level stakeholders, ensure transparency and accountability, produce tangible results, be well-funded and integrate with other eutrophication management tools. Societal participation offers a strong platform for non-economic incentive-based regulation[124] to help reduce nutrient loading.

Examples of societal participation instruments include Catchment Management Forums (CMFs), citizen-based monitoring and reporting on compliance to water quality standards and objectives.

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[122] Refer to **POLICY STATEMENT 7**: Incentive-based regulation.

[123] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

[124] Refer to **POLICY STATEMENT 7**: Incentive-based regulation.

Policy status

The use of management instruments for environmental compliance is well-established but introducing a formal requirement for their synchronised application in eutrophication management marks meaningful progress. This new policy emphasises a coordinated effort to leverage each instrument's strengths, effectively addressing the complex challenge of eutrophication. It represents an innovative shift towards more integrated and strategic eutrophication governance, aimed at achieving the eutrophication management goals and policy objectives.

POLICY STATEMENT 2

5.4.2 The Mitigation Hierarchy for decision-making on eutrophication

Premise

In any situation where several policies determine management goals, it is important to establish priorities.

Mitigation Hierarchy for decision-making

To ensure consistency in reaching and implementing management decisions, a mitigation hierarchy for decision-making on eutrophication applies. This hierarchy for decision-making reflects present government policy and requires the following mitigation options to be considered sequentially in a hierarchy of increasing risk:

- Anthropogenic nutrient loading and excessive primary production, *inter alia* causing degradation of aquatic ecosystems and adverse impacts on society and the economy, must be **avoided and prevented**!
- Or, where anthropogenic nutrient loading and excessive primary production, *inter alia* causing degradation of aquatic ecosystems and negative socio-economic impacts, cannot be altogether avoided and prevented, are **minimised**!
- Or, where undue anthropogenic nutrient loading and excessive primary production, *inter alia* causing degradation of aquatic ecosystems and negative socio-economic impacts, have occurred, are **remedied**!
- Or, where anthropogenic nutrient loading and excessive primary production, *inter alia* causing degradation of aquatic ecosystems and negative socio-economic impacts, cannot be altogether

avoided and prevented, or sufficiently minimised or remedied, are **offset** elsewhere!

Most importantly – the Mitigation Hierarchy for decision-making on eutrophication, as illustrated in **FIGURE 68**, needs to be consistently interpreted and applied within the context of a catchment area. This involves employing both the Differentiated[125] and Receiving Water Quality Objectives[126] Approaches. Decision-makers should prioritise the Best Practicable Environmental Option (BPEO)[127] and adhere to the Precautionary Principle[128] where relevant, as outlined in this policy.

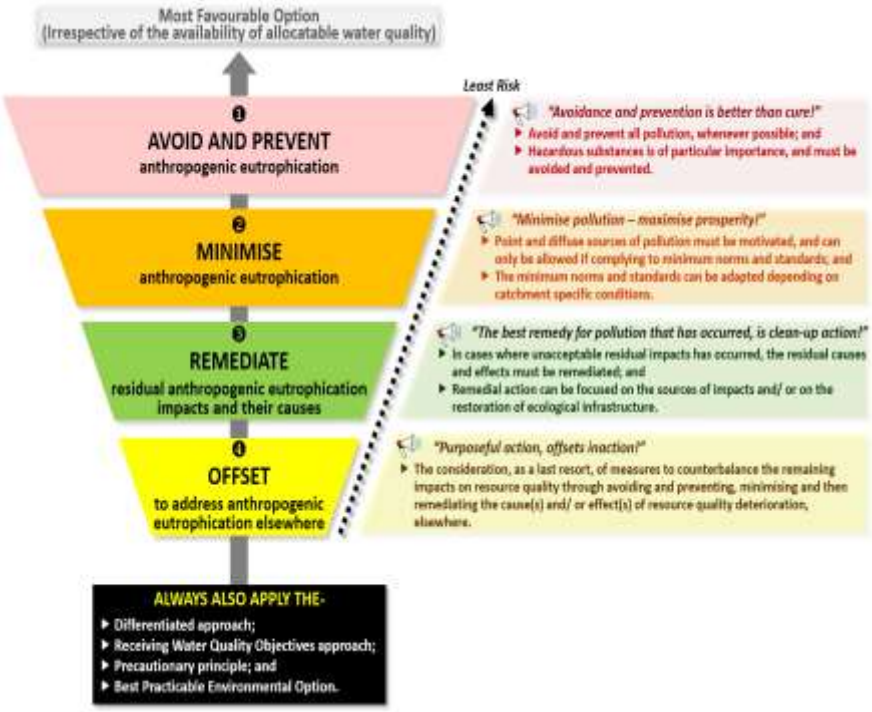

FIGURE 68: The Mitigation Hierarchy for decision-making on eutrophication.

Avoidance and prevention of anthropogenic eutrophication

Irrespective of the amount of allocatable water quality – water users must be strongly encouraged to avoid and prevent all anthropogenic nutrient loading of receiving water resources, whenever possible. This will be effected by pursuing the BPEO.[127]

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[125] Refer to **POLICY STATEMENT 3**: The Differentiated Approach for the control of excessive nutrient loading.
[126] Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.
[127] Refer to **POLICY STATEMENT 9**: The application of the Best Practicable Environmental Option.
[128] Refer to **POLICY STATEMENT 4**: The application of the Precautionary Principle.

When striving for a *"zero effluent"* state for effluent-producing water users, it is important to consider downstream water budgets. Pollution avoidance and prevention are key, particularly in controlling hazardous substance. Substances with high toxicity, persistence, bioaccumulation capacity and emerging pollutants like endocrine disruptors pose significant threats to water resources and users. For these hazardous substances, the Differentiated and Receiving Water Quality Objectives Approaches may not apply, because very little to no allocatable water quality exists and due to difficulties associated with determining appropriate RQOs for hazardous pollutants. In such cases, all decisions must be based on the Precautionary Principle.

Minimisation of anthropogenic eutrophication

In many cases, some degradation of water quality in receiving water resources is inevitable and sometimes even necessary for socio-economic development. Regardless of the amount of allocatable water quality, minimising anthropogenic nutrient loading, and promoting water conservation and water demand management by pursuing the BPEO will always be encouraged. For point sources like effluent discharges, the Precautionary Principle will be enforced using conservative national norms and standards, such as uniform WDSs, which can be adjusted according to Differentiated and Receiving Water Quality Objectives Approaches. When diffuse pollution sources are persistently contributing towards excessive nutrient enrichment in receiving water resources, the DWS will approach the responsible authority, examine the causes of the problem and identify appropriate interventions to correct the problem and minimise anthropogenic eutrophication.

Remediation of residual anthropogenic eutrophication impacts and their causes

When anthropogenic nutrient loading causes unacceptable residual impacts, the sources and/or affected water resources must be remediated to a near-natural or agreed-upon state, especially in stressed catchments where remediation is necessary, practical and equitable. Remediation can be extremely costly and sometimes impractical, such as in certain aquifers restoration, underscoring the importance of pollution avoidance, prevention and waste minimisation. The Polluter-Pays Principle will be enforced for all

remediation efforts. If polluters cannot be held accountable, the government must cover the remediation costs.

Offsetting to address anthropogenic eutrophication elsewhere

In special cases, environmental offsetting can be utilised to limit and reverse the effects of anthropogenic eutrophication in the catchment. This involves counterbalancing the impacts on water resources after all efforts to avoid, prevent, minimise and remediate causes and effects have been made, by carrying out these efforts elsewhere. Offsetting entails quantifying causes and effects to compare with potential offsets, ensuring a net gain or no change in total allocatable water quality. The responsible authority must maintain a public register of all offsets to aid compliance monitoring. A water quality allocation plan is essential for implementing nutrient-loading offsets in South Africa.[129] The Environmental Offset Policy [DEA, 2018:3] designates the DWS, as the Offset Authority, to develop and publish specific offset policies for wetlands and water quality, facilitating offsetting strategies for eutrophication management.

Policy status

The first policy in South Africa to address hierarchical decision-making aimed at mitigating environmental degradation initially focused on water pollution.[130] Over time, it evolved into a general requirement for sustainable development and was incorporated into environmental legislation in the late 1990s. This aims to limit degradation of aquatic ecosystems, pollution, biodiversity loss, landscape disturbance, waste and impacts on environmental rights. Recently, the policy has been expanded by DFFE to include offsetting as a consideration for environmental preservation and management. The current mitigation hierarchy for eutrophication management incorporates these aspects.

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[129] Refer to **Section 6.4.1.2.4, [C]**: Reconciliation and allocation of water quality.

[130] Refer to IWQM Policy Statement B.2-1: The hierarchy of pollution management decision-making [DWS, 2017c:44].

5.4.3 The Differentiated Approach for the control of excessive nutrient loading

Premise

A one-size-fits-all approach ignores local differential requirements for either stricter levels of protection or more lenient approaches that are beneficial to socio-economic development.

Differentiated Approach

The Differentiated Approach considers catchment-specific conditions when managing water pollution, ensuring the protection of significant water resources against point and diffuse pollution sources at a socially acceptable cost. Effect must be given to any MCs (and RQOs/ Reserves).

In general, where a particular impact is unavoidable or cannot be prevented, the Precautionary Principle[131] will be applied by enforcing conservative minimum norms and standards, such as uniform WDSs[132] for point wastewater discharges – even if considerable allocatable water quality exists.

In **unstressed** catchments, these norms and standards may be **relaxed** under special circumstances only if the MCs (and RQOs/ Reserves) will be maintained, also acknowledging that the solution to non-compliance is never to relax applicable norms and standards for compliance's sake. Exemptions from compliance with WDSs will be considered only as a last resort on a temporary basis and only if receiving surface water resources have enough dilution capacity to accommodate additional nutrient loading, without jeopardising their fitness-for-use. Relaxations would have to be justified based on technological, economic and socio-political considerations.

In **stressed** catchments, or catchments where the application of minimum norms and standards is insufficient to maintain the MCs (and RQOs/ Reserves), **stricter** norms and standards, particularly in respect of point wastewater discharges, must be considered. In special cases it may be necessary to impose additional regulatory

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[131] Refer to **POLICY STATEMENT 4**: The application of the Precautionary Principle.

[132] Currently the General and Special Standards and the Special Standards for phosphate [GN R.991, 1984].

measures and/or to prohibit unsustainable practices, in order to comply with the MCs (and RQOs/ Reserves).

Stricter or more lenient WDSs will be site-specific, based on waste load investigations, and aligned with the Receiving Water Quality Objectives Approach.[133] If current MCs (and RQOs/Reserves) are found inappropriate, reclassification or re-determination may be necessary.[134]

Groundwater

In South Africa, the widespread and localised occurrence of groundwater makes it physically and economically unfeasible to protect all groundwater resources equally. Furthermore, South African policies does not aim to prevent all impacts on water resources as this would stifle socio-economic development. Therefore, a differentiated approach to groundwater protection is necessary, focusing on vulnerability, connectivity to other water resources and the importance of aquifers at local and regional levels. Importance is determined by potential yield and community dependence. For instance, aquifers that are a community's sole water source receive special status and the highest protection [adapted from DWAF, 2000:(3)2].

Due to uncertainties in managing groundwater, the existence of environmental risk in the absence of proof to the contrary, must be presumed, placing the burden of demonstrating no harm on the risk source. When scientific uncertainty exists about potential adverse effects, the Precautionary Principle[135] must be applied.

Resilience

The ability of water resources to assimilate waste, specifically nutrients, may not be compromised. This threshold, for water quality, is defined by water quality goals,[136] such as the MCs (and RQOs/ Reserves). In cases where this threshold has been compromised, affected water resources must be remediated without delay. If the

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[133] Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.

[134] The NWA (36:1998), at the moment, does not make explicit provision for the re-classification of water resources or the re-determination of RQOs/ Reserves and a legislative amendment will be required. Refer to **Annexure H** for a list of all recommended legislative amendments.

[135] Refer to **POLICY STATEMENT 4:** The application of the Precautionary Principle.

[136] Refer to **Section 6.4.1.2.3**: Goal setting.

water resource, for whatever reason, cannot be remediated, offsetting, with special motivation, may be considered as a last resort.

Policy status

The discriminatory application of environmental measures to suit local or regional requirements for environmental preservation and protection is not a new policy concept. This policy position has been included because of its importance to eutrophication management and because it should be implemented in conjunction with the Mitigation Hierarchy for decision-making on eutrophication. This policy statement was derived from existing policy.[137]

POLICY STATEMENT 4

5.4.4 The application of the Precautionary Principle

Premise

The Precautionary Principle applies when there is a lack of scientific certainty regarding impacts, or when there is an unacceptable risk to human health or ecological integrity.

Precautionary Principle

In managing eutrophication, the Precautionary Principle applies specifically–

- when determining WDSs for **point wastewater discharges** without sufficient scientific certainty, especially if catchment-specific water quality load-based information is unavailable to guide the determination of suitable *"end of pipe"* standards;
- when determining suitable best practices and interventions for managing **diffuse pollution sources** without sufficient scientific certainty, particularly when catchment-specific data is lacking to address diffuse nutrient loading;
- to all **groundwater**, assumed vulnerable unless proven otherwise;
- for the prohibition of **hazardous substances**;
- in scenarios where actions might unintentionally conflict with the aims of another policy, requiring consideration of the **most restrictive approach**; and

[137] Refer to IWQM Policy Statement B.2-4: Differentiated water use authorisations [DWS, 2017c:48].

- when making management decisions with unacceptable risks, without sufficient **scientific certainty**.

In these cases, the Precautionary Principle ensures risk-averse, conservative decisions to support ecologically sustainable development.

Policy status

The policy statement advocating a risk-averse and cautious approach has been included due to its critical role in eutrophication management and its significance in many of the other pertinent eutrophication management policy statements. This approach considers the limits of current knowledge about the consequences of management decisions and actions. This policy statement was derived from existing policy.[138]

POLICY STATEMENT 5

5.4.5 The Receiving Water Quality Objectives Approach applied to eutrophication management

Premise

The impacts originating from upstream sources, whether from point or diffuse anthropogenic nutrient loading, need to be collectively assessed on a cumulative basis and effectively managed to ensure that–

- receiving water resources remain fit-for-use;
- MCs (along with RQOs/Reserves), designated for all significant waterbodies, are maintained; and
- these efforts promote ecologically sustainable development.

Nutrient load investigations must be carried out and used to integrate receiving water resources requirements with WDSs and to inform fitting SDCs.

Assimilative capacity

"Assimilative capacity" refers to a water resource's ability to absorb and process waste without adversely impacting its fitness-for-use or the health of aquatic ecosystems [DWAF, 1995:9]. Factors influencing this capacity include– **chemical processes** like adsorption and degradation into other substances (which can be less or more

[138] Refer to IWQM Policy Statement B.1-4: Targeted, risk-based approaches [DWS, 2017c:41].

harmful); **physical processes** such as aeration, volatilisation, sedimentation, dispersion and dilution; and **biological processes** including uptake by plants and microorganisms, and bioaccumulation [Roux, *et al.*, 1999:15-29].

Assimilative capacity of groundwater

Good-quality groundwater and interflow play a crucial role in sustaining base flow and the assimilative capacity of many freshwater resources. To safeguard groundwater, the Precautionary Principle[139] will be applied. As a protective measure, all groundwater will be presumed to have no inherent assimilative capacity and be susceptible to harm unless proven otherwise. This strategy for groundwater protection will be implemented through all source, resource and remediation directed measures and controls [DWAF, 2000:(3)4].

Dilution capacity

Accurately quantifying assimilative capacity in a manner that renders it a practical management instrument is a highly intricate endeavour. While recognising the general phenomenon of *"assimilative capacity"*, the Department's policy dictates utilising it primarily as a routine management instrument only in the context of dilution capacity. This approach will be directly linked to the notion of *"allocatable water quality"* as illustrated in **FIGURE 69**.

Dilution

Dilution relates to the mixing of waters to ensure that the resultant mixed water meets the MCs (and RQOs/Reserves). Dilution can occur either prior to discharge or within a receiving water resource downstream of a *"mixing zone"*.

Allocatable water quality

The concept of allocatable water quality can be complex due to the various water quality attributes involved. Different water users in a catchment may need specific water quality attributes to fall within certain ranges for the water resource to be considered *"fit-for-use"*. These attributes can include chemical concentrations or loads, biological responses (like toxicity) and measures of physical pollution.

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[139] Refer to **POLICY STATEMENT 4**: The application of the Precautionary Principle.

For water resources to be *"fit-for-use"* for multiple water users in the same catchment, it must meet the needs of the most demanding user.

Just as water quantity can be *"used"*, so can water quality, typically quantified by individual attributes. *"Allocatable water quality"* can be defined from two perspectives:

- **First**, it can be regarded as that water quality, if any, that remains allocatable (available) to uses other than the strategic national priority uses (Reserve, international obligations, etc.) and ELUs; and
- **Secondly**, it can also be more formally regarded as the maximum allowable change in any water quality attribute from its current value, keeping it within a pre-defined range that reflects the desired future state, typically defined by RQOs. If the current state is outside this range, the allocatable water quality is considered zero.

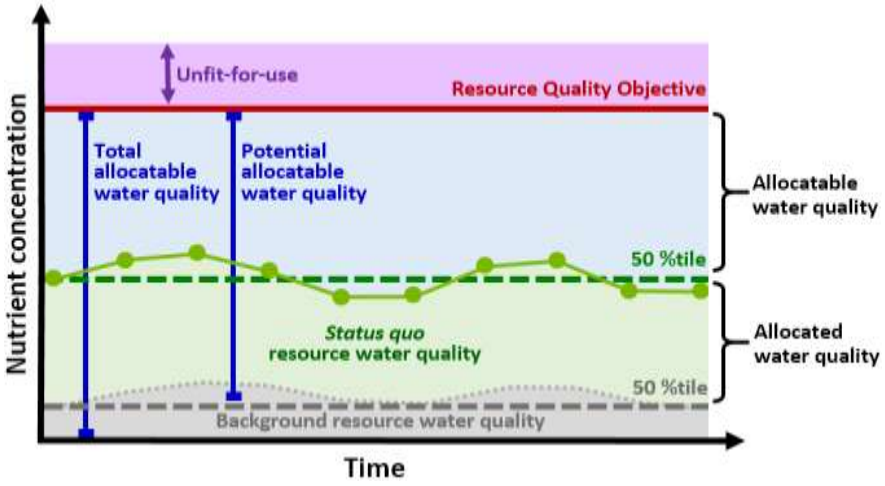

FIGURE 69: Simple conceptual illustration of allocatable water quality for an unstressed water resource.

A water resource is considered *"stressed"* for a particular water quality attribute if there is no allocatable water quality available for that attribute [DWAF, 2006b:5]. Allocatable water quality can be estimated using the Total Maximum Daily Load (TMDL) approach, which models a specific water quality goal to determine the maximum contaminant level that can be discharged without degrading the receiving water resource to an unacceptable level.

There is no requirement for the Department to fully allocate all the allocatable water quality available in a water resource. Instead, care must be taken to implement the Receiving Water Quality Objectives Approach in conjunction with the Mitigation Hierarchy for decision-making[140] – this being necessary to prevent water resources from deteriorating to the point where all water resources eventually become only marginally fit-for-use.

Policy status

The Receiving Water Quality Objectives Approach has been in existence since 1991 [DWAF, 1991:12]. While this approach has been acknowledged, the comprehensive implementation of this principle through Source-Directed Measures and Controls is yet to be fully realised. The importance of applying suitable Source-Directed Measures and Controls in eutrophication management cannot be understated, thereby warranting the inclusion of this policy statement as a crucial component of relevant eutrophication governance policy. This policy statement was derived from existing policy.[141]

POLICY STATEMENT 6

5.4.6 A life cycle view on nutrient loading

Premise

Taking a life cycle view of nutrients has become essential, as shown in **FIGURE 70**. Life Cycle Assessments (LCAs) of household products revealed that the impact of detergent-derived phosphorus on WwTWs' phosphate loading varies significantly, depending on the contribution mix within a facility's catchment. In WwTWs mainly treating residential wastewater, detergent phosphorus can make up as much as 50% of Soluble Reactive Phosphorus (SRP) and 32% of Total Phosphorus (TP) [Pillay & Buckley, 2001:1; Quayle, *et al.*, 2010:98].

[140] Refer to **POLICY STATEMENT 2**: The Mitigation Hierarchy for decision-making on eutrophication.

[141] Refer to IWQM Policy Statement B.2-1: The hierarchy of pollution management decision-making [DWS, 2017c:44], which mentions the Receiving Water Quality Objectives approach.

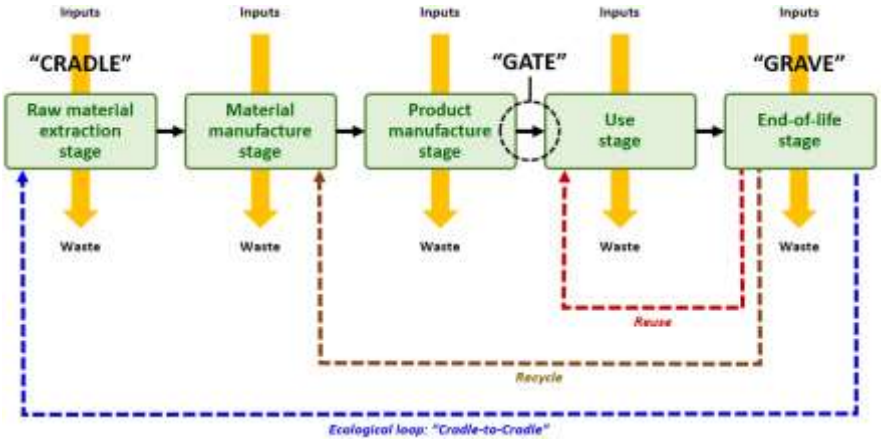

FIGURE 70: An illustration of the Life Cycle Assessment stages [US EPA, 2006:13].

Life Cycle Assessment

LCA expands on the principle of *"treating causes rather than symptoms"*, emphasising the cost-effectiveness and fairness of addressing root causes. Manufacturers of products contributing to nutrient loading and anthropogenic eutrophication act like effluent dischargers, indirectly impacting water resources through consumer use. Collaborating with industry to apply the LCA methodology can help identify and manage the sources and destination of nutrients in household products.

Efforts to promote the production of nutrient-free or low-nutrient products can be mandated through regulations or initiated voluntarily. Voluntary measures could include eco-labelling,[142] public awareness campaigns or adherence to the ISO 14040 series standards [ISO, 2006], which provide LCA guidelines to encourage eco-friendly manufacturing and use. While most food products may not be subject to strict nutrient limits, a broader shift toward nutrient-conscious production is important, transitioning to a circular economy approach.

Producers of household products, in collaboration with authorities, are expected to:

- Compile inventories detailing nutrient inputs in production processes and linked environmental emissions;

[142] Refer to **POLICY STATEMENT 7**: Incentive-based regulation.

- Assess the impacts of these inputs and emissions on water resources;
- Analyse findings for informed decision-making; and
- Follow the Mitigation Hierarchy for decisions on eutrophication[143] by managing nutrient flow through the LCA *"gateway"* (as shown in **FIGURE 70**).

Policy status

While LCA has long been an established instrument for environmental analysis, introducing a policy directive to maintain a life cycle perspective on nutrient loading is a new development. This initiative highlights a forward-looking and comprehensive approach to managing nutrient inputs throughout the product and process lifecycle, aimed at effectively limiting anthropogenic eutrophication. Further exploration and implementation will help assess the potential expansion of this approach to address other pollutants in the future.

POLICY STATEMENT 7

5.4.7 Incentive-based regulation

Premise

Incentive-based regulation is a valuable instrument for managing eutrophication – available in two forms:

- **Economic incentives:** These rely on the principles of user-pays and polluter-pays, leveraging market forces and price structure adjustments to influence water user and polluter behaviour. By changing relative prices, they aim to encourage actions that protect or improve water resources; and
- **Non-economic incentives:** In contrast, these incentives are driven by non-monetary benefits, such as positive recognition or an enhanced public image. They focus on motivating behaviours that positively affect water resources through rewards unrelated to financial gain.

Incentive-based regulation to limit anthropogenic eutrophication

Examples of incentive-based regulation, as outlined in **TABLE 26**, should be considered and utilised in eutrophication management to support the Mitigation Hierarchy for decision-making on

[143] Refer to **POLICY STATEMENT 2**: The Mitigation Hierarchy for decision-making on eutrophication.

eutrophication.[144] Any, or any combination of the management instruments for environmental compliance,[145] can be utilised to promote incentive-based regulation of anthropogenic eutrophication.

TABLE 26: Examples of incentive-based regulation.

ECONOMIC INCENTIVE-BASED REGULATION	NON-ECONOMIC INCENTIVE-BASED REGULATION
(1) The application of subsidies and similar transfers; **(2)** Tax abatements; **(3)** Taxes, fees or charges, *e.g.,* as applied through the WDCS; **(4)** Deposit-refund systems; **(5)** Tradable licences; and **(6)** Administrative penalties.	**(1)** Certification schemes, such as Green Drop certification; **(2)** Voluntary certification schemes, such as Global G.A.P. for *"Good Agricultural Practice"*; **(3)** Water Polluter Register; **(4)** Management-by-shame; and **(5)** Eco-labelling.

Economic incentives to reward responsible behaviour

The array of economic incentive-based regulatory instruments outlined above (**TABLE 26**) provide a versatile and potentially cost-effective approach to achieving eutrophication governance policy objectives. For instance, audited nutrient-loading credentials can be utilised to reward responsible behaviour in integrated land and water resources management. However, while subsidies and other support measures can have positive effects, they may also distort prices and resource allocation, potentially harming water resources. For example, agricultural subsidies might lead to the overuse of fertilisers, contributing to eutrophication.

Payments for improving ecosystem services at the catchment-scale

Innovative approaches to ecosystem service provision[146] include the concept of *"payments for improving ecosystem services at the catchment scale"*. This strategy motivates downstream users to offer financial or other incentives to upstream communities, encouraging them to adopt land management practices that enhance ecosystem services and benefit downstream users [Lin & Thornton, 2014:69-92]. For example, subsidies might be provided to upstream farming

[144] Refer to **POLICY STATEMENT 2**: The Mitigation Hierarchy for decision-making on eutrophication.
[145] Refer to **POLICY STATEMENT 1**: Application of management instruments for environmental compliance in eutrophication management.
[146] Refer to **POLICY STATEMENT 8:** Nature-based solutions.

communities to implement buffer strips for better downstream water quality or funding could support drip irrigation to conserve downstream-critical stream flow.

Implementing these arrangements often requires an impartial intermediary or *"honest broker"*, such as a CMA or NGO, to facilitate agreements, ensure timely payments and monitor stakeholder performance. In South Africa, CMAs are well-suited to serve as honest brokers, fostering cooperation and investment in sustainable land and water management practices that benefit all stakeholders in a catchment.

Economic incentive-based regulation and the User-Pays Principle

The User-Pays Principle operates on the premise that optimal resource allocation occurs when consumers bear the full or partial cost of the goods they use. To effectively tackle anthropogenic eutrophication and development challenges, it is important to maximise investment benefits and create economic incentives that drive sustained improvements, reducing excessive nutrient loading. Implementing this principle is crucial for encouraging actions that promote the reuse and recycling of wastewater, which helps mitigate nutrient overloading and anthropogenic eutrophication. The reconciliation of water supply and demand should be considered in all instances.

Economic incentive-based regulation and the Polluter-Pays Principle

The Polluter-Pays Principle seeks to internalise externalised pollution costs by holding polluters financially accountable for their actions. This approach ensures that pollution costs are addressed in the public interest without unfairly distorting trade and investment. To effectively address anthropogenic eutrophication and development challenges, it is crucial to maximise investment benefits and establish economic incentives that promote lasting systematic change and reduce excessive nutrient loading. Employing the Polluter-Pays Principle is essential to limiting anthropogenic nutrient loading.

Non-economic incentive-based regulation

Water users should, where feasible and desirable, be incentivised through non-economic regulation to limit anthropogenic nutrient loading. Certification schemes, such as Green Drop Certification, play

a crucial role in this process. They not only incentivise excellence but also promote transparency[147] and cooperative management.[148]

Employee performance incentives

Combining employee performance recognition with financial incentives and rewards can be an effective strategy in sectors impacting anthropogenic eutrophication. For example, using Green Drop Certification scores to incentivise municipal employees can motivate improved performance, ultimately enhancing the trophic status of water resources. This approach recognises achievements while aligning employee goals with eutrophication governance policy objectives.

The importance of management performance and resource quality data and information

The sustainable implementation of incentive-based regulation, whether economic or non-economic, relies on the regular availability of appropriate and reliable data and information.[149] Under the Constitution [1996, S.32], everyone has the right to access information held by others that is necessary for protecting constitutional rights. Therefore, systems like the Green Drop System (GDS) not only support effective regulatory frameworks but also fulfil this constitutional obligation by promoting transparency and access to information.

Policy status

Although incentive-based regulation has been considered for some time, with examples like the GDS and the development of the WDCS demonstrating its potential, its implementation and continued application have seen limited success. Given its potential benefits for eutrophication management and alignment with similar requirements in the IWQM Policy, it was decided to include this policy statement as relevant to eutrophication governance. This statement is derived from existing policy.[150]

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147 Refer to **POLICY STATEMENT 13**: Information management.

148 Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

149 Refer to **POLICY STATEMENT 12** and **POLICY STATEMENT 14**, respectively on: Monitoring and Information management.

150 Refer to IWQM Policy Statements B.2-7: Administrative penalties; B.2.8: Alternative instruments to incentivise responsible behaviour [DWS, 2017c:49]; and C.2-5: Implementation of the WDCS [DWS, 2017c:57].

5.4.8 Nature-based solutions

Premise

Ecological infrastructure refers to the natural counterpart of built or hard infrastructure. It offers both renewable (**FIGURE 71**) and non-renewable services or *"nature-based solutions"* [Costanza, *et al.*, 1997:253], providing benefits in four main categories [WRC, 2014:13]:

- **Supporting services**, which include nutrient dispersal and cycling, seed dispersal and primary production;
- **Provisioning services**, such as the supply of food (*e.g.*, freshwater fish and game), crops, wild foods, spices, water, minerals, medicinal plants, pharmaceuticals, biochemicals, industrial products and energy (via hydropower and biomass fuels);
- **Regulating services**, which encompass carbon sequestration and climate regulation, waste decomposition and detoxification, purification of water and air, crop pollination, and pest and disease control; and
- **Cultural services**, offering cultural, intellectual and spiritual inspiration, recreational experiences (including ecotourism) and opportunities for scientific discovery.

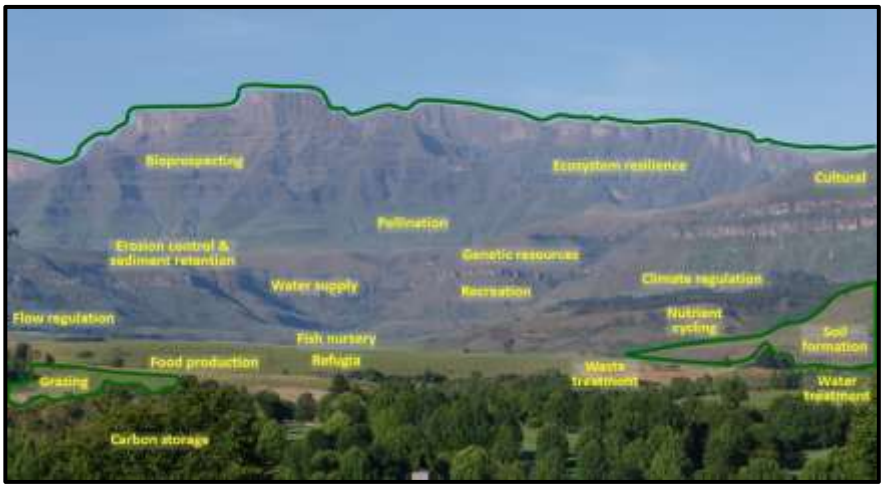

FIGURE 71: Integrated ecosystem services. Photo: © J.J. van Wyk.

Catchment services and water security

In the context of eutrophication, ecological infrastructure that supports water-related ecosystem services, known as *"catchment services"*, is crucial. Healthy catchments function like water treatment plants, or other constructed systems, but operate without the need for costly equipment and operational expenses. They also provide additional

benefits, such as wildlife habitat protection and carbon sequestration [WRC, 2014:13]. Enhancing these services aligns with South Africa's developmental goals of ensuring water security, alleviating poverty, promoting rural development and creating employment opportunities [NPC, 2012:62]. To summarise, *"healthy catchments directly contribute to human health and well-being"* [Pers. coms. Riddell, 2021].

Ecological infrastructure associated with high yield water source areas

The protection of high-yield water source areas,[151] especially strategic water source areas, is of crucial importance. These areas are identified as key contributors, supplying a disproportionately large volume of mean annual runoff to their respective geographical regions [Colvin, *et al.*, 2013:14; le Maitre, *et al.*, 2018:4; Nel, *et al.*, 2013:9]. Consequently, they serve a vital role in enhancing the dilution capacity of receiving waterbodies, thereby helping to mitigate downstream water quality issues by bolstering the capacity of water resources further downstream to assimilate waste.

Water-rich areas, often associated with wetlands, are crucial for improving water quality. Although the potential for water quality improvement by wetlands in strategic water source areas may be limited – since they are typically located above point and diffuse sources of pollution – the collective water quality enhancement function of clusters of catchment wetlands is likely substantial.

Ramsar Convention

As a signatory of the Ramsar Convention on wetlands of international importance, South Africa has committed to ensuring that designated wetlands are both conserved and used sustainably. Anthropogenic eutrophication represents a significant threat to wetlands at large and must be rigorously controlled and managed, particularly in the case of Ramsar Wetlands. Such efforts are crucial to preserve rare or unique wetland types and to conserve biological diversity, including the habitats of water birds, fish and other taxa.

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[151] The NWA (36:1998) allows for only the prohibition of activities in high yield water source areas. A legislative amendment is necessary to allow for the declaration of strategic water source area as protected areas. Refer to **Annexure H** for a list of all recommended legislative amendments.

National Freshwater Ecosystem Priority Areas

In response to the significant threats facing river, wetland and estuary ecosystems in South Africa, Freshwater Ecosystem Priority Areas (FEPAs) have been identified. The purpose of these FEPAs is twofold, *viz.*– (1) to help meet the national biodiversity goals for freshwater ecosystems; and (2) to create a foundation for the effective implementation of protective measures. As such, FEPAs represent strategic spatial priorities for the conservation of the country's freshwater ecosystems. They play a crucial role in supporting the sustainable use of water resources through the management of eutrophication and the application of other regulatory strategies.

Functioning ecological infrastructure

Effective decision-making in eutrophication management should prioritise protecting functional ecological infrastructure, particularly in designated special areas such as strategic water source areas, Ramsar Wetlands and FEPAs. Restoration efforts should target degraded ecological infrastructure to ensure long-term sustainability. It is essential to integrate ecological infrastructure considerations into all land use development, water resource planning and management, including national initiatives. Additionally, the private sector has a vital role in this process by investing in ecological infrastructure, which can help manage risks, secure a *"license to operate"* in ecologically sensitive areas and serve as stewards of these vital systems.

Policy status

While specific policy frameworks focusing on the protection of designated areas are already in place, the integration of ecological infrastructure into policy as a means for combating eutrophication marks a novel policy stance and forward-looking approach. This shift toward leveraging nature-based solutions underscores a growing recognition of the importance of ecosystem services in addressing environmental issues.

POLICY STATEMENT 9

5.4.9 The application of the Best Practicable Environmental Option

Premise

When considering several options for eutrophication management purposes, the Best Practicable Environmental Option (BPEO) must be selected, based on scientifically defensible evidence.

Best Practicable Environmental Option (BPEO)

The BPEO is defined as *"the option that offers the most benefits or causes the least harm to the environment overall, at a cost that society finds acceptable both in the short and long term"* [NEMA, 1998, S.2.(4)(b)].

Eutrophication management options and identification of the Best Practicable Environmental Option

To determine the BPEO for managing eutrophication, it is essential to identify and evaluate all feasible options. This evaluation process must take place within the framework of the Mitigation Hierarchy,[152] considering ecological, social and economic implications. Various optioneering instruments, such as Cost Benefit Analysis (CBA), Life Cycle Assessment (LCA), Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA), Environmental Risk Assessment (ERA) and Social Impact Assessment (SIA), among others, can be utilised to analyse and compare options.

It is important that the analysis is biased towards the polluter-pays principle and considers both short-term and long-term impacts. Long-term costs should not outweigh short and medium-term benefits, and solutions should be free of unintended consequences like shifting impacts from point to diffuse sources or evaporating water as a means of managing wastewater.

Project alternatives should be thoroughly evaluated based on desirability, necessity, feasibility in the short and long term, location, scale, layout, technology and phasing. Options with significant drawbacks or fatal flaws should be discarded to ensure that only viable and sustainable solutions are considered for implementation.

BPEO appraisal

The appraisal of the BPEO typically involves several key stages, *viz.*:

- **Objectives definition:** This stage includes the identification of all relevant MCs (and RQOs/ Reserves) and/or any RWQOs/ WQPL that may exist;
- **Options generation:** Generating a range of potential options to address the identified objectives and requirements;

[152] Refer to **POLICY STATEMENT 2**: The Mitigation Hierarchy for decision-making on eutrophication.

- **Options analysis:** Evaluating and analysing the identified options based on various criteria, including environmental, social and economic considerations;
- **Documentation of results:** Documenting the outcomes of the options analysis, including the strengths and weaknesses of each option;
- **Authorities' consultation:** Consulting with relevant authorities and stakeholders to gather feedback and input on the proposed options;
- **BPEO selection:** Selecting the BPEO based on the analysis and consultation;
- **Authorities sanction and/or authorisation:** Seeking approval or authorisation from the appropriate authorities to proceed with the chosen BPEO;
- **BPEO implementation:** Implementing the chosen BPEO in line with the approved plan;
- **Monitoring and review:** Monitoring the implementation progress and reviewing the outcomes to ensure that the BPEO is achieving the desired results; and
- **Adaptively modifying options:** Making adaptive modifications to the selected options as needed to optimise outcomes based on monitoring and review feedback.

Best management practice

Additionally, best management practice options must always be considered in the context of the Mitigation Hierarchy for decision-making on eutrophication [153] and from a catchment management perspective,[154] and should, amongst others and where appropriate, include:

- The application of best available technology;
- Utilisation of cleaner technology and cleaner production;
- The conversion of environmental problems into socio-economic and developmental solutions;

[153] Refer to **POLICY STATEMENT 2**: The Mitigation Hierarchy for decision-making on eutrophication.
[154] Refer to **POLICY STATEMENT 10**: Holistic eutrophication management.

- Waste reduction, recycling and reuse; and
- The use of buffer zones.

Operation and Maintenance (O&M) of infrastructure solutions

Infrastructure solutions encompass both ecological[155] and built or hard infrastructure. The operation of these solutions must align with the ambitions of the eutrophication governance strategy for South Africa. This includes prioritising the prevention and avoidance of anthropogenic nutrient loading and excessive primary production,[153] and the obligation to lawfully[156] use water, as required by the NWA (1998:36).

Furthermore, the maintenance of infrastructure solutions, particularly in the case of built and hard infrastructure, involves planned maintenance, repairs, refurbishment and renewal, as well as provisions for replacement. It is crucial to integrate infrastructure maintenance into the whole-life cycle costing of infrastructure development during the planning stage. This maintenance should be carried out in line with the ambitions of the eutrophication governance strategy for South Africa.

Policy status

Although BPEO is mentioned in other water quality management policy statements,[157] distinct water quality management policy requiring the application of the BPEO has not been published. Suitable solutions, such as addressing challenges in connection with untreated sewage spills, are vital, and must be identified and implemented. This is a new policy statement.

POLICY STATEMENT 10

5.4.10 Holistic eutrophication management

Premise

Water quality management, particularly concerning eutrophication, cannot be effectively conducted on an *ad hoc* basis. The presence of multiple point and diffuse sources of anthropogenic nutrient loading within catchments, which affect receiving aquatic ecosystems and

[155] Refer to **POLICY STATEMENT 8**: Nature-based solutions.
[156] Refer to **Section 6.4.2.2.2, [E]**: Lawful water use.
[157] Refer to IWQM Policy Statement B.2-6: Compliance monitoring and enforcement [DWS, 2017c:48].

various water users differently, requires well-planned, coordinated and integrated management efforts.

To comprehensively address these challenges, control and management efforts must be strategically planned and seamlessly integrated across different scales from the catchment upward to the national strategic scale, and from the catchment downward to the source-specific operational scale.

Holistic thinking deals with *"wholes"* rather than *"parts"*

Land use activities typically occur within small sub-catchments nested within larger catchment areas, which may connect to neighbouring or downstream catchments *inter alia* through inter-basin transfers, shared aquifer systems or return flows generated upstream. The condition of receiving waterbodies reflects the nature and characteristics of upstream and donating areas. Anthropogenic activities within a catchment mostly have incremental negative impacts downstream. This cascading effect on water resource quality highlights the need for a holistic perspective of the entire catchment water value chain – *"from resource to source to resource to sea"*.

Access to water resources that are fit-for-use is essential for socio-economic progress. Achieving a balance between ecological considerations, protection of downstream water users, and the demands of social development and economic growth at various geographical and political scales is crucial. Furthermore, water resources often transcend administrative boundaries, crossing local, provincial, national and even international borders. This complexity necessitates integrated and cooperative [158] eutrophication management.

Responsibilities for regulating and controlling eutrophication-related impacts are shared across different government spheres and departments, emphasising the interconnected nature of managing eutrophication. Consequently, management focus varies across geographical scales (**FIGURE 72**), underscoring the importance of strategic considerations in guiding local actions. Strategic planning

[158] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

must inform local initiatives and vice versa to effectively tackle eutrophication challenges.

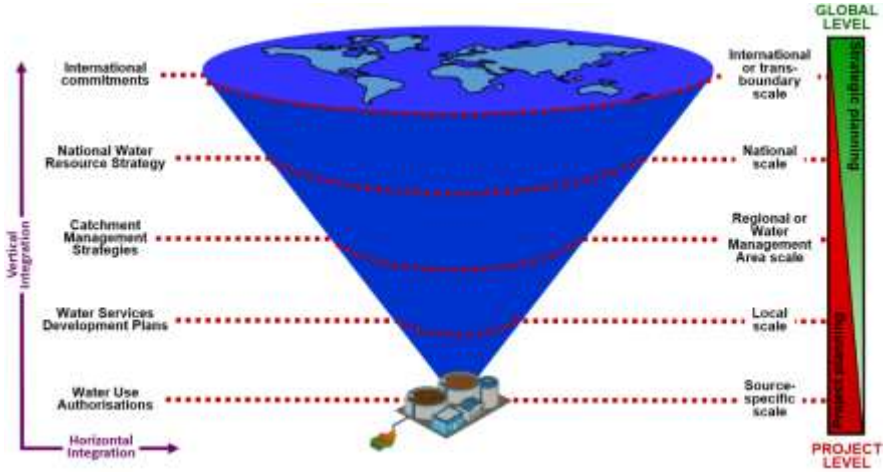

FIGURE 72: Geographical scales of eutrophication management in the context of integrated water resource management.

"Horizontal" and *"vertical"* integration

In managing eutrophication, it is essential to ensure both *"vertical"* and *"horizontal"* integration across the various management scales. This means that any Water Use Authorisation, WSDP or CMS should not contradict broader frameworks like the NWRS. Additionally, there should be no *"horizontal"* contradictions at any given management scale, such as incompatible authorisations for water, atmospheric fallout, waste, mining or any other type of authorisation. This integrated approach helps create coherent management strategies that can effectively address eutrophication challenges.

Application of the most restrictive approach

Local level plans and policies should be based on national policies and priorities. Actions within any given policy level should also be informed by the Precautionary Principle,[159] meaning that the most restrictive approach be applied across agencies.

[159] Refer to **POLICY STATEMENT 4**: The application of the Precautionary Principle.

Instruments for holistic eutrophication management

To effectively manage eutrophication and translate broader strategies into focused local actions, several instruments must be used in coordination. These include:

- **Water management strategies and service plans** should be established and implemented, supported by integrated water resource and services planning that outlines frameworks for eutrophication management at local, catchment, WMA, national and transboundary scales, as needed;
- Appropriate **statutory RDMs**, *i.e.,* MCs (and RQOs/ Reserves), and any other requirements for complying with the RQOs, such as RWQOs/ WQPLs, must be determined, planned and operationalised, in line with the Receiving Water Quality Objectives Approach;[160]
- All **eutrophication management instruments** [161] should be applied collectively to ensure that impacts on water resources remain within acceptable levels; and
- Appropriate **water resource and services data** must be collected[162] and management information generated[163] to provide the water quality intelligence necessary for informed decision-making[164] and effective eutrophication management.

Institutions to facilitate integrated eutrophication management

To effectively manage eutrophication, it is essential to establish, support and strengthen Water Management and Services Institutions, particularly CMAs and WSAs. These entities must be equipped to fulfil their responsibilities and decentralise eutrophication management to appropriate levels, enabling broad stakeholder participation.[165]

Additionally, it is vital that water use pricing aligns with catchment eutrophication management priorities to ensure that water institutions are adequately resourced. Collaboration between water institutions and other entities responsible for environmental management and

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[160] Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.
[161] Refer to **POLICY STATEMENT 1**: Application of management instruments.
[162] Refer to **POLICY STATEMENT 12**: Monitoring.
[163] Refer to **POLICY STATEMENT 13**: Information management.
[164] Refer to **POLICY STATEMENT 14**: Water resource assessment and planning to inform decision-making.
[165] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

land use activities that could affect nutrient loading and anthropogenic eutrophication is also crucial.

Policy status

Given the multifaceted nature of eutrophication, it is crucial to address the matter holistically. In response to this need, a new policy statement on holistic eutrophication management has been introduced.

POLICY STATEMENT 11

5.4.11 Eutrophication management responsibility and accountability

Premise

The escalating anthropogenic eutrophication and the lack of ownership by those in positions of influence highlight an urgent need for responsibility and accountability regarding actions taken, or not taken, toward addressing this issue.

Everybody is responsible

Every land and water user **must act responsibly** and in accordance with the law, to avoid, prevent or minimise anthropogenic eutrophication. Engaging in unlawful conduct includes undertaking a water use that is not permissible in terms of the NWA (36:1998), and causing water pollution, such as runoff from land or discharging effluent that contributes to excessive primary production in receiving waterbodies.

Duty of care

By law, every water user who causes, has caused or may cause significant pollution or degradation of water resources has a duty of care to **take reasonable measures** to avoid and prevent such harm from occurring, continuing or recurring. If such harm to water resources is authorised by law or cannot reasonably be avoided or prevented, efforts should be made to minimise and rectify any pollution or degradation of water resources [NEMA, 1998, S.28(1)].

Accountability is assigned

Accountability is designated by mandates outlined in the Constitution (108:1996), other legislation or through a specific water use authorisation, typically assigning a particular activity or assignment to a party. Furthermore, accountability involves the

obligation to regularly report on the status or outcomes related to that specific activity or assignment.

When the discharge of wastewater is authorised or when a municipality (WAS) is designated to provide water services, accountability associated with that mandate cannot be transferred to another party, unless legally permitted. Moreover, appealing for any form of support by a water user, including a state-owned entity or municipality, does not exempt that water user from adhering to any legal requirements or provide immunity from obeying the law.

Liable parties and liability

Under the NWA (36:1998), S.19, certain parties are obligated to take reasonable measures to prevent anthropogenic eutrophication in water resources. This obligation applies if any activity or process on the land causes, has caused or is likely to cause excessive nutrient loading of a water resource. The individuals responsible include:

- The landowner;
- A person in control of the land; and
- A person who occupies or uses the land.

Importantly, the person required to take preventative measures may not necessarily have been responsible for the activity, process or situation causing the eutrophication. Such activities or processes might have happened prior to the current responsible party's ownership, control or use of the land. Additionally, the affected water resource that was polluted or that could be polluted does not have to be located on the implicated land.

The National Environmental Laws Amendment Act, 2009 (Act No. 14 of 2009) further emphasises this responsibility by extending liability retrospectively. This includes pollution or degradation that–

- occurred before the NEMA (107:1998) came into effect in 1998;
- arises or is likely to arise at a different time from the actual activity that caused the contamination; or
- arises through an act or activity of a person that results in a change to pre-existing contamination levels.

Failure to fulfil this duty of care, specifically to avoid, prevent or minimise anthropogenic eutrophication, may result in legal action for relief. In such cases, the responsible parties could be held legally liable and might potentially be guilty of an offence, as part of consequence management.[166]

Policy status

The apparent deficit in responsibility and accountability is seen as a critical factor in the ongoing challenges related to the release of substandard effluents that contribute to the eutrophication of water resources. To address this issue, a new policy statement has been introduced, emphasising responsibility, duty of care and accountability in managing eutrophication.

POLICY STATEMENT 12

5.4.12 Monitoring

Premise

An appropriate base of data and information is essential for effective water quality planning and management, specifically regarding eutrophication (**FIGURE 73**). This data may include information on water quality, quantity and the health of aquatic ecosystems or focus on underlying socio-economic factors and causal relationships. For accuracy, it is important to collect sufficient data over an adequate period and at the correct spatial scale.

FIGURE 73: The water quality monitoring value chain [Pers. coms. Grobler, 2012].

[166] Refer to **POLICY STATEMENT 12**: Monitoring.

Purpose of eutrophication-related monitoring

In compliance with the obligation established by the NWA (36:1998), Chapter 14, to set up a monitoring system for water resources, it is imperative to collect data and information related to eutrophication for several critical assessments:

- Identifying sources of anthropogenic eutrophication and their relative load contributions, particularly in cases of point discharges, ensuring adherence to WDSs, and diffuse contributions;
- Evaluating the implementation of wastewater, waste reuse and recycling strategies;
- Assessing the impact on receiving water quality, especially concerning nutrient loading and ensuring compliance with RDMs and RWQOs/ WQPLs;
- Gauging the health of aquatic ecosystems, serving as indicators of water resource system health;
- Measuring the effectiveness of remediation projects designed to address the effects of excessive nutrient loading;
- Determining whether offset initiatives are delivering the expected improvements; and
- Understanding causal chains linking eutrophication to socio-economic factors and identifying the root causes of eutrophication.

Furthermore, eutrophication-related monitoring efforts must–

- contribute meaningfully to ecologically sustainable development;
- acknowledge the ecological interdependence of water resources, including aspects related to water quantity, and adjust strategies accordingly; and
- serve as a crucial component for adaptive and integrated water quality management, enabling effective responses to changing conditions and knowledge.

Use of technology

The adoption of smart technology and advanced eutrophication monitoring techniques is encouraged when evaluated as cost-effective.

Temporal extent

At monitoring stations where water quality shows significant variation, sampling frequencies must be higher compared to stations with

relatively stable water quality. Generally, collecting samples monthly can provide a good characterisation of water quality over extended periods. However, for more immediate control and management purposes, more frequent sampling may be necessary. Should significant changes in water quality be suspected or detected, it may be required to collect samples daily or on a continuous basis.

The importance of sustainable, long-term monitoring, along with the availability of robust historical data and information, cannot be overstated. **It is crucial to maintain such data collection efforts diligently to ensure ongoing water security.**

Spatial extent

Eutrophication monitoring requires implementation across suitable spatial scales to ensure comprehensive coverage, including:

- **National water resource status and trends monitoring:** This level offers an integrated overview of the nation's overall effectiveness in managing eutrophication. It helps in understanding the broad patterns and trends in nutrient loading across the country;
- **Regional water resource performance monitoring:** At this level, the *status quo* quality of water resources is compared against predetermined RDMs (such as RQOs) and/or RWQOs/ WQPLs. This provides insights at the specific spatial and temporal scales for which these objectives have been set, facilitating targeted management decisions; and
- **Source compliance monitoring:** This is the most localised form of monitoring, offering site-specific information critical for evaluating the effectiveness of Source-Directed Measures and Controls. It focuses on specific sources of eutrophication and assesses compliance with regulatory standards to ensure that localised pollution control efforts are effective.

Compliance monitoring and enforcement

A significant challenge in managing eutrophication stems from weak enforcement of legislation and authorisation conditions outlined in the NWA (36:1998), leading to costs being shifted onto communities and society. It is crucial to regularly measure, assess and report on the extent to which individual water users are adhering to the conditions specified in their water use authorisations, such as licenses.

Enhancing the capacity to monitor and control discharges of water containing waste is essential. Strict measures need to be implemented against the unlawful discharge of water containing waste and disposal of waste, ensuring compliance with authorisation conditions through collaborative efforts, particularly by the DWS and DFFE. Facilitating the exchange of information when needed and conducting joint compliance initiatives is key. Strengthening environmental compliance monitoring and enforcement capabilities through the appointment and training of Environmental Management Inspectors (EMIs) is vital. A zero-tolerance policy towards non-compliance, especially regarding excessive nutrient loading, is necessary.

Policy status

Given the pivotal role of data and information in eutrophication management, a policy statement on monitoring was incorporated into the eutrophication governance policy framework. This policy statement was derived from existing policy.[167]

POLICY STATEMENT 13

5.4.13 Information management

Premise

Collecting data and interpreting trophic status information are crucial components of eutrophication management. Without precise information, a clear understanding of eutrophication challenges is not possible, potentially hindering the development and execution of effective strategies. Data and information management systems are essential prerequisites for evaluating eutrophication, understanding the scale of the issues and addressing associated challenges effectively.

Gathering of data and information

Data management systems should be cost-effective and capable of meeting the demands of national and regional eutrophication monitoring programmes effectively. The objective is to furnish the necessary information for planning, decision-making, operational and

[167] Refer to IWQM Policy Statements B.2-6: Compliance monitoring and enforcement [DWS, 2017c:48]; and D.1-1: Strengthening of national water quality monitoring networks [DWS, 2017c:61].

strategic water resource management, as well as the development of pertinent infrastructure at local, regional and national levels.

Access to information

Recognising the obligation to grant access to information under the Access to Information Act, 2000 (Act No. 2 of 2000),[168] data gathered in national and regional eutrophication monitoring programmes, overseen by entities like the DWS, CMAs or other government entities, should be accessible or be made available upon reasonable request.

Government institutions are encouraged not to wait for data requests and should proactively make data available. For data that is already in the public domain, such as hydrological and chemical data published on websites, these practices should be sustained.

Use of technology

Moreover, implementing an Application Programming Interface (API) would simplify access to data for app developers as needed.

Data and information cost

While reasonable charges for data provision can be applied, caution should be exercised against creating a paywall that may deter or disadvantage South African users, such as schoolchildren, university students or pensioners. The costing approach should ensure equitable access to essential eutrophication-related information for all user groups.

Information management, cooperation and efficiency

All management-related data and information linked to eutrophication monitoring programmes should utilise the accepted corporate data management systems. There is a need to explore and endorse the alignment of monitoring systems across various scales, including transboundary, national, WMA, local and water use-specific scales, to enhance eutrophication management practices. Strengthening and improving collaboration with local governments, particularly concerning eutrophication data handling and management, are crucial steps for effective coordination, data utilisation and management.

[168] Hereafter referred to as AIA (2:2000).

Policy status

A policy statement on information management was incorporated into the eutrophication governance policy due to the necessity of producing relevant information and its significance in eutrophication management. This policy statement was formulated based on existing policy.[169]

POLICY STATEMENT 14

5.4.14 Water resource assessment and planning to inform decision-making

Premise

It is essential to address the complexities and uncertainties linked to water resource management, particularly in the context of eutrophication management. A comprehensive understanding of catchment processes and issues is crucial to effectively tackle these challenges.

Holistic catchment context

Enhancing one's understanding by aiming for a holistic comprehension[170] of all catchment processes and issues is crucial. This understanding should be based on sufficient and objective observations to the extent feasible. It is imperative to undertake this process before making catchment management decisions aimed at enhancing the present state of water resources, as emphasised by [DWAF, 2006b:38].

Assessment and water quality planning

In addition to addressing eutrophication knowledge gaps through theoretical or applied research,[171] it is essential to promote water resource planning, beginning with a thorough situation assessment. Assessments are valuable but hold limited worth if not paired with forward planning. While identifying existing problem areas is important, the added value of water quality forecasts, trend analysis, integrated system operation, reconciliation and scenario planning is essential. This is especially true in modern eutrophication management, where pressures from human activities are continually increasing.

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[169] Refer to IWQM Policy Statement D.1-2: Strengthening and improvement of information management systems [DWS, 2017c:62].

[170] Refer to **POLICY STATEMENT 10**: Holistic eutrophication management.

[171] Refer to **POLICY STATEMENT 16**: Promotion of eutrophication-related research.

Informed decision-making

The focus should be on relevant issues within the specific geographical context, usually at the catchment level, to guide planning efforts. Data and information obtained from monitoring should be analysed within the catchment or water resource system to support management and remediation efforts, thereby enhancing decision-making processes. When management knowledge is lacking and unacceptable risk levels are identified, the Precautionary Principle[172] should be applied. Effective water resource assessment and planning provide the foundation for robust eutrophication management and the continual improvement of practices.

Policy status

Eutrophication management measures should ideally be informed by appropriate water resource knowledge, assessment and planning, motivating the inclusion of policy on water resource assessment and planning to inform decision-making. This policy statement was derived from existing policy.[173]

POLICY STATEMENT 15

5.4.15 Resourcing of eutrophication management

Premise

The development of the eutrophication governance strategy marks a significant initial step in enhancing the trophic state of numerous water resources. However, an even more critical phase in the eutrophication management process involves empowering stakeholders to engage actively in identifying and implementing crucial eutrophication management measures.

Budget, human capital and equipment

It is the constitutional responsibility of all spheres of government to protect the quality of South Africa's water resources, supported by the constitutional requirement for collaborative governance and the maintenance of conducive inter-governmental relations. Sufficiently skilled public and/or private sector personnel must be appointed and tasked with eutrophication management roles, as needed. Adequate

[172] Refer to **POLICY STATEMENT 4**: The application of the Precautionary Principle.

[173] Refer to IWQM Policy Statements B.1-2: Strengthening of integrated water resource planning at all scales [DWS, 2017c:40]; and B.1-3: Development of integrated planning approaches at the catchment scale [DWS, 2017c:41].

budgetary allocations and procurement of necessary equipment are essential to enable personnel to effectively carry out their eutrophication management responsibilities. Budgetary constraints will necessitate the identification of priorities and the phased allocation of financial resources over time.

Policy status

Good intentions without the necessary resources will achieve little. Therefore, it is important to include a policy statement on appropriately resourcing eutrophication management as part of the eutrophication governance policy framework. This is a new policy statement.

POLICY STATEMENT 16

5.4.16 Promotion of eutrophication-related research

Premise

The eutrophication management landscape is constantly evolving, driven by factors like the increasing need for advanced, cost-effective water treatment technologies, escalating nutrient enrichment in water resources due to developmental pressures and the anticipated impacts of climate change. As new eutrophication-related challenges continue to emerge and the demand for innovative solutions to address longstanding issues grows, ongoing Research and Development (R&D) plays a crucial role in shaping effective eutrophication governance strategies.

National water quality research and development plan

The DWS and the WRC will have a critical role in formulating a national water quality R&D plan that aligns applied research priorities across the entire water value chain. It is essential to ensure that water R&D contributes directly to resolving challenges in the water sector, particularly those related to eutrophication, and addresses emerging areas such as the increasing demand for water reuse and recycling strategies. The involvement of South Africa's academic institutions and independent research organisations will be pivotal in the development and implementation of this plan.

Transfer of new and applied technologies

The DWS, along with the WRC and various sector organisations, academic institutions and other stakeholders, will actively promote innovation and knowledge sharing to facilitate the adoption of new and

suitable technologies. There will be a specific emphasis on assisting municipalities in integrating appropriate and innovative technologies, and collaborating with the private sector, civil society and the research community to design, develop and market new technologies and approaches. To support these efforts, the WRC and the Department of Science and Innovation (DSI) will continue to enhance the impact of the Water Technologies Demonstration Programme. This initiative aims to streamline the applied R&D and commercialisation phases of the water innovation process, bridging the gap between water research and the market to establish a cohesive water innovation system that generates socio-economic advantages for South Africa.

Policy status Applied research and technology development play a crucial role in advancing and enhancing eutrophication-related knowledge. This underscores the importance of incorporating a policy statement on eutrophication-related research into the eutrophication governance policy framework. This policy statement was derived from existing policy.[174]

POLICY STATEMENT 17

5.4.17 Transparency

Premise Decisions regarding eutrophication management should be made openly and transparently, with information access [175] provided in compliance with the law [NEMA, 1998, S.2].

Communication Communication channels should be established, as needed, to inform, persuade, build relationships and foster open dialogue in the public interest on eutrophication management-related topics.

Policy status Aligned with the democratic values upheld in our Constitution (108:1996), active citizen participation in civic life is crucial. This participation hinges, among other aspects, on the accessibility of information. The involvement of civil society and other

[174] Refer to IWQM Policy Statement D.1-5: Availability of water quality data to the public [DWS, 2017c:62].
[175] Refer to **POLICY STATEMENT 13**: Information management.

stakeholders in matters concerning eutrophication, both current and potential future roles, necessitates openness and transparency.[176] Therefore, a policy on transparency has been integrated into the eutrophication governance policy framework. This policy statement was derived from existing policy.[176]

POLICY STATEMENT 18

5.4.18 Technical capacity to take eutrophication management action

Premise

A highly skilled and competent cohort of professionals in the water sector, particularly in government departments and institutions, is vital for effective eutrophication management. Although capacity exists, it is often overstretched, underscoring the need to further enhance and expand the pool of role players with the necessary skills to tackle eutrophication challenges.

Community well-being and empowerment

Community well-being and empowerment should be promoted through various means, including raising environmental awareness, engaging in community-based science, leveraging the expertise of retired professionals, sharing knowledge and more. Increasing awareness of eutrophication management is crucial and can be achieved through campaigns in schools, public spaces and community outreach programmes. These initiatives should be supported by broader efforts encouraging societal action to improve the trophic state of water resources. Public awareness significantly influences perceptions and attitudes towards eutrophication, underscoring the importance of protecting water resources and aquatic ecosystems.

Education and training

Education and training programmes should be formulated and implemented in schools, universities and workplaces to enhance environmental and water management knowledge and capacity. Programmes in schools and universities should prepare young individuals before they enter the workforce, while workplace training

[176] Refer to IWQM Policy Statements D.2-1 and D.2-2: Research and innovation [DWS, 2017c:63].

should effectively equip all individuals involved in eutrophication management with the necessary skills and knowledge.

Capacity building programme to develop sector capacity

The DWS will take the lead in developing and implementing capacity-building programmes to enhance sector capacity [DWS, 2017c:33]. The initiatives will include:

- Providing bursaries to students pursuing water quality-related subjects at universities to cultivate a pool of skilled recruits for the government;
- Spearheading the creation of relevant on-the-job and technical training programmes for officials from various state institutions to enhance the government's capacity in managing water quality effectively and addressing future eutrophication challenges;
- Collaborating closely with other government departments to bolster sector-wide capacity in regulating activities affecting eutrophication management. This effort will encompass interventions to enhance inter-departmental capacity to ensure and enforce compliance with regulations and other legislative requirements;
- Partnering with CMAs to enhance the capacity of CMFs to contribute to local water quality management, including eutrophication management; and
- Working alongside the DFFE to provide training opportunities to civil society organisations active in the water sector, facilitating their informed engagement in IWQM processes, particularly related to eutrophication management.

Attracting human resources capital

Employers in relevant sectors should position themselves as institutions that draw in appropriate candidates and employees, fostering an environment conducive to building and sustaining crucial eutrophication management capacity.

Professionalisation of staff in key positions in local government

The DWS, in partnership with the Department of Cooperative Governance and Traditional Affairs (CoGTA), will work towards creating regulations that promote the professionalisation of key water services positions within WSAs. This initiative aims to guarantee that

personnel responsible for managing water and wastewater systems at the municipal level possess the requisite training and competencies.

Policy status

Suitable capacity is a vital component for implementing eutrophication management, which justifies the inclusion of a policy statement on capacity building in the eutrophication governance policy framework. This policy statement was derived from existing policy.[177]

POLICY STATEMENT 19

5.4.19 Cooperative eutrophication management

Premise

Eutrophication management will be enhanced through effective coordination, appropriate institutional arrangements, cooperative planning and synergistic approaches involving basin states, relevant South African government departments, different spheres of government and various sectors. Active engagement with the private sector and civil society is also essential.

Transboundary cooperation and water diplomacy

To promote the sustainable and coordinated use of resources in the Southern African Development Community (SADC) Region's shared watercourses, parties, including South Africa, agreed in 2000 to the revised SADC Protocol on Shared Watercourses. Under this Protocol [SADC, 2000:3], parties commit to–

- facilitate the establishment of shared watercourse agreements and River Basin Organisations (RBOs) for management;
- advance sustainable, equitable and reasonable utilisation of shared watercourses;
- encourage coordinated and environmentally sound development and management;
- promote harmonisation and monitoring of legislation and policies for planning, development, conservation, protection and resource allocation; and

[177] Refer to IWQM Policy Statements D.3-1 and D.3-2: Capacity building and training [DWS, 2017c:65].

- support research, technology development, information exchange, capacity building and use of appropriate technologies in shared watercourse management.

Government-wide eutrophication management

All spheres of government in South Africa have a constitutional duty to protect the quality of the country's water resources. This duty is supported by the constitutional requirement for cooperative governance and constructive intergovernmental relations. Any actual or potential conflicts of interest between organs of state should be addressed using the relevant conflict resolution procedures [NEMA, 1998, S.2].

Civil society and corporate business partnerships

The private sector and civil society are crucial in minimising their impact on water resources. CMFs and other consultative forums have been established to tackle water challenges, align plans and enhance collaboration, ensuring stakeholder engagement. Effective stewardship and partnerships will be established to address eutrophication in priority areas. To manage eutrophication strategically, the DWS will need to forge highly focused, fit-for-purpose, civil society and corporate business partnerships that are relevant to the eutrophication challenge. This partnership approach requires polluters to take cradle-to-grave[178] responsibility for their products and improve self-regulatory processes to lessen the regulatory burden on the state[179] [DWS, 2017c:36].

Stakeholder consultation

The objective is to solicit public feedback on analyses, alternatives and decisions, recognising concerns and offering feedback on how stakeholder contributions have impacted decision-making processes. Decisions should consider the interests, needs and values of all relevant and impacted parties, integrating diverse forms of knowledge, including traditional and local knowledge [NEMA, 1998, S.2].

Harmonisation of policy, strategy and legislation

The DWS will spearhead a collaborative effort to ensure alignment and inter-departmental harmonisation of policies, legislation, regulations,

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[178] Refer to **POLICY STATEMENT 6**: A life cycle view on nutrient loading.

[179] Refer to **POLICY STATEMENT 1**: Application of management instruments for environmental compliance in eutrophication management.

integrated planning, compliance monitoring and enforcement [NEMA, 1998, S.2].

Policy status

One of the notable distinctions between the 1991 and 2017 policies for water quality management is the significant stride towards integrating water quality management initiatives by acknowledging the contributions of the public and private sector, as well as civil society stakeholders.[180] This collaborative approach is also extended to eutrophication management, prompting the inclusion of a policy statement on cooperative management in the eutrophication governance policy framework. This policy statement was derived from existing policy.[181]

5.5 CONCLUSION

Chapter 5 provided a detailed framework for eutrophication management in South Africa, grounding its approach in a clear vision, mission, goal and objectives. These foundational elements were translated into a series of succinct policy statements deemed essential for mitigating anthropogenic eutrophication effectively. The chapter underscored the significance of government policy as a guiding instrument that reflects political mandates and sets high-level objectives. The policy's development drew from a thorough evaluation of eutrophication governance in South Africa, including analyses of eutrophication challenges, projections of future governance trends, findings from a nationwide survey,[182] insights garnered from the DPSIR Framework and extensive stakeholder engagement.[183]

The envisioned eutrophication governance policy approach aligns with the broader IWQM Vision and Mission, delineating precise objectives to proficiently manage eutrophication, protect aquatic ecosystems and maintain water resources that are fit-for-use. These objectives and their associated policy statements were differentiated into chief and complementing imperatives, aiming to provide a robust policy framework (summarised in **Annexure I**) that aligns with existing

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[180] Refer to **Section 6.5.3**: Collaboration and management participation.

[181] Refer to IWQM Policy Statements A.1-1 to A.1-6 and A.2-1 to A.2-3: Inclusive approach to IWQM [DWS, 2017c:33].

[182] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[183] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

policies while introducing new perspectives where necessary. The policy statements in this chapter were designed to broaden the scope of the IWQM Policy, specifically addressing strategic aspects of eutrophication management.

A significant focus was placed on the causal analysis based on the DPSIR Framework to shape policy formulation. Despite the hurdles in mitigating all eutrophication root causes, attributable to factors such as climate change and socio-economic disparities, the policy stressed the critical nature of managing human-induced pressures through focused measures and strategically influencing societal drivers.

Key policy responses were outlined, targeting the management of anthropogenic pressures from various sectors, including mining, agriculture and urban development, encapsulating national policy goals like reducing nutrient loading, protecting aquatic ecosystems, ensuring the sustainability of water resources and preferring enduring solutions to temporary fixes.

The policy statements were enumerated, differentiating between existing policy positions that required adjustments to incorporate a eutrophication focus and entirely new policy positions proposed to address specific challenges. These policy statements cover a wide range of measures, from environmental compliance to promoting research and transparency.

Policy formulation was guided by acknowledging the need for a mix of engineered and non-engineered solutions, addressing water uses in a catchment context, integrating eutrophication management with broader water quality management issues and emphasising the importance of monitoring, research, government cooperation and public-private-civil society collaboration.

In conclusion, **Chapter 5** presented a detailed policy framework for the implementation of a targeted eutrophication governance policy in South Africa. It advocates for a blend of updated and new policy statements aimed at adopting a holistic, integrated response to eutrophication by confronting root causes, championing sustainability and enhancing collaborative efforts among diverse stakeholders. A comprehensive strategy is now essential to outline structured and cohesive implementation approaches for these eutrophication governance policy directives.

THE RESEARCH CONTEXT OF CHAPTER 6

Chapter 6 develops the strategic response through which the policy positions established in Chapter 5 can be implemented. It, therefore, has extensive substantive and textual overlap with Part 3 of the EMSSA, *Eutrophication Management Strategy for South Africa* [DWS, 2023b]. Section 6.3 corresponds with the EMSSA core strategies for source, resource and remediation directed management; Section 6.4 corresponds with the Plan-Do-Check-Act operational strategies; Section 6.5 corresponds with the supporting strategies for capacity building, research and technology development, and collaboration and management participation; and Section 6.6 corresponds with the EMSSA governance component. Closely corresponding wording also occurs in a number of strategic action formulations and implementation tables.

Development of the corresponding EMSSA strategy component likewise benefited from specialist, research and stakeholder inputs. W. Mosefowa, as Co-Author, provided input principally on pollution source control, source directed controls, water use authorisation, the Waste Discharge Charge System, monitoring and compliance; K. Makanda and S. Mnyango provided research support during development of the EMSSA, with S. Mnyango also supporting stakeholder engagement and coordination; and wider stakeholder inputs assisted in refining remediation, operational arrangements, governance responsibilities, diffuse source management, monitoring and implementation priorities and timeframes. These contributions are recorded in the *Issues and Response Register* [DWS, 2023c] and the *Document Change Log* [DWS, 2023e].

The strategic formulations were developed within the integrated research process and are reflected in the EMSSA as an applied implementation response. Consistent wording was retained where the same strategic formulation, responsibility or implementation requirement served the same function in both outputs, particularly in relation to authority, prescribed actions, spatial application, temporal implementation and specific strategic actions. Within the doctoral thesis, however, Chapter 6 places these measures within their fuller scholarly and analytical context: Section 6.2 derives the strategic response from the preceding causal chain and DPSIR analysis, and the chapter links the detailed strategy architecture to the academic reasoning and evidence developed throughout the thesis. The EMSSA adapts and presents the relevant strategic responses for national water sector implementation and departmental use.

CHAPTER 6 TOWARDS A EUTROPHICATION GOVERNANCE STRATEGY FOR SOUTH AFRICA

6.1 INTRODUCTION

FIGURE 74 positions the reader in terms of the high-level thesis structure, whereas **FIGURE 75** depicts the section content of Chapter 6 (this chapter).

FIGURE 74: High-level thesis structure (Y*ou have arrived at Chapter 6*).

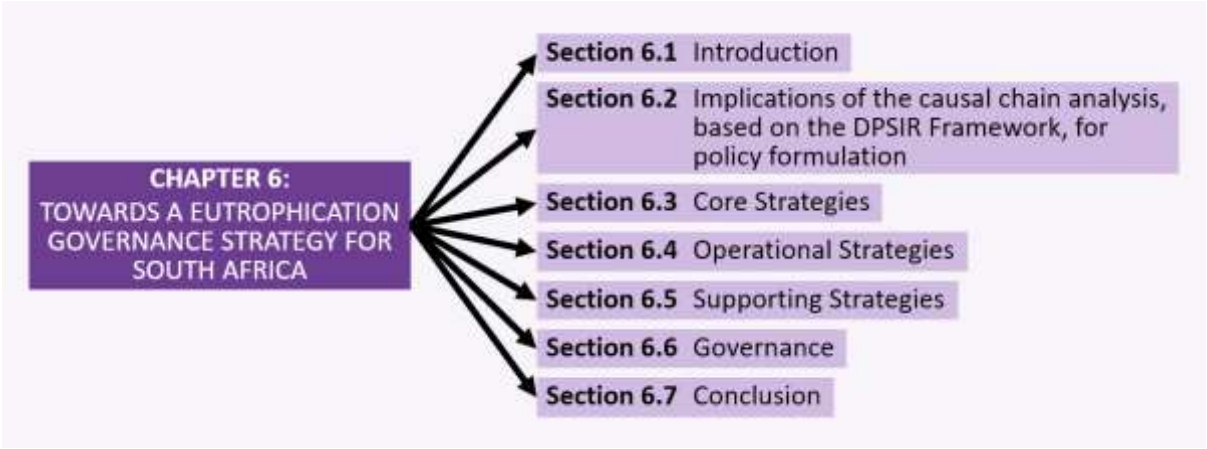

FIGURE 75: Section topics covered in Chapter 6.

"Government strategies", generally, delineate broad approaches for implementation aimed at realising strategic imperatives, including the enforcement of policy directions [Presidency,

2020:8]. This chapter outlines these broad approaches for governing eutrophication in South Africa. Together, these approaches must guarantee effective management aimed at protecting aquatic ecosystems and securing water resources that are fit-for-use. The DPSIR Framework, which was completed following a thorough review of relevant literature, evaluations of key challenges, examination of governance trends, analysis of national survey[184] results and engagements with stakeholders[185] (as detailed in **Chapter 4**), has significantly contributed to shaping and enhancing eutrophication governance strategies in this chapter.

A dual approach was adopted, defining policy in **Chapter 5** and strategy in this chapter separately. This separation facilitated more impactful and concise discussions. Referencing relevant eutrophication governance policies and aligning them with relevant strategies in the discussions outlined in **Chapter 6** was made possible due to this approach.

The process of strategy formulation involved specifying the authority (***"who"***), defining the approach and actions (***"what and how"***), and determining the spatial (***"where"***) and temporal (***"when"***) implementation scales.[186] South Africa's efforts to tackle eutrophication hinge on developing and implementing three types of interconnected and supportive strategies for eutrophication management (depicted in **FIGURE 76**), *viz.*:

- Core strategies;
- Operational strategies; and
- Supporting strategies.

These three strategies collectively aim to achieve the national eutrophication management goal and its objectives.[187]

Chapter 6 establishes a connection between strategy development and the DPSIR Framework in **Section 6.2**, outlines the core, operational and supporting strategies in **Sections 6.3**, **6.4** and **6.5**, respectively, and summarises sectoral mandates and governance responsibilities in **Section 6.6**. The chapter concludes with closing remarks in **Section 6.7**.

While efforts were made to keep discussions focused on a strategic level without going into detailed guidelines, the Strategy was compiled to be comprehensive, allowing implementers to

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[184] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

[185] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

[186] The four headings, ***"Authority"***, ***"Prescribed approaches"***, "***Spatial scale of implementation***" and "***Temporal scale of implementation***", were used to structure strategy formulation throughout **Chapter 6**, and to specify "***who?***", must do "***what and how?***", "***where?***" and "***when?***".

[187] Refer to **Section 5.3** for the visionary perspective.

consult relevant sections for strategic guidance. Some elements of the eutrophication governance strategy are specific to managing eutrophication, while others address its role within the broader context of water quality management. These strategies were chosen to establish a cohesive framework for eutrophication governance in South Africa.

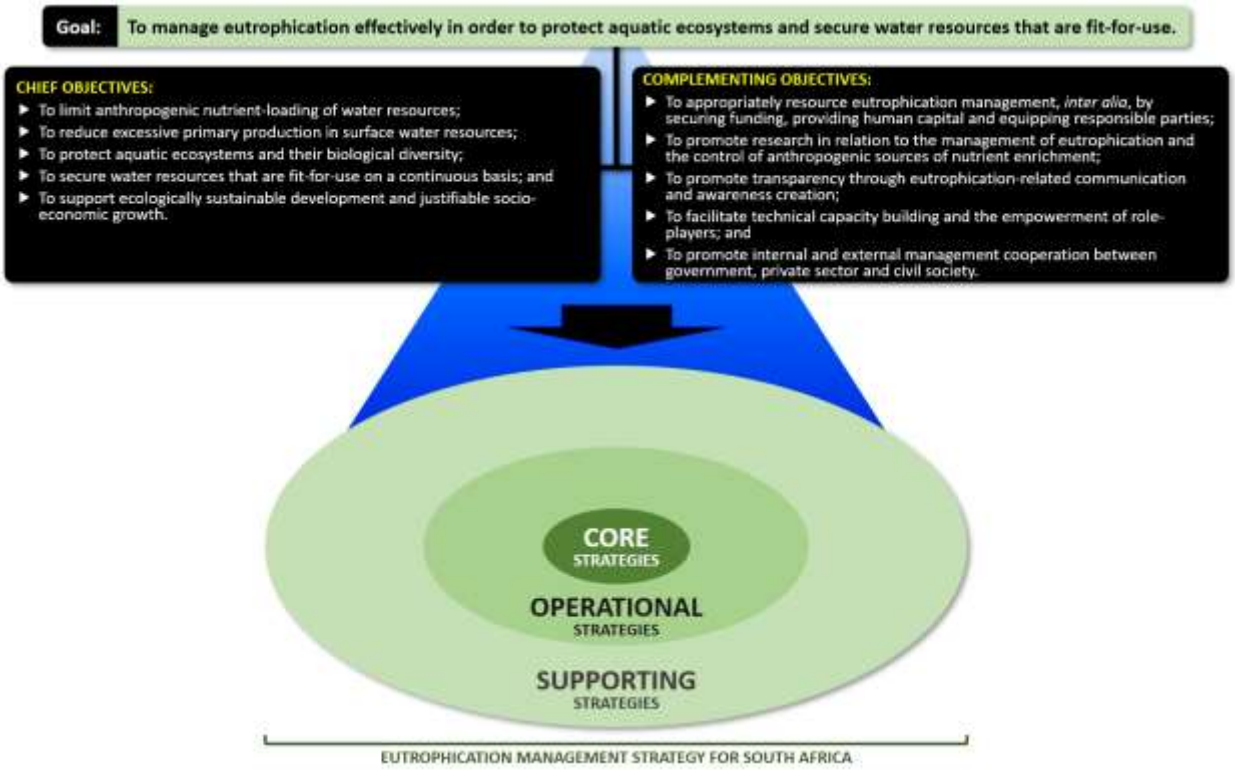

FIGURE 76: Outline of the eutrophication governance strategy.

6.2 IMPLICATIONS OF THE CAUSAL CHAIN ANALYSIS, BASED ON THE DPSIR FRAMEWORK, FOR STRATEGY ESTABLISHMENT

As with the Policy in the previous chapter, the goal was to address original or root causes with strategy by starting with societal drivers and then tackling anthropogenic pressures, rather than merely addressing the symptoms of excessive nutrient loading. However, it was not possible to address all root causes equally; for instance, factors like climate change, administrative and political instability, poverty and criminality proved challenging to directly address within the scope of eutrophication governance.

TABLE 27 summarises the societal drivers and anthropogenic pressures that serve as the *"original"* causes of eutrophication. This table synthesises information from the DPSIR Framework (**TABLE 22**) and is organised to guide the development of robust

eutrophication governance strategies. National strategy responses were categorised based on their characteristics to facilitate the creation of structured and tiered strategy approaches.

TABLE 27: Potential national strategy responses to the societal drivers and anthropogenic pressures that contribute to eutrophication.[188]

DRIVER [189]	PRESSURE [190]	NATIONAL STRATEGY[191] RESPONSES[192]
▶ Mining; ▶ Industry; ▶ Agriculture; ▶ Tourism; ▶ Human settlement areas; ▶ Other land uses; ▶ Local government; ▶ Poverty and criminality; ▶ Administrative and political instability; ▶ Population dynamics; and ▶ Climate variability and change.	▶ Blasting; ▶ Exposing of phosphorus-bearing rock; ▶ Disturbance of habitat and soil layers. ▶ Discharge of substandard wastewater; ▶ Atmospheric emissions of NH_3 and NO_2 affecting the nutrient content of precipitation; ▶ Atmospheric emissions of NO_2 and SO_2 generating acid precipitation; ▶ Habitat disturbance. ▶ Poor fertilising practices and over-fertilising causing fertiliser-laden diffuse runoff from agricultural fields; ▶ Prevalence of erosion, mobilising sediments on which chemical elements are adsorbed; ▶ Over-irrigation to satisfy leaching requirements; ▶ Feedlot waste disposal and wastewater discharged; ▶ Habitat disturbance; ▶ Organic waste, food leftovers and excreta associated with aquaculture; ▶ Inadequate farm advisory and extension services; ▶ Poor farming practices. ▶ Fluctuating and increased waste and wastewater production; ▶ Fluctuating and increasing pressure on urban wastewater handling. ▶ Nutrient-laden diffuse runoff from built-up areas; ▶ Habitat disturbance. ▶ Fertiliser and nutrient-laden diffuse runoff from golf courses; ▶ Habitat disturbance. ▶ Inadequate operation and maintenance of offsite and onsite sanitation systems; ▶ Theft and vandalism of wastewater infrastructure;	**CORE APPROACHES:** **Source-directed management:** ▶ Improved regulation; ▶ Operationalising of the Receiving Water Quality Objectives Approach; and ▶ Integration across sectors. **Resource-directed management:** ▶ Determine RDMs; and ▶ Improved regulation. **Remediation-directed management:** ▶ Develop and implement a Remediation Strategy to address cases of legacy nutrient pollution; and ▶ Improved regulation. **OPERATIONAL APPROACHES:** **Plan:** ▶ Holistic water resource system and catchment planning; ▶ Structured planning to ensure that WwTWs are timeously upgraded to not exceed design capacities; ▶ Validation and verification (V&V) of all water uses with a water quality impact potential; and ▶ Waste load accounting to be introduced as a planning instrument.

[188] **TABLE 27** is based on **TABLE 22: An analysis of anthropogenic nutrient enrichment and the effects of eutrophication in South Africa, based on the DPSIR Framework.**

[189] Defined as the socio-economic or demographic developments, OR production or consumption practices that trigger *"pressures"*.

[190] Defined as the anthropogenic activities or consequences that disturb the *"state"* of ecosystems.

[191] "Strategy" is colloquially, defined as those approaches that are necessary to give effect to policy (for eutrophication management).

[192] *"Response"* is defined as the societal measures aimed at preventing, minimising or mitigating negative *"impacts"* by feeding back to the *"drivers"*, *"pressures"* (and *"state"*).

DRIVER [189]	PRESSURE [190]	NATIONAL STRATEGY[191] RESPONSES[192]
	▶ Discharge or loss of untreated and/or substandard wastewater; ▶ Poor waste practices; ▶ Inadequate investment in wastewater infrastructure. ▶ Washing in streams and in rivers; ▶ Inappropriate onsite sanitation and bush-toileting; ▶ Theft and destruction of sanitation services infrastructure; ▶ Overflowing utility access holes caused by sewer system blockages and sabotage; and ▶ Discharge of untreated and/or substandard urban wastewater. ▶ Exceeding the design capacity of WwTWs; ▶ Destruction of water resource and services infrastructure; ▶ Failing operation and maintenance of water resource and services infrastructure; ▶ Discharge of untreated and/or substandard urban wastewater; ▶ Variety of upstream pollution sources; ▶ Operating rules for the water resource infrastructure that promote enrichment. ▶ Return flows becoming an increasingly important component of the country's water budget; ▶ Habitat disturbance; ▶ Increased urban waste production; ▶ The nutrient-loading character of wastewater is changing; ▶ Pressure on urban wastewater handling; ▶ Negative effect on the affordability of rural water services infrastructure, affecting operation and maintenance; ▶ Altered flow and water quality regimes associated with the establishment of impoundments and related infrastructure; ▶ Lack of skilled water scientists and engineers; ▶ Inadequately capacitated water institutions. ▶ Changing water temperatures; ▶ Altered dilution capacity of water resources; ▶ Increasing levels of erosion; ▶ Altered flow and water quality regimes associated with the establishment of impoundments and related infrastructure; ▶ More frequent mixing of stratified layers and inversion of epilimnion and hypolimnion may lead to more regular recycling of nutrients from the anaerobic hypolimnion; and ▶ Exacerbated poor trophic conditions	**Do:** ▶ Integration of authorisation conditions with water resource requirements; ▶ Increased reuse and recycling of waste and water containing waste; ▶ Revision of nutrient discharge standards; ▶ Ensure that all water uses with a potential to contribute towards eutrophication are permissible, compliant and lawful; ▶ Improved water use authorisation and administration; ▶ Improved regulation; ▶ Enforcement of conservation agriculture; ▶ Enforcement of buffer zones and other best management practices; and ▶ Implementation of the WDCS. **Check:** ▶ Improved monitoring programmes and reporting for local and national government; ▶ Regular and targeted compliance monitoring; and ▶ Appropriate information management systems are in place. **Act:** ▶ Effective enforcement of big and regular offenders; ▶ Rehabilitation and restoration of ecological infrastructure; ▶ Rehabilitation of hard infrastructure; and ▶ Adequate maintenance of water resource and services infrastructure. **SUPPORTING APPROACHES:** ▶ Skills development training and capacity building; ▶ Appointment of employees, who possess appropriate skills levels, in technical positions; ▶ Research and technology development; ▶ Creation of an informed, supportive and responsible public;

DRIVER [189]	PRESSURE [190]	NATIONAL STRATEGY[191] RESPONSES[192]
		▶ Behavioural change communication programmes to facilitate behavioural change and a sense of responsibility in communities aimed at limiting and preventing excessive nutrient loading; and ▶ Management participation and cooperative governance.

6.3 CORE STRATEGIES

The strategies that are considered ***"core"*** to giving effect to the ambitions of the eutrophication governance policy, are based on three critical requirements:

(1) Establishment of sustainable land and water use: Sustainable land and water use practices are vital for combating eutrophication. Implementing a core strategy to address existing and potential sources of excessive nutrient loading is essential.

(2) Improvement of the trophic status of water resources: The increased use of land and water resources, alongside heightened competition for these limited resources, places significant strain on waterbodies. This situation hampers the ability of water resources to support consumptive and non-consumptive water uses, compromises water quality and poses a threat to water supply security. A core strategy focusing on ensuring water resources that are fit-for-use, enhancing water quality and directing appropriate levels of source-directed control is essential.

(3) Remediation of historical causes and effects of anthropogenic eutrophication: Legacy sources and the enduring effects of excessive nutrient loading continue to contribute to anthropogenic eutrophication. Addressing these residual causes and effects through remedial actions is an essential aspect of an effective core strategy to combat eutrophication.

The core strategies for eutrophication governance, therefore, are devised within an adapted management framework, comprising (1) **source-directed**; (2) **resource-directed;** and (3) **remediation-directed management** (**FIGURE 77**). Whereas source-directed and resource-directed management employ proactive measures and controls, remediation-directed

management, by its inherent nature, employs reactive measures to tackle residual causes and effects.[193]

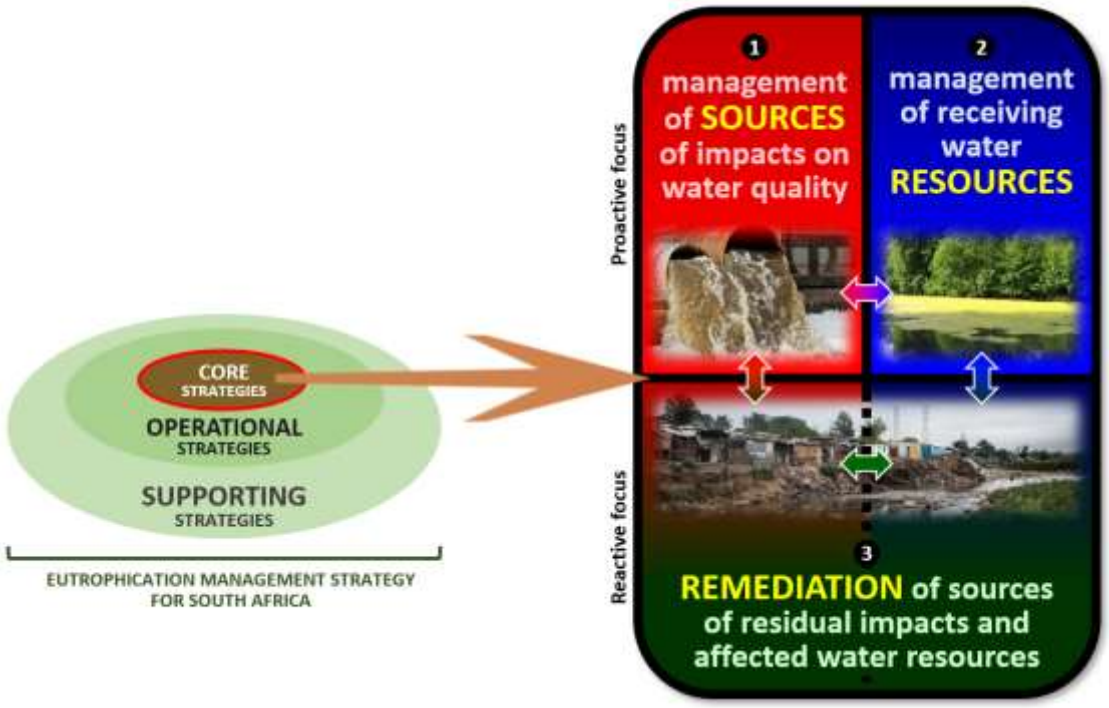

FIGURE 77: Core strategies for the management of eutrophication.

In **Sections 6.3.1**, **6.3.2** and **6.3.3** below, each of these three core strategies is discussed in detail. The discussions explore the conceptual elements of eutrophication governance strategy and emphasise the interconnected nature of these *"three unique facets"* of eutrophication management. Recognising the interconnectedness of these core strategies underscores the importance of cohesive implementation to effectively manage eutrophication, protect aquatic ecosystems and secure water resources that are fit-for-use. It is crucial to pursue the effective implementation of these core strategies while avoiding fragmented approaches. For detailed operational guidance, please consult **Section 6.4**, which addresses operational strategies for eutrophication governance.

[193] Notably, these remedial actions can target both the legacy causes (sources of impacts) and the legacy effects (affected water resources) of excessive nutrient loading and anthropogenic eutrophication.

6.3.1 Source-directed management

6.3.1.1 Authority

From a eutrophication management perspective, Source-Directed Measures and Controls must be imposed on land and water uses to protect aquatic ecosystems and receiving water users from the impacts of excessive nutrient loading and anthropogenic eutrophication. Given that these actions may not all fall under water legislation, and since land use regulation mostly falls under the oversight of authorities other than the DWS, the roles of other government departments in managing sources of anthropogenic eutrophication must be acknowledged. This aligns with the need for cooperative management of eutrophication.[194]

The sectors with relevant competencies related to environmental media, such as air, land, water, or aspects thereof, include: ♦ agriculture; ♦ the environment; ♦ human settlements; ♦ infrastructure; ♦ mining; and ♦ water and sanitation. The roles of competent authorities are outlined in **Section 6.6** under ***"Governance responsibilities"***, which provides additional clarity on the allocation of tasks concerning eutrophication governance.

6.3.1.2 Prescribed approach

Source-directed management involves applying regulatory measures and controls on land and water use activities to achieve specific levels of water resource protection, primarily targeting anthropogenic eutrophication at its sources.[195] This is done through operational strategies such as best management practices, authorisations,[196] conditional regulations, emission standards,[197] and pollution management regulations established under enabling legislation, following the policy on applying management instruments for environmental compliance.[198]

While source-directed management mainly relies on regulatory approaches, it also incorporates other management instruments to support pollution avoidance, prevention and minimisation.[199] Incentivised regulation is crucial in this approach and should be developed in line with the relevant policy.[200]

Operational strategies detailed in **Section 6.4** are key to implementing source-directed management. These strategies may overlap with other core strategies, such as water quality

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[194] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.
[195] Refer to **POLICY STATEMENT 6:** A life cycle view on nutrient loading.
[196] Includes any environmental authorisation, including water use authorisations, such as a water use licence.
[197] Can relate to WDSs or Ambient Air Quality and Emission Standards.
[198] Refer to **POLICY STATEMENT 1:** Application of management instruments for environmental compliance in eutrophication management.
[199] Refer to **POLICY STATEMENT 2:** The Mitigation Hierarchy for decision-making on eutrophication.
[200] Refer to **POLICY STATEMENT 7:** Incentive-based regulation.

monitoring, or be unique, like regulating land and water use. Supporting strategies, elaborated in **Section 6.5**, further strengthen source-directed management.

Though source-directed and resource-directed management focus differently on eutrophication management, Source-Directed Measures and Controls are guided by the existing RDMs, notably RQOs and their supporting RWQOs/WQPLs. Statutory RDMs designate levels of protection to significant water resources and are part of the resource-directed management core strategy, outlined in **Section 6.3.2**.

6.3.1.3 Spatial scale of implementation

Source-Directed Measures and Controls can vary in scope, being uniform at national, regional or catchment levels, differentiated based on land or water use types, or other forms of categorisation, or specific to pollution sources. Regardless of their scope, these measures are always applied to land and water use activities at the sources of impact to effectively prevent, avoid or minimise water pollution.[201]

6.3.1.4 Temporal scale of implementation

The prioritisation of developing, implementing and revising Source-Directed Measures and Controls will largely depend on insights from long-term water quality planning and executing CMSs. It is essential to not only consider and develop current and additional Source-Directed Measures and Controls but also refine and enhance them as needed for effective implementation.

Special attention should be given to operationalising the Receiving Water Quality Objectives Approach.[202] The actions in **TABLE 28** are generally strategic, whereas operational actions, outlined in **Section 6.4**, focus on practical implementation. Balancing strategic planning with operational execution is essential to ensure the effectiveness of Source-Directed Measures and Controls.

TABLE 28: Strategic actions to strengthen the source-directed management of eutrophication.

SHORT TERM	
(1)	Develop and implement (an) approach(es) to ensure that the conditions in water use authorisations, including those that specify WDSs, ensure compliance to statutory RDMs, specifically RQOs. Better integration between source and resource-directed management is essential;
(2)	Evaluate and/or develop model by-laws, in support of local government, to limit excessive nutrient loading and to protect raw water quality;

[201] Refer to **POLICY STATEMENT 2:** The Mitigation Hierarchy for decision-making on eutrophication.
[202] Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.

(3)	Develop and gazette water management regulations for impacting sectors (*e.g.,* feedlots, industries, etc.) that also contribute towards anthropogenic eutrophication;
(4)	The umbrella Environmental Offset Policy [DEA, 2018:3] mandates that the Offset Authority, which is the DWS, compile and publish specific offset policies for wetlands and water quality. This will facilitate the rolling out of offsetting for eutrophication management; and
(5)	In cases where regulations or compulsory national standards were made or were prescribed in terms of the NWA (36:1998) or the WSA (108:1997), an evaluation can be considered of the suitability and/or effectiveness of those measures that deal with the control and regulation of sources of anthropogenic eutrophication – specifically also their suitability to assist with realising the eutrophication management goal. In cases where the enabling legislation allows for the making of regulations that could assist with the management of sources of anthropogenic eutrophication, but such regulations do not exist, consideration must be given to the development and publication of such regulations.
LONGER TERM	
(6)	Develop and implement a Diffuse Source Management Strategy for South Africa that harmonises with, and supports the eutrophication governance policy and strategy for South Africa; and
(7)	Develop and implement sector specific action plans to reduce diffuse source pollution (in support of the Diffuse Source Management Strategy for South Africa).

6.3.2 Resource-directed management

6.3.2.1 Authority

The DWS is responsible for overseeing the management of the country's water resources [NWA, 1998, S.3]. According to the Act, the Minister of Water and Sanitation, through the Director General, any organ of state or any Water Management Institution, must adhere to RDMs determined for significant water resources, when exercising powers or performing duties under the Act [NWA, 1998, S.15].

While the national government, represented by the DWS, holds the responsibility of managing the nation's water resources and recognises the crucial connection between RDMs and source- as well as remediation-directed eutrophication management, it is vital to acknowledge the involvement of other authorities[203] in governing land and water use practices.

Sectors with relevant competencies, including: ♦ disaster management; ♦ the environment; ♦ health; ♦ land use and development planning; and ♦ water and sanitation, are involved in resource-directed management and aspects related to eutrophication and receiving water resources. The roles of competent authorities are outlined in **Section 6.6** under ***"Governance responsibilities"***, which provides additional clarity on the allocation of tasks concerning eutrophication governance.

[203] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

6.3.2.2 Prescribed approach

Resource-directed management of anthropogenic eutrophication inherently takes a catchment and water resources perspective.[204] The **primary objective** of resource-directed management is to ensure continued fitness-for-use of the country's water resources, which serve five main groups of recognised water users, *viz.*: (1) Agriculture; (2) Domestic; (3) Industry; (4) Recreation; and (5) Aquatic ecosystems.

To achieve this objective, it is crucial to have a comprehensive understanding[205] of various factors, including the relationships between water resources and their quality, the diverse current and future water user needs, existing and anticipated pressures on resource quality, the intrinsic socio-economic dynamics within the catchment, available allocatable water quality,[206] desired levels of water resource protection and the potential opportunities for expanding ecologically sustainable development within catchments. This understanding serves as the foundation for planning, determining management objectives[207] and establishing strategies and plans to frame the preferred eutrophication management approaches for progressive implementation over time. These strategies and plans are also essential for monitoring and evaluating implementation progress.

Resource-directed management plays a vital role in guiding both source- and remediation-directed management of eutrophication in catchments:

- **RDMs must influence source-directed management**, and any WDSs, that are applied to upstream water uses in order to protect downstream aquatic ecosystems and water users, and to ensure continued fitness-for-use of receiving water resources; and
- **RDMs must influence remediation-directed management**, such that-
  - upstream residual sources of excessive nutrient loading, for instance degraded land, are ameliorated to protect downstream aquatic ecosystems and water users, and to ensure continued fitness-for-use of receiving water resources; and
  - degraded or impaired receiving water resources and associated aquatic ecosystems are ameliorated to meet the applicable RDMs, specifically the Reserve, if determined, and any other environmental requirements that may exist.

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[204] Refer to **POLICY STATEMENT 10**: Holistic eutrophication management.

[205] Refer to **POLICY STATEMENT 14**: Water resource assessment and planning to inform decision-making.

[206] Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.

[207] Management objectives include the MC, RQOs, Reserves, and supporting RWQOs or WQPLs.

It is imperative that all three core strategies for eutrophication management are aligned and RDMs are integrated with pertinent Source- and Remediation-Directed Measures and Controls for effective management.

Resource-directed management is operationalised through several operational strategies detailed in **Section 6.4**, which may be shared among any of the core strategies, *e.g.*, water quality monitoring or be unique to resource-directed management, *e.g.*, the determination of statutory RDMs. Supporting strategies elaborated in **Section 6.5** further bolster resource-directed management efforts.

6.3.2.3 Spatial scale of implementation

Resource-directed management of eutrophication, with its focus on the catchment and receiving water resources, is also a matter of national importance as it pertains to the fitness-for-use of water resources that underpin the national economy.

From a catchment and receiving water resource perspective, resource-directed management of anthropogenic eutrophication necessitates a comprehensive evaluation of all pertinent attributes within a catchment for effective forward planning, goal setting and intervention planning. It is crucial not only to look inward at the dynamics at play within individual catchments but also to consider potential external linkages between catchments. These linkages, such as inter-basin transfers or return-flow transfers, can impact trophic status in adjacent receiving catchments. Additionally, it is essential to recognise that municipal borders, as well as WMA and catchment boundaries may not always align perfectly, leading to the need for collaboration [208] and management coordination when addressing eutrophication causes and effects across different political and management areas.

While not explicitly mentioned above, the interaction between groundwater and surface water resources is a critical consideration in resource-directed eutrophication management. Good-quality groundwater and interflow play a significant role in supporting base flow and the assimilative capacity of many surface-freshwater systems. Additionally, hydrogeological regions and catchment boundaries often do not align, linking different catchments through underground pathways. The presence of extensive opencast or underground mining, for instance, can exacerbate pollution in receiving catchments.

On a national scale, decision-makers need to understand that anthropogenic eutrophication and the emergence of hypertrophic conditions in many impoundments cannot be sustained.

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[208] Refer to **Section 6.5.3**: Collaboration and management participation.

Socio-economic development and related policy and strategy must align with the protection of the country's water resources and ecological infrastructure. Efforts should be made to elevate eutrophication management and water resource protection to the same level as other national priorities like economic growth, poverty eradication and rural development. This alignment is crucial to integrate water resource management into the national economy, acknowledging water's pivotal role in meeting human needs, ensuring food security, alleviating poverty and maintaining ecosystems.

6.3.2.4 Temporal scale of implementation

The DWS has made significant strides in establishing RDMs across the nation, beginning with priority WMAs. Furthermore, RWQOs and WQPLs, in support of resource-directed management, are now becoming available in many sub-catchments. The next crucial step is to fully operationalise the Receiving Water Quality Objectives Approach[209] to ameliorate the trophic conditions in eutrophic waterbodies by employing suitable Source-Directed Measures and Controls.

To support the resource-directed management of eutrophication, several concrete actions have been outlined in **TABLE 29**. These actions are primarily strategic in nature, designed to guide the long-term direction and policy framework for effective eutrophication management. For more immediate and practical implementation, actions of a more operational character can be found in **Section 6.4**.

TABLE 29: Strategic actions to strengthen the resource-directed management of eutrophication.

	SHORT TERM
(1)	Operationalise the Receiving Water Quality Objectives Approach and achieve compliance to the requirements of the MCs (and RQOs/ Reserves) and/or supporting RWQOs/ WQPLs. Better integration between source and resource-directed management is essential;
(2)	Gazette regulations to protect high yield water source areas, particularly the strategic water source areas (*i.e.,* strategic surface water source and critical groundwater recharge areas); and
(3)	In cases where regulations or compulsory national standards were made or were prescribed in terms of the NWA (36:1998) or the WSA (108:1997), evaluation can be considered of the suitability and/or effectiveness of those measures that deal with the protection of water resources against anthropogenic eutrophication – specifically also their suitability to assist with realising the eutrophication management goal. In cases where the enabling legislation allows for the making of regulations that could assist with the protections of water resources against the effects of anthropogenic eutrophication, but such regulations do not exist, consideration must be given to the development and publication of such regulations.
(4)	Support SDG 6.3.2D and internalise reporting on the fitness-for-use of South Africa's water resources.

[209] Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.

6.3.3 Remediation-directed management

6.3.3.1 Authority

Remedial action targeting the management of eutrophication concentrates on residual sources of pollution that contribute to excessive nutrient enrichment in water resources, as well as addressing areas of land and water that are degraded, impaired or contaminated. Such actions are typically governed by a range of regulatory requirements and, in scenarios where there are no legislated standards or where standards are merely advisory, may also be guided by assessments of human health and ecological risk factors. Beyond the DWS, remedial actions to tackle these challenges can also be mandated by other authorities, necessitating a collaborative approach across various sectors and regulatory bodies[210] to effectively manage and mitigate eutrophication impacts.

Sectors with relevant competencies, where requirements for remediation to protect water resources and aquatic ecosystems may exist, include: ♦ agriculture; ♦ the environment; ♦ mining; and ♦ water and sanitation. The roles of competent authorities are outlined in **Section 6.6** under ***"Governance responsibilities"***, which provides additional clarity on the allocation of tasks concerning eutrophication governance.

6.3.3.2 Prescribed approach

Currently, without a dedicated strategy for contaminant removal from soil, surface water, groundwater and sediment, which may aggravate eutrophic conditions in receiving waters, existing regulatory instruments not specifically designed for remediation are applied. This practice has led to inadequate and inconsistent handling of legacy water pollution cases. Enhancing the focus on remediation-directed management would improve regulatory capabilities to match those related to source- and resource-directed eutrophication management. Consideration should be given to amending the NWA (36:1998) to enforce financial provisioning for post facto remedial activities.[211]

The accumulated stores of phosphorus (P) and nitrogen (N) in catchments could continue to fuel algal blooms and hypertrophic conditions for decades, indicating a need for innovative solutions to reduce and recover these nutrients. The impact of agriculture on eutrophication may be overestimated in some areas, and a more accurate accounting[212] of nutrient sources, their bioavailability and lag times is crucial for directing effective mitigation efforts

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[210] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

[211] Refer to **Annexure H** for a list of all recommended legislative amendments.

[212] Refer to **Section 6.4.1.2.2, [B]**: Waste load accounting**.**

[Withers, *et al.*, 2014:5855]. Efficient use of P and N across all sectors of society is necessary for developing long-term sustainable solutions, with nutrient reduction strategies considering the full catchment-to-coast continuum. However, local interventions will need to be precisely tailored and supported by research[213] that explores sustainable practices, nutrient delivery patterns, biological responses[214] and recovery trajectories across different waterbody types.[215]

To ensure sustainable water resource use, protection and fitness-for-use, steps must be taken to address or mitigate residual pollution sources and restore degraded water resources and ecosystems at a pace that matches or exceeds their rate of contamination and degradation.

The Polluter Pays Principle[216] will be enforced for cleaning up legacy pollution cases, with state-financed and implemented remediation efforts continuing in instances deemed state responsibility. Remedial actions will be assessed and implemented on a case-by-case basis, reflecting relative risk levels[217] and assigned priorities. In situations where remedial measures are associated with ongoing land or water use activities, it is crucial to ensure that suitable Source-Directed Measures and Controls are already in place before starting remediation efforts.

6.3.3.3 Spatial scale of implementation

Remediation measures and controls for managing eutrophication are targeted locally on legacy sources of excessive nutrient loading or on specific impaired surface and groundwater resources and their ecosystems. When multiple sources or resources require attention, remedial actions may adopt a regional or catchment-wide approach. Therefore, remediation efforts are emphasised not only at individual sites but also on a larger operational scale to understand cumulative effects. This involves actively supporting research into remediation techniques and integrating these efforts into regional planning strategies.[218]

6.3.3.4 Temporal scale of implementation

When specific remediation strategies are lacking to direct the management of eutrophication, existing regulatory instruments will be utilised to address situations necessitating remedial action. **TABLE 30** outlines essential actions required to accelerate the implementation of remediation-focused eutrophication management. The actions detailed in **TABLE 30** primarily encompass strategic initiatives aimed at propelling the advancement of remediation efforts. For

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[213] Refer to **Section 6.5.2**: Research and technology development to address eutrophication-related challenges.

[214] Refer to **Section 6.4.4.2.1, [D]**: The remediation of adversely affected water resources.

[215] Refer to **Section 6.4.1.2.4, [F]**: Establishment of geographic water quality management strategies and thematic plans.

[216] Refer to **POLICY STATEMENT 7**: Incentive-based regulation.

[217] Refer to **Section 6.4.2.2.2, [L],** Differentiated water use management based on risk.

[218] Refer to **Section 6.4.1:** The *"plan"* stage.

more practical, hands-on activities, operational actions can be found in **Section 6.4**, offering more detailed steps and tasks for effective implementation of remediation strategies.

TABLE 30: Strategic actions to strengthen the remediation-directed management of eutrophication.

SHORT-TERM	
(1)	Establish a *"Remediation Working Group"* to initiate the development of the necessary instruments and to guide remedial activities;
(2)	Develop and implement a dedicated Remediation Strategy for South Africa to guide the removal of contaminants from, amongst others, soil, surface water, groundwater and sediment, which may also exacerbate eutrophic conditions in receiving water resources;
(3)	Investigate the implementation of financial provision, in conjunction with the WDCS, to cover the cost of remedial action;
(4)	Develop a risk-based approach to prioritise remedial action;
(5)	Investigate and develop desired remediation *"clean-up levels"* or *"targets"* that support the statutory RDMs. All eutrophication concerns must be suitably addressed by any remedial action to be taken;
(6)	Develop rule-based best management practice measures to inform remedial action; and
(7)	In cases where regulations or compulsory national standards were made or were prescribed in terms of the NWA (36:1998) or the WSA (108:1997), it can be considered to evaluate the suitability and/or effectiveness of those measures that potentially deal with any remedial actions that relate to anthropogenic eutrophication – specifically also their suitability to assist with realising the eutrophication management goal. In cases where the enabling legislation allows for the making of regulations that could potentially assist with the management of anthropogenic eutrophication through remedial action, but such regulations do not exist, consideration must be given to the development and publication of such regulations.
LONGER TERM	
(8)	Develop and implement a programme to remediate priority impoundments and water resources, like the Hartbeespoort Dam, aligned with relevant geographic water quality management strategies and thematic plans, utilising revenue from the WDCS. Consider lessons learned from the Harties-Metsi-A-Me project.

6.4 OPERATIONAL STRATEGIES

Given that the operational strategies cannot be neatly categorised in a hierarchical manner under the three core strategies and are often common across more than one core strategies, they have been organised within the internationally recognised Shewhart-Deming or PDCA Cycle [Moen & Norman, 2009:1.10]. PDCA, which stands for *"**P**lan-**D**o-**C**heck-**A**ct"*, serves as a generic management framework emphasising continuous improvement through practical implementation and learning-by-doing.[219]

[219] The PDCA Cycle is handy for describing the nature of water quality management [Van Wyk, et al., 2003]. For easy reference purposes, all the operational strategies for the management of eutrophication are also presented within the context of the PDCA Cycle.

FIGURE 78 presents a conceptual framework for the operational management of eutrophication in South Africa, illustrating how these strategies are structured within the PDCA Cycle to ensure effective and iterative management practices aimed at addressing eutrophication challenges.[220]

The operational eutrophication governance strategies serve a dual purpose, namely to–

(1) complement the core strategies for eutrophication management; and

(2) provide additional and operational resolution on the four stages within the eutrophication management framework.

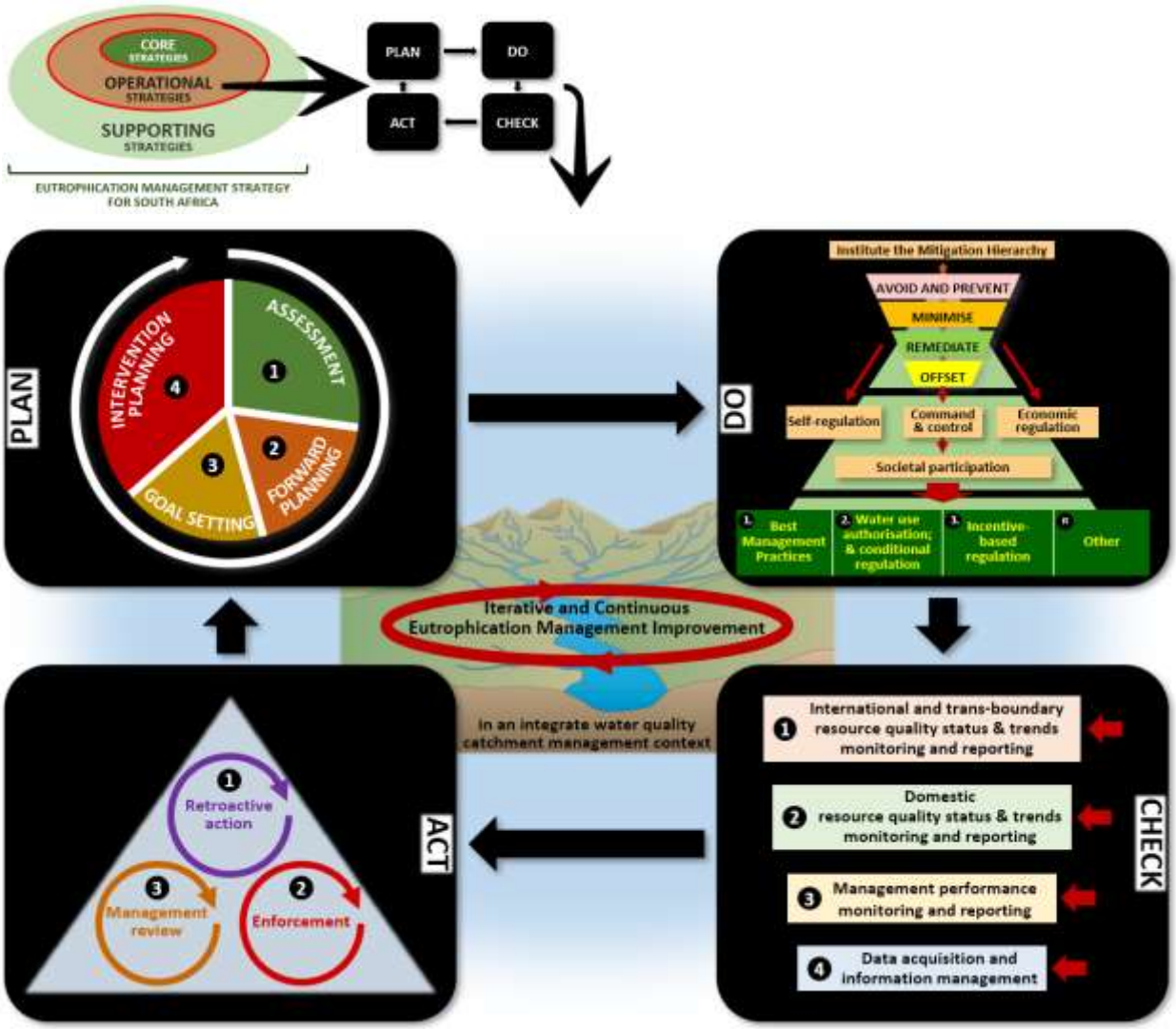

FIGURE 78: Framework with operational strategies for the management of eutrophication.

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[220] While it is recognised that the operational strategies within this framework for eutrophication management can also be viewed through a *"**P**lan-**D**o-**C**heck-**A**ct"* lens, where individual activities like *"Domestic status and trends monitoring and reporting"*, for instance, are also planned, implemented, verified for effectiveness and improved if necessary, the focus in **Section 6.4** of this document is on the overall management of eutrophication rather than solely on managing individual operational strategies.

6.4.1 The *"plan"* stage

Altogether, the *"plan"* stage in the eutrophication management framework should encompass the following key actions:

- Engage stakeholders, gather input and establish common ground to ensure buy-in and collaboration;
- Collect relevant catchment information essential for the effective management of eutrophication;
- Reduce uncertainties and gather vital eutrophication management intelligence to facilitate informed decision-making;
- Proactively identify challenges, leverage strengths and capitalise on opportunities;
- Make informed projections about future scenarios to prepare for potential management outcomes;
- Define clear objectives and endpoints, outlining the necessary steps to achieve desired results;
- Develop coherent strategies and plans that account for the specific dynamics of relevant catchments;
- Coordinate actions across sectors if needed to avoid reactive responses and align efforts towards holistic eutrophication management;
- Foster responsibility and accountability among stakeholders and role-players;
- Allocate limited resources, including financial, human capital, time and equipment, effectively to implement strategies, plans and achieve set goals; and
- Regularly assess and evaluate progress in implementation according to predetermined procedures to support an adaptive management approach effectively.

Addressing eutrophication in South Africa is a crucial process that is supported by a well-defined framework for water quality planning. This framework is illustrated in a simplified diagram in **FIGURE 79**, showcasing a planning cycle that comprises four consecutive key operational strategies, *viz.*: **(1) *"Assessment"***; **(2) *"Forward planning"***; **(3) *"Goal setting"***; and **(4) *"Intervention planning"***. While the chronology of individual operational strategies and their components in the Cycle are illustrated, the linkages that exist between these operational strategies and their components are not explicitly depicted. However, iterative linkages between these components are described in more detail in **Section 6.4.1.2** below. The connections between the individual components are highlighted through footnotes, providing cross-references to related components. This approach aims to enhance clarity and facilitate a comprehensive understanding of the planning cycle and the interrelationships between its various elements.

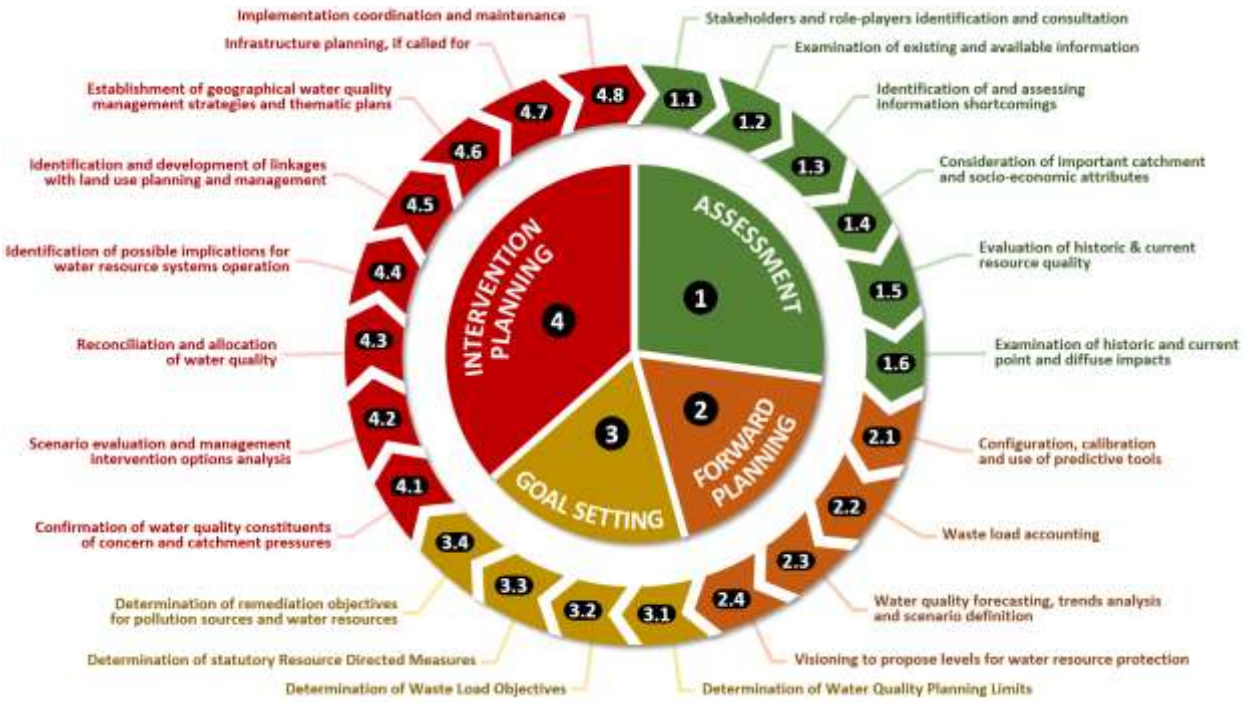

FIGURE 79: Planning for eutrophication management.

The four operational strategies [adapted from DWAF, 2003a:15], that form the ***"plan"* stage** in the eutrophication management framework, along with their purposes and composition, are outlined in **TABLE 31** below for easy reference purposes:

TABLE 31: The operational strategies in the *"plan"* stage of the eutrophication management framework, and their composition.

OPERATIONAL STRATEGIES AND PURPOSE		KEY COMPONENT(S)
(1) Assessment	*To describe and understand the catchment, or geographical area, and the water resources, under investigation.*	**[A]** Stakeholders and role-player identification and consultation;
		[B] Examination of existing and available information;
		[C] Identification of, and assessing information shortcomings;
		[D] Consideration of important catchment and socio-economic attributes;
		[E] Evaluation of the historic and current resource quality; and
		[F] Examination of historic and current point and diffuse impacts.
(2) Forward planning	*To support decision-making by adding value to the assessment.*	**[A]** Configuration, calibration and use of predictive tools;
		[B] Waste load accounting;
		[C] Water quality forecasting, trends analysis and scenario definition; and
		[D] Visioning to propose levels for water resource protection.

OPERATIONAL STRATEGIES AND PURPOSE		KEY COMPONENT(S)
(3) Goal setting	*To define desired outcomes, based on information from the assessment and forward planning.*	**[A]** Determination of Resource Water Quality Objectives or Water Quality Planning Limits;
		[B] Determination of Waste Load Objectives;
		[C] Determination of statutory Resource-Directed Measures; and
		[D] Determination of remediation objectives for pollution sources and water resources.
(4) Intervention planning	*To devise detailed approaches to realise the desired outcomes.*	**[A]** Confirmation of the water quality constituents of concern and catchment pressures;
		[B] Scenario evaluation and management intervention options analysis;
		[C] Reconciliation and allocation of water quality;
		[D] Identification of possible implications for water resource systems operation;
		[E] Identification and development of linkages with land use planning and management;
		[F] Establishment of geographic water quality management strategies and thematic plans;
		[G] Infrastructure planning; and
		[H] Implementation coordination and maintenance.

6.4.1.1 Authority

During the *"plan"* stage of eutrophication management, in addition to the DWS, several other key authorities can significantly impact the trophic status of receiving waterbodies. Authorities outside the water sector, particularly those involved in land use development planning and management, should be mindful of the consequences of their decisions on eutrophication.[221] Competencies (sectors), which are relevant here, include: ♦ the environment; ♦ health; ♦ land use and development planning; and ♦ water and sanitation. The roles of competent authorities are outlined in **Section 6.6** under ***"Governance responsibilities"***, which provides additional clarity on the allocation of tasks concerning eutrophication governance.

6.4.1.2 Prescribed approaches

6.4.1.2.1 Assessment

The intricacies and uncertainties involved in land use and water resource management, particularly in managing eutrophication, underscore the necessity for a comprehensive understanding of processes and issues. This emphasises the importance of developing

[221] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

knowledge systems that can effectively inform the establishment of water resource goals, planning, management and remediation approaches.

As the first operational strategy within the *"plan"* stage of the eutrophication management framework, **catchment assessment**[222] involves collecting, analysing and interpreting data and information pertaining to water-related conditions, issues and trends within a catchment context. This assessment aims to offer insights into the past and present status of the designated catchments, inclusive of data and information crucial for informed decision-making in eutrophication planning and management. The components and purposes of catchment assessment, as adapted from DWAF (2003a:20), are outlined in **sections [A]** to **[F]**, below:

[A] Stakeholders and role-player identification and consultation

It is essential to identify catchment stakeholders and key role-players, relevant institutional arrangements and linkages to assist with consultative processes,[223] information gathering and management participation.[224]

Understanding and acknowledging individuals and institutions interested in eutrophication management issues is crucial to ensure their involvement and input. Local expertise on eutrophication should be tapped into to supplement existing information and knowledge where needed.[225]

The trophic status of receiving waterbodies is intricately tied to land use and physical developments in catchments that can lead to excessive nutrient loading during the terrestrial phase of the hydrological cycle. Oversight of many of these land uses and developments falls outside the statutory domain of the NWA (36:1998), with other laws and authorities beyond the DWS or Water Management Institutions having jurisdiction. Given this decentralised landscape, it is imperative to comprehend and effectively utilise the relevant institutional arrangements and linkages to support the goal, objectives and policy imperatives of eutrophication management, fostering collaboration and cooperation among various stakeholders and authorities.

[B] Examination of existing and available information

In many cases, long-term residents of a catchment area, as well as government officials and professionals involved in water-related affairs within that catchment, possess valuable experience-based insights into the functioning of certain parts of the catchment.[226] Similarly, the

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[222] Refer to **POLICY STATEMENT 14**: Water resource assessment and planning to inform decision-making.
[223] Refer to **POLICY STATEMENT 17**: Transparency.
[224] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.
[225] Refer to **POLICY STATEMENT 4**: The application of the Precautionary Principle.
[226] Refer to **Section 6.4.1.2.1, [A]**: Stakeholders and role-player identification and consultation.

existence of water-related issues and problems is often common knowledge and/or particular water-related studies have historically been conducted in the catchment(s) under consideration.[227] Relevant sources of existing information must be identified, acquired and considered to prevent undue duplication of effort and to utilise scarce government resources judiciously.

[C] Identification of, and assessing information shortcomings

To address any gaps in information related to eutrophication effectively, it is critical to consider conducting additional field surveys and investigations. This approach might involve undertaking more *"snapshot"* sampling campaigns[228] to support the assessment of the catchment. Employing technology tools, such as remote sensing, for evaluating the impact of eutrophication on resource quality [Matthews & Bernard, 2015:1], represents a valuable approach for enhancing the availability of historic and current resource quality data and information.[229] Furthermore, using modelling and data gap infilling techniques to generate extrapolated data and information, albeit not at the same confidence level as actual data, can be considered.[230]

Having sufficient and relevant data is essential to informed forward planning, goal setting and developing effective intervention strategies. A lack of adequate data and information can undermine the confidence in planning outcomes. Therefore, appropriate monitoring, analysis and data management practices[231] are crucial for the successful management of eutrophication.

[D] Consideration of important catchment and socio-economic attributes

In considering the management of eutrophication within a particular catchment, it is crucial to account for a wide range of natural and human-induced factors, their interconnections and the accompanying socio-economic characteristics. These aspects, as summarised in **TABLE 32**, can encompass, but are not limited to, the following categories, which may overlap or not cover all possible attributes entirely:

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[227] Refer to **Section 6.4.1.2.4, [A]**: Confirmation of the water quality constituents of concern and catchment pressures.

[228] Refers to once-off sampling run(s), *e.g.,* once under low-flow and once under high-flow conditions to augment currently available data and information.

[229] Refer to **Section 6.4.1.2.1, [E]**: Evaluation of the historic and current resource quality.

[230] Refer to **Section 6.4.1.2.2, [A]**: Configuration, calibration and use of predictive tools.

[231] Refer to **Section 6.4.3.2.4**: Data acquisition and information management.

TABLE 32: Catchment and socio-economic attributes to be considered during catchments assessment.	
WATER RESOURCE SYSTEM ATTRIBUTES	
▶ **River system details:**	This includes information on main stem and tributary channel locations, names and characteristics, along with spatial data on catchments and sub-catchments, including various levels of drainage regions and estuary details, if applicable.
▶ **Groundwater details:**	Locations, boundaries and aquifer characteristics.
▶ **Water use information:**	Identification of water uses that could potentially worsen the trophic status of receiving water resources, through data from Water use Authorisation and Registration Management System (WARMS) or Validation and Verification (V&V) studies related for waste and water containing waste related- water uses.[232]
▶ **Water infrastructure information:**	Details on dams, reservoirs, irrigation and water transfer schemes, and water and WwTWs.
▶ **Resource quality monitoring information:**	Information on monitoring stations for surface and groundwater, effluents, water quality, river health and flow.[233]
▶ **Weather monitoring and climate information:**	Data from rainfall, weather and evaporation stations, including rainfall, runoff and evaporation data.
▶ **Existing resource objectives:**	Currently established MCs (RQOs/Reserves), supporting RWQOs/WQPLs and remediation objectives for consideration during goal setting.[234]
▶ **Existing water management strategies and plans:**	Documents such, as the NWRS, NW&S MP, CMSs and WSDPs, must be sourced, *inter alia* for further consideration during geographical water quality management strategy and thematic plan establishment.
▶ **Transboundary requirements or obligations:**	International obligations relevant to eutrophication management must be identified and examined.
BIO-PHYSICAL ATTRIBUTES	
▶ **Natural features:**	Geology, soil types, topography, vegetation, wetlands and areas prone to erosion and sediment production.
▶ **Areas and ecological infrastructure that must be protected:**	Nature reserves, indigenous vegetation areas, NFEPAs, strategic water source areas,[235] Ramsar Wetlands, buffer zones, etc.[236]
DEMOGRAPHIC ATTRIBUTES	
▶ **Population statistics:**	Size, structure and changes in population numbers that are necessary to analyse and predict socio-economic trends, water demand and water quality impacts.

[232] Refer to **Section 6.4.1.2.1, [F]**: Examination of historic and current point and diffuse impacts.

[233] Refer to **Section 6.4.1.2.1, [E]**: Evaluation of the historic and current resource quality.

[234] Refer to **Section 6.4.1.2.3**: Goal setting.

[235] Refer to **Section 6.4.1.2.2, [D]**: Visioning to propose levels for water resource protection.

[236] Refer to **POLICY STATEMENT 8**: Nature-based solutions.

SOCIO-POLITICAL AND DEVELOPMENTAL ATTRIBUTES	
▶ **Socio-economic profiles:**	Types and extent of economic outputs per management unit in terms of absolute values, as well as proportions of Gross Domestic Product (GDP), Gross National Product (GNP) and *per capita* data. Understanding the socio-economic dynamics is critical for scenario analysis, such as through Cost Benefit Analyses.[237]
▶ **Areas, jurisdictions and boundaries:**	WMAs and relevant Water Management Institutions, such as CMAs, municipal areas and relevant Water Services Institutions, such as WSAs, along with others relating to the municipal, provincial, national and transboundary scales.[238]
▶ **Other infrastructure details:**	Location of major roads, railway lines.
LAND USE ATTRIBUTES	
▶ **Land use information:**	Types of human settlements, commercial and industrial areas, irrigation activities, plantations, agriculture, mining activities, waste disposal sites.[239]
▶ **Other strategies, plans, etc.:**	Provincial growth strategies, IDPs, Environmental Management Frameworks (EMFs), and others relevant to land use coordination and eutrophication management must be sourced, *inter alia* for further consideration during the identification and development of linkages with land use management.[240]

[E] Evaluation of the historic and current resource quality

Evaluating the historical and *status quo* resource quality statuses – encompassing water quantity, water quality and the integrity of aquatic ecosystems – is critical for supporting well-informed decision-making in eutrophication management on a catchment basis. To achieve a comprehensive understanding, it is essential to source reliable data,[241] which can be analysed to provide–

- an overview of the health of aquatic ecosystems, water quality and flow within the catchment;
- insights into the residual effects on water resources and associated aquatic ecosystems resulting from historical nutrient loading;
- identification of any significant spatial trends; and
- detection of any noteworthy temporal trends that may raise concerns.

Prior to goal setting,[242] the South African Water Quality Guidelines can be utilised as benchmark when evaluating historic and current water quality data and information. This review will help

[237] Refer to **Section 6.4.1.2.4, [B]**: Scenario evaluation and management intervention options analysis.

[238] Refer to **Section 6.4.1.2.1, [A]**: Stakeholders and role-player identification and consultation.

[239] Refer to **Section 6.4.1.2.1, [F]**: Examination of historic and current point and diffuse impacts.

[240] Refer to **Section 6.4.1.2.4, [D]**: Identification and development of linkages with land use planning and management.

[241] The Water Management System (WMS), maintained by Resource Quality Information Services (RQIS) of the Department of Water and Sanitation (DWS) constitutes an important source of water quality data and information.

[242] Refer to **Section 6.4.1.2.3**: Goal setting.

develop a preliminary understanding of the critical pollutants and determine the suitability of water resources for various user groups.

[F] Examination of historic and current point and diffuse impacts

Point sources of nutrient pollution are typically easier to quantify than diffuse sources. Authorised discharges are generally subject to conditions requiring regular effluent sampling and flow rate monitoring. However, unlawful water use does occur. Therefore, assessing point sources not only involves analysing effluent records but also examining streamflow water quality data[243] to detect unknown contaminant loadings, indicating unlawful discharges. V&V studies may be required to identify and confirm all waste and water containing waste-related water uses within relevant catchments.

Diffuse sources of nutrient loading arise from various land uses and activities that mobilise contaminants through surface runoff or groundwater seeps. In South Africa, this is primarily driven by rainfall, leading *inter alia* to urban and agricultural runoff contamination. These sources are often intermittent, covering large areas like storm runoff or concentrated near specific sites such as mines, feedlots and industrial zones. While surface runoff impacts are immediate, groundwater discharge effects are delayed due to the time required for contaminants to travel through the soil profile to surface waterbodies.

Identifying and quantifying diffuse sources often involves scrutinising streamflow water quality records[243] to identify unknown contaminant loadings, indicating diffuse impacts. Quantification largely relies on predictive tools[244] and confirmation through waste load accounting.[245] The essential information to be collected or generated includes:

- A summary table detailing general information on both point and diffuse sources, including locations, types, the primary activities involved, and identities, positions and contact details of the accountable persons, etc.;
- Databases documenting historical annual and/or monthly time series of waste and water containing waste disposal or discharge volumes and nutrient concentrations;
- Historical data on diffuse waste loads associated with water uses, quantified through predictive tools and waste load accounting; and
- Information on legacy point and diffuse nutrient sources.

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[243] Refer to **Section 6.4.1.2.1, [E]**: Evaluation of the historic and current resource quality.
[244] Refer to **Section 6.4.1.2.2, [A]**: Configuration, calibration and use of predictive tools.
[245] Refer to **Section 6.4.1.2.2, [B]**: Waste load accounting.

6.4.1.2.2 Forward planning

This next operational strategy within the *"plan"* stage of the eutrophication management framework utilises the data and information that were produced during the assessment to identify possible permutations of alternative future realities and to evaluate likely outcomes. Forward planning[246] must provide statements on the expected and recommended future statuses of the catchment in question. The components of **forward planning** and their purposes [adapted from DWAF, 2003a:15] are outlined in **sections [A]** to **[D]**, below:

[A] Configuration, calibration and use of predictive tools

The configuration and calibration of water quality predictive tools necessitate crucial land and water use data as fundamental inputs.[247] Beyond contemporary data, historical land and water use trends, with reasonably reliable records of both point and diffuse nutrient sources alongside their respective constituent loadings, are imperative for accurate calibration of these predictive tools over an adequately representative time span and within a predetermined margin of acceptable error. The application of predictive tools plays a crucial role in water quality-focused forward planning, as exemplified below:

- Modelling the impact of **point sources** of nutrient loading on water resources, including estimating the mixing zone, will assist in determining both the allocatable water quality and appropriate WDSs;
- Once the input from point sources of nutrient loading on streamflow and groundwater is determined, any remaining excessive nutrient loading observed from monitoring data must stem from **diffuse sources**.[248] Quantification of these diffuse nutrient sources remains essential, as their nature precludes direct measurement. Consequently, a key aspect of modelling support crucial for eutrophication-focused forward planning pertains to assessing the impacts of diffuse sources;
- Effective management decisions hinge on the ability to **forecast combinations of streamflow and water quality** across various river reaches and scenarios[249] of land and water use within the catchment. An array of predictive methods is available to address management queries cantered on eutrophication, ranging from process-based catchment models and rule-based methods to simpler regression-based formulas;

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[246] Refer to **POLICY STATEMENT 14**: Water resource assessment and planning to inform decision-making.
[247] Refer to **Section 6.4.1.2.1, [D]**: Consideration of important catchment and socio-economic attributes.
[248] Refer to **Section 6.4.1.2.2, [B]**: Waste load accounting.
[249] Refer to **Section 6.4.1.2.2, [C]**: Water quality forecasting, trends analysis and scenario definition.

- Models are also invaluable for predicting outcomes resulting from **different operational rules** for existing or proposed river-reservoir systems over extended periods;[250]
- The substantial year-to-year variability in rainfall and streamflow in South Africa underscores the need for a comprehensive assessment of surface water availability and water quality patterns. The inherent limitations of water quality databases in terms of duration and spatial representation can be mitigated using mathematical predictive tools. Catchment modelling, driven by long rainfall sequences, offers a practical approach to **infill, extend or supplement streamflow and surface water quality time series synthetically**,[251] capturing temporal and spatial variability more effectively. Alternatively, simple empirical predictive tools driven by statistical streamflow sequences or heuristic land-use interpretations can estimate long-term statistics of specific eutrophication-related constituents of concern;[252] and
- RWQOs/ WQPLs and RDMs strike an economic balance between water user and ecological water quality requirements on one hand, and the costs associated with mitigation measures to achieve these objectives on the other. Future scenarios[253] are typically **evaluated on a cost-benefit basis** by utilising predictive tools to compare the economic dis-benefit stemming from water quality received by water users against the cost of implementing specific management options.

[B] Waste load accounting

Nutrient load accounting must be utilised for balancing input and output specific constituent loads and for creating nutrient load budgets for sub-catchments and catchments under consideration.

Point source nutrient loads and nutrients from diffuse sources, which are collected and discharged through identifiable conveyances like irrigation and urban stormwater return flows, are relatively straightforward to quantify. However, the remaining portion of diffuse nutrient contributions that cannot be directly measured often necessitates the use of predictive tools.[254] It is crucial to incorporate the impacts of both legacy point and diffuse nutrient sources of pollution in the nutrient load budgets of catchments.

Establishing nutrient load accounts for the sub-catchments and catchments in question will provide the foundation for reconciling and allocating water quality[255] once the required in-water

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[250] Refer to **Section 6.4.1.2.4, [E]**: Identification of possible implications for water resource systems operation.
[251] Refer to **Section 6.4.1.2.1, [C]**: Identification of, and assessing information shortcomings.
[252] Refer to **Section 6.4.1.2.1, [E]**: Evaluation of the historic and current resource quality.
[253] Refer to **Section 6.4.1.2.4, [B]**: Scenario evaluation and management intervention options analysis.
[254] Refer to **Section 6.4.1.2.2, [A]**: Configuration, calibration and use of predictive tools.
[255] Refer to **Section 6.4.1.2.4, [C]**: Reconciliation and allocation of water quality.

resource water quality objectives and associated Nutrient Load Objectives (NLOs)[256] have been determined.

[C] Water quality forecasting, trends analysis and scenario definition

To predict future eutrophication-related pressures on water quality, it is essential to conduct water quality forecasting and trend analysis. Spatial and temporal distributions of nutrient concentrations and loads need to be examined to proactively identify areas of concern. It is important to analyse time series data over an appropriate period, ideally longer than five years, particularly if there is significant seasonality present. Seasonality manifests when certain parts of the year consistently yield higher or lower values compared to others.

Effective water quality foresight relies on nutrient modelling [257] and evaluating various eutrophication management and developmental scenarios.

During scenario definition and construction, it is crucial to generate a comprehensive list of all potential eutrophication management and developmental scenarios. A preliminary screening process should be conducted to eliminate non-feasible scenarios with fatal flaws. This process involves considering options such as the reuse and recycling of nutrient-rich waste and water containing waste return flows as mechanisms to address eutrophication concerns.

The identified scenarios can only be evaluated after goal setting, as scenario evaluation and the analysis of management options [258] are intricately linked and reliant on the management objectives established through goal setting.[256]

[D] Visioning to propose levels for water resource protection

Visioning is forward-looking and aspirational, serving as a crucial link between forward planning and goal setting. In the absence of water resource classification, visioning becomes essential to establish desired levels of water resource protection, guiding the determination of RWQOs or WQPLs,[259] and RQOs. Additionally, the vision proposes the direction of change from the *status quo* that is necessary or that can be justified. During the classification of water resources, visioning is inherently part of the classification process.[260]

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[256] Refer to **Section 6.4.1.2.3**: Goal setting.

[257] Refer to **Section 6.4.1.2.2, [A]**: Configuration, calibration and use of predictive tools.

[258] Refer to **Section 6.4.1.2.4, [B]**: Scenario evaluation and management intervention options analysis.

[259] Common narrative descriptions used to assess the fitness of water resources for various uses include *"ideal"*, *"acceptable"*, *"tolerable"*, and *"unacceptable"*. In the context of visioning, it is crucial to connect the necessity of safeguarding water resources to the first three levels, *viz.*, *"ideal"*, *"acceptable"* or *"tolerable"*. Water quality categorised as *"unacceptable"* does not align with ecologically sustainable development and should not be considered as a viable option.

[260] Refer to **Section 6.4.1.2.3, [C]**: Determination of statutory Resource-Directed Measures.

Water use needs, user requirements and water resource quality are dynamic across both space and time. Visioning provides the mechanism within which this dynamic variability can be aligned towards an agreed sustainable future in a catchment context (**FIGURE 80**) [DWAF, 2006c:2].

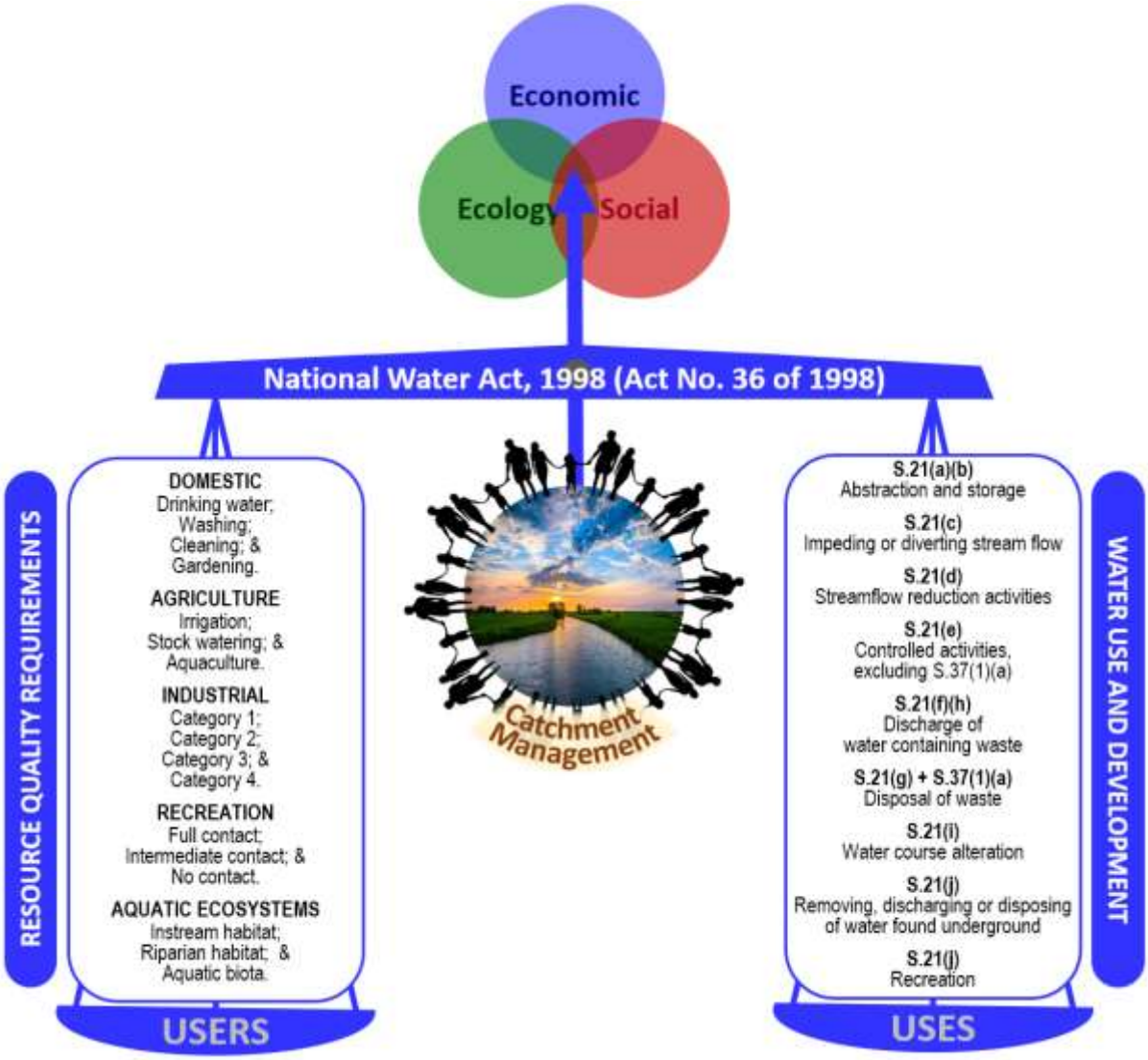

FIGURE 80: Balancing water resource protection with water resource use and development [Van Wyk, *et al.*, 2003:7].

The catchment vision considers the existing trophic status of water resources and the potential for enhancing trophic conditions. This may lead to an idealistic vision of the desired trophic status, requiring a balance between this vision and the impacts of anthropogenic land use activities on eutrophication. It is crucial to recognise that most water use activities result in either point source and/or diffuse source pollution. This realisation leads to accepting the necessity of utilising water resources for waste disposal or discharging water containing waste (including its diffuse forms), thereby shaping more realistic water quality requirements.

6.4.1.2.3 Goal setting

The next operational strategy within the *"plan"* stage focuses on **goals** as inherent building blocks of any management process, a principle that is equally valid for eutrophication management. The goals outlined within the eutrophication management framework guide management actions and efforts during the *"Do"* stage and serve as ultimate benchmarks for monitoring implementation progress and success during the *"Check"* stage. In instances where goals are not achieved, they prompt corrective actions during the *"Act"* stage.

The goals commonly associated with eutrophication management typically include the following:

- RWQOs or WQPLs;
- NLOs, as a type of Waste Load Objective;
- Gazetted RDMs, *i.e.,* MCs (and RQOs/ Reserves);[261]
- Remediation objectives; and
- Any other complementary management goals.

These goals can be established in any order, with no predefined sequence. However, the gazetted goals, namely the MCs and RQOs/Reserves, established based on the Water Resource Classification System (WRCS), set the tone, and other goals should align with these gazetted goals. In scenarios where statutory RDMs have yet to be determined and gazetted, but other goals are in place, these existing goals will inform the determination of statutory RDMs, when commissioned in future. The components of goal setting in eutrophication management and their purposes are outlined in **sections [A]** to **[D]**, below:

[A] Determination of Resource Water Quality Objectives or Water Quality Planning Limits

The management of catchment areas involves determining *"Resource Water Quality Objectives"* (RWQOs), by the CMA, or in its absence the proto-CMA, and *"Water Quality Planning Limits"* (WQPLs) by the DWS. These objectives, narrative or numeric, aim to maintain or improve water quality within discrete water management units, *i.e.*, sub-catchment areas delineated by considering catchment and socio-economic attributes.[262] RWQOs and WQPLs often have finer

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[261] Collectively, when referring to the water quality components of RQOs and to either the RWQOs or WQPLs, reference is sometimes made to *"in water resource water quality objective"*, or *"in stream water quality objective"* for surface water and *"in aquifer water quality objectives"* for groundwater.

[262] Refer to **Section 6.4.1.2.1, [D]**: Consideration of important catchment and socio-economic attributes.

spatial or temporal resolution compared to statutory RQOs, ensuring more frequent monitoring and closer spatial analysis.

Managing eutrophication is complex due to the interdependence of water quantity, aquatic ecosystems and the trophic status of water bodies, linked by intricate biological, physical and chemical processes. Catchment water quality continuously evolves, influenced by waste disposal, effluent discharge, flow dynamics, estuarine interactions with tides and nutrient assimilation affected by water abstractions and impoundments.

Establishing RWQOs and WQPLs is crucial for eutrophication management, gaining stakeholder support and setting clear goals for technical, allocation[263] and planning[264] processes. This process involves assessing pollution sources and water use within the catchment.[265] This iterative process starts with a benchmark against the South African Water Quality Guidelines,[266] culminating in objectives tailored to instream and aquifer conditions.[263] It emphasises the parallel progress of catchment assessments and objective formulation.

RWQOs and WQPLs influence both upstream and downstream water use, aiming for a balance that protects downstream water users and ecological infrastructure while permitting upstream water use and development (**FIGURE 81**). These objectives support water quality management strategies for eutrophication and other concerns and must ensure compliance with determined RQOs.

RWQOs and WQPLs are premised on avoiding water quality deterioration without well-supported reasons, improving water quality in degraded areas, meeting minimum ecological and other water user requirements and adhering to the strictest requirements among different water users. Where no specific requirements exist, a minimum *"Tolerable"* water quality level for ecosystems is implied. Through this structured approach, eutrophication management aims to harmonise water resource protection with use and development, fostering a sustainable relationship between water resources and societal needs [DWAF, 2006b:4].

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[263] Refer to **Section 6.4.1.2.4, [A]**: Confirmation of the water quality constituents of concern and catchment pressures.
[264] Refer to **Section 6.4.1.2.4, [F]**: Establishment of geographic water quality management strategies and thematic plans.
[265] Refer to **Section 6.4.1.2.1, [F]**: Examination of historic and current point and diffuse impacts.
[266] Refer to **Section 6.4.1.2.1, [E]**: Evaluation of the historic and current resource quality.

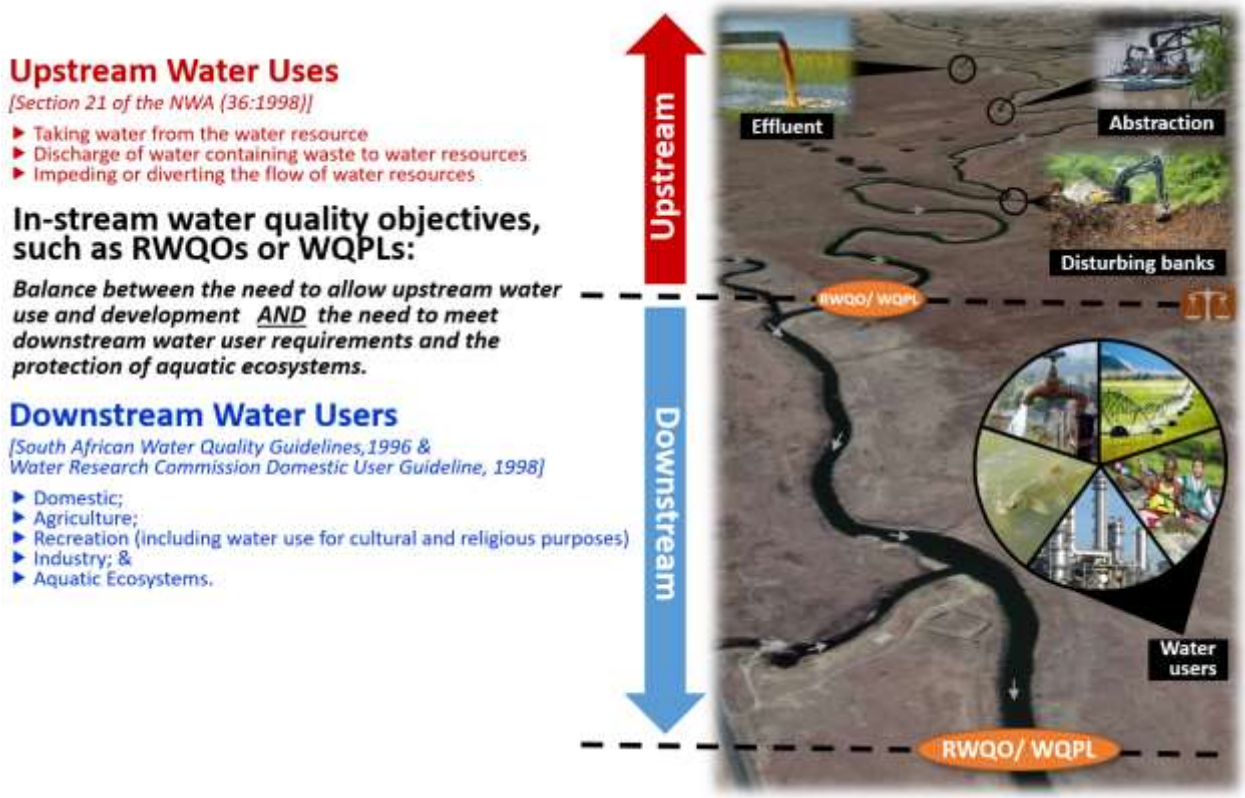

FIGURE 81: In-stream water quality objectives in support of sustainable development.

[B] Determination of Waste Load Objectives

Waste Load Objectives (WLOs) are crucial benchmarks set for specific water quality constituent that raise concern,[267] particularly focusing on phosphorus or nitrogen compounds identified as Nutrient Load Objectives (NLOs) in the case of eutrophication management. NLOs are established by finding a balance between the ideal nutrient load targets and the practicalities encompassing technical, economic and administrative capabilities to achieve these targets. Thus, NLOs expand upon the in-stream water quality objectives, such as RWQO, WQPL and/or RQO,[268] within a water management unit (**FIGURE 82**). They link to water quality allocation[269] and facilitate geographic water quality management strategies and plans.[270]

Furthermore, NLOs establish a framework for achieving incremental nutrient load targets – primarily in surface waters across different geographic scales up to the WMA level. They focus on predefined objectives that outline necessary actions – but not specifics of who or how, which

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[267] Refer to **Section 6.4.1.2.4, [A]**: Confirmation of the water quality constituents of concern and catchment pressures.

[268] Although NLOs can be conservative in nature, or take account of multiple factors, such as seasonality, it is imperative that the NLOs give effect to the relevant in-stream water quality objectives.

[269] Refer to **Section 6.4.1.2.4, [C]**: Reconciliation and allocation of water quality.

[270] Refer to **Section 6.4.1.2.4, [F]**: Establishment of geographic water quality management strategies and thematic plans.

are covered through subsequent allocations[271] and the implementation of geographic water quality management strategies and thematic plans.[272] NLOs may call for reductions in stressed sub-catchments or potential increases in less stressed areas, considering water use and user needs amid development.[273]

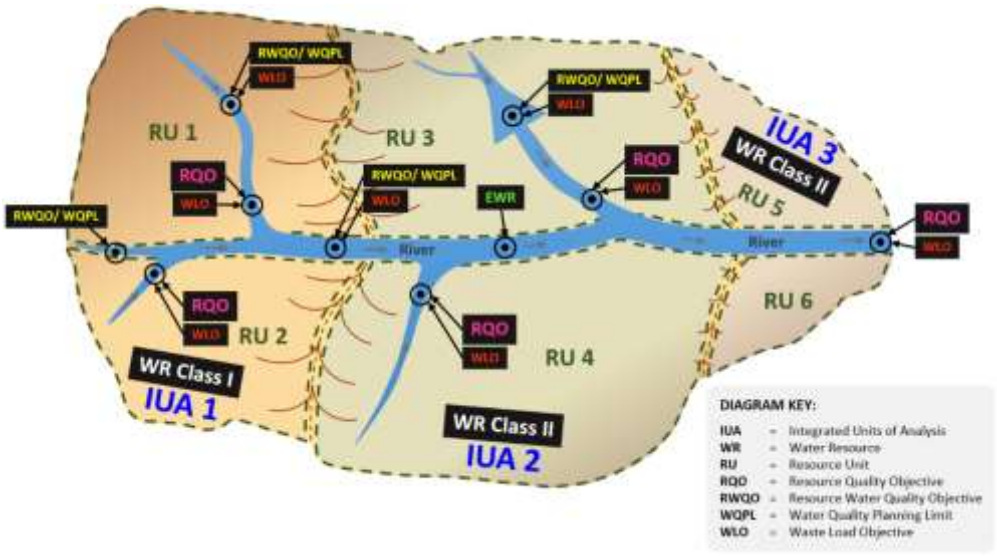

FIGURE 82: In-water resource water quality objectives and Waste Load Objectives.

Notably, the development of NLOs does not always require precise cause-and-effect relationships. Instead, it can be based on a basic understanding of the effects and feasibility of nutrient adjustments or rely on insights from modelling studies.[274] This approach helps identify necessary shifts in nutrient concentration and loads to achieve the water quality objectives set forth.

For **stressed catchments**, achieving NLOs might require substantial nutrient load reductions.[275] In catchments identified as threatened, the emphasis is on preventing any increase in nutrient loads. This need not prevent further development of the catchment, but rather indicates that development in the catchment must be balanced by reductions in nutrient loading elsewhere in the catchment or nutrient load off-setting.[276] The management emphasis in these cases will,

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[271] Refer to **Section 6.4.1.2.4, [C]**: Reconciliation and allocation of water quality.

[272] Refer to **Section 6.4.1.2.4, [F]**: Establishment of geographic water quality management strategies and thematic plans.

[273] Refer to **Section 6.4.1.2.2, [C]**: Water quality forecasting, trends analysis and scenario definition.

[274] Refer to **Section 6.4.1.2.1, [B]**: Examination of existing and available information.

[275] Between 2004 and 2015, a series of projects were carried out to demonstrate the benefits of employing a load-based method in South Africa. In these studies, nutrient loads were modeled in both forward and reverse annual time-steps within a selection of 30 reservoirs, which varied significantly in their levels of impact. The objective was to identify the necessary reductions in nutrient loads to transition these reservoirs to a mesotrophic state, characterized by moderate levels of productivity. The findings suggested that achieving a mesotrophic condition in these waterbodies would require substantial load reductions, specifically in the range of 50 to 75% [Pers. coms. Harding, 2022].

[276] Refer to **POLICY STATEMENT 2**: The Mitigation Hierarchy for decision-making on eutrophication.

therefore, be on allocating nutrient loads to different sectors according to a water quality allocation schedule.[277]

In **unstressed catchments**, NLOs could allow for increased nutrient loads if justified by socio-economic benefits,[278] ensuring ecologically sustainable development in line with the eutrophication management goal of maintaining water resources that are fitness-for-use.

[C] Determination of statutory Resource-Directed Measures

In September 2010, as a reinforcement of Chapter 3 of the NWA (36:1998), which mandates the necessity for adequate protection and effective management of water resources, the DWS promulgated regulations introducing a Water Resources Classification System (WRCS). This system is instrumental in guiding the establishment of RDMs, designed to maintain the desired state of water resources over time. Key components outlined by the WRCS, include:

- Determining the **Water Resource Class** (Management Class or MC) for Integrated Units of Analysis (IUAs), which specifies the degree of usage a water resource is subject to, ranging from *"minimally used"* (Class I) through to *"moderately used"* (Class II) and *"heavily used"* (Class III).[279] This classification aims at ensuring sustainable use, regulatory clarity and a structured approach to achieving other objectives such as RQOs and the Reserve;
- Determining ***"the Reserve"***, which encompasses the quantity, quality and reliability of water resources required for fulfilling basic human needs (referred to as the Basic Human Needs Reserve) and sustaining aquatic ecosystems (the Ecological Reserve). The Reserve underscores the foundational right to water as stipulated by the NWA (36:1998), prioritising these essential needs before permitting other economic endeavours. For managing eutrophication, the Ecological Reserve is particularly relevant (**FIGURE 83**), although designed for river reaches and not impoundments, considered unnatural systems. The Reserve forms part of the RQO; and
- Determining **RQOs** for each significant water resource within Resource Units (RUs) [DWAF, 2006b:46]. These objectives provide explicit goals concerning the water quantity, quality and aquatic ecosystem integrity, incorporating both narrative and quantitative elements to ensure the protection of water resources aligned with their designated MC.

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[277] Refer to **Section 6.4.1.2.4, [C]**: Reconciliation and allocation of water quality.

[278] Refer to **Section 6.4.1.2.2, [C]**: Water quality forecasting, trends analysis and scenario definition.

[279] Labelling the three MCs as *"minimally used"*, *"moderately used"* and *"heavily used"* introduces ambiguity due to it emphasising water use, seemingly overlooking the effect of natural background water quality. Using terms such as *"minimally modified"*, *"moderately modified"* and *"heavily modified"* could offer a clearer description.

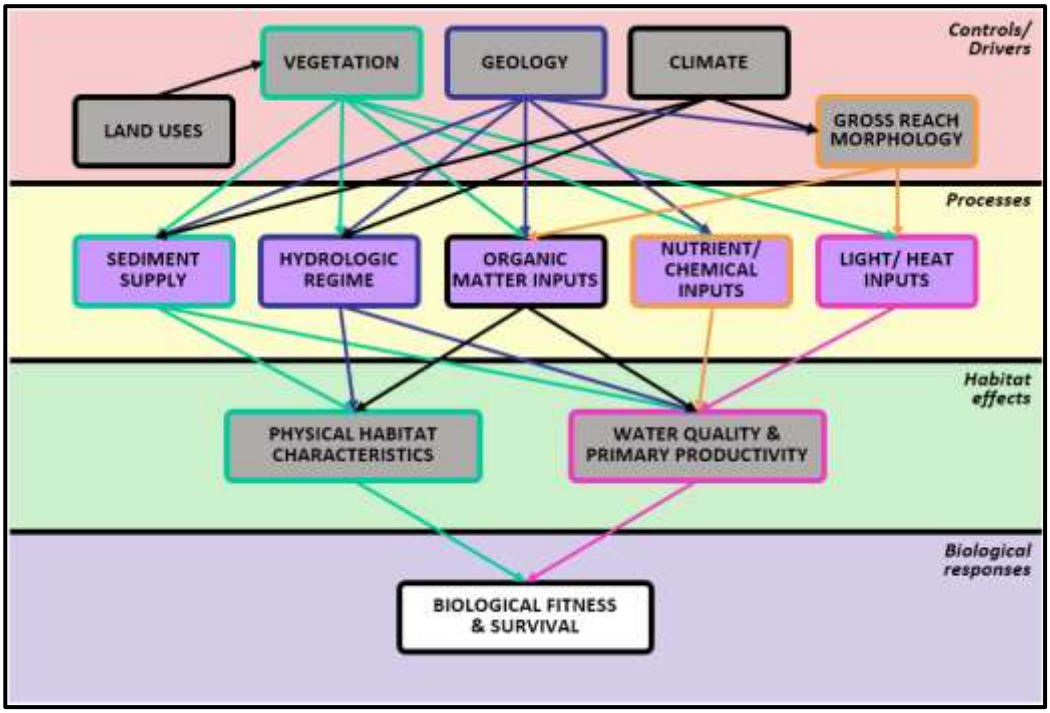

FIGURE 83: The Ecological Water Requirements components of the Reserve [Beechie & Bolton, 1999:6].

The WRCS accounts for the social, economic and ecological aspects of a catchment to balance the costs and benefits linked with the development, use and protection of water resources. This process is part of a broader water resource planning effort, highlighting the WRCS's role in not only classifying but also actively managing and protecting water resources. The successful implementation of RDMs is crucial for effective eutrophication management, ensuring the integrity of water resources for current and future needs.

[D] Determination of remediation objectives for pollution sources and water resources

During the catchment assessment process, the identification and evaluation of **legacy point and diffuse nutrient sources**, along with their lasting impacts on water resources and the associated ecosystems due to historical anthropogenic eutrophication,[280] are crucial steps. To address these issues effectively, quantification of these legacy nutrient loads must be carried out as part of waste load accounting.[281] The data obtained from waste load accounting, alongside insights from water quality allocation,[282] play a significant role in shaping the determination of remediation objectives for legacy sources of nutrient pollution.

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[280] Refer to **Section 6.4.1.2.1, [F]**: Examination of historic and current point and diffuse impacts.

[281] Refer to **Section 6.4.1.2.2, [B]**: Waste load accounting.

[282] Refer to **Section 6.4.1.2.4, [C]**: Reconciliation and allocation of water quality.

Establishing remediation objectives to address **residual impacts on water resources and associated ecosystems** is essential. These remediation objectives should be guided by the Reserve,[283] where available, which *inter alia* outlines the quantity, quality and reliability of water to sustain aquatic ecosystems. By aligning with the Reserve, the remediation objectives can be set in a way that ensures the long-term integrity of ecosystems alongside meeting economic development requirements.

Furthermore, these remediation objectives should guide the creation of geographic water quality management strategies and thematic plans.[284] **Integrating these objectives into strategic planning** allows for effective management of legacy nutrient sources and supports the restoration and protection of healthy aquatic ecosystems and catchment water quality.

6.4.1.2.4 Intervention planning

*"**Intervention planning**"* constitutes the last operational strategy within the *"plan"* stage of the eutrophication management framework. The end-purpose of planning interventions focused on eutrophication[285] is to delineate preferred pathways forward, manifested in geographic water quality management strategies and/or thematic plans. These documents detail the practical steps for water quality management, encompassing various interventions aimed at tackling eutrophication issues. Furthermore, they serve as instruments for monitoring the progress of implementation efforts. The elements and objectives of intervention planning within the context of the eutrophication management framework, are detailed in the following **sections** [adapted from DWAF, 2003b:3], labelled **[A]** to **[H]**:

[A] Confirmation of the water quality constituents of concern and catchment pressures

The comparison of historic and *status quo* data on concentrations[286] and waste loads,[287] along with insights from water quality forecasting,[288] is essential against established in-resource water quality objectives and WLOs.[289] This comparison is crucial to identify all water quality concerns accurately and to select appropriate indicators for ongoing monitoring efforts.[290] Given the

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[283] Refer to **Section 6.4.1.2.3, [C]**: Determination of statutory Resource-Directed Measures.
[284] Refer to **Section 6.4.1.2.4, [F]**: Establishment of geographic water quality management strategies and thematic plans.
[285] Refer to **POLICY STATEMENT 14**: Water resource assessment and planning to inform decision-making.
[286] Refer to **Section 6.4.1.2.1, [E]**: Evaluation of the historic and current resource quality.
[287] Refer to **Section 6.4.1.2.2, [B]**: Waste load accounting.
[288] Refer to **Section 6.4.1.2.2, [C]**: Water quality forecasting, trends analysis and scenario definition.
[289] Refer to **Section 6.4.1.2.3**: Goal setting.
[290] Refer to **Section 6.4.3**: The *"check"* stage.

dynamic nature of water quality and the potential for new pollutants to emerge, additional and follow-up assessments might be necessary over time to identify potential emerging pollutants.

To thoroughly understand the water quality status, spatial and temporal profiles of water quality and loads need to be created for all pertinent Management Units. These profiles should be elucidated by pinpointing probable point and diffuse sources of pollution. By identifying these sources, it becomes possible to rank the pressures they impose on water resources in terms of their observed and projected impacts. This ranking is vital for evaluating different scenarios, guiding the prioritisation of interventions and analysing management options effectively.[291] The aim is to ensure a targeted and informed approach to improving water quality and managing the aquatic environment proactively.

[B] Scenario evaluation and management intervention options analysis

Effective eutrophication management decisions are underpinned by the ability to forecast the outcomes of streamflow and nutrient loading across various segments of a river and under different scenarios of land and water use within the catchment. To achieve this, a spectrum of predictive approaches is utilised, encompassing process-based catchment models, rule-based methods and straightforward regression-based formulas.

The comprehensive *"mosaic"* of information generated through catchment assessments, coupled with the strategic value of forward planning and setting management goals, provides a framework for a management-oriented evaluation of potential future water quality trends both spatially and temporally. It is important to recognise that, as with all forecasts, predictions of nutrient loading and their impacts on trophic conditions carry inherent uncertainties. Consequently, conducting a broad array of sensitivity analyses, to understand how variations in key factors might influence predictions, should be a fundamental component of scenario evaluations.

To identify feasible scenarios,[292] scenario-building involves correlating each scenario with corresponding management and intervention strategies, which are then evaluated against pre-established criteria to ensure comparability. This process facilitates the ordered ranking of scenarios and eutrophication management options based on their feasibility. Criteria for screening scenarios and management options might encompass:

- **Economic considerations:** Assessing the financial costs and benefits associated with each option;

[291] Refer to **Section 6.4.1.2.4, [B]**: Scenario evaluation and management intervention options analysis.
[292] Refer to **Section 6.4.1.2.2, [C]**: Water quality forecasting, trends analysis and scenario definition.

- **Socio-political considerations:** Understanding the social acceptability and political implications of proposed actions;
- **Ecological considerations:** Identifying the potential impacts on ecosystems and biodiversity;
- **Recreational and/or eco-tourism aspects:** Considering how water quality management affects recreational and tourism opportunities;
- **Legal considerations:** Ensuring compliance with existing laws and regulations;
- **Technical viability:** Evaluating the physical and operational feasibility of implementing options; and
- **Statutory and institutional responsibilities:** Accounting for the responsibilities and cooperative arrangements among different entities and stakeholders involved.

Typically, these options are evaluated through cost-benefit analysis, which allows for a straightforward comparison based on the economic outcomes of each option compared to its costs. This comprehensive approach ensures that eutrophication governance strategies are not only scientifically sound but also economically viable, socially responsible, ecologically sustainable, legally compliant, technically feasible and in line with statutory and institutional mandates.

[C] Reconciliation and allocation of water quality

The issue of excessive nutrient loading is becoming increasingly critical in many waterbodies, surpassing their natural capacity to assimilate nutrients without detrimentally affecting their fitness-for-use. To counter this, aligning demands for allocatable water quality with availability is crucial.[293] This is achieved through a *"water quality allocation plan"*, supported by a detailed *"water quality allocation schedule"*, which serves as the framework for managing water quality within allocated concentration and load limits.

This plan works in tandem with the broader Water Allocation Plan, as required by Section 9(e), NWA (36:1998). Specifically for eutrophication management, it distributes allowable nutrient loads, determined by NLOs, among water user sectors within water resource *"Management Units"*. It identifies and mandates measures for source control or remediation that each sector must implement, ensuring effective management of both point and diffuse nutrient pollution to achieve targeted reductions, if necessary.

The methodology assigns nutrient load quotas via NLOs to catchment areas, which are then distributed to sectors or sources within the water quality allocation plan. Developing these plans

[293] Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.

involves collaboration with stakeholders, taking a catchment-wide approach to meet sector-specific targets.

Furthermore, the plan addresses impacts from point and diffuse sources and directs in-stream management efforts, which may include practices such as optimising reservoir release operating rules,[294] engaging in stream restoration or rehabilitation[295] and meeting ecological water requirements.[296] Beyond these measures, the plan is instrumental in managing nutrient load offsets,[297] maintaining a transparent register of all such offsets.

At the heart of geographic water quality management strategies and thematic plans, the water quality allocation plan,[298] not only supports the existing framework, but also highlights opportunities for further ecologically sustainable development. This, in turn, paves the way for additional socio-economic growth, illustrating how a carefully managed water quality strategy can underpin broader development ambitions.

[D] Identification and development of linkages with land use planning and management

Management of catchment eutrophication is part of a broader scope of planning and development, which is complicated by the fragmentation within South Africa's water, land-use and environmental legislation and administration. This fragmentation necessitates the establishment of institutional linkages during the catchment assessment study[299] to ensure a cohesive approach to eutrophication management.

Equally critical is addressing the disjointed statutory frameworks governing spatial, land-use and infrastructural development planning that contribute to anthropogenic eutrophication. Identifying and fostering potential synergy with national, provincial, regional and local planning processes is essential to mitigate the impacts of human-induced eutrophication. This requires a commitment to cooperative governance and consultation[300] to harmonise efforts across different levels of planning and management.

Furthermore, the increasing nutrient-loading trends, driven by population growth and development patterns within many catchments, must be recognised. It is crucial to influence development planning and land use management strategically to safeguard water security.

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[294] Refer to **Section 6.4.1.2.4, [E]**: Identification of possible implications for water resource systems operation.
[295] Refer to **Section 6.4.4.2.1**: Retroactive action.
[296] Refer to **Section 6.4.1.2.3**: Goal setting.
[297] Refer to **POLICY STATEMENT 2**: The Mitigation Hierarchy for decision-making on eutrophication.
[298] Refer to **Section 6.4.1.2.4, [F]**: Establishment of geographic water quality management strategies and thematic plans.
[299] Refer to **Section 6.4.1.2.1, [A]:** Stakeholders and role-player identification and consultation.
[300] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

Successfully integrating this approach into the development and implementation of geographic water quality management strategies and thematic plans[298] necessitates a deep understanding of the interconnections between land use planning and water quality management, transferring these insights into actionable strategies that are cognisant of the broader socio-economic and ecological landscape.

[E] Identification of possible implications for water resource systems operation

The DWS has the critical responsibility of developing and maintaining the operating rules for water resource systems. This includes rules for individual reservoirs, interconnected reservoir networks and large-scale schemes crucial to major economic regions, as well as for smaller reservoirs serving towns and rural communities. These operating rules are often underpinned by sophisticated decision support systems, integrating stochastic simulation models that perform monthly forecasting. These models are invaluable in advising users about the likelihood of entering water restriction phases in the future, thus facilitating informed decision-making. For example, such rules can dictate the transfer of water between various sources, the conjunctive use of surface and groundwater, the dilution of water pollution or the activation of desalination plants during drought conditions.

Regulating the use of developed surface water resources impacts the health of aquatic ecosystems and plays a pivotal role in complying to the RQOs/Reserve. Manipulating water flow has emerged as an effective method to address eutrophication in certain river systems by focusing on key factors such as residence time and stratification [Davis & Koop, 2006:49; Davis & Koop, 2001:93], which are significant contributors to algal blooms. This insight suggests that a sharper focus on flow management and system operations could play a crucial role in decreasing primary production levels and replicating natural flow patterns in downstream waters,[301] especially in highly controlled river systems. Adjusting the reservoir discharge pattern, instead of simply increasing water release, may serve as an efficient short to medium-term strategy for eutrophication management. Nonetheless, for sustainable long-term success, the emphasis must shift towards tackling the root causes of anthropogenic eutrophication, rather than merely managing symptoms.

[F] Establishment of geographic water quality management strategies and thematic plans

The geographic water quality management strategy integrates various elements of water quality management to effectively address specific eutrophication challenges and priorities within sub-catchments (Management Units) and WMAs as illustrated in **FIGURE 84**. These strategies,

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[301] Refer to the Reserve, as per **Section 6.4.1.2.3, [C]**.

along with sub-strategies, are complemented by the development of specific water quality management plans tailored to address key themes such as eutrophication management and water quality allocation.

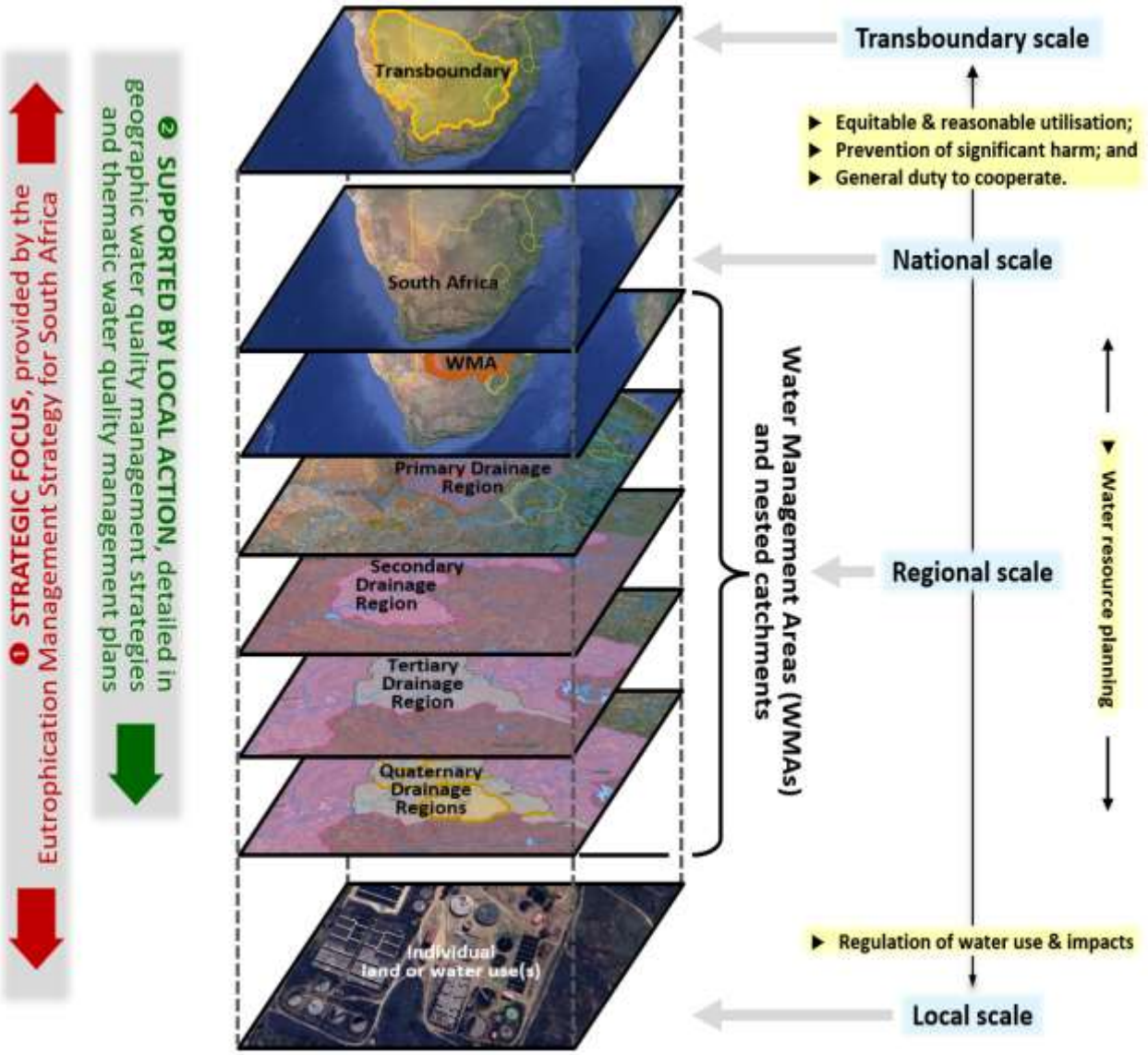

FIGURE 84: The *eutrophication governance strategy for South Africa* must ideally be *"regionalised"* through geographic water quality management strategies and/or thematic plans, to ensure informed local action through holistic and integrated eutrophication management.

This holistic approach ensures that the overarching vision[302] and relevant management goals[303] are translated into actionable plans and strategy through the implementation and tracking[304] of

[302] Refer to **Section 6.4.1.2.2, [D]**: Visioning to propose levels for water resource protection.

[303] Refer to **Section 6.4.1.2.3**: Goal setting.

[304] Refer to **Section 6.4.1.2.4, [H]**: Implementation coordination and maintenance.

selected management intervention options.[305] These interventions encompass a range of management approaches, including– source [306] and remediation-focused [307] approaches; cooperative land use development and management measures;[308] water resource systems operating rules;[309] and the deployment of infrastructure solutions[310], to mitigate excessive primary production in waterbodies.

In instances where specific geographic water quality management strategies and thematic plans are not yet in place, ongoing *ad hoc* eutrophication management activities should persist until these comprehensive plans are fully developed and operational. For CMAs already in operation, the geographic water quality management strategies and thematic plans outlined here will become integral components of their CMSs and associated documentation, forming a cohesive framework for sustainable integrated water quality management and eutrophication control.

[G] Infrastructure planning

While nature-based solutions are often preferred,[311] built infrastructure is sometimes necessary to address point and diffuse nutrient challenges. In many instances, the analysis of intervention options[312] may prioritise the establishment of built infrastructure to combat eutrophication-related issues. The lack of essential infrastructure for managing nutrient-rich waste and wastewater can accelerate anthropogenic eutrophication. Infrastructure addressing nutrient pollution includes wastewater treatment facilities, pollution control structures, water distribution systems, reservoirs, pumping systems, stormwater management facilities, and more. These infrastructure solutions are leveraged by government entities at various levels and the private sector to prevent, manage and treat nutrient-rich pollution sources and their impacts.

Government-funded infrastructure planning requires an incremental approach to avoid spending on non-feasible projects. This involves conducting planning investigations at different levels to identify non-viable projects early in the planning process, ensuring resources are focused on feasible options. These planning investigation levels typically include the following:

- **Reconnaissance level:** Determines development potential at minimal cost;

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[305] Refer to **Section 6.4.1.2.4, [B]**: Scenario evaluation and management intervention options analysis.
[306] Refer to **Section 6.3.1**: Source-directed management.
[307] Refer to **Section 6.3.3**: Remediation-directed management.
[308] Refer to **Section 6.4.1.2.4, [D]**: Identification and development of linkages with land use planning and management.
[309] Refer to **Section 6.4.1.2.4, [E]**: Identification of possible implications for water resource systems operation.
[310] Refer to **Section 6.4.1.2.4, [G]**: Infrastructure planning.
[311] Refer to **POLICY STATEMENT 8**: Nature-based solutions.
[312] Refer to **Section 6.4.1.2.4, [B]**: Scenario evaluation and management intervention options analysis.

- **Pre-feasibility level:** Compares projects to select the best option based on economic and environmental factors; and
- **Feasibility level:** Demonstrates technical feasibility and economic viability in detail, including Environmental Impact Assessments (EIAs).

Build infrastructure planning is essential to meet growing demands on wastewater management systems and support development. Preventive measures against vandalism should be implemented to protect these critical assets.

[H] Implementation coordination and maintenance

The implementation and maintenance of geographic water quality management strategies, along with the associated thematic plans (or in the case of operational CMAs, the CMS), particularly concerning the management of eutrophication,[313] are essential in mitigating excessive nutrient loading and enhancing the trophic status of waterbodies. To ensure the successful execution and continuity of these strategies, the formation of Strategy Steering Committees (SSCs) is recommended. This committee will be tasked with overseeing the implementation and maintenance efforts. Regular meetings of the SSC will be necessary to track progress effectively and update strategies as needed.[314] The Committee should consist of relevant authorities, key stakeholders from land and water user sectors, as well as selected experts to provide their insights and expertise.

By establishing SSCs with diverse representation and expertise, the governance structure can facilitate informed decision-making, effective coordination and successful implementation of strategies tailored to manage eutrophication and improve water quality.

6.4.1.3 Spatial scale of implementation

Assessments[315] can be carried out periodically or on an as-needed basis. It is essential to conduct assessments at the appropriate geographical scales, spanning from transboundary and national levels to regional, catchment, sub-catchment and local scales.

Operational strategies, as part of the planning stage in the eutrophication management framework, should also be designed for different geographical scales, including transboundary, national, regional, catchment or sub-catchment and local levels.

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[313] Effective implementation and maintenance of the geographic water quality management strategies and associated thematic plans is dependent on and linked to the *"check"* stage (Section 6.4.3) for data, information and performance tracking.

[314] Refer to **Section 6.4.3**: The *"check"* stage.

[315] Refer to **POLICY STATEMENT 14**: Water resource assessment and planning to inform decision-making.

The assessments, forward planning, goal setting and intervention planning should occur at spatial scales that strike a balance between the complexities of the specific area under consideration, environmental coherence and the necessity to decentralise water quality management to the most appropriate and practical level. This approach ensures that management efforts are tailored to the unique characteristics and needs of each scale, promoting effective and integrated eutrophication management practices across different geographic levels.

6.4.1.4 Temporal scale of implementation

In the *"plan"* stage of the eutrophication management framework, operational strategies can be implemented either *ad hoc* or regularly, depending on the specific purpose. **TABLE 33** gives a summary of potential actions, in the *"plan"* stage, which must be considered, to improve the trophic status of water resources:

TABLE 33: Operational actions to strengthen the *"plan"* stage of the eutrophication management framework.

SHORT TERM	
(1)	Determine statutory RDMs, *i.e.,* MCs (and RQOs/ Reserves), for significant water resources that are still outstanding;
(2)	Determine RWQOs/ WQPLs, based on the South African Water Quality Guidelines [DWAF, 1996:Vol.1-7], in support of statutory RDMs, specifically the RQOs;
(3)	Develop and roll out the methodologies to determine NLOs; and
(4)	First establish and implement geographic water quality management strategies and thematic plans for three priority WMAs; followed by the establishment and implementation of water quality management strategies and plans for the remaining WMAs. Waste load accounting, goal setting and water quality allocation plan development constitute important components of this process;
LONGER TERM	
(5)	Influence WSDPs, IDPs and any other relevant strategies, plans or frameworks to reflect eutrophication management priorities and management requirements.
(6)	Establish and implement geographic water quality management strategies and thematic plans for the remaining WMAs.

6.4.2 The *"do"* stage

Frequently, concerns are raised that even the most well-crafted legislation and government policies hold little weight unless they are supported by a systematic *"plan"* that outlines the implementation approach. The actual execution or *"doing"* of what is outlined in the plan stage is crucial. A *"plan"* stage devoid of a corresponding *"do"* stage is as ineffective as implementing actions without a prior plan. These two stages are interdependent and must work in tandem within the eutrophication management framework to achieve meaningful outcomes.

Altogether, the *"do"* stage, in the eutrophication management framework, must–

- implement the goals, geographic strategies and thematic plans established during the *"plan"* stage to effectively manage eutrophication within catchments;[316]
- protect aquatic ecosystems and other water users by ensuring that compliant waste and water containing waste are returned to water resources;[317]
- advocate for incentive-based regulation to drive positive environmental outcomes;[318]
- be executed collaboratively, fostering cooperation with other regulatory role-players;[319]
- approach eutrophication challenges holistically,[320] and in a *"cradle-to-grave"* fashion by addressing pollution as close as possible to its source or origin;[321]
- leverage management instruments for environmental compliance effectively;[322]
- promote pollution avoidance, prevention and minimisation in alignment with the established policies;[323] and
- encourage the use of nature-based solutions[324] and the BPEO[325] where appropriate.

In the eutrophication management framework, the *"do"* stage is about translating the eutrophication governance strategy into actionable steps that lead to tangible results. This stage focuses on applying the strategy to generate outcomes that align with the eutrophication management goal and associated policy imperatives.

In the eutrophication management framework, the *"do"* stage focuses on three interconnected operational strategies, as illustrated in **FIGURE 85**. It is recommended that these three strategies receive primary attention initially. These operational strategies revolve around– **(1) *"best management practice"***; **(2) *"water use authorisation and conditional regulation"***; and **(3) *"incentive-based regulation"***. They can be expanded, as may be necessary and rolled out in the interest of combatting excessive eutrophication. Additional operational strategies can be identified and developed under the *"do"* stage of the eutrophication management framework in future.

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316 Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.
317 Refer to **POLICY STATEMENT 3**: The Differentiated Approach for the control of excessive nutrient loading.
318 Refer to **POLICY STATEMENT 7**: Incentive-based regulation.
319 Refer to **POLICY STATEMENT 19:** Cooperative eutrophication management.
320 Refer to **POLICY STATEMENT 10**: Holistic eutrophication management.
321 Refer to **POLICY STATEMENT 6**: A life cycle view on nutrient loading.
322 Refer to **POLICY STATEMENT 1**: Application of management instruments for environmental compliance in eutrophication management.
323 Refer to **POLICY STATEMENT 2**: The Mitigation Hierarchy for decision-making on eutrophication.
324 Refer to **POLICY STATEMENT 8**: Nature-based solutions.
325 Refer to **POLICY STATEMENT 9**: The application of the Best Practicable Environmental Option.

FIGURE 85: Limiting nutrient loading through– best management practices; water use authorisation and conditional regulation; and incentive-based regulation.

The three operational strategies in the *"do"* stage, and their purposes and composition, are narrated for easy reference purposes in **TABLE 34**:

TABLE 34: The operational strategies, in the *"do"* stage of the eutrophication management framework, and their composition.

OPERATIONAL STRATEGIES AND PURPOSE		KEY COMPONENT(S)
(1) Best management practice	*To apply management practices that limit excessive nutrient loading.*	**[A]** Best available technology;
		[B] Cleaner technology and cleaner production
		[C] Conversion of environmental problems into socio-economic and developmental solutions;
		[D] Waste reduction, recycling and reuse;
		[E] The use of buffer zones; and
		[F] The use of constructed wetlands.

OPERATIONAL STRATEGIES AND PURPOSE		KEY COMPONENT(S)
(2) Water use authorisation and conditional regulation	*To enforce conditional authorisations and other regulatory requirements that limit excessive nutrient loading.*	**[A]** National Water Pollutant Register
		[B] Waste Discharge Standards (WDSs);
		[C] Water use;
		[D] Registration of water use;
		[E] Lawful water use;
		[F] Schedule 1 water use;
		[G] Generally authorised water use;
		[H] Existing Lawful water Use (ELU);
		[I] Water use licensing;
		[J] Alternative authorisations;
		[K] Diffuse pollution sources; and
		[L] Differentiated water use management based on risk
(3) Incentive-based regulation	*To incentivise responsible behaviour that limits excessive nutrient loading.*	**[A]** Waste Discharge Charge System (WDCS);
		[B] Administrative penalties;
		[C] Certification Schemes;
		[D] Water Polluter Register; and
		[E] Eco-labelling.

6.4.2.1 Authority

There are several authorities responsible for authorising activities that could contribute to excessive nutrient loading. The DWS and CMAs typically handle water use authorisations, while other authorities oversee various land use activities. The current fragmented approach to environmental authorisations is often identified as a barrier to economic development. This siloed system can also hinder government objectives, such as effective eutrophication management, especially when environmental authorisations fall under agencies focused on non-water resource issues.

In conjunction with the establishment of the One Environmental System, aimed at streamlining environmental approvals,[326] regulatory cooperation among authorities must be enhanced, especially concerning the management of anthropogenic eutrophication.[327] Competencies (sectors), which are relevant here, include: ♦ agriculture; ♦ the environment; ♦ human settlements; ♦ infrastructure; ♦ mining; and ♦ water and sanitation. The roles of competent

[326] Refer to **POLICY STATEMENT 1**: Application of management instruments for environmental compliance in eutrophication management.
[327] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

authorities are outlined in **Section 6.6** under ***"Governance responsibilities"***, which provides additional clarity on the allocation of tasks concerning eutrophication governance.

6.4.2.2 Prescribed approaches

6.4.2.2.1 Best management practice

The first operational strategy within the *"do"* stage of the eutrophication management framework deals with Best Management Practices (BMPs). BMPs are essential instruments in eutrophication management, designed to be the most effective and practical methods for mitigating excessive nutrient loading from point and diffuse sources. They are crucial in achieving the eutrophication management goal and associated policy imperatives. BMPs can focus on specific catchments, water resource or target sources of anthropogenic eutrophication.

While the following list of important BMPs and their descriptions is not exhaustive, it serves as a starting point for developing a comprehensive portfolio of BMPs. Over time, this can lead to the creation of a suite of Best Practice Guidelines (BPGs) that establish sector-specific norms for BMP implementation. By applying these guidelines to land and water use activities through cooperative management,[328] there is potential to make some BMPs mandatory in the future.[329]

It is essential that the BPGs for eutrophication management align with the Mitigation Hierarchy that prioritises pollution avoidance and prevention, minimisation, remediation and offsetting.[330] The components some BMPs for eutrophication management and their purposes are outlined in **sections [A]** to **[F]** below:

[A] Best available technology

Various wastewater treatment technologies have been proven effective for South African conditions, supported by a local knowledge base to facilitate planning, designing, building, operating and maintaining a wide array of treatment technologies and WwTWs. BMPs offering guidance to smaller and traditional treatment technologies and WwTWs should be considered and where necessary, developed.

While some advanced technologies like advanced oxidation and membrane desalination have been utilised in a few local projects, there is a need for the South African water and waste disposal

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[328] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

[329] Refer to S. 26(1)(i), NWA (36:1998): *"The Minister may make regulations prescribing the outcome or effect which must be achieved through management practices for the treatment of waste, or any class of waste, before it is discharged or deposited into or allowed to enter a water resource."*, and **Annexure G** for other regulations.

[330] Refer to **POLICY STATEMENT 2**: The Mitigation Hierarchy for decision-making on eutrophication.

industry to expand its capacity[331] to confidently adopt and sustain these more sophisticated wastewater treatment technologies.[332] It is essential to consider also developing BMPs with guidelines specifically tailored for these advanced treatment technologies and WwTWs.

[B] Cleaner technology and cleaner production

The concept of *"cleaner production"* has emerged as an industry initiative aimed at minimising waste and emissions while maximising product output and profitability. By analysing the material and energy flow in industrial production processes, opportunities to minimise waste and emissions can be pinpointed, leading to the establishment of source reduction strategies within the industry. Enhancements in organisation and technology play a crucial role in suggesting improved practices for the efficient use of materials and energy, thereby preventing waste generation, minimising wastewater production, curbing undesired gaseous emissions, waste heat and noise. This approach also promotes more effective resource utilisation, boosts business profitability and competitiveness, and enhances overall production process efficiency.

The principles of *"cleaner production"* are applicable to businesses of all sizes and types. In addition to BPGs for wastewater treatment and management, it is vital to consider and potentially develop BMPs with guidelines tailored for cleaner production and technology. These initiatives can further contribute to sustainable practices within industries.

[C] Conversion of environmental problems into socio-economic and developmental solutions

In situations where pollution issues arise, it is crucial to proactively seek opportunities to transform challenges into solutions. Such opportunities may include recognising the following:

- The issue of water scarcity in South Africa and transitioning towards waterless sanitation options for all South Africans; and
- Viewing human excreta (faeces and urine) not as waste but as a resource that can be utilised, especially for fertiliser products and the reclamation of vital elements like phosphorus – a globally limited resource critical for crop production.

It is essential to identify opportunities to convert challenges into solutions and, where appropriate, to implement these solutions through research,[333] development and broader implementation. BMPs with guidelines should be considered to further drive the conversion of specific challenges into viable solutions.

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[331] Refer to **Section 6.5.1**: Technical capacity building to give impetus to eutrophication management.

[332] Refer to **Section 6.5.2**: Research and technology development to address eutrophication-related challenges.

[333] Refer to **Section 6.5.2**: Research and technology development to address eutrophication-related challenges.

[D] Waste reduction, recycling and reuse

In most cases, the discharge and disposal of wastewater and waste, which also includes evaporation and non-beneficial irrigation with water containing waste, is considered a last resort. The recycling and reuse of wastewater are preferred alternatives, whenever feasible and appropriate, over the use of potable water. Strategies for reuse and recycling play a critical role, especially in urban areas where substantial amounts of wastewater are continuously produced and discharged by municipal WwTWs after treatment.

Possible municipal water reuse options encompass various activities such as irrigating public open spaces like parks, sports fields (municipal, school, club facilities and golf courses), as well as for cooling purposes in industries and power generation, firefighting, toilet flushing, cooling systems, street cleaning, dust control and other non-potable water applications [DWA, 2011a:5]. When considering reuse strategies, it is essential to be mindful of any water budget and downstream indirect water reuse requirements that may be in place. To further boost pollution minimisation efforts, it is important to identify BMPs with guidelines to support and enhance the implementation of these strategies.

[E] The use of buffer zones

The utilisation of buffer zones offers significant potential to address various challenges, including but not limited to sediment retention, removal of nutrients and toxins, preservation of channel stability, flood mitigation, enhanced groundwater replenishment, provision of wildlife habitats, screening of adjacent disturbances, promoting habitat connectivity, enhancing visual appeal and regulating water temperatures through the moderating effects of vegetation along waterbodies, which impact the microclimate of stream areas nearest to stream banks [Macfarlane, *et al.*, 2009:1]. It is crucial to review existing guidelines and, if necessary, make adjustments to align with eutrophication management and this strategy. Prioritising full implementation of these guidelines is essential.

[F] The use of constructed wetlands

Like buffer zones, constructed wetlands serve as an effective nature-based solution[334] for controlling and managing pollution sources, particularly those responsible for excessive nutrient loading and human-induced eutrophication. Constructed wetlands are artificial systems designed to treat municipal or industrial wastewater, greywater or stormwater runoff. These systems include properly designed depressions or basins that contain water; various substrates like soil, sand, gravel, rock and organic compost materials; vascular plants; and communities of microbes

[334] Refer to **POLICY STATEMENT 8:** Nature-based solutions.

and aquatic invertebrates. Nutrients, sediments and organic matter accumulate in these systems due to the low water velocities and high productivity inherent in wetlands. However, to maintain their nutrient removal efficiency, constructed wetlands require proper maintenance to prevent saturation.

The presence of substrates, nutrients, sediments and organic matter within constructed wetlands serves multiple essential purposes [Davis, 1995:7]:

- Supporting diverse living organisms in wetlands;
- Influencing water movement through the wetland due to substrate permeability;
- Facilitating various chemical and biological transformations, especially by microbial activity within the substrates;
- Acting as storage for contaminants; and
- Enhancing litter and organic matter accumulation, providing sites for material exchange and microbial attachment and serving as a carbon source for driving key biological reactions in wetlands.

When substrates become flooded, their physical and chemical characteristics undergo alterations. In saturated substrates, water displaces atmospheric gases in pore spaces, leading to microbial metabolism depleting available oxygen. As oxygen is consumed faster than it can be replenished through atmospheric diffusion, substrates become anoxic. This oxygen-deficient environment plays a crucial role in removing pollutants like nitrogen and metals [Davis, 1995:7].

6.4.2.2.2 Water use authorisation and conditional regulation

"Water use authorisation and conditional regulation" constitutes the second operational strategy within the *"do"* stage of the eutrophication management framework. Command-and-control, also known as direct regulation, is a fundamental approach employed by governments worldwide to enforce environmental compliance.[335] In the realm of eutrophication management, it is ideal for a range of regulatory measures to be in place to tackle various types and combinations of point and diffuse sources contributing to excessive nutrient loading on a catchment-specific basis. However, the reality does not fully align with this ideal scenario, as current regulatory efforts predominantly concentrate on addressing point sources of pollution. The following **sections [A]** to **[L]** elaborate on these Source-Directed Measures and Controls:

[335] Refer to **POLICY STATEMENT 1**: Application of management instruments for environmental compliance in eutrophication management.

[A] National Water Pollutant Register

The quality of water resources in a catchment is a direct reflection of all activities within it, as human actions and lifestyles inevitably impact water resources through both point and diffuse runoff processes. Anthropogenic eutrophication, a direct result of nutrient introduction from catchment activities, is a significant concern. Various factors such as increasing industrialisation, urbanisation, intensive agricultural practices and climate change all contribute to the dynamic evolution of water pollution (**FIGURE 86**). Notably, many emerging pollutants observed in water resources contain phosphorus and nitrogen, further exacerbating anthropogenic eutrophication. To effectively manage these challenges, continuous monitoring and evaluation of changing pollution patterns are essential.[336]

To enhance management strategies, the establishment of a *"National Water Pollutant Register"* in conjunction with the development of WDSs (refer to **section [B]** below) and other emission standards like ambient air quality regulations is recommended. Such a register would provide a structured approach to pollution control and integrated water quality management in response to evolving environmental conditions. The Register can categorise pollutants or substances requiring to be dealt with in specific ways, including:

- A **list of national priority substances** posing a significant threat to water users and aquatic ecosystems nationwide, with corresponding WDSs and emission standards, to be periodically reviewed, possibly coinciding with the review of the NWRS;
- A **list of WMA or sub-catchment specific priority substances** posing localised threats, requiring tailored WDSs and emission standards, periodically reviewed in collaboration with CMAs possibly aligning with the review of CMSs;
- A ***"watch list"* containing new or emerging substances** needing monitoring for risk assessment and to establish necessary WDSs or emission standards. This list should be periodically reviewed to influence research and technology priorities,[337] possibly coinciding with the review of the NWRS; and
- A **list of priority hazardous substances** necessitating complete elimination from water resources[338] due to persistency, bioaccumulation, potential toxicity or other concerns. This list should be periodically reviewed, possibly coinciding with the review of the NWRS.

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[336] Refer to **POLICY STATEMENT 14**: Water resource assessment and planning to inform decision-making.

[337] Refer to **Section 6.5.2**: Research and technology development to address eutrophication-related challenges.

[338] Refer to **POLICY STATEMENT 4**: The application of the Precautionary Principle.

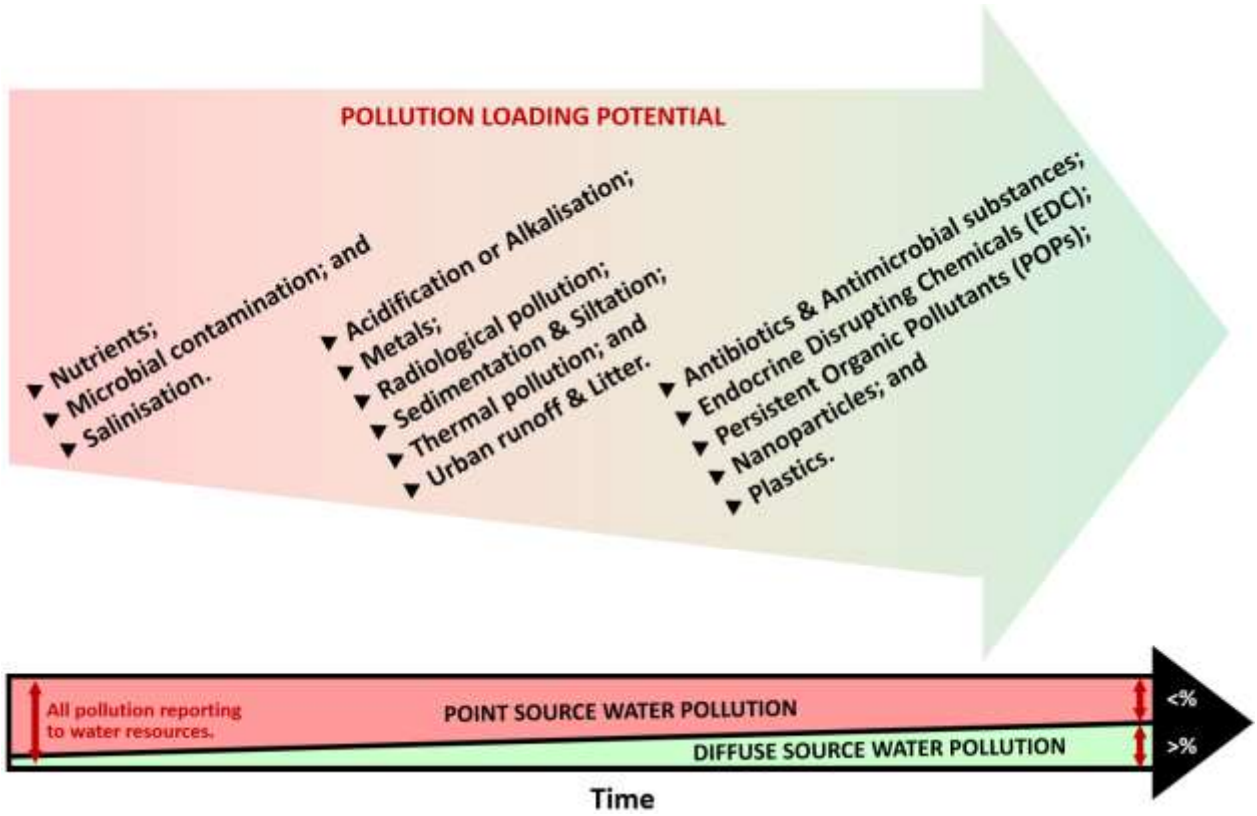

FIGURE 86: Changing character of water pollution and the introduction of emerging pollutants.

Hazardous substances may overlap in the national or WMA/sub-catchment priority categories, with periodic transfers between the *"watch list"* and other lists based on evolving information. The establishment of a list of non-priority substances (*i.e.,* a list of *"dropped"* substances) may be considered for record purposes.

[B] Waste Discharge Standards (WDSs)

The *General and Special Standards for the purification of Wastewater or Effluent*, dating back to 1984 [GN R.991, 1984], are overdue for revision, especially the uniform Special Standard for phosphorus with a limit of 1mg/ℓ orthophosphate. According to Section 15 of the NWA (36:1998), the Minister of Water and Sanitation, the Director-General, organs of state and any Water Management Institution **must give effect to any determination of a MC and RQOs**, and any other requirements for complying with the RQOs.[339]

Ideally, WDSs should be determined separately for each point discharge to ensure compliance with statutory RDMs and to ensure fitness-for-use at a high confidence (**FIGURE 87**). However,

[339] Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.

due to practical limitations, a more feasible and efficient approach is to establish uniform WDSs, either nationally or for specific areas, to support source-directed management.

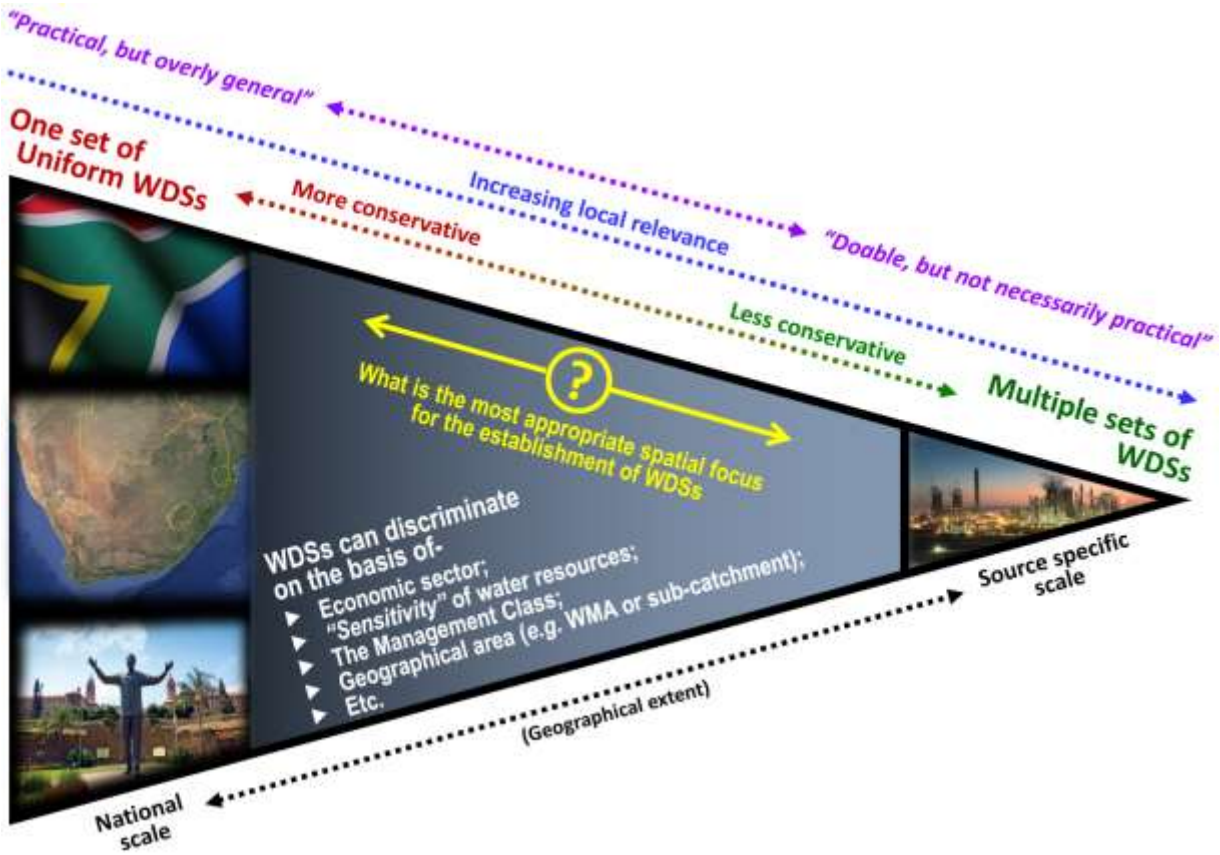

FIGURE 87: The establishment of uniform Waste Discharge Standards (WDSs) to support water use authorisation.

Uniform WDSs serve several purposes because they–

- act as benchmarks when authorising waste and water containing waste related- water uses;
- offer a practical approach to enforcing RDMs;
- complement the Mitigation Hierarchy for decision-making on eutrophication[340] and promote precaution[341] in cases of uncertainty by representing conservative standards;
- can be referenced in waste and water containing waste related water use authorisations, allowing for periodic updates without modifying the authorisations themselves; and
- can be administered effectively through the publication in regulations.[342]

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[340] Refer to **POLICY STATEMENT 2**: The Mitigation Hierarchy for decision-making on eutrophication.

[341] Refer to **POLICY STATEMENT 4**: The application of the Precautionary Principle.

[342] Refer to S. 26(1)(h), NWA (36:1998): *"The Minister may make regulations prescribing waste standards which specify the quantity, quality and temperature of waste which may be discharged or deposited into or allowed to enter a water resource."*, and **Annexure G** for other regulations.

Developing uniform WDSs for various water use scenarios requires considering factors such as (1) effluent volume, (2) effluent quality, (3) river flow, (4) quality of the receiving water resource, (5) background water quality, (6) mixing ratio, (7) effect of seasonality, (8) environmental sensitivity, (9) water resource protection requirement, (10) treatment technologies available, (11) historical activities and (12) socio-economic impact.

Unique WDSs can be determined on an *ad hoc* basis, for inclusion in water use authorisations, on a case-by-case basis. This may be necessary in the absence of suitable uniform WDSs, or when there is a justified need for deviation from the uniform WDSs, such as to enforce stricter or more lenient WDSs, in accordance with the Differentiated Approach.[343]

Whether enforcing WDSs that were determined on an *ad hoc* basis, or that were derived from any regulation containing uniform WDSs, it is vital that the Receiving Water Quality Objectives Approach[344] must be operationalised, locally, for the water resource in question, and regionally, for a water resource system concerned. The further the application of WDSs diverges horizontally from the source-specific to the national scales in **FIGURE 87**, the more stringent they will have to be to uphold RDMs.

[C] Water use

Section 21 of the NWA (36:1998) collectively defines 11 consumptive, non-consumptive and in-water resource water uses (**TABLE 35**), which may have a profound or more subtle effect on the trophic status of receiving water resources:

TABLE 35: The nutrient-loading potential of water uses that can affect eutrophication.

IN TERMS OF THE NWA (36:1998), WATER USES INCLUDES –		DIRECT[345] RELEVANCE	NOTES
S.21(a)	taking water from a water resource;	×	These water uses can affect the dilution capacity of receiving water resources, which may affect nutrient concentrations and eutrophication. Taking water from water resources for agricultural irrigation purposes is often associated with nutrient-rich return flows that can enhance eutrophication. The storing of water effects eutrophication since stagnant water promotes algal growth and the recycling of nutrients in deoxygenated bottom waters.
S.21(b)	storing water;	×	
S.21(c)	impeding or diverting the flow of water in a watercourse;	×	
S.21(d)	engaging in a stream flow reduction activity;	×	

[343] Refer to **POLICY STATEMENT 3**: The Differentiated Approach for the control of excessive nutrient loading.

[344] Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.

[345] ✓ denotes direct relevance and × denotes indirect relevance to persistent nutrient loading.
While the purpose of the table is to demonstrate the direct nutrient-loading potential of individual water usages, eutrophication, in turn, also affects downstream consumptive [*i.e.*, S.21(a) and (b)] and in-water resource [*i.e.*, S.21(k)] water uses. These impacts arise from impaired water quality, excessive primary production and the presence of nuisance biomass, which adversely affect the water supplied from dams and other water resources, negatively impact abstraction and distribution infrastructure and impair recreational activities.

IN TERMS OF THE NWA (36:1998), WATER USES INCLUDES –		DIRECT[345] RELEVANCE	NOTES
S.21(e)	**engaging in a controlled activity;**	✓	The irrigation of any land with waste or water containing waste, generated through any industrial activity or by a waterwork, has the potential to generate excessive diffuse nutrient pollution of surface and groundwater resources.
S.21(f)	**discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;**	✓	The discharge of water containing waste, such as sewage or industrial effluent, has the potential to promote excessive nutrient loading, and to worsen the effects associated with anthropogenic eutrophication.
S.21(g)	**disposing of waste in a manner which may detrimentally impact on a water resource;**	✓	Many waste disposal activities have the potential to generate excessive diffuse nutrient pollution of surface and groundwater resources.
S.21(h)	**disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process;**	✓	Sea-outfalls have the potential to promote excessive nutrient loading and enhanced anthropogenic eutrophication of coastal marine waters.
S.21(i)	altering the bed, banks, course or characteristics of a watercourse;	×	Together with S.21(c), disturbances of beds and banks can mobilise nutrients from soil profiles, promoting nutrient loading of water resources, albeit generally in the short term. Additionally, the alteration of terrestrial and aquatic ecosystems can indirectly affect eutrophication.
S.21(j)	**removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people; and**	✓	Mine water handling, including the discharge of some mine water containing waste to water resources,[346] has the potential to generate excessive point and diffuse nutrient pollution of surface and groundwater resources.
S.21(k)	using water for recreational purposes.	×	Recreational water use does not have a direct relationship with nutrient loading, other than being detrimentally affected by undue eutrophic conditions. Nevertheless, some recreational activities can also be associated with other water uses, such as the discharge of water containing waste, which contribute to eutrophication. Additionally, some recreational activities, *e.g.,* boating, can have a link to eutrophication symptoms through the active mixing of surface waters that enhances primary productivity in highly utilised surface waters. Another rumoured possibility is the use of phosphate blocks by some fishermen to create feeding sites for better fishing.

TABLE 35 illustrates that all waste and water containing waste-related water uses potentially have a direct impact on the nutrient loading of receiving water resources. A person who uses water – specifically discharges water containing waste or that disposes of waste, as contemplated in Sections 21(e), (f), (g), (h) and (j)–

- must use the water subject to the conditions specified in the relevant water use authorisation;

[346] The pumping of mine water from underground, to safely continue with mining activities, constitutes a S.21(j) water use. However, when the pumped underground mine drainage is treated and/or discharged, the latter action constitutes a S.21(f) water use. Irrigation of mine drainage constitute a S.21(e) water use and the disposal of mine residue constitute a S.21(g) water use. All these water use examples may promote excessive nutrient loading, for instance in cases where blasting; or where phosphorus mining is involved.

- is subject to any limitation, restriction or prohibition, in terms of the NWA (36:1998), or any other applicable law;
- must comply with any applicable WDSs or BMPs prescribed under the NWA (36:1998),[347] unless the conditions of the relevant water use authorisation provide otherwise;
- may not waste that water; and
- must return any seepage, runoff or water containing waste, which emanates from that use to the water resource from which the water was taken, unless the DWS or a CMA directs otherwise, or the relevant water use authorisation provides otherwise.

[D] Registration of water use

Any person using water under Section 21 of the NWA (36:1998) must register[348] such water use, except in the following circumstances:

- Water use listed in Schedule 1 of the NWA (36:1998);
- Where registration is not required in terms of a GA; and
- A person sourcing water from a bulk water supplier, a Water Management Institution or a communal scheme.

Registration of a water use is not an entitlement to use water and must not be confused with a water use authorisation. A person who no longer wishes to continue with his or her registered water use must apply to the responsible authority for the deregistration of such water use.

The information obtained from water use registration plays a critical role in eutrophication management as it–

- serves as official notification of lawful waste and water containing waste related- water uses;
- serves as basis for eutrophication planning and management; and
- potentially supports the determination of allocated and allocatable water quality.

V&V of waste and water containing waste related-water uses must be prioritised to ensure proper registration of such water uses and to determine the extent of lawfulness.

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[347] Refer to Section 26(1)(h) and (i) of the NWA (36:1998).

[348] Section 26(1)(c) of the NWA (36:1998) allows for registration of all water uses, including ELU in terms of Section 34(2). Section 29(1)(b)(vi) also states that in the case of a GA, the responsible authority may attach a condition requiring the registration of such water use.

[E] Lawful water use

Water uses are only permissible, in terms of the NWA (36:1998), if any of the following five entitlements are in place (**FIGURE 88**), *i.e.,* if a water use is–

- listed in Schedule 1 of the NWA (36:1998);
- generally authorised;
- an Existing Lawful water Use (ELU);
- authorised under an alternative authorisation, if dispensing with the requirement for a licence; or
- licenced.

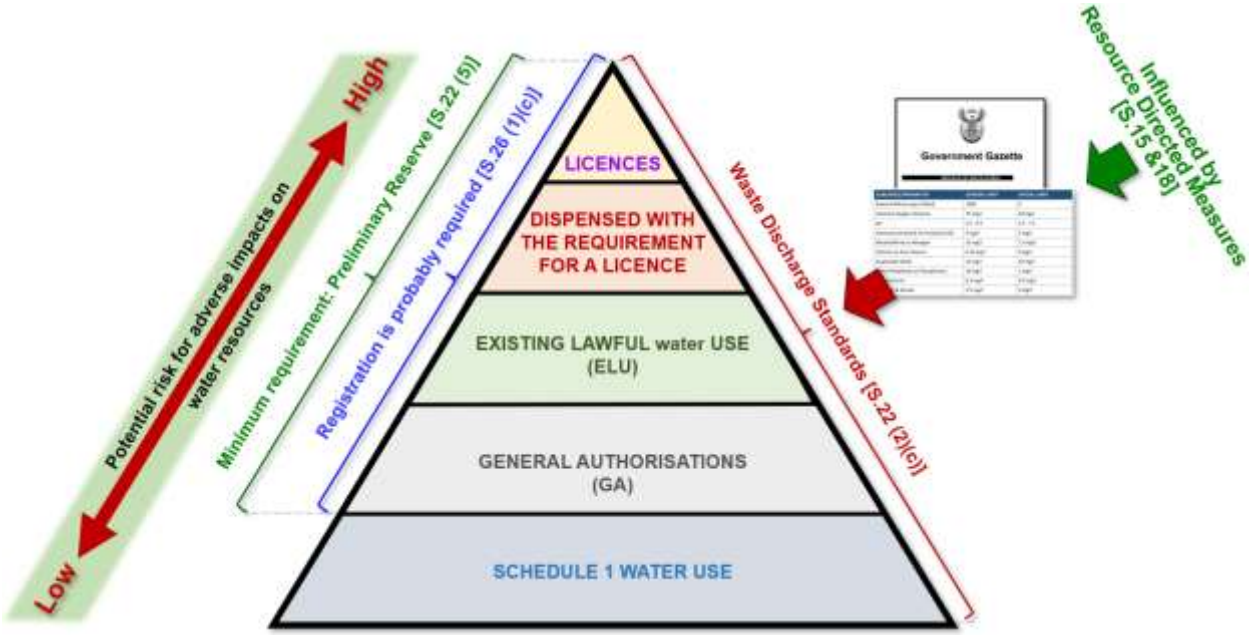

FIGURE 88: Illustration of permissible water use, with references to sections in the NWA (36:1998).

The terms of these entitlements are typically outlined as conditions within authorisations or approvals. For waste and water-containing waste-related water uses, as detailed in **TABLE 35**, these conditions serve to regulate and mitigate anthropogenic eutrophication while concurrently supporting socio-economic development needs. Additionally, these conditions often also specify WDSs (refer to **section [B]** above). Consequently, a lawful water use is a water use that is both permissible, in terms of the NWA (36:1998), and that is compliant with the applicable conditions, including the stipulated WDSs, contained in the water use authorisation or approval in question (**FIGURE 89**).

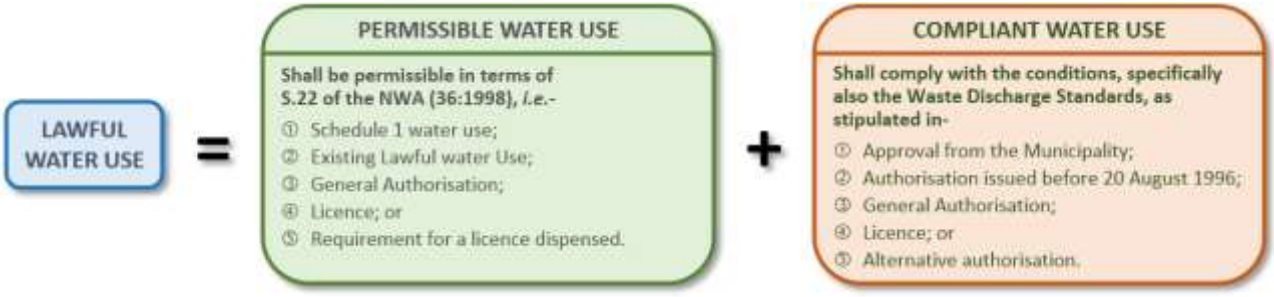

FIGURE 89: Illustration of lawful water use.

The purpose of water use authorisations [adapted from DWAF, 2006a:2] includes ensuring–

- water is used solely for the authorised purpose(s); and
- DWS can give effect to RDMs, such as RQOs, and to contribute towards ecologically sustainable development.

Compliance monitoring[349] and enforcement[350] play vital roles in the implementation of WDSs and constitute an essential aspect of eutrophication management.

[F] Schedule 1 water use

The purpose of Schedule 1 water use is to allow small-impact water uses to continue without adding to the administrative burden of the licensing process. Schedule 1 water use entitles a person to use water for reasonable domestic purposes, excluding commercial use. It encompasses activities such as the discharge of–

- waste or water containing waste; or
- runoff water, including stormwater from residential, recreational, commercial or industrial sites,

into a canal, sea outfall or other conduit controlled by a third party, such as a municipality, who are authorised to undertake the purification, treatment and/or disposal of waste or water containing waste, subject to the approval of the third party controlling the canal, sea outfall or other conduit.

Cumulatively, industrial and commercial waste, water containing waste and runoff water have the potential to detrimentally affect the functioning and performance of municipal WwTWs, as well as the extent to which such WwTWs can give effect to the Receiving Water Quality Objectives

[349] Refer to **Section 6.4.3.2.2, [A]:** Compliance monitoring programmes.
[350] Refer to **Section 6.4.4.2.2:** Enforcement.

Approach.[351] A better understanding of the water quality character of these Schedule 1 water uses and their influence on municipal wastewater handling is necessary for an improved national understanding on the performance of municipal WwTWs.

Enhanced comprehension is anticipated to benefit eutrophication management in South Africa and foster the generation of additional water quality management insights, including:

- Insight into the nature of wastewater and stormwater streams from commercial and industrial sources and their impacts on municipal WwTWs;
- Knowledge about Source-Directed Measures and Controls within the municipal water management environment, including the employment of municipal WDSs, the issuing of approvals and the use of bylaws;
- Compliance details related to wastewater and stormwater treatment by commercial and industrial activities discharging into municipal sewer network systems; and
- Data on wastewater and stormwater reuse and recycling practices to bolster water conservation and demand management efforts.

This additional water quality management data can serve various purposes, including guiding–

- research on the **treatment and management** of waste, water containing waste and stormwater from commercial, industrial and municipal activities; and
- research and development endeavours aimed at **enhancing treatment technologies** and their practical application.

[G] Generally authorised water use

The purpose of generally authorised water use[352] is to permit relatively low-impact water uses to continue while alleviating the administrative burden of the licensing process. These authorisations allow water users to use water without a license, provided that such usage adheres to the conditions outlined in the relevant GA. GAs for waste and water containing waste related-water uses, *i.e.,* for Section 21 (e), (f), (g), (h) and (j) water uses, are available. GAs may not be applicable nationwide and could be specific to certain rivers or catchment areas. They are typically subject to review every five years.

It is crucial that the cumulative effects of generally authorised water uses align with the Receiving Water Quality Objectives Approach[353] and do not lead to a breach of relevant RDMs.

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[351] Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.

[352] Refer to Section 39 of the NWA (36:1998).

[353] Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.

The data and information regarding water use and water resources mandated by GAs are essential. To ensure the information's utility, the relevant water quality and volumetric data must be accepted through a public e-portal into databases that facilitate centralised interrogation within an information management system, such as a potential IRiS-WMS combination. This approach can provide a clearer insight into the cumulative impacts of generally authorised water uses, other water uses and their collective relationship with RDMs within the catchment's context.

Following the development of uniform WDSs, the wastewater limit values specified in GAs should be substituted with the updated WDSs, or alternatively, references to revised WDSs should be included in the GAs.

[H] Existing Lawful water Use (ELU)

Section 32 of the NWA (36:1998) identifies water uses that were authorised under legislation in force immediately before the commencement of the Act as Existing Lawful water Use (ELU). This applies to water uses that occurred within the two years leading up to the commencement date of the Act, *viz.* 1 October 1998. The purpose of ELUs is to allow existing economic activities dependent on water to continue until compulsory licensing is called for in a specific area.

It is highly probable that ELUs with the potential to contribute to excessive nutrient loading, such as those linked to municipal, industrial or agricultural activities, still exist today. Additionally, the conditions set during the authorisation of these water uses, often many years ago, are likely outdated or insufficient. The impact of compounded nutrient loading on receiving water resources due to potentially outdated and inadequate ELU authorisation conditions remains uncertain. To determine whether this poses a barrier to the implementation of RDMs, it would be necessary to initiate the required V&V studies on all waste and water containing waste-related water uses mentioned in **TABLE 35**. This process would involve updating the Water use Authorisation and Registration Management System (WARMS) and evaluating the effects of these water uses on RDMs. Adhering to the Receiving Water Quality Objectives Approach[353] is essential, enabling the DWS to conduct compulsory licensing campaigns where needed to replace heritage authorisations with licenses or GAs.

In the meantime, before the full extent of the potential issue or the outcomes of V&V studies are known, and before compulsory licensing campaigns are concluded, the DWS may consider enhancing the regulation of ELUs through a regulation issued under Section 26 of the NWA (36:1998).[354]

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[354] Refer to S. 26(1)(a), NWA (36:1998): *"The Minister may make regulations limiting or restricting the purpose, manner or extent of water use."*, and **Annexure G** for other regulations.

[I] Water use licensing

Water users are required to apply for water use licenses for any new water use not listed under Schedule 1 of the NWA (36:1998) or not covered by a GA. The purpose of licensing is to control water uses that surpasses the limits specified in Schedule 1 of the Act and those allowed under GAs.

Efficient administration of licenses plays a crucial role in eutrophication management, along with knowledge of waste and water containing waste-related water uses not permissible under the NWA (36:1998). Currently, licensing is the single most important instrument in the DWS's arsenal to manage and control waste and water containing waste related- water uses with an adverse impact potential. Unlawful water use poses a threat to ecologically sustainable development and the country's growth prospects.

Water use licenses provide formal authorisation to existing or new water users to use water for productive and beneficial purposes, laying down conditions, including WDSs, under which the water can be used. It is imperative that the combined effects of all authorised water uses adhere to the Receiving Water Quality Objectives Approach, not breaching relevant RDMs.[355]

The NWA (36:1998) stipulates two types of water use license applications; **individual and compulsory applications**. Compulsory licensing prioritises areas facing water scarcity issues or severe pollution (stressed catchments). The **compulsory licensing process** aims to achieve fair water allocation from stressed water resources, equity in water allocation through the Water Allocation Reform (WAR) programme, promotion of beneficial water uses in the public interest, enhancement of water use efficiency and protection of water resource quality.

Users must register their existing water use to ensure consideration during compulsory licensing. Catchments significantly impacted by excessive nutrient loading or where license conditions, particularly WDSs, do not fully align with the Receiving Water Quality Objectives Approach and do not comply with RDMs, need to be prioritised for compulsory licensing.

The data and information required by licenses concerning water use and water resources are vital. To make this information actionable, the provision of relevant water quality and volumetric data must be requested and accepted through a public e-portal, feeding into databases allowing centralised analysis in an information management system, like a potential IRiS-WMS combination. This approach enables a comprehensive understanding of the cumulative impacts of licensed water uses, as well as other water uses and their relationship with RDMs within the catchment's context.

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[355] Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.

A license can be issued for a maximum of 40 years,[356] with license conditions subject to review at periods specified in the license, not exceeding five years.[357] In the case of **individual licence applications**, the responsible authority may modify the conditions of such licenses through mutual agreement with the licensee.[358]

[J] Alternative authorisations

The DWS or a CMA has the authority to dispense with the requirement for a water use license if satisfied that the purpose of the NWA (36:1998) will be met by the granting of a licence, permit or other authorisation under any other law. This approach facilitates cooperative management,[359] encouraging the DWS or a CMA to engage in agreements with other organs of state to streamline the authorisation process into a combined or single comprehensive environmental authorisation.

Alternative authorisations that could impact eutrophication management encompass a range of controls and regulatory measures. These include the regulation of land use and development activities, Environmental Management Programme Reports (EMPRs) for mining operations, Environmental Impact Assessments (EIAs) for listed activities, atmospheric emission licenses, waste management licenses, coastal water discharge permits and the prohibition of specified activities in accordance with the NFEPAs. They also involve the establishment of product or technical production standards, as well as performance standards.

To ensure effective and cooperative eutrophication management,[359] it is essential to explore the potential synergy that may exist between alternative authorisations, including the examples mentioned above.

[K] Diffuse pollution sources

Unlike point sources, diffuse pollution sources and their impacts on human and ecosystem health are often under-reported and under-regulated. The challenge in regulating and monitoring these sources arises from several factors, as identified by the OECD (2017:5). Their spatial and temporal variability complicates the attribution of pollution sources. Additionally, there are significant transactional costs in managing large numbers of diverse polluters, such as those in agriculture, settlements and industry. Furthermore, effective control requires cooperative efforts and agreements within catchments, across sub-national jurisdictions and even between co-basin states.

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[356] Refer to Section 28(1)(e), NWA (36:1998).
[357] Refer to Section 28(1)(f), NWA (36:1998).
[358] Refer to Section 52(4), NWA (36:1998).
[359] Refer to **POLICY STATEMENT 19:** Cooperative eutrophication management.

Addressing the challenges of diffuse pollution requires a multifaceted approach using a combination of management instruments for environmental compliance.[360] This approach aims to enhance pollution control, manage diffuse nutrient loading and mitigate anthropogenic eutrophication. Potential instruments for managing eutrophication from diffuse sources are outlined in **TABLE 36** and should be further investigated, developed and implemented as part of a broader strategy for non-point source (NPS) pollution, supported by BMPs and BPGs.

TABLE 36: Management instruments to address excessive diffuse nutrient loading of water resources.

Command and control management instruments:	**Societal participation management instruments:**
(1) The use of WDSs to control the discharge of collected diffuse polluted return-flow water, *e.g.,* irrigation return flows and stormwater; **(2)** The use of WDSs to control modelled diffuse water quality outputs; **(3)** Conditional water use authorisations to control the discharge of collected diffuse polluted return-flow water, *e.g.,* irrigation return flows and stormwater; **(4)** Mandatory BMPs,[361] including the introduction and maintenance of buffer areas; **(5)** BPGs to promote eutrophication management efficacy; **(6)** Mandatory diffuse source pollution management plans, *e.g.,* irrigation management plans, etc.; and **(7)** Load allocations to diffuse nutrient contributors.	**(1)** Information and awareness campaigns; **(2)** Farm advisory and extension services for improved farming techniques (to minimise negative impacts on water quality/ eutrophication and to protect agricultural resources); **(3)** *"Management-by-shame"* as a tool, is sometimes employed by Catchment Management Forums, which enjoy diverse representation of forum members with many different interest, views and objectives, that require balancing; **(4)** The establishment of task teams within Catchment Management Forums have proved to be effective in, proactively, resolving many technical challenges; **(5)** Best environmental practices (or good management practices); and **(6)** Eco-labelling of products meeting certain environmental criteria can be marketed and sold at a premium/ subsidised.
Economic management instruments:	**Self-regulatory management instruments:**
(1) Pollution taxes (on inputs), *e.g.,* additional tax on herbicides and pesticides; ***** **(2)** Tax abatements; subsidies or transfers to incentivise good farming practices; **(3)** WDCS (on outputs); **(4)** Replace synthetic fertilisers with organic fertilisers, thereby promoting recycling and reuse of waste; **(5)** Government capital funding to upgrade and maintain wastewater sludge infrastructure and waste disposal; and **(6)** Payment for ecological infrastructure services.	**(1)** Contracts/ bonds (*e.g.,* land retirement contracts); **(2)** Voluntary standards and management systems (*e.g.,* ISO 14001); and **(3)** Voluntary certification schemes (*e.g.,* Global G.A.P.), linked to independent audits. Good audit results can be incentivised through tax rebates, subsidies or similar transfers.

Note: ***** May require a legislative amendment.[362]

[360] Refer to **POLICY STATEMENT 1**: Application of management instruments for environmental compliance in eutrophication management.

[361] Refer to Refer to S. 26(1)(i), NWA (36:1998): *"The Minister may make regulations prescribing the outcome or effect which must be achieved through **management practices** for the treatment of waste, or any class of waste, before it is discharged or deposited into or allowed to enter a water resource"*, and **Annexure G** for other regulations.

[362] Refer to **Annexure H** for a list of all recommended legislative amendments.

Given the broad scope of managing diffuse pollution beyond eutrophication, it is critical to establish a Diffuse Source Strategy for South Africa. This strategy should address the full spectrum of diffuse pollution challenges, including identifying vulnerable P and N zones for special regulatory attention, mandatory specific practices in these zones and legislative reviews[363] to support these initiatives.

[L] Differentiated water use management based on risk

To use limited government resources effectively and achieve the greatest impact, a targeted risk-based approach[364] must be adopted to control and manage water use. This approach prioritises state intervention based on the potential significance of water pollution impacts. Thus, areas of high sensitivity, activities with significant pollution potential and heavily affected regions will receive increased focus. Implementing this strategy involves:

- Categorising water polluters according to risk levels to enhance differentiated control and management practices, thereby supporting ecologically sustainable development;
- Adjusting administrative fees for water use authorisations to reflect relative risk and workload;
- Ensuring high-risk activities are appropriately regulated through the water use authorisation process;
- Extending financial provisioning requirements, currently applied to mining, to other high-risk water users to cover the need for potential *post facto* remedial actions.

Continuous improvement of the processes controlling and managing water uses is crucial for maintaining ecologically sustainable development and enabling swift, adaptive responses[365] to eutrophication challenges. Given that regulatory conditions serve as the practical implementation mechanism for policy and strategy, it is imperative that these conditions are reflective of catchment-specific needs. This may necessitate periodic revisions to regulatory conditions to accommodate evolving requirements for adaptive eutrophication management [DWS, 2017*c*:48].

6.4.2.2.3 Incentive-based regulation

The third operational strategy within the *"do"* stage of the eutrophication management framework, *viz. "incentive-based regulation"*, aims to align the interests of regulated anthropogenic activities with the eutrophication management goal by offering incentives to such activities for achieving

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[363] Refer to **Annexure H** for a list of all recommended legislative amendments.

[364] An amendment to the NWA (36:1998) is required to allow for the categorisation of polluting industries, based on risk. Refer to **Annexure H** for a list of all recommended legislative amendments.

[365] Refer to **Section 6.4.4.2.3, [B]**: Continuous management improvement – closing the loop!

desired outcomes. The potential components of incentive-based regulation and their purposes are outlined in **sections [A]** to **[E]**, below:

[A] Waste Discharge Charge System (WDCS)

Raw water pricing, in most cases, is undervalued and any waste discharge pricing will need to be commensurate with contemporary water pricing. The Waste Discharge Charge System (WDCS) is being developed to encourage waste reduction and water conservation. It is a component of the Pricing Strategy established under the NWA (36:1998). The WDCS is grounded in the Polluter-Pays Principle and aims to–

- promote the efficient use of water resources and support ecologically sustainable development;
- internalise potential external environmental costs;
- Create financial incentives, rather than punitive measures, to encourage the avoidance, prevention, and minimisation of water pollution, as well as the recycling and reuse of waste and water containing waste, in line with the Mitigation Hierarchy.[366] Furthermore, it promotes the optimal use of water resources; and
- Recover costs associated with mitigating the impacts on resource quality caused by waste and water containing waste related water uses.

The WDCS can apply differential rates for discharges to target those contributing to excessive nutrient loading. Factors considered include:

- Characteristics of the waste being discharged;
- Load and concentration of any substances in the discharge;
- Nature and extent of the impact on water resources caused by the discharged or disposed waste;
- Extent of deviation, if any, from prescribed WDSs or management practices; and
- The required extent and nature of monitoring the water use.

The implementation of the WDCS is essential in catchments or sub-catchments, regardless of whether relevant MCs (and RQOs/ Reserves) are being met, aligning with the waste mitigation hierarchy requirements of Section 2(4) of NEMA (107:1998).[366] Implementing the WDCS can significantly contribute to reducing anthropogenic eutrophication.[367]

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[366] Refer to **POLICY STATEMENT 2**: The Mitigation Hierarchy for decision-making on eutrophication.

[367] For the Waste Discharge Levy to be introduced, an amendment to the NWA (36:1998) is required to give the Minister permission to promulgate a Money Bill. Refer to **Annexure H** for a list of all recommended legislative amendments.

[B] Administrative penalties

Implementing a system of effective administrative penalties for water pollution offenses[368] extends enforcement by complementing criminal prosecution and fining offenders. While punitive, this system incentivises[369] polluters to reduce their pollution levels. Investigating and potentially implementing such a system is crucial, as it is supported by international best practices [Mandiberg & Faure, 2009:458] and would empower environmental compliance officers to issue penalties on the spot. However, this would require an amendment to the NWA (36:1998).[370]

[C] Certification Schemes

Non-economic incentive-based regulatory approaches, specifically the utilisation of certification schemes, have gained significant momentum in South Africa [DWS, 2014:42]. The current schemes include the–

- **Blue Drop Certification Programme:** Focuses on drinking water regulation;
- **No Drop Certification Programme:** Concentrates on water use efficiency and water loss management; and
- **Green Drop Certification Programme:** Addresses wastewater regulation.

The Green Drop process involves measuring and comparing the performance results of water service authorities and their providers using a standardised scorecard. Subsequently, the municipality is rewarded or penalised based on evidence of excellence or failures in meeting defined minimum requirements. Awareness of performance is heightened through pressure from customers, the media, political entities and NGOs.

The Programme centres around identifying municipalities with mediocre performance, prompting them to address identified shortcomings. It also aims to foster competitiveness among municipalities through benchmarking in a market where direct competition is challenging to implement. Strengthening, expanding and consistently implementing the GDS[371] is crucial for improving the unacceptable trophic conditions prevalent in many receiving water resources.

[D] Water Polluter Register

The introduction of a Water Polluter Register (or Water User Register) would expand reporting beyond municipalities and incentivise polluters to reduce their pollution. This initiative should be thoroughly investigated and potentially implemented. In the Water Polluter Register, entities

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[368] Refer to **Section 6.4.4.2.2, [A]**: Administrative penalties.

[369] Refer to **POLICY STATEMENT 7**: Incentive-based regulation.

[370] Refer to **Annexure H** for a list of all recommended legislative amendments.

[371] The Green Drop Certification Programme has been relaunched by the Department of Water and Sanitation with a full Green Drop audit to be conducted in 2021/22.

adhering to BMP standards would be acknowledged, while non-compliance by polluters would be highlighted. Such a system would necessitate an amendment to the NWA (36:1998).[370]

[E] Eco-labelling

Eco-labelling can be viewed as an extension of traditional marketing practices – a response driven by industry to the growing commercial demands of environmentally conscious consumers [Ecolabel Index, 2021]. According to Wojnarowska, *et al*. (2021:4), the objectives of eco-labelling encompass:

- Improving sales or enhancing the image of labelled products;
- Increasing consumer awareness;
- Providing accurate information to the public;
- Encouraging manufacturers to consider the environmental impact of their products; and
- Contributing to environmental protection.

Given the aspirations of the eutrophication governance policy,[372] it is imperative to explore and potentially implement an eco-labelling scheme for addressing problem nutrients. This endeavour would necessitate an amendment to the NWA (36:1998).[373]

6.4.2.3 Spatial scale of implementation

The *"do"* stage of the eutrophication management framework focuses on operational strategies that emphasise source-directed management. This approach targets the sources of impacts by applying measures and controls customised for each specific source. Typically, relevant authorities are responsible for establishing and enforcing these Source-Directed Measures and Controls. However, the private sector also plays a significant role through self-regulation and voluntary initiatives. Furthermore, civil society actively engages in the management decisions and frequently acts as watchdogs, playing crucial roles in oversight processes.

6.4.2.4 Temporal scale of implementation

The development and implementation of BMPs tailored to South Africa can be a time-consuming process. As a result, building a comprehensive portfolio of these practices may take a significant amount of time. In the absence of a complete set of BMPs, existing measures and controls need to be maintained and utilised. These measures primarily focus on adhering to emission and

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[372] Refer to **POLICY STATEMENT 6**: A life cycle view on nutrient loading.

[373] Refer to **Annexure H** for a list of all recommended legislative amendments.

WDSs, and conditional authorisations to avoid, prevent and minimise adverse water pollution resulting from land and water use.[374]

Operational strategies within the *"do"* stage of the eutrophication management framework can be executed either on an *ad hoc* or regular basis, depending on their intended purpose. A summary of potential actions in the *"do"* stage, aimed at improving the trophic status of water resources, is provided in **TABLE 37** and should be carefully considered for implementation.

TABLE 37: Operational actions to strengthen the *"do"* stage of the eutrophication management framework.

	SHORT TERM
(1)	Deal comprehensively with phosphorus loads in wastewater from WwTWs and render these in line with the assimilative capacity of receiving water resources;
(2)	Promote the reduction, recycling and re-use of excessive nutrient load containing waste and/or wastewater, in accordance with relevant geographic water quality management strategies and thematic plans;
(3)	Gazette uniform mandatory national WDSs, specifically revising all eutrophication-related standards, in support of water use authorisations;
(4)	Address shortcomings with respect to the authorisation conditions of some ELUs that cause, or may potentially cause, excessive nutrient loading and anthropogenic eutrophication;
(5)	Develop and implement a protocol to differentiate between water users in terms of risk. The differentiated control and management of sources of excessive nutrient loading will enable the prioritisation of action and resources;
(6)	Develop and implement a protocol for an integrated licencing processes to streamline authorisations, including CMA engagement. Efficient authorisation is vital to effective eutrophication control and management;
(7)	Finalise the WDCS strategy for implementation nationally, including waste discharge charges for nutrient loading;
(8)	Establish financial incentives to promote water-reuse and recycling, including the reuse of municipal wastewater, when the water budg*et al*lows for it;
(9)	Develop and/or implement (an) incentive-based programme(s) to benefit eutrophication management, *e.g.,* revitalisation of the GDS;
(10)	Validate and verify (V&V) registered water use with a direct water quality impact;
(11)	Develop and publish a National Pollution Register, which, amongst others, shows compliance to nutrient standards;
(12)	Achieve and ensure compliance to the requirements of all water use authorisations, specifically including water users that contribute, or may potentially contribute, towards anthropogenic eutrophication;
(13)	Undertake targeted compulsory licensing/ revision of water use authorisations to ensure compliance with statutory RDMs in key river systems/ WMAs, as necessary;
(14)	Promote cleaner production and technologies, specifically to combat anthropogenic eutrophication;

[374] Refer to **POLICY STATEMENT 2:** The Mitigation Hierarchy for decision-making on eutrophication.

SHORT TERM	
(15)	Eliminate hazardous substances and identify priority substances (including a priority list of unacceptable chemical compounds/ constituents);
(16)	Investigate and establish stormwater quality measures and controls;
(17)	Investigate and establish measures and controls for diffuse pollution;
(18)	Develop BPGs for pollution avoidance and prevention, minimisation, remediation and offsetting; and
(19)	Develop sectoral standards of best management practices and continuous improvement.
LONGER TERM	
(20)	Develop and implement (a) management system(s) to support an integrated licensing approach;
(21)	Develop and implement sectoral off-setting policies for water quality and wetlands, based on the Overall Policy on Environmental Offsetting in South Africa [DEA, 2018:3]; and
(22)	Develop a publicly accessible register of all offsets to facilitate compliance monitoring.

6.4.3 The *"check"* stage

Altogether, the *"check"* stage in the eutrophication management framework must–

- support transboundary and international monitoring campaigns;
- monitor compliance of land and water use activities with relevant regulatory requirements aimed at reducing anthropogenic eutrophication;
- generate national and regional intelligence on nutrient loading and the trophic status of water resources;
- evaluate the implementation and effectiveness of management interventions designed to limit anthropogenic eutrophication; and
- establish suitable information management systems to enhance data handling and facilitate the generation of valuable eutrophication-related management information and intelligence.

The *"check"* stage, thus, emphasises four key operational strategies, as outlined in **FIGURE 90**, *viz.*: **(1)** ***"International and transboundary status and trends monitoring and reporting"***; **(2)** ***"Domestic status and trends monitoring and reporting"***; **(3)** ***"Management performance monitoring and reporting"*** and **(4)** ***"Data acquisition and information management"***.

These four operational strategies aim to gather essential data and information to guide effective management interventions, preventing and reducing the harmful impacts of excessive nutrient levels in waterbodies. By consistently monitoring various parameters, authorities can pinpoint trends, hotspots and potential pollution sources, enabling targeted and evidence-based actions. Taking a data-driven approach facilitates timely measures, such as reducing nutrient loads,

restoring ecological infrastructure and promoting sustainable land and water use practices. Therefore, the operational strategies executed during the *"check"* stage are crucial for improving and redirecting management interventions to protect the health and biodiversity of waterbodies.

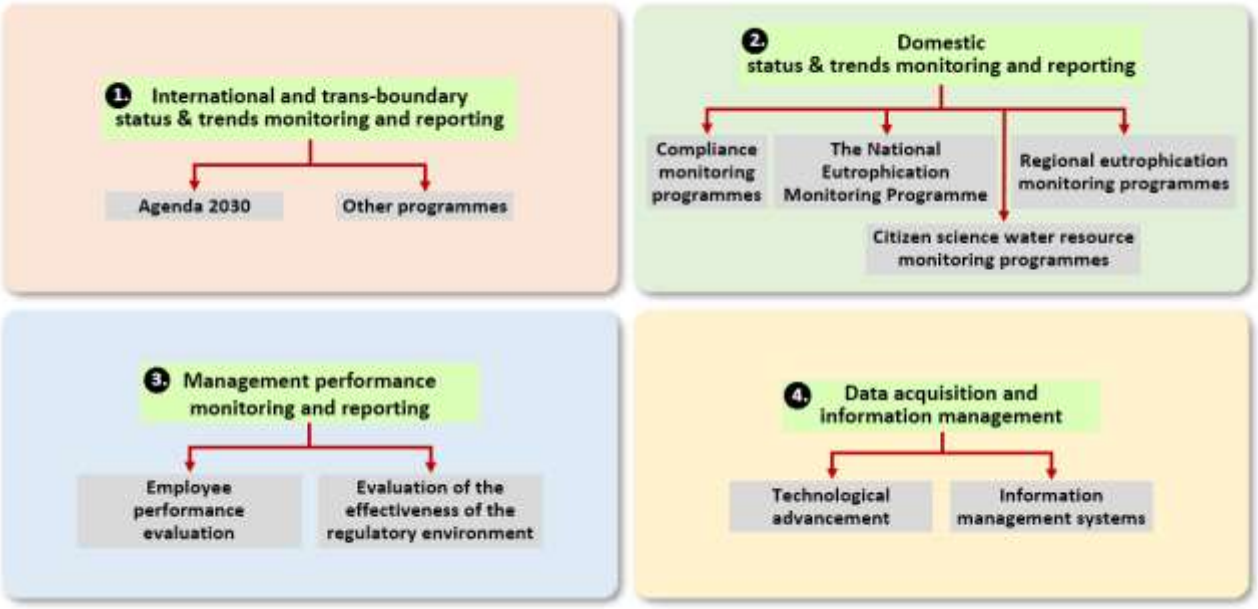

FIGURE 90: Conceptual outline of the *"check"* stage in the eutrophication management framework.

The four operational strategies in the *"check"* stage of the eutrophication management framework, and their purposes and composition, are narrated for easy reference purposes in **TABLE 38**:

TABLE 38: The operational strategies, in the *"check"* stage of the eutrophication management framework, and their composition.

OPERATIONAL STRATEGIES AND PURPOSE		KEY COMPONENT(S)
(1) International and transboundary status and trends monitoring and reporting	*To support transboundary and international eutrophication management related monitoring programmes.*	**[A]** Agenda 2030 and potential similar future programmes; and
		[B] Other international and transboundary eutrophication-related monitoring programmes;
(2) Domestic status and trends monitoring and reporting	*To monitor land and water use compliance to eutrophication management related regulatory requirements, and to track the national and regional trophic statuses of water resources.*	**[A]** Compliance monitoring programmes;
		[B] The National Eutrophication Monitoring Programme;
		[C] Regional eutrophication monitoring programmes; and
		[D] Citizen science water resource monitoring.
(3) Management performance monitoring and reporting	*To track the implementation and effectiveness of eutrophication management measures.*	**[A]** Employee performance evaluation; and
		[B] Evaluation of the effectiveness of the regulatory environment
(4) Data acquisition and information management	*To ensure access to eutrophication-related data and information.*	**[A]** Technological advancement; and
		[B] Information management systems.

6.4.3.1 Authority

Monitoring the causes of anthropogenic eutrophication, the impacts of excessive nutrient loading on water resources and the effects on socio-economic development by relevant authorities[375] is crucial. This monitoring is essential for evaluating the effectiveness of regulatory measures, identifying potential management gaps and recognising opportunities for improvement. Competencies (sectors), which are relevant here, include: ♦ agriculture; ♦ the environment; ♦ health; ♦ monitoring and evaluation; and ♦ water and sanitation. The roles of competent authorities are outlined in **Section 6.6** under ***"Governance responsibilities"***, which provides additional clarity on the allocation of tasks concerning eutrophication governance.

6.4.3.2 Prescribed approaches

6.4.3.2.1 International and transboundary status and trends monitoring and reporting

The first operational strategy within the *"check"* stage of the eutrophication management framework, namely *"international and transboundary status and trend monitoring and reporting"*, plays a crucial role in supporting the objectives of international water law. These objectives include preventing significant harm to co-basin states, ensuring equitable and reasonable use of water resources among co-basin states, and fostering transboundary and international water cooperation [McIntyre, 2022]. The components of *"international and transboundary status and trend monitoring and reporting"*, and their purposes are outlined in **sections [A]** and **[B]**, below:

[A] Agenda 2030 and potential similar future programmes

Agenda 2030 mandates consistent monitoring of designated targets and their indicators. South Africa is required to update the UN every three years on six primary and two ancillary targets concerning the sustainability of *"clean water and sanitation"*. The six **primary targets** under Goal 6 on *"clean water and sanitation"* address (**6.1**) *"drinking water"*, (**6.2**) *"sanitation and hygiene"*, (**6.3**) "*wastewater and water quality"*, (**6.4**) *"water use and scarcity"*, (**6.5**) *"integrated water resource management"* and (**6.6**) *"water related ecosystems"*, while the **ancillary targets** include (**6.a**) *"international cooperation"* and (**6.b**) *"local participation"*.

FIGURE 91 illustrates the indicators for **Target 6.3** on *"wastewater and water quality"*. Indicator 6.3.2 serves as the ultimate indicator for assessing and monitoring the fitness-for-use of a country's water resources. Reporting on this indicator includes the statuses and trends of nitrate-nitrite (NO_3-NO_2) and orthophosphate (PO_4^{3-}) in receiving water resources.

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[375] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

FIGURE 91: Relationship between SDG Target 6.3 and its indicators [Van Wyk, *et al.*, 2020:3].

Furthermore, Agenda 2030 emphasises the significance of regular compliance monitoring and reporting to the UN on several point and diffuse[376] sources of water pollution that potentially contribute towards anthropogenic eutrophication.

Reporting on these aspects to the UN should not be seen as additional obligations but should instead be seamlessly integrated into daily activities. This integration will enhance South Africa's domestic monitoring programmes,[377] and contribute towards the effective management of eutrophication and ensuring water security.[378] Just as the SDGs should form part of a country programme, eutrophication management should also be integrated into the national agenda to promote and facilitate ecologically sustainable development.

[B] Other international and transboundary eutrophication-related monitoring programmes

International and transboundary status and trend monitoring programmes are focused on shared water basins, ecological infrastructure of international significance and other critical global issues. These programmes aim to address matters of common interest, promote healthy relations and

[376] It is foreseen that diffuse sources of pollution will be addressed through the inclusion of *"Additional"* indicators. See **FIGURE 91**.

[377] Refer to **Section 6.4.3.2.2:** Domestic status and trends monitoring and reporting**.**

[378] Refer to **TABLE 13**: SDG 6 targets and indicators, with direct relevance to eutrophication management.

encourage sustainable water resource use and development through collaboration and water diplomacy.

Launched in 1978 as a collaborative interagency effort under the UN, the **GEMS/Water Programme** stands as an exemplary international monitoring initiative. It is designed to collect water quality data to evaluate trends in global inland water quality. South Africa joined the GEMS/Water Programme in 2003 and has been an active participant since, as documented by Van Niekerk (2004:1). The programme operates in over 124 countries worldwide, providing water quality data to the GEMStat central database. **FIGURE 92**, a product of this programme, presents an international perspective on TP loading in major lakes, highlighting differences in modes of anthropogenic eutrophication between industrialised and agricultural economies, as well as developed and developing countries.

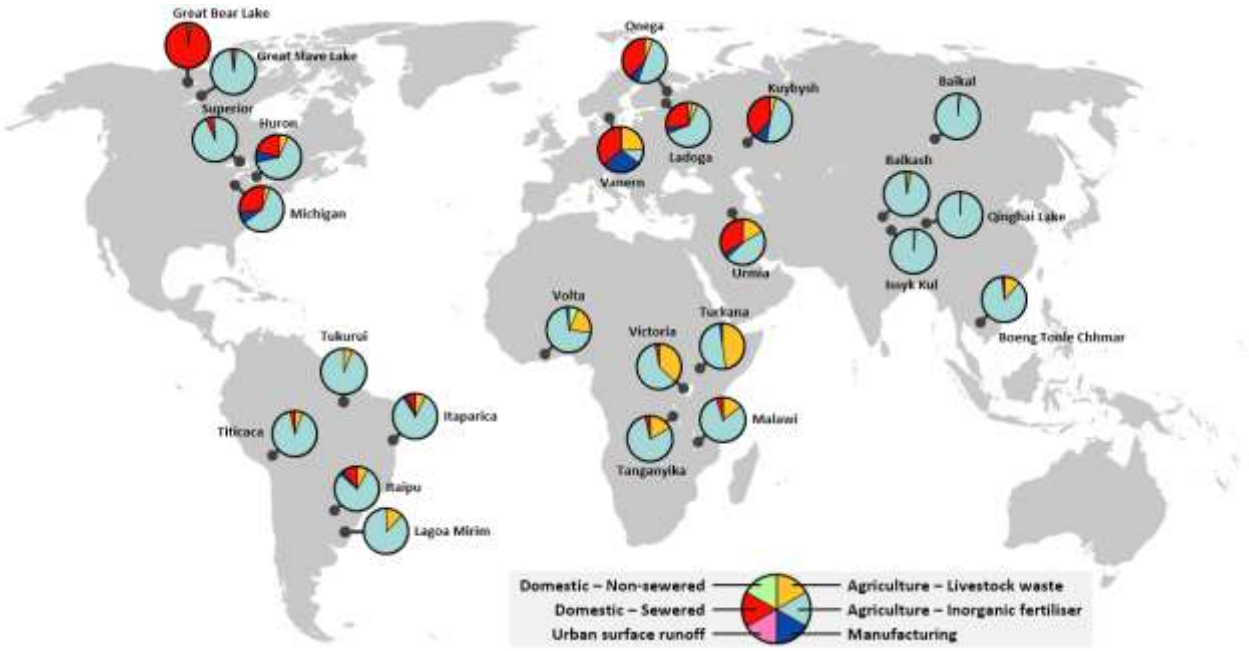

FIGURE 92: Sources of anthropogenic Total Phosphorus (TP) loadings of major lakes, shown as average percentage contributions to annual loading between 2008 and 2010 [UNEP, 2016:45].

The **Ramsar Convention on Wetlands** [379] represents another significant international collaborative drive. South Africa, along with over 170 other countries, signed this convention to manage recognised significant wetlands. Since becoming a signatory in 1975, South Africa has the obligation to regularly report on the status of its 27 designated Ramsar Wetlands [Ramsar, 2021]. The Blesbokspruit Wetland and Orange River Mouth Estuary, both recognised as Ramsar sites in South Africa and currently listed on the Montreux Record, faces significant

[379] Refer to **POLICY STATEMENT 8**: Nature-based solutions.

challenges from excessive nutrient and hydraulic overloading – symptoms of highly regulated river systems.

Additionally, South Africa shares three river basins with neighbouring countries in the SADC Region (**TABLE 39**). Among the transboundary RBOs linked with South Africa, ORASECOM became fully operational first, in 2000. ORASECOM undertook its inaugural **joint basin survey** in 2010 with plans for five yearly repetitions. The latest survey revealed trends of exacerbating eutrophic conditions in the Orange-Vaal River System, particularly near urban centres, including downstream of Maseru, Lesotho [ORASECOM, 2022:10,43]. This underscores the importance of transboundary collaboration in monitoring, data sharing, reporting and managing eutrophication.[380]

TABLE 39: Shared River Basins and River Basin Organisations (RBOs).

SHARED BASIN	CO-BASIN STATES	RIVER BASIN ORGANISATIONS	AGREEMENT
Inco-Maputo	(1) Eswatini; (2) Mozambique; and (3) South Africa.	Tripartite Permanent Technical Committee between the Republic of Mozambique, the Republic of South Africa and the Kingdom of Eswatini ***(TPTC)***	Tripartite Interim Agreement between the Republic of Mozambique and the Republic of South Africa and the Kingdom of Eswatini for co-operation on the protection and sustainable utilisation of the water resources of the Inkomati and Maputo Watercourses (2002)
Orange Senqu	(1) Botswana; (2) Namibia; (3) Lesotho; and (4) South Africa.	Orange-Senqu River Commission ***(ORASECOM)***	Revised Agreement between the governments of the Republic of Botswana, the Kingdom of Lesotho, the Republic of Namibia and the Republic of South Africa on the establishment of the Orange-Senqu Watercourse Commission (2019)
Limpopo	(1) Botswana; (2) Mozambique; (3) South Africa; and (4) Zimbabwe.	Limpopo Watercourse Commission ***(LIMCOM)***	Agreement between the Republic of Botswana, the Republic of Mozambique, the Republic of South Africa and the Republic of Zimbabwe on the establishment of the Limpopo Watercourse Commission (2003)

6.4.3.2.2 Domestic status and trends monitoring and reporting

The second operational strategy within the *"check"* stage of the eutrophication management framework is *"domestic status and trends monitoring and reporting"*. Domestic compliance and resource quality status and trends monitoring, particularly concerning eutrophication management, should prioritise focus, cost-effectiveness and sustainability, ensuring that monitoring programmes adhere to the following guidelines [DWAF, 2006b:53], *viz.*:

- Monitoring programmes should have clearly defined objectives;

[380] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

- Monitoring designs should offer valuable information at minimal cost;
- Data evaluations and reports should facilitate informed decision-making;
- Efforts should be made to avoid duplication at all stages of implementation; and
- Relevant partnerships with stakeholders willing to share costs and benefits should be pursued.

Given potential limitations in financial and other resources, it is crucial to consistently collect reliable and verified resource quality data to support effective water resource planning, informed decision-making, efficient eutrophication management and internationally or transboundary-supported programmes.

Water quality, quantity and aquatic ecosystems are interconnected, and specific eutrophication-related data and information (as outlined in **TABLE 40**) are considered essential depending on whether causes or effects are being monitored. Regular utilisation of TSIs to classify waterbodies based on their biological productivity, in conjunction with nutrient-loading data, can inform eutrophication management and assess performance. Consideration must also be given to include TSI information in the MCs (and RQOs/ Reserves) to firmly link resource requirements with SDCs, and regional water quality monitoring programmes.

TABLE 40: Eutrophication-related variables.

MONITORING TYPE	PARAMETER
Drivers/ stressors	
Physico-chemical monitoring	Typically, inorganic variables, but also physical attributes, organic and inorganic toxicants, including temperature, pH, turbidity, Secchi disk depth, DO, BOD, COD and nutrients.
Microbial monitoring	Typically, faecal microorganisms, such as *Escherichia coli*, which are also often associated with poorly operated WwTWs. Microbial processes happen within the cycle of aquatic life and are relevant in the assessment of eutrophication and nutrient budgets.
Volumetric monitoring	Typically stream flow or effluent discharge volumes, necessary to determine loading * and dam volumes for assimilative capacity.
Responses	
Eutrophication monitoring	Use TSIs (*e.g.,* TP and Chl-α) as indication of the trophic conditions of surface water resources.
Biomonitoring	Use bio-indicators, such as diatoms, and other invertebrates, and fish, to assess aquatic ecosystem health. Silicon (Si) is an indicator of freshwater dispersion and potential for diatom blooms.
Toxicity monitoring	Such as neuro- and hepato-toxins, released from some algal species, which can kill animals and pose a threat to human health. The presence of specific algal species will contribute to knowing which toxins to measure for.

Note: * *"Total load"* is a useful indicator of eutrophication impacts on water resources. A *"high concentration"* indicates an immediate problem, but if only present in a small flow volume, the overall impact will be limited and/or local. The use of grab sampling with relatively low sampling frequencies for the calculation of nutrient loading would fail to provide accurate load estimates, and generally under-estimate the total loads being moved through a river system.

Adequate resourcing and reinforcement of monitoring programmes are necessary to combat excessive nutrient loading and anthropogenic eutrophication effectively.

Eutrophication-related information needs can vary significantly, influenced by factors such as the spatial scale of interest, depicted in **FIGURE 93**.

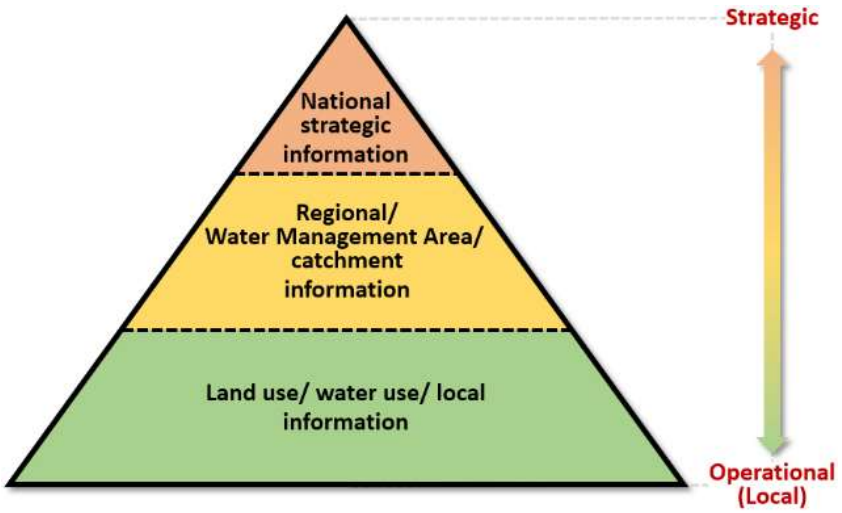

FIGURE 93: Hierarchy of domestic information requirements for eutrophication management [adapted from DWAF, 2006e:9].

The following components of *"domestic compliance and resource quality status and trends monitoring and reporting"* are essential:

- Compliance monitoring;
- National eutrophication monitoring;
- Regional eutrophication monitoring; and
- Citizen Science water resource monitoring.

The purposes and details of each component (also referred to as *"monitoring programmes"*) within this operational strategy are detailed in **sections [A]** to **[D]**, as outlined below:

[A] Compliance monitoring programmes

The **purpose of compliance monitoring**, includes assessing the compliance levels of–

- land and water users, such as municipalities, with **non-economic incentive-based regulatory schemes** like Green Drop certification;[381]
- land and water users with local or regional water resource quality requirements as a means to control **diffuse impacts**;[382] and

[381] Refer to **POLICY STATEMENT 7**: Incentive-based regulation.
[382] Refer to **Section 6.4.2.2.2, [K]:** Diffuse pollution sources**.**

- land and water users with relevant regulatory requirements, such as **conditions outlined in authorisations** (including alternative authorisations),[383] specifically also WDSs[384] set for effluent discharges, BMPs,[385] and requirements of voluntary regulatory schemes like ISO14001.

In the interim until revised, the General and Special Standards for the purification of Wastewater or Effluent can be used to assess most effluent data [GN R.991, 1984]. The South African Water Quality Guidelines, in the absence of suitable RDMs, can be used to assess water resources [DWAF, 1996:Vol.1-7]. Where RQOs and supporting RWQOs/ WQPLs were determined, these should be sensibly back-calculated to WDSs to assess effluent data in a catchment context.[386]

The primary users and the utility of compliance information, along with their responsibilities, are summarised in **TABLE 41**. It is important to classify regulatory non-compliance based on specific criteria, which may include the frequency of non-compliance, the potential severity, the likelihood of recurrence, existing management systems to ensure compliance and the management measures taken to resolve non-compliance.

TABLE 41: Compliance monitoring information – key users, use and management responsibilities.

KEY USER	USE OF INFORMATION	MANAGEMENT RESPONSIBILITY
Land or water user	The information will indicate to land and water users the extent to which adequate measures have been taken to limit and control likely impacts on the quality of local water resources. Non-compliance can indicate the need for pro-active corrective actions to be taken by such land and water users.	The primary responsibility for regulatory compliance resides with the individuals or organisations whose water or land use is being monitored. Water use licence conditions typically stipulate upstream and downstream monitoring, and monitoring of any discharge of water containing waste.
Relevant authority	The information will indicate whether land and water uses are complying with regulatory conditions, such as those contained in water use licenses. Non-compliance may lead to several possible actions to ensure regulatory compliance.	Relevant authorities have the responsibility to audit the results by performing their own sampling and analysis.

Expanding non-economic incentive-based regulation,[387] like Green Drop Certification, to other non-municipality water users should be considered to broaden compliance monitoring programmes,[388] reporting and transparency.[389]

Regulatory non-compliance can potentially be classified as follows:

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[383] Refer to **Section 6.4.2.2.2, [J]**: Alternative authorisations.

[384] Refer to **Section 6.4.2.2.2, [B]**: Waste Discharge Standards (WDSs).

[385] Refer to **Section 6.4.2.2.1**: Best management practice.

[386] Refer to **POLICY STATEMENT 5**: The Receiving Water Quality Objectives Approach applied to eutrophication management.

[387] Refer to **POLICY STATEMENT 7**: Incentive-based regulation.

[388] Refer to **Section 6.4.2.2.3, [D]**: Water Polluter Register.

[389] Refer to **POLICY STATEMENT 17**: Transparency.

- **Critical non-compliance:** Presents a significant risk that requires immediate interruption or cessation of an activity (*e.g.*, an activity causing adverse human health effects);
- **Major non-compliance:** Presents a significant risk that necessitates immediate intervention (*e.g.*, an activity causing adverse economic effects on tourism);
- **Minor non-compliance:** Presents a low risk (*e.g.*, some non-compliances that are administrative in nature); and
- **Observations:** Identifies an opportunity for improvement (*e.g.*, a potential issue that could develop into non-compliance without further action).

Catchment compliance monitoring (**FIGURE 94**) typically includes–

- monitoring upstream and downstream of point and diffuse sources of impact (*"Level 3"*);
- monitoring of discharges of water containing waste for compliance with authorisation conditions purposes (*"Level 4"*); and
- the monitoring of resource quality variables relevant to the impact or as specified in the applicable authorisation.

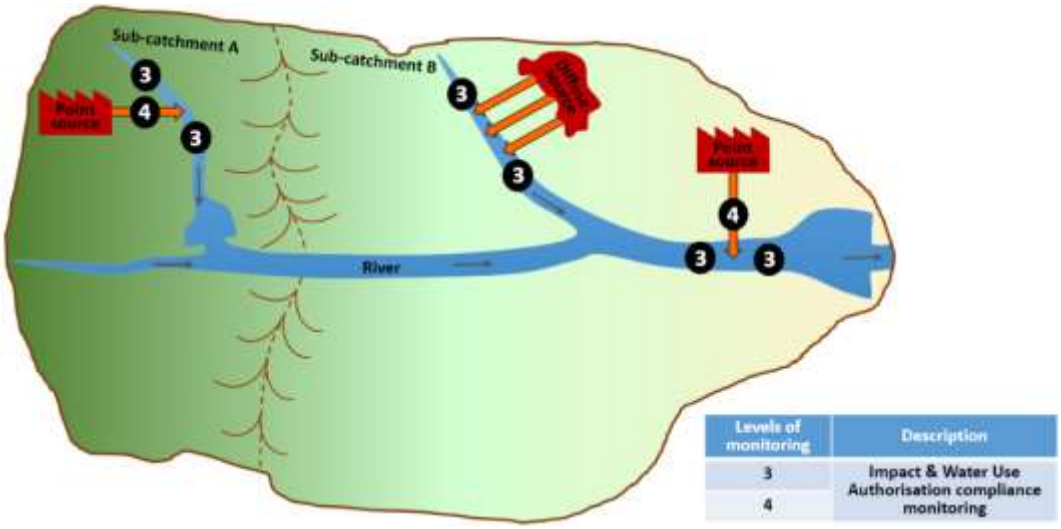

FIGURE 94: Illustration of compliance monitoring levels [adapted from DWAF, 2006e:26].

Data will be converted into information and regularly (quarterly or longer) published in compliance monitoring reports that explicitly also address nutrient loading-related compliance.

[B] The National Eutrophication Monitoring Programme (NEMP)

The **purpose of national eutrophication monitoring** is to regularly measure, assess and report the status, spatial patterns and trends concerning excessive nutrient loading and anthropogenic eutrophication in South African water resources. This process is designed to provide crucial

support for making strategic eutrophication management decisions at a national level, within the contexts of fitness-for-use and aquatic ecosystem integrity.[390]

National water resource quality monitoring, as shown in **FIGURE 95**, typically involves–

- monitoring at sites that are chosen at a low spatial resolution, but at strategically important sites from a national point of view (*"Level N"*);
- the monitoring of resource quality variables that may relate to any international responsibilities; the Reserve and any in-water resource water quality objectives, such as RQOs.

The strategic responsibilities underlying the necessity for national eutrophication monitoring include:

- Evaluating the overall national effectiveness of eutrophication governance policies and strategies, which are often regionally focussed;
- Fulfilling international obligations and engaging in sanctioned global and transboundary initiatives;
- Staying informed about international trends in emerging issues; and
- Building monitoring capacity, particularly during the existing transitional phase as CMAs are established, on which further region-specific capacity development can be built.

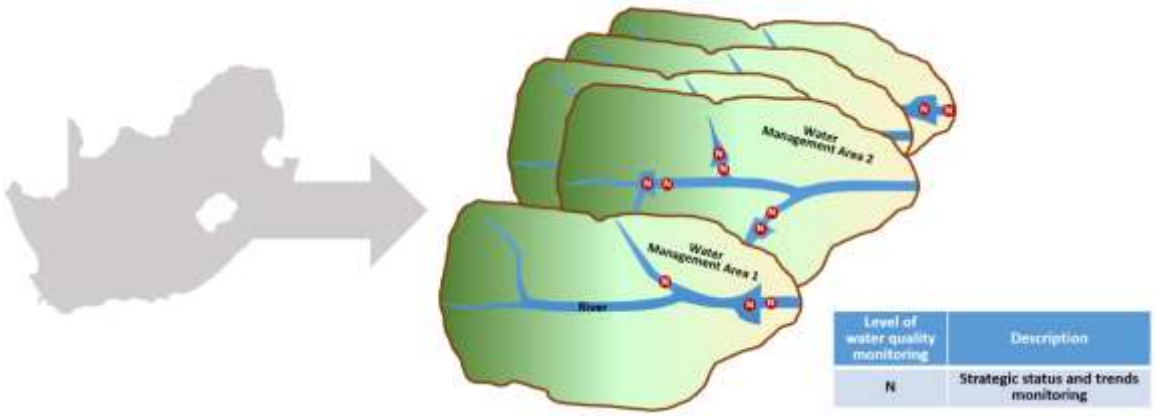

FIGURE 95: Illustration of national (N) status and trend monitoring [adapted from DWAF 2006e:26].

The DWS oversees the NEMP. The NEMP's objectives, as outlined by DWAF (2002:(6)14-(6)40) include:

[390] The National Aquatic Ecosystem Health Monitoring Programme (NAEHMP) incorporates, among others, the River Eco-status Monitoring Programme (REMP) previously known as the River Health Programme (RHP), the National Estuaries Monitoring Programme (NEsMP), and the National Wetland Monitoring Programme (NWMP). This comprehensive programme offers insights into various facets of aquatic ecosystem quality. When paired with the National Eutrophication Monitoring Programme (NEMP), it enhances the understanding of how nutrient loading affects aquatic ecosystems.

- Assessing the trophic status of key reservoirs (*i.e.,* TSIs); and
- Establishing early warning systems for wastewater treatment, algal blooms, the presence of invasive macrophytes, longer-term impacts and strategic nutrient balances.

Data will be converted into information and regularly (annually or longer) published as eutrophication management related status and trends reports, such as the Status of the Water Resources Reports and Water Quality Planning-level Review Reports.

[C] Regional eutrophication monitoring programmes

The **purpose of regional eutrophication monitoring** is to consistently measure, assess and report on the status and spaciotemporal trends of excessive nutrient loading and anthropogenic eutrophication in significant water resources. This process is structured to aid strategic and operational eutrophication management decisions in WMAs, with a focus on fitness-for-use and aquatic ecosystem integrity.

While *"Level N"* monitoring sites are part of the national eutrophication monitoring network, *"Levels 1 to 4"* monitoring sites are dedicated to regional water resource quality monitoring [DWS, 2017f:17]. These regional sites are selected to provide crucial eutrophication management-related intelligence, supporting IWQM at the WMA level and its sub-catchments (illustrated in **FIGURE 96**), as follows:

- **Impact and water use authorisation compliance monitoring:** This typically involves upstream and downstream monitoring to identify sources of impact, including diffuse impacts at *"Level 3"*, and monitoring effluent discharges to ensure compliance with *"end-of-pipe"* WDSs at *"Level 4"*;
- **Strategic status and trends monitoring:** This includes monitoring major watercourses (*"Level 1"*) and significant tributaries (*"Level 2"*), benchmarking *status quo* monitoring results against in-water resource water quality objectives and NLOs; and
- **Reserve monitoring:** Assessing if the water quality, flow or ecosystem health components of the Reserve is met, possibly requiring monitoring at *"Level 3"*, *"Level 2"* or *"Level 1"*.

The DWS assumes the primary responsibility for all national and, in the absence of CMAs, regional water quality monitoring programmes through proto-CMAs. However, the responsibility for implementing and managing data for regional monitoring programmes will transition to CMAs once they are established, fully operational and adequately equipped. In areas where CMAs are established, regional eutrophication monitoring should be embedded into corresponding CMSs.

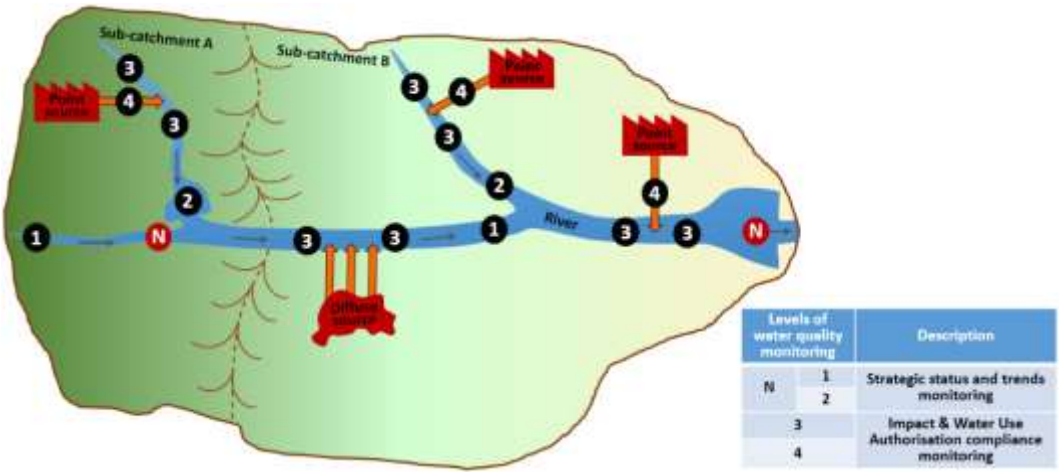

FIGURE 96: Illustration of compliance, and national and regional monitoring [adapted from DWAF 2006e:26].

There is a need to increase the number of monitoring sites within the NEMP to achieve a resolution more appropriate for managing eutrophication in WMAs and their sub-catchments, as depicted in **FIGURE 97**. Adequate flow measurement at these sites is critical for assessing compliance with NLOs.[391] Data collected will be transformed into actionable information and published regularly (monthly or at greater intervals) in reports such as WMA Water Quality Status Reports, providing updates on eutrophication management status and trends. The application of TSIs for reporting purposes is recommended.

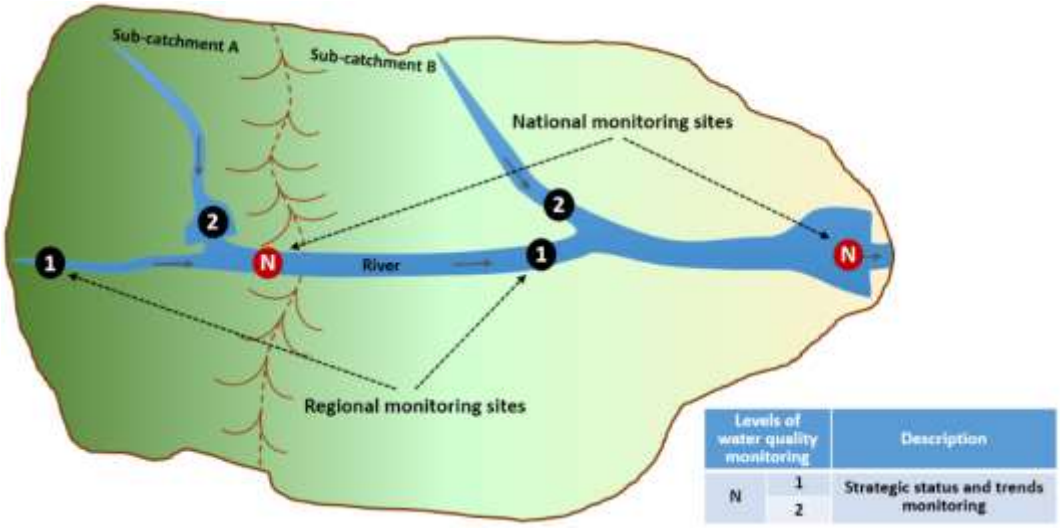

FIGURE 97: Augmenting national monitoring to obtain a regional profile [adapted from DWAF, 2006e:30].

[391] Refer to **Section 6.4.1.2.3, [B]**: Determination of Waste Load Objectives.

[D] Citizen science water resource monitoring

"Citizen science" refers to scientific research conducted by amateur scientists, non-professionals, retirees from water resource professions, engineers and interested individuals, often relying on crowdsourcing and crowdfunding. It involves the organised collection and analysis of data, development of technology, testing of natural phenomena and dissemination of findings by volunteers. This approach is also known as *"public participation in scientific research"*, as noted by Graham & Taylor (2018:10).

This monitoring approach is gaining traction and generating significant interest across scientific and societal spheres. It introduces a variety of water resource monitoring tools (see **TABLE 42**) that support catchment eutrophication management and enhance the public's understanding of eutrophication issues at grassroots level. This dual-direction learning helps citizens grasp the complexity of catchment eutrophication management while providing authorities with critical insights into significant eutrophication challenges.

TABLE 42: The Water Research Commission citizen science toolkit [Graham & Taylor, 2018:86-87].

AVAILABLE TOOLS	SUITABILITY TO MONITOR ASPECTS OF EUTROPHICATION
(1) Aquatic biomonitoring tool (miniSASS)	A low technology, scientifically reliable and inexpensive participatory tool which can be used by anyone to monitor the health of a river.
(2) The Riparian Health Audit;	The Riparian Health Audit is based on the scientific *"Index for Habitat Integrity"* (IHI) method. Users assess a riparian reach by determining its natural condition, identifying the extent of impacts in the reach and then rating the principal impacts, if any, that alter the ecological health of the riparian reach being assessed.
(3) The Water Clarity Tube;	Suspended solids affect water clarity and comprises several types of material, including soil particles, planktonic organisms and organic matter.
(4) The Transparent Velocity Head Rod;	A very simple tool to measure the velocity and discharge of a stream or river.
(5) The Wetland assessment tool;	A method for assessing wetland ecological condition based on land-cover type.
(6) The Estuary tool;	Assists with the monitoring and management of an estuary on a routine and structured basis.
(7) The Spring tool;	The Spring Health Index tool leads the citizen scientists through several steps to determine the current ecological condition of springs, starting with determining the location and type of such springs, investigating the surrounding land cover and use and the geomorphology of the area. The ecological condition is calculated as the percentage of change that has occurred to the spring system, compared to its natural (original) condition, giving a description of the current conditions of the spring.
(8) Rain Gauge;	Capturing of rainfall data.
(9) Weather monitoring tools; and	Capturing wind speed and direction, as well as temperature.

Despite the existing tools, as discussed in **TABLE 42**, which improve understanding of eutrophication-related conditions and contribute to better management efforts, a specific monitoring tool dedicated to nutrient enrichment *per se* is yet to be developed. This gap highlights an opportunity for further innovation in citizen science projects, focusing on nutrient enrichment and its management.

6.4.3.2.3 Management performance monitoring and reporting

The third operational strategy within the *"check"* stage of the eutrophication management framework deals with management performance monitoring and reporting. Achieving sound monitoring and reporting of the cause-and-effect indicators of eutrophication, as outlined in the preceding **Sections 6.4.3.2.2, [A], [B], [C] and [D]**, is by far the most pressing need. This view, however, need to be expanded to a more ambitious perspectives on monitoring to better understand the eutrophication causal chain. The third operational strategy in the *"check"* stage, entitled *"management performance monitoring and reporting"*, emphasises this crucial requirement for comprehensive monitoring and reporting. The paradigm shift, outlined in **sections [A]** and **[B]** below, consist of two components, *viz.,* ***"Employee performance evaluation"*** and ***"Evaluation of the effectiveness of the regulatory environment"***, that will assist in understanding, interpreting and presenting the results obtained through compliance and resource quality monitoring (presented in preceding sections).

[A] Employee performance evaluation

In most organisations, the performance of employees is methodically managed, evaluated on a regular basis and often reported in an annual summary through the implementation of performance management and development systems. These systems are invariably aligned with the organisation's goals or business plans.

This approach is similarly adopted within the civil service. To foster individual excellence and achievement, the government's approach to employee performance management, as outlined in DPSA (2007:10), aims to–

- cultivate a culture of performance and learning within the Public Service;
- improve service delivery;
- ensure all jobholders are fully aware and understand their job expectations;
- encourage regular discussions on performance between jobholders and their supervisors;
- identify, manage and support the development needs of jobholders;
- evaluate performance in a fair and objective manner;
- acknowledge performance levels that meet or exceed expectations; and
- address and manage underperformance effectively.

For annual evaluations, it is essential to incorporate specific performance criteria in the performance agreements of individual employees, particularly those civil servants and officials in local government with responsibilities related to managing the causes or effects of excessive nutrient loading. Performance criteria related to eutrophication management could include but are not limited to:

- The results of internal audits connected to the environmental compliance performance of the particular organisation (*e.g.,* industry or municipality);
- The Green Drop scores of one or more WwTWs;
- The percentage of waste or water containing waste that is recovered, recycled or reused within a specific geographic area or by a specific organisation (*e.g.,* industry or municipality);
- The percentage of effluent discharges or waste disposed in a given geographic area that are appropriately authorised and lawful; and
- The percentage of waterbodies, including groundwater, in a specific area that meets the determined in-water resource water quality objectives.

These criteria ensure that the performance evaluation process is comprehensive and focuses not only on meeting but also on exceeding eutrophication and sustainability management criteria.

[B] Evaluation of the effectiveness of the regulatory environment

This type of broader evaluation applies to the general ***"policy, strategy and law environment"*** and the effectiveness of specific ***"interventions"*** implemented to combat causes and effects of anthropogenic eutrophication. **Policies** guide **strategies** and often shape **legislation** too, highlighting the crucial role of evidence in the policy cycle [Presidency, 2020:15]. This evidence-based approach helps distinguish facts from opinions, assessing if policies meet their goals or need adjusting.[392]

The DPSIR Framework[393] can be utilised to evaluate how social and economic activities affect ecosystems, guiding societal responses to mitigate adverse effects by tackling root causes. Alternatively, the Government's Socio-Economic Impact Assessment System (SEIAS) can be utilised to review the social and economic impacts of policies, strategies and legislation related to eutrophication management.

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[392] Refer to **Section 6.4.4.2.3, [A]**: Policy and strategy revision, where necessary**.**

[393] The River Health Programme, amongst others, uses the DPSIR Framework.

Effectiveness monitoring and evaluation [Presidency, 2020:15], focus on:

- **Relevance:** Addressing nutrient loading to meet the eutrophication management goal;[394]
- **Significance:** Making impactful improvements on the trophic status of affected waterbodies;
- **Originality:** Generating new insights that were previously unknown;
- **Legitimacy:** Gaining the support of all relevant stakeholders;
- **Reliability:** Ensuring consistent data collection across different contexts;
- **Validity:** Linking outcomes directly to evaluated policies and strategies;
- **Objectivity:** Conducting evaluations impartially, with minimal bias; and
- **Timeliness:** Using recent data to guide future actions.

Continuous monitoring and evaluation of South Africa's eutrophication governance strategy are vital, with resource quality and trophic status as ultimate indicators. Strategy and implementation shortcomings are implied by ongoing deterioration and non-compliance. Evaluations should periodically benchmark progress against the Strategy and its implementation arrangements.

Effective intervention in relation to anthropogenic eutrophication requires robust water resource planning[395] and coherent execution based on geographic water quality management strategies and thematic plans.[396] Strategy steering committees, overseeing the implementation of geographic water quality management strategies and thematic plans, are pivotal in–

- identifying water quality (including eutrophication) concerns;
- coordinating strategy and plan implementation;
- promoting IWQM across sub-catchments;
- ensuring and updating strategy and plan implementation; and
- providing feedback on implementation progress and performance.

6.4.3.2.4 Data acquisition and information management

The last operational strategy within the *"check"* stage of the eutrophication management framework, *viz. "data acquisition and information management"*, plays a pivotal role in collecting, organising and analysing data to inform decision-making and optimise operational processes. The potential components of this operational strategy and their purposes are outlined in **sections [A]** and **[B]**, below:

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[394] Refer to **Section 5.3**: Visionary perspective.

[395] Refer to **POLICY STATEMENT 14**: Water resource assessment and planning to inform decision-making.

[396] Refer to **Section 6.4.1.2.4, [F]**: Establishment of geographic water quality management strategies and thematic plans.

[A] Technological advancement

The world is swiftly transitioning into the Fourth Industrial Revolution era, where mobile communications, social media and sensor technologies are reshaping how individuals interact with the internet and the physical world. It is vital to explore smarter working methods to leverage these technological advancements effectively. Strategic planning can help convert short-term costs into long-term benefits and upgrading information management practices is essential to enhance management efforts, ultimately improving the trophic status of waterbodies in South Africa.

The DWS was a pioneer in using satellite data for eutrophication monitoring in the 1980s [Howman, *et al.*, 1989:1-9; Howman & Kempster, 1986:1]. However, challenges such as limited sensor types, high costs of satellite imagery and inadequate computing power led to the discontinuation of the project. In recent times, advancements in space technology and satellite remote sensing have made it feasible to monitor eutrophication in standing waterbodies from space. With the aid of sophisticated algorithms and data from the Medium-Resolution Imaging Spectrometer (MERIS) on the European Space Agency's Envisat [Matthews, 2014:3-4; Matthews & Bernard, 2015:8], retrospective analyses of chlorophyll-α levels,[397] cyanobacterial blooms and surface scum in South African dams from 2002 to 2012 have become achievable and are readily accessible through the DWS's WMS database.

The development of newer sensors on the European Space Agency's Sentinel satellites [Matthews & Kravitz, 2019:5], in combination with cellular technology, has led to the creation of the CyanoLakes™ App in collaboration with the WRC [WRC, 2022:32-34]. This innovative app provides quantitative water quality information for South Africa's waterbodies using a time series of Earth observation data. Available globally on Android and Apple devices, the app is groundbreaking in its ability to offer critical water quality insights not only in South Africa but also internationally for waterbodies within specific size limits. Calibration against *in-situ* monitoring remains crucial for the success of satellite remote sensing, underscoring the ongoing importance of initiatives like the NEMP.

Exploring alternative, cost-effective technologies is essential for more efficient eutrophication management.[398] Solutions like drone technologies (despite existing legislative hurdles) for water channels and reservoir monitoring, smart sensors for effluent tracking from WwTWs, and predictive maintenance scheduling can significantly enhance monitoring efforts.

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[397] Chlorophyll-α (Chl-α) is a proxy for eutrophication.

[398] **POLICY STATEMENT 16**: Promotion of eutrophication-related research.

In alignment with the Fourth Industrial Revolution, ensuring data and information availability keeps pace with the evolving technological landscape is crucial. Embracing Application Programming Interface (API) technology can facilitate easier access to data for app developers, enabling the real-time display of eutrophication management-related information in user-friendly applications, akin to weather apps.

[B] Information management systems

The process of primary data capture can generally occur in at least two ways, *viz.*:

- Capturing results in the laboratory; or
- Capturing laboratory results by the data owner (whether an authority, a land or water user) onto a centralised database.

In both scenarios, it is crucial to minimise the likelihood of human error. Establishing clear and robust protocols is essential to ensure that captured data, once inputted into a centralised database, are stored in a manner conducive to subsequent efficient access and processing. All data must be stored so they can be made available–

- upon reasonable requests from stakeholders or interested parties. Data held by the state should be available at a reasonable cost, if necessary, in accordance with the AIA (2:2000) and the NWA (36:1998);
- preferably online and free of charge, particularly to learners, scholars and pensioners; and
- to report on eutrophication-related matters as part of formal and regular information dissemination mechanisms, including requirements of water use authorisations for resource quality data.

TABLE 43 provides descriptions of relevant DWS corporate information management systems:

TABLE 43: Departmental information management systems.

INFORMATION MANAGEMENT SYSTEM	APPLICATION
Electronic Water Use License Application and Authorisation System ***(e-WULAAS)***	The online web portal for the submission, processing and authorisation of water use licence applications.
Green Drop System ***(GDS)***	The GDS for the evaluation of water service authorities and their providers, via a standardised scorecard, has now been replaced by IRiS.
Hydrological Data System ***(HYDSTRA)***	The database containing long time-series hydrological data, such as dam water levels, evaporation, rainfall and streamflow.

INFORMATION MANAGEMENT SYSTEM	APPLICATION
Integrated Regulatory information System ***(IRiS)***	To capture an organisation's engagement in the locally and nationally determined wastewater treatment requirements to ensure that wastewater treatment is up to the set standards.
National Integrated Water Information System ***(NWIS)***	To provide information products to the public through web-based dashboards to facilitate efficient analysis and reporting across the water value chain.
Water use Authorisation and Registration Management System ***(WARMS)***	The national register of water uses to store and produce accurate water use information.
Water Management System ***(WMS)***	A suite of water quality monitoring systems to provide information on water resource monitoring and management.

As outlined in the DWS Data Management Strategy, the enhancement of four main pillars is essential for efficient and effective data acquisition and management, namely:

- Data governance;
- Data life cycle management;
- Data management systems; and
- Alignment between stakeholders in the water and sanitation sectors.

Strengthening these pillars is crucial to enhance the authority, availability, accessibility, timeliness and security of data, ensuring that data processes are streamlined and effective in supporting decision-making and resource management in the water and sanitation sector [DWS, 2020:1].

6.4.3.3 Spatial scale of implementation

The *"check"* stage of the eutrophication management framework addresses a range of geographical scales, from the international and transboundary levels to national, regional and specific water and land use levels. It involves monitoring and evaluating the causes and effects of anthropogenic eutrophication, assessing employee performance, evaluating the broader policy and legal environment, and gauging the effectiveness of catchment-specific interventions. This holistic approach ensures that eutrophication management efforts are comprehensive, addressing issues at multiple geographic scales and involving a range of stakeholders to achieve effective and sustainable outcomes.

6.4.3.4 Temporal scale of implementation

The operational strategies within the *"check"* stage of the eutrophication management framework typically require continuous attention.

Here is a summary of potential actions outlined in **TABLE 44** within the *"check"* stage that must be considered to enhance the trophic status of water resources:

TABLE 44: Operational actions to strengthen the *"check"* stage of the eutrophication management framework.

	SHORT TERM
(1)	Resolve supply chain management challenges to ensure the availability of back-to-back laboratory services to support eutrophication management on a continuous basis. The running of a laboratory supply chain has similarities with pharmacy supply chains, *e.g.,* strict specifications, on-time delivery, unbroken cold-chain, safe disposal of expired reagents, etc.;
(2)	Undertake routine national eutrophication monitoring, considering the recommendations of the Review of the South African Water Resource Monitoring Network report [DWS, 2016b:35];
(3)	Strengthen the NEMP and establish a TSI for rivers and streams.
(4)	Realign/ establish regional eutrophication monitoring programmes, in cooperation with all relevant role-players, and undertake routine regional eutrophication monitoring;
(5)	Undertake appropriate flow measurements, as part of the national and regional eutrophication monitoring programmes, to enable nutrient load monitoring and apportionment on a WMA and sub-catchment basis;
(6)	Consider and, where desirable, develop and implement citizen science eutrophication monitoring programmes, in support of other resource quality monitoring programmes;
(7)	Consider and, where necessary, introduce and mainstream advanced technology to monitor eutrophication, *e.g.,* remote sensing, drone technology, etc.;
(8)	Improve the effectiveness and efficiency of the water quality data management system(s) through the implementation of the findings of the Data Management Strategy [DWS, 2020:1]. Good data management is a prerequisite for effective eutrophication management;
(9)	Expand IRiS to capture data and information from water users that monitor the disposal of waste/ discharge of water containing waste for compliance monitoring purposes. The availability of suitable data and information will improve the management of eutrophication;
(10)	Develop and gazette regulations to compel water users to register and upload waste discharge water quality and volumetric data, specifically data and information that will aid eutrophication management, on the Integrated Regulatory Information System (IRiS), or alternative system(s);
(11)	Develop a scheme for classifying non-compliance according to risk to enable prioritisation of interventions;
(12)	Generate and compile annual national eutrophication-related compliance monitoring status reports;
(13)	Generate and compile biennial national eutrophication status reports;
(14)	Generate and compile annual catchment eutrophication status report(s);
(15)	In conjunction with regular reporting, implement the provision of near real time and on-demand information so that managers do not have to wait such reports;
(16)	Learn from the SDG Programme, and expand South Africa's domestic monitoring programmes, in support of effective eutrophication planning, regulation and management, to incorporate the useful concepts from the SDG Programme;
(17)	Harmonise the systems and approaches being used across sector departments and catchments for resource water quality data and information management;

SHORT TERM	
(18)	Structures, such as the National Water Quality Management Forum, the Anti-Pollution Task Team and the Water Quality Management Steering Committee, must be utilised as platforms for regular reporting, performance tracking and deliberating;
(19)	The DWS will be responsible for the national assessment of water quality, and will report annually to Parliament on the state of water quality in the country, including Municipalities' Green Drop performance; and
(20)	Law review to enforce monitoring within the municipal water value chain, especially monitoring and submission of data by commercial and industrial activities that discharge to municipal sewer network systems.
LONGER TERM	
(21)	Harmonise the systems and approaches being used across sector departments and catchments for resource water quality, including eutrophication, data and information sharing and management; and
(22)	Government to ensure the harmonisation of data and information systems pertaining to source control, especially with respect to land use that contribute towards anthropogenic eutrophication.

6.4.4 The *"act"* stage

The *"act"* stage, in the eutrophication management framework, focuses on three linked operational strategies, namely– **(1)** ***"Retroactive action"***; **(2)** ***"Enforcement"***; and **(3)** ***"Management review"***, as depicted in **FIGURE 98**.

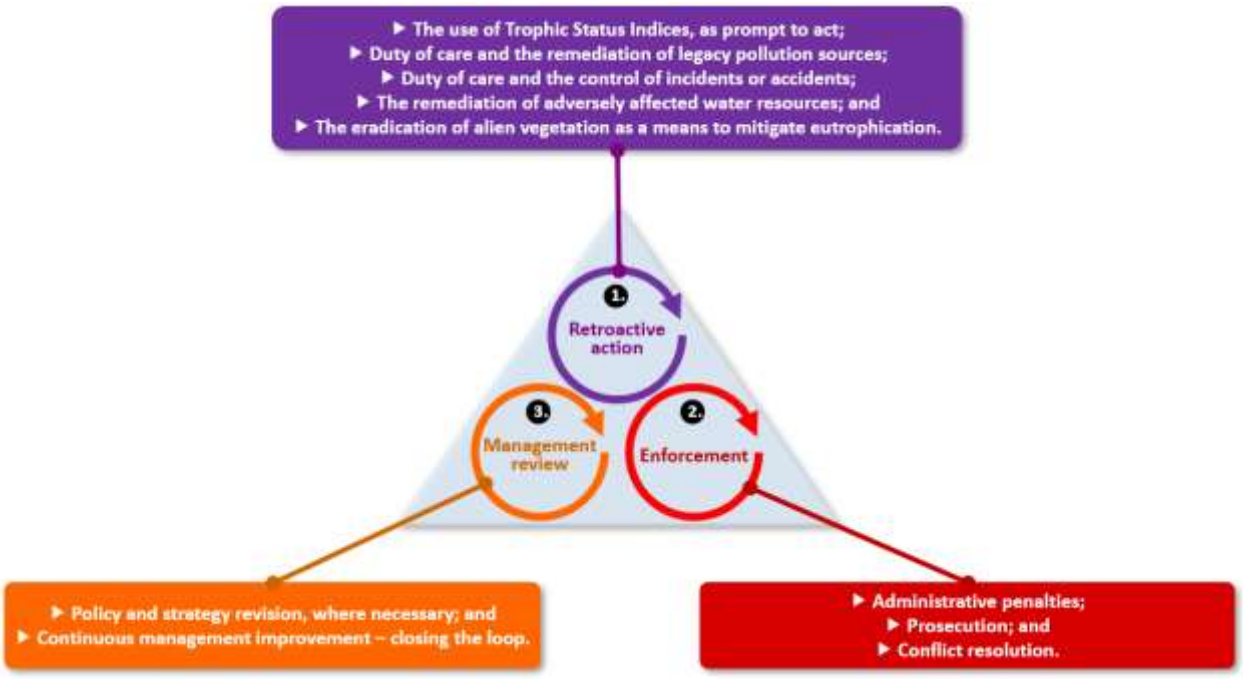

FIGURE 98: Conceptual outline of the *"act"* stage in the eutrophication management framework.

Altogether, the *"act"* stage, in the eutrophication management framework, must ensure that–

- all remaining sources of excessive nutrient loading, or residual effects of anthropogenic eutrophication, are appropriately addressed;
- all regulatory and administrative measures are adequately enforced;
- management measures, such as policy and strategy, are improved, where necessary; and
- management improvement is facilitated through a continuous process of learning-by-doing and adapting.

The three operational strategies in the *"act"* stage of the eutrophication management framework, and their purposes and composition, are narrated for easy reference purposes in **TABLE 45**:

TABLE 45: The operational strategies, in the *"act"* stage of the eutrophication management framework, and their composition.

OPERATIONAL STRATEGIES AND PURPOSE		KEY COMPONENT(S)
(1) Retroactive action	*To institute retroactive action to address legacy cases of excessive nutrient loading or residual effects of anthropogenic eutrophication.*	**[A]** The use of Trophic Status Indices (TSIs), as prompt to act;
		[B] Duty of care and the remediation of legacy pollution sources;
		[C] Duty of care and the control of incidents or accidents;
		[D] The remediation of adversely affected water resources; and
		[E] The eradication of alien vegetation as a means to mitigate eutrophication.
(2) Enforcement	*To impose administrative and regulatory sanction that is fair and just.*	**[A]** Administrative penalties;
		[B] Prosecution; and
		[C] Conflict resolution.
(3) Management review	*To effect policy and strategy review, where necessary, and to facilitate continuous management improvement.*	**[A]** Policy and strategy revision, where necessary; and
		[B] Continuous management improvement – closing the loop!

6.4.4.1 Authority

The data and information gathered during the *"check"* stage of the eutrophication management framework play a crucial role in informing and guiding the necessary responses to be implemented in the *"act"* stage of the framework. These responses primarily target the remaining sources of excessive nutrient loading or their effects, as well as the regulators' role[399] in effectively enforcing relevant policies, strategies and laws. Competencies (sectors), which are relevant here,

[399] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

include: ♦ agriculture; ♦ disaster management; ♦ the environment; ♦ human settlements; ♦ mining; and ♦ water and sanitation. The roles of competent authorities are outlined in **Section 6.6** under ***"Governance responsibilities"***, which provides additional clarity on the allocation of tasks concerning eutrophication governance.

6.4.4.2 Prescribed approaches

6.4.4.2.1 Retroactive action

The first operational strategy within the *"act"* stage of the eutrophication management framework, namely *"retroactive action"*, holds a critical position in safeguarding human health and well-being. It involves addressing legacy sources of nutrient loading, handling detrimental incidents or accidents, remediating adversely affected water resources and ecological infrastructure and eliminating alien vegetation. The potential components of *"retroactive action"* and their respective purposes are delineated in **sections [A]** to **[E]**, below:

[A] The use of Trophic Status Indices (TSIs), as prompt to act

The use of TSIs can act as a prompt for action.[400] It is essential to establish formal *"alert levels"* for problematic water resources as part of an early warning system that integrates trophic status assessments.[401] This system should notify various water users, especially recreational and vulnerable raw water users (including those for traditional ceremonies and rituals), about potential water quality, health and safety concerns. Potential alert levels to be considered include:

- **Vigilance Level:** This level is characterised by relatively low nutrient concentrations in raw water. When surpassed, affected waterbodies should be monitored more frequently to promptly detect any potential rapid changes in cyanobacterial biomass;
- **Alert Level 1:** This alert level is triggered by a specific cyanobacterial cell count and/or chlorophyll-α concentration. It necessitates an evaluation of the total toxin concentration in raw water, in consultation with relevant authorities, to continuously assess the bloom's status and the water's suitability for human and animal consumption. Advisory public notices through the media or other means are warranted at this stage; and
- **Alert Level 2:** This alert level is triggered when unacceptable cyanobacterial cell counts and/or chlorophyll-α concentrations are detected, along with confirmed toxin presence through chemical or bioassay techniques. Such cell densities suggest toxic blooms with high biomass and potentially localised scums. Effective water treatment and evaluation of treatment performance become essential. In severe cases, providing safe drinking water from tanks to

[400] Refer to **Section 6.4.3.2.2**: Domestic status and trends monitoring and reporting for the gathering of TSI information.
[401] Refer to **Section [B]**, 6.4.1.2.1: Examination of existing and available information.

consumers might be necessary. Public information should advise against using water from such water resources for human or animal consumption but clarify that it remains suitable for purposes like washing, laundry and toilet flushing.

It is important to recognise that **anthropogenic eutrophication is often associated with other water pollution concerns** like microbial water pollution. This understanding can help the public grasp potentially risky conditions related to the trophic status of specific water resources [EU & WHO, 2002:f9]. Leveraging mobile applications[402] can assist recreational water users (including those for cultural or religious purposes) in planning their visits to safe environments in near real-time.

[B] Duty of care and the remediation of legacy pollution sources

"Pollution", according to the NWA (36:1998), is an omission,[403] activity, process,[404] or situation[405] that alters the physical, chemical or biological properties of a water resource, either directly or indirectly, to render it–

- less fit for any beneficial purpose for which it may reasonably be expected to be used or harmful or potentially harmful to–
  - human health, safety or welfare;
  - aquatic or non-aquatic organisms;
  - resource quality; or
  - property.[406]

For an omission, activity, process or situation to cause water pollution, the change in the waterbody's properties does not necessarily have to make it entirely *"unfit-for-use"* or *"harmful"* but can make it *"less fit-for-use" or "potentially harmful"*, as in cases of excessive nutrient loading affecting water resources and trophic conditions. Thus, even after water pollution has occurred, such water resources, in many cases, may still be fit-for-use – albeit with caution.[407]

While an individual activity might not alone render a receiving water resource *"unfit-for-use"* or *"harmful"*, the combined point and diffuse impact of several activities can do so. Even if an activity meets all regulatory requirements and causation between the activity and the cumulative impact

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[402] Refer to **Section 6.4.3.2.4, [A]:** Technological advancement**.**

[403] Refer to Section 151(1)(i), NWA (36:1998).

[404] Refer to Section 19(1)(a), NWA (36:1998).

[405] Refer to Section 19(1)(b), NWA (36:1998).

[406] Refer to Section 1(1)(xv), NWA (36:1998).

[407] Refer to **Section 6.4.4.2.1, [A]**: The use of Trophic Status Indices (TSIs), as prompt to act.

is not too distant, it can be considered polluting alongside the other activities, making all responsible parties jointly and severally liable.

Therefore, there is a duty on landowners, persons in control of land or those who occupy or use the land to take all reasonable steps to *"prevent water pollution"* [408] from activities performed on the land. This responsibility may fall on a person who was not responsible for the initial activity causing pollution on the land they currently control.

Measures to prevent and address water pollution may involve actions like adjusting or ceasing polluting activities, controlling pollutant movement, eliminating pollution sources and remediating pollution effects.[409] If the person tasked with prevention or mitigation fails to act, the Minister may issue directives mandating specific actions,[410] with consequences for non-compliance. The CMA (or proto-CMA in the absence of a CMA) can also effect necessary measures to remedy the situation, recovering costs collectively from those responsible – applying the Polluter Pays Principle.[411]

Failure to comply with directives is an offense that may attract fines or imprisonment[412] depending on the severity and frequency of such offenses. Most pieces of environmental legislation, today, contains provisions to enforce the environmental duty of care principle, further reinforced by Section 28, NEMA (107:1998), enabling *ex post facto* or retrospective enforcement.

[C] Duty of care and the control of incidents or accidents

A person responsible for an *"incident"* or *"accident",*[413] in which a substance pollutes; or has the potential to pollute water resources; or has a detrimental effect on water resources, must, as soon as reasonably practicable, after obtaining knowledge of the *"incident"* or *"accident"*, report the *"incident"* or *"accident"* to the DWS, the South African Police Service (SAPS) or the relevant fire department, or the relevant CMA (or proto-CMA).[414]

In terms of Section 20 of the NWA (36:1998), such *"incidents"* and *"accidents"* include tanker accidents leading to hazardous substance spills, hazardous substance spills at factories,

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[408] Refer to **POLICY STATEMENT 2:** The Mitigation Hierarchy for decision-making on eutrophication**.**

[409] Refer to Section 19(2), NWA (36:1998).

[410] Refer to Sections 19(3), NWA (36:1998), read with Section 1(5), NWA (36:1998).

[411] Refer to **POLICY STATEMENT 7**: Incentive-based regulation.

[412] Refer to Section 151(1)(d) and (2), NWA (36:1998). See Section 154, NWA (36:1998) for the acts and omissions by an employee or agent that constitute an offence.

[413] The word *"emergency"*, although present in the explanatory note and in the section heading, does not feature in Section 20, NWA (36:1998). Section 1(4), NWA (36:1998) states that explanatory notes must not be used in the interpretation of the Act. Therefore, the courts have not dealt with the word *"emergency"* in the context of Section 20, NWA (36:1998).

[414] Refer to Section 20(1) to (3), NWA (36:1998).

accidents involving hazardous substances at factories, French drain leaks into water resources and water containing waste overflows from evaporation dams.

The person concerned must–

- take all reasonable measures to contain and minimise the effects of the *"incident"* or *"accident"*;
- undertake clean-up procedures;
- remedy the effect of the *"incident"*; and
- take measures as the CMA (or proto-CMA) may either verbally (which must be confirmed in writing within 14 days) or in writing, direct.[415]

If the responsible person fails to comply adequately, or if it is not feasible to issue a directive promptly, the CMA (or proto-CMA) has the authority to take the necessary actions to contain, minimise, clean up and remedy the aftermath of the incident.[416] The CMA (or proto-CMA), by applying the Polluter Pays Principle,[417] may recover all reasonable costs incurred by taking these steps, from the persons responsible.[418]

[D] The remediation of adversely affected water resources

When water pollution has rendered water resources *"less-fit-for-use"*, *"potentially harmful"*, *"unfit-for-use"* or *"harmful"* **restorative actions**, tailored to each scenario, **must be considered** to ensure they are both reasonable and effective. Remediation efforts focus on mitigating the lasting impacts of elevated trophic conditions in waterbodies, supplementing existing regulatory measures[419] and embracing retroactive actions. Funding for cleaning up legacy pollution cases typically follows the Polluter Pays Principle.[420]

Three categories of water resource remediation are recognised *viz.*, ***"physical"***, ***"chemical"*** and ***"biological"***. Physical and chemical approaches provide immediate responses for short-term improvements but may not fully address legacy eutrophication cases due to high costs and incomplete solutions. Chemical methods, such as using copper sulphate ($CuSO_4$), herbicides, and algaecides to control phytoplankton blooms, can result in secondary pollution if not properly administered. Biological methods, while more sustainable and cost-effective, require long-term commitment [Zhang, *et al.*, 2020:1099]. Combining these approaches can provide effective short- and long-term strategies for managing cyanobacterial blooms and restoring ecosystems.

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[415] Refer to Section 20(4) and (5), NWA (36:1998).
[416] Refer to Section 20(6), NWA (36:1998).
[417] Refer to **POLICY STATEMENT 7**: Incentive-based regulation.
[418] Refer to Section 20(7) to (9), NWA (36:1998).
[419] Refer to **Section 6.4.2**: The *"do"* stage.
[420] Refer to **POLICY STATEMENT 7**: Incentive-based regulation.

Physical methods, or engineering solutions, like flushing, aeration and sediment dredging, aim to reduce legacy nutrient levels and prevent phosphorus release. Biological methods support ecosystem restoration by re-establishing natural cycles, enhanced when combined with physical or chemical techniques. Ecological remediation uses biological techniques to stabilise waterbodies and rebuild ecosystems. Bioremediation, utilising specific microorganisms, plants and animals, helps degrade, absorb and transform nutrients, enhancing water purification [Zhang, *et al.*, 2020:1104]. Leveraging biological manipulation in food chains, controls unwanted species and manages algal growth [Mitchell, *et al.*, 2016:150; Van Ginkel, 2011:697].

BMPs with guidelines to address impaired, degraded and contaminated water resources, should be developed and included as part of a remediation strategy for South Africa.[421] It is essential to implement remediation actions comprehensively within a catchment context, through appropriate catchment assessment, the establishment and implementation of geographic water quality management strategies, and thematic plans.[422]

[E] The eradication of alien vegetation as a means to mitigate eutrophication

Invasive alien plants pose a significant threat to South Africa's terrestrial and freshwater ecosystems by increasing above-ground biomass and evapotranspiration, which reduces surface water runoff and groundwater recharge. This occurs because alien trees and shrubs often have greater height, root depth and senescence than the native species they replace [Chamier, *et al.*, 2012:345]. Most South African catchments are water-scarce, with almost all freshwater allocated for use [DWA, 2010:5]. This scarcity is worsened by water quality problems at a national scale, such as elevated nutrient concentrations [DWA, 2011b:28]. Anthropogenic eutrophication can further exacerbate invasions by aquatic weeds, which disrupt water transport, breed waterborne pathogens and degrade water quality [Chamier, *et al.*, 2012:352].

Impacts of invasive plants on water quality must be addressed, especially where they could worsen existing issues:

- **Reduction in streamflow and groundwater storage:** Increased evapotranspiration reduces streamflow and recharge, decreasing dilution capacity and increasing concentrations of nutrients and other pollutants;

[421] Refer to **Section 6.3.3**: Remediation-directed management.

[422] Refer to **Section 6.4.1.2.4, [F]**: Establishment of geographic water quality management strategies and thematic plans.

- **Plant biomass and nutrient cycling:** Increased biomass and litter affect ecosystem chemistry, impacting nutrient cycling and soil chemistry, thus affecting water quality and trophic status;
- **Fire regimes, soil erosion and water quality:** Changes in vegetation and fire behaviour can lead to soil erosion and nutrient loading in water;
- **Aquatic invasive plants and water quality:** These plants can directly impair water quality by their presence in waterbodies.

However, large-scale eradication of invasive vegetation to combat eutrophication must be carefully managed to avoid releasing additional nutrients into water resources, which can increase erosion and sediment transport. Effective coordination with riparian zone restoration is essential to mitigate eutrophication without worsening the situation.

6.4.4.2.2 Enforcement

The second operational strategy within the *"act"* stage of the eutrophication management framework, namely *"enforcement"*, must ensure compliance with regulations and policies aimed at reducing nutrient pollution, thereby preventing excessive algal growth and ecosystem degradation. It serves to hold polluters accountable and promote sustainable practices that maintain water quality and ecological balance. The components of *"enforcement"* and their respective purposes are delineated in **sections [A]** to **[C]**, below:

[A] Administrative penalties

The current penalties for non-compliance seem neither effectively implemented nor sufficiently priced to change behaviour and must be reviewed. A system of administrative penalties for water pollution offences, particularly concerning anthropogenic eutrophication, should be adopted alongside the existing criminal prosecution route. The DWS will collaborate with the DFFE to establish the necessary legislative framework and regulatory authority to impose administrative penalties that reflect the societal cost of water quality violations. This intervention will enable the State to achieve greater compliance with water quality regulations among waste dischargers and will require an amendment to the NWA (36:1998).[423] In line with the inter-departmental approach to eutrophication management, this regulatory authority could serve both DWS and DFFE in relation to administrative penalties for water and environmental non-compliance. However, certain activities causing water pollution, such as acts of vandalism, will still follow the criminal prosecution route. The DWS will continue to collaborate with DFFE on training inspectors and enforcing legislation [DWS, 2017b:49].

[423] Refer to **Annexure H** for a list of all recommended legislative amendments.

[B] Prosecution

Legal action will be pursued as a last resort against offenders who wilfully or negligently violate regulations and are unwilling to comply with statutory provisions. Regulatory efforts will focus on wastewater dischargers with a history of non-compliance. Prosecution is essential to prevent deterioration of trophic conditions in water resources and to enhance water quality. Enforcement will include compliance assistance, incentives and ultimately – prosecution and legal sanctions. Negotiations on preventive measures, aimed at achieving relevant in-water resource water quality objectives[424] and the effective internalisation of costs,[425] will be conducted up-front to establish the compliance framework.

While prosecution is vital, the current approach has not fully addressed diffuse water pollution cases. Emphasising holistic eutrophication management[426] through statutory RDMs will lead to improvements. Greater attention should be given to tracking diffuse pollution sources[427] while establishing and implementing geographic water quality management strategies and thematic plans.[428] Establishing *"cause and effect"* relationships[429] at local levels within sub-catchments and WMAs will be central to these strategies. Any changes in enforcement practices must account for the available administrative and technical capacity to implement them effectively.

[C] Conflict resolution

Possible areas of potential conflict that may arise from managing eutrophication include:

- Imposing Source-Directed Measures and Controls on water use;
- Stipulating conditions and standards for water use;
- Determining and implementing water quality goals;
- Executing roles and responsibilities among different spheres of government, departments and Water Services and Management Institutions; and
- Other potential areas of conflict.

During the water use authorisation process, efforts will be made to engage with water users to ensure clarity and justification for the conditions imposed. Should conflicts arise post-authorisation, they will be escalated to the Water Tribunal[430] for resolution.

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[424] Refer to **Section 6.4.1.2.3**: Goal setting.

[425] Refer to **POLICY STATEMENT 7**: Incentive-based regulation.

[426] Refer to **POLICY STATEMENT 10**: Holistic eutrophication management.

[427] Refer to **Section 6.4.1.2.4, [F]:** Establishment of geographic water quality management strategies and thematic plans**.**

[428] Refer to **Section 6.4.1.2.4, [F]:** Establishment of geographic water quality management strategies and thematic plans**.**

[429] Refer to **Section 6.4.1.2.2, [B]:** Waste load accounting**.**

[430] Refer to *Chapter 15: Appeals and dispute resolution* in the NWA (36:1998).

6.4.4.2.3 Management review

The last operational strategy within the *"act"* stage of the eutrophication management framework, called *"management review"*, plays a pivotal role in redirecting resources and improving policies, strategies, legislation and intervention measures when necessary. This ensures adaptive management to achieve the long-term goal of eutrophication management. The components of this operational strategy and their purposes are outlined in **sections [A]** and **[B]**, below:

[A] Policy and strategy revision, where necessary

Reviewing policies, strategies and laws, and taking corrective action when needed, is a crucial aspect of ongoing eutrophication management. Data and insights gathered during the *"check"* stage of the eutrophication management framework should be utilised to evaluate the efficiency of the regulatory environment.[431] Regular reviews of eutrophication management practices should be carried out at suitable intervals to verify the ongoing relevance, sufficiency and effectiveness of policies, strategies, etc. The scope of the management review must be broad enough to account for all activities, products and services associated with the eutrophication management framework.

[B] Continuous management improvement – closing the loop!

By monitoring management performance,[432] it is ensured that those responsible for eutrophication management are held accountable for their actions or inactions. This process, akin to *"quality control monitoring"*, evaluates whether managers effectively fulfil their duties. Eutrophication managers must adapt their performance based on monitored results.

Compliance with, or progress towards, MCs and RQOs, particularly regarding eutrophication, serves as a measure of management effectiveness. Committee structures such as the National Water Quality Management Forum, Anti-Pollution Task Team and Water Quality Management Steering Committee are crucial for communication and fostering improvements. Establishing and formalising clear communication lines about the performance and outcomes of South Africa's eutrophication governance strategy is essential.

Given the complexity and interdisciplinary nature of water resource management, adaptive eutrophication management aims for continuous improvement in a dynamic, systematic way. This approach combines robustness with flexibility, allowing for adjustments as needed.

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[431] Refer to **Section 6.4.3.2.3, [B]:** Evaluation of the effectiveness of the regulatory environment**.**

[432] Refer to **Section 6.4.3.2.3:** Management performance monitoring and reporting**.**

6.4.4.3 Spatial scale of implementation

Within the *"act"* stage of the eutrophication management framework, operational strategies primarily concentrate on corrective actions, typically targeting sources of the impacts or improving the statuses of the affected water resources. At times, corrective action may also be directed at the policy, strategy or law environment to enhance eutrophication management practices and effectiveness.

6.4.4.4 Temporal scale of implementation

The operational strategies within the *"act"* stage of the eutrophication management framework, can be conducted on an *ad hoc* basis or regularly, depending on the purpose. **TABLE 46** gives a summary of potential actions, within the *"act"* stage, which must be considered, to improve the trophic status of water resources:

TABLE 46: Operational actions to strengthen the *"act"* stage of the eutrophication management framework.

SHORT TERM	
(1)	Committee structures, such as the National Water Quality Management Forum, the Anti-Pollution Task Team and the Water Quality Management Steering Committee, must be utilised as platforms to effect improvement.
(2)	Achieve compliance to the requirements of in-water resource water quality objectives, *i.e.,* the RQOs and supporting RWQOs/ WQPLs, to ensure fitness-for-use of receiving water resources through the implement of adaptive, systems-based catchment eutrophication management, and adjust the control of impacts on the trophic status of receiving water resources;
(3)	Implement programmes to rehabilitate and manage resource water quality *"hotspots"* in priority catchments, in accordance with the relevant geographic water quality management strategies and thematic plans (if justified, utilising revenue from the WDCS);
(4)	Undertake targeted compliance monitoring and enforcement of key polluting sectors, specifically those that contribute to anthropogenic eutrophication;
(5)	Turn the performance/ functionality of five, currently non-compliant/ dysfunctional, large WwTWs around, and initiate an accompanying publicity campaign, followed by a programme to address remaining non-compliant/ dysfunctional WwTWs;
(6)	Roll-out intervention plans to address priority non-compliant industries;
(7)	Establish and implement a mechanism for applying Administrative Penalties;
(8)	Restructure the grant funding mechanisms and conditions for water supply and sanitation, to ensure a focus on maintaining and restoring existing infrastructure, rather than the construction of new infrastructure. Where appropriate new and innovative technology should be considered; and
(9)	Standardise and enforce required Operation and Maintenance (O&M) budgeting and expenditure.
LONGER TERM	
(10)	Develop an IWQM investment framework.
(11)	Devise and implement a system of alert levels.

SHORT TERM	
(12)	Evaluate and improve the eutrophication governance policy, strategy and regulatory environment at appropriate intervals.

6.5 SUPPORTING STRATEGIES

Three strategies, as depicted in **FIGURE 99**, have been developed to support the core and operational strategies, discussed earlier in this chapter, thereby contributing to eutrophication management in South Africa.

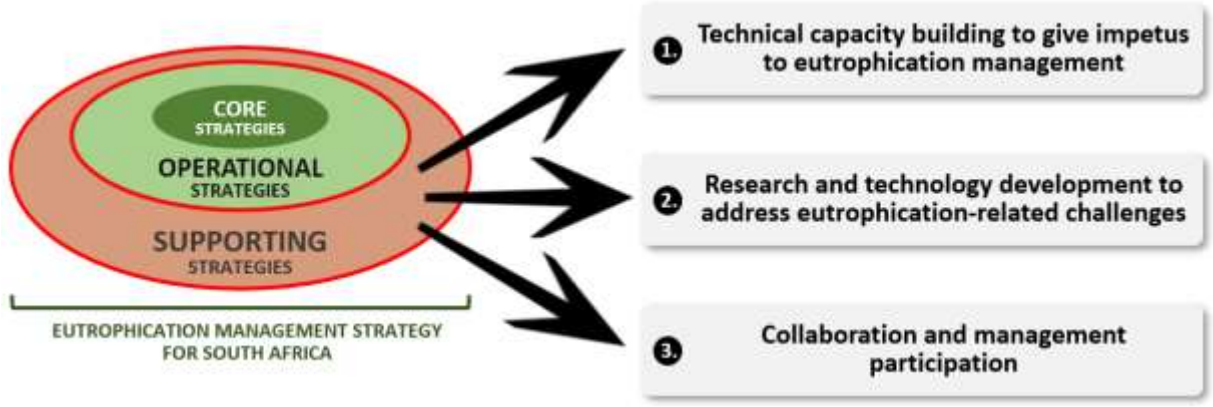

FIGURE 99: Supporting strategies for the management of eutrophication.

These three supporting strategies cover–

- technical capacity building to drive eutrophication management forward;
- research and technology development to tackle eutrophication challenges; and
- collaboration and management participation,

which will be discussed next.

6.5.1 Technical capacity building to give impetus to eutrophication management

6.5.1.1 Authority

National government, through the Minister of Water and Sanitation and the DWS, acts as the trustee of the nation's water resources and is responsible for providing leadership in building technical capacity for water services and resource management, including eutrophication management. Strengthening capacity throughout the water value chain necessitates robust partnerships with stakeholders who have specific roles and responsibilities towards the common goal of capacity building, with the DWS guiding and coordinating these efforts.

The responsibility for the harmonisation of education, training and skills development across various sectors is vested in the Department of Higher Education and Training (DHET), and its education and training institutions and agencies. The South African Qualifications Authority (SAQA) oversees the National Qualifications Framework (NQF) that recognises learner achievements nationwide. The Skills Development Act, 1998 (Act No. 97 of 1998), as amended,[433] provides the statutory framework for the integration of skills development strategies into the NQF. Sector Education and Training Authorities (SETAs), specifically the Energy and Water Sector Education and Training Authority (EWSETA), previously the Local Government Sector Education and Training Authority (LGSETA), allocate workplace training funds and handle skills planning within the water sector [DWS, 2018b:158].

The EWSETA, through its Sector Skills Plan, focuses on determining skills development priorities, setting sector-specific objectives, identifying strategies, activities and resources for skills development and reporting on the implementation of the sector skills plan [DWS, 2013:1]. Public service employers in the national or provincial spheres of government must budget for skills development, while private sector employers and municipalities meeting specific criteria must register with the South African Revenue Service (SARS) to pay the skills development levy, allocated to SETAs for employee training.

Capacity building, training and skills development related to eutrophication involve multiple authorities and agencies representing various interests and mandates[434] across competencies (sectors) like ♦ agriculture; ♦ disaster management; ♦ education; ♦ the environment; ♦ health; ♦ human settlements; ♦ infrastructure; ♦ land use and development planning; ♦ mining; ♦ research and development; and ♦ water and sanitation. The roles of competent authorities are outlined in **Section 6.6** under ***"Governance responsibilities"***, which provides additional clarity on the allocation of tasks concerning eutrophication governance.

6.5.1.2 Prescribed approach

Capacity creation, with respect to the management of anthropogenic eutrophication, must:

- Establish ***"individual capacity"*** by enabling people to better perform defined functions, as individuals, through improved technical skills and professional understanding, and as groups by aligning their activities to achieve common purpose, as articulated through the national goal for eutrophication management in South Africa;

[433] Hereafter referred to as SDA (97:1998).

[434] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

- Enable institutions through the creation and maintenance of the requisite ***"institutional"*** or ***"organisational capacity"*** (*i.e.,* the structure, processes and resources of the organisations themselves), to plan for, and manage anthropogenic eutrophication; and
- Create appropriate ***"environmental capacity"*** through the establishment of suitable external enablers, such as sector policy, strategies, plans, legislation, funding and institutional arrangements for effective regulation and seamless accountability.

The effectiveness of eutrophication management, therefore, relies on building capacity at all levels. Individual capacity forms the foundation for organisational[435] and environmental[436] capacity, making it a fundamental aspect. While other sections delved into organisational and environmental capacity, the following discussion will home in on the enhancement of individual capacity.[437]

The water and sanitation sector heavily relies on professionals and technicians with the need for professional experience on site and continual professional development. Municipalities face challenges in attracting and retaining skilled professionals, especially in rural areas. Shortages in critical skills hinder effective eutrophication governance across water sector institutions.[438] Focus is directed towards four key areas, *viz.*, (1) engineering and sciences, (2) artisans and process controllers, (3) socio-economic and environmental skills, and (4) emerging professions [DWS, 2013:96]. Avoiding excessive reliance on consultants to address technical staff shortages is essential.

Despite challenges, significant progress has been made in addressing skills and capacity gaps across the water value chain. Successful initiatives include:

- The Framework Programme for Education and Training in Water (FETwater), a collaborative effort between the DWS, WRC, UNESCO and the Flemish Government [UNESCO-IHP, 2021];
- The DWS Learning Academy's bursary programs and internship development, aiming to groom upcoming engineers, scientists and technicians into professionals [DWS, 2013:97]; and
- The 2020 Vision for Water and Sanitation Education Programme, launched in 1996, enhancing awareness of integrated water resources management through various projects and competitions targeting learners [DWS, 2021].

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[435] Refer to **Section 6.5.3**: Collaboration and management participation, in combination with **Section 6.6:** Governance responsibilities**.**

[436] Refer to **Section 6.4.3.2.3, [B]:** Evaluation of the effectiveness of the regulatory environment, in combination with **Section 6.4.4.2.3, [A]**: Policy and strategy revision, where necessary**.**

[437] Refer to **Section 4.2.6**: Lack of skilled water scientists and engineers.

[438] Refer to **POLICY STATEMENT 18**: Technical capacity to take eutrophication management action.

6.5.1.3 Spatial scale of implementation

Capacity building for technical water services and resource management is executed through various means. Methods of building individual capacity include:

- Formal training at academic institutions;
- Informal on-the-job training by mentors within organisations;
- *"Outward"* training programmes where sector-wide capacity support is offered;
- *"Inward"* training through internal training programmes; and
- Initiatives driven by national, regional or local priorities for capacity development.

Regardless of the mode of capacity building, it is crucial that relevant programmes allocate adequate focus on eutrophication-related capacity building objectives, proportionate to the impact it has on ecologically sustainable development.

6.5.1.4 Temporal scale of implementation

Specific technical capacity is required to facilitate eutrophication management for certain well-defined scenarios in the short term. However, more sophisticated capacity will be required in the longer term to enable a more complete implementation of the NWA (36:1998). As roles and responsibilities evolve and water resource management becomes more decentralised, there is a growing demand for institutional capacity. It is urgent to improve eutrophication management in the short term while gradually progressing towards more effective practices, even if it involves radical changes in government's capacity-building approach. Short-term needs should be addressed using current instruments and in line with adaptive management principles.[439] The long-term strategy should focus on fundamental knowledge creation, where knowledge is seen as the capacity for informed action, necessary both within government and externally.

Several technical capacity building interventions should be considered, developed, refined or enhanced for implementation, as outlined in **TABLE 47**.

TABLE 47: Supporting actions to strengthen technical capacity building.

	SHORT TERM
(1)	There is inadequate human resource planning, *i.e.,* a lack of succession planning, weak retention strategies and the inadequate induction of professional entrants. Staff turnover is a normal phenomenon, but the Department should take appropriate measures to ensure that it does not lead to an unacceptable loss of institutional memory. These may include the option of retain offers as well as the option for staff to become specialist scientists. Human resource planning must be improved to protect, develop and extend existing technical eutrophication management capacity;

[439] Refer to **Section 6.4.4.2.3, [B]**: Continuous management improvement – closing the loop!

(2)	Investing in good training programmes to ensure continuous learning and a clear professional development path for incumbents is important. This will require the reviving (and inclusion of an introductory section on eutrophication) of some of the old water quality training programmes, such as the Water Quality Management Orientation Course. Whilst the introductory courses could be made available in-house, financial resources must be allocated to support the development and roll-out of more detailed and phased programmes that address the technical and detailed complexities of IWQM, and specifically reservoir limnology and eutrophication management, to improve performance, productivity, skills development, and to gain and increase knowledge;
(3)	Define (and reinstate in some cases) career paths with defined training and on the job experience to build a cadre of sector professionals;
(4)	Provide bursaries and/or learnerships pertaining to water quality management at tertiary institutions;
(5)	Develop and implement a programme for recruiting and retaining experienced and qualified technical and managerial staff with technical qualifications in South Africa or abroad; and
(6)	Establish and strengthen IWQM awareness creation campaigns at national, WMA and municipal levels.
LONGER TERM	
(7)	There is a shortage of specific critical skills within various institutions, across the water value chain, *i.e.,* engineering skills, artisans, socio-economic, environmental health and management skills, which also negatively impact on the management of eutrophication. The demands for these skills should be addressed;
(8)	Develop and implement a capacity building programme for officials in DWS, CMAs and other sector departments, and for the private sector and civil society on systems based, adaptive IWQM, applicable legislation and law enforcement;
(9)	The DWS' Learning Academy initiative in conjunction with on-the-job training and mentorship has made strides in filling the skills gap within the water sector and should continue to receive the necessary support.

6.5.2 Research and technology development to address eutrophication-related challenges

6.5.2.1 Authority

The three core partners – the DWS, DSI and WRC – are the national drivers of water research, development and innovation.[440] Linked to these three core partners is a range of traditional research role-players, including the National Research Foundation (NRF), the Technology Innovation Agency (TIA), research councils, units and universities [DWS, 2018b:215]. Many other organisations are pivotal in scaling up, testing and deploying new innovations: These include utility entities, municipalities, the private sector and non-profit organisations.

The WRC hosts a Portfolio Management Unit financed by DSI to coordinate and implement national strategies for water research, development and innovation [DST, 2015:5]. This unit is tasked with:

- Prioritisation and project management;

[440] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

- Developing partnerships and sourcing investment;
- Raising awareness of achievements in water research;
- Monitoring and evaluation; and
- Ensuring effective governance and implementation.

Competencies (sectors),[440] which are relevant here, include: ♦ education; ♦ research and development; and ♦ water and sanitation. The roles of competent authorities are outlined in **Section 6.6** under ***"Governance responsibilities"***, which provides additional clarity on the allocation of tasks concerning eutrophication governance.

6.5.2.2 Prescribed approach

Despite a robust institutional framework and a wealth of expertise, water research, development and innovation in South Africa face several hurdles. These include inadequate coordination, ineffective collaboration among institutions, a limited understanding of the roles of water sector organisations in driving innovation, challenges in scaling solutions to market readiness and severely restricted funding for innovation, especially for scaling up and deployment. Consequently, many solutions developed from research and development are not applied in practice. To prepare for the future, South Africa must bridge the innovation chasm that prevents emerging solutions from being tested at scale or transform these solutions into viable businesses that can collaborate with various stakeholders in the public and private sectors [DWS, 2018b:214].

The National Water Research, Development and Innovation (RDI) Roadmap serves as the implementation framework for the NWRS3's Chapter 17 on *"… research, development and innovation"* [DWS, 2023a:92-93]. To advance water quality research and address issues like eutrophication, the DWS and WRC will spearhead the development of a national water quality research, development and innovation strategy. This strategy will coordinate applied research priorities across the water value chain, ensuring research efforts are directly tied to solving the water sector's challenges and addressing new concerns such as emerging pollutants.[441] The crucial roles of South Africa's academic bodies and independent research institutions in crafting this strategy are emphasised [DWS, 2017c:63].

[441] **POLICY STATEMENT 16:** Promotion of eutrophication-related research.

6.5.2.3 Spatial scale of implementation

Since its establishment, the WRC has made significant contributions to eutrophication research, publishing over 84 reports focused on understanding, treating and managing eutrophication [Frost & Sullivan, 2010:8]. The breadth of this research spans six main categories:

(1) The eutrophication phenomenon: This research characterises eutrophication, exploring its causes, the processes that lead to its occurrence, and policy and strategy for addressing it;

(2) The sources of eutrophication: Detailed examinations of eutrophication's causes are conducted, including the impact of contributing factors, underpinned by field studies and simulations;

(3) The management of eutrophication: Strategies for controlling and managing eutrophication across different freshwater systems are developed, assessing innovative approaches for their applicability both in South Africa and globally;

(4) Blue-green algae (cyanobacteria): The focus here is on understanding blue-green algae, a potentially toxic result of eutrophication, including their monitoring, causes, effects and management methods;

(5) Drinking water treatment adaptations: The implications of eutrophication on drinking water treatment are explored, particularly the adaptation of processes to eliminate algae and associated toxins, tastes and odours; and

(6) Wastewater treatment to remove phosphorus: Addressing a primary cause of eutrophication, this category looks at methods for removing phosphorus from wastewater treatment plant effluents as a proactive measure to alleviate eutrophication's impact on freshwater systems.

Over the years, the focus of the WRC's research has evolved from simply understanding eutrophication to developing and assessing treatment and management strategies. Despite the shift, attention has been fairly distributed across these six areas, supporting a comprehensive approach to tackling eutrophication [WRC, 2011:2].

6.5.2.4 Temporal scale of implementation

The National Water RDI Roadmap outlines a plan for, and identifies investment priorities in water research, development and innovation. It envisions: ***"South Africa to become a leader among middle income countries in the development and deployment of water management practices and technologies and to compete with leading countries in providing sustainable solutions"***.

To achieve this, a range of research and technological interventions must be appraised, developed, or, where necessary, refined and enhanced for practical use. **TABLE 48** outlines several actions necessary to accelerate research and technology development to address challenges related to eutrophication:

TABLE 48: Supporting actions to strengthen research and technology development.

SHORT TERM	
(1)	Develop, demonstrate, validate and encourage the use of alternative sanitation, such as water-less and off-grid sanitation solutions and urine-diversion toilets. This potentially includes the development of strategies and regulations to mainstream appropriate sanitation technology;
(2)	Investigate recent innovative treatment technologies to improve water quality;
(3)	Provide sufficient and sustained funding for appropriate applied research;
(4)	Develop and demonstrate appropriate domestic and industrial wastewater technologies for cost effectiveness, energy efficiency and beneficiation;
(5)	Initiate a case study *"pilot"* approach to upgrading the treatment processes employed in WwTWs;
(6)	Determine the typical relative nutrient-loading point and diffuse contributions of different land use sectors.
(7)	Invest in communities of practice that bring together built and ecological infrastructure experts and raw water quality improvement solutions;
(8)	Continue to do research on land use impacts on water linked ecosystems and raw water quality;
(9)	Test a suite of information and communication technology, and citizen science tools for data sourcing; and
(10)	Review all relevant guidelines and R&D products to understand where training modules need to be developed around new knowledge.
LONGER TERM	
(11)	DWS and the WRC will lead the sector in developing a national water quality research, development and innovation plan;
(12)	Continue to invest in understanding emerging contaminants (detection and treatment) in order to improve the transition to reuse, reclamation and recycling of return-flow water; and
(13)	Support a hydrological monitoring centre for South Africa to re-establish a robust data, monitoring and information capability for more effective water resources planning and climate change forecasting in future.

6.5.3 Collaboration and management participation

6.5.3.1 Authority

The DWS plays a pivotal role in managing eutrophication, particularly in terms of sector coordination and support, regulation and oversight. It is assisted by Water Management and Services Institutions in tackling various operational and water management functions, many of which can adversely impact the trophic status of water resources. Furthermore, numerous other

government departments across the various spheres of government may also hold regulatory responsibilities, especially those concerning land use planning, development and management, which could influence anthropogenic eutrophication. Hence, different mandates and regulatory responsibilities can affect the nation's water resources from a eutrophication perspective, underscoring the importance of collaboration and management participation to meet the common goal of eutrophication management.

As discussed earlier in Chapter 6, managing eutrophication involves a variety of competencies (sectors). Effective eutrophication governance necessitates collaboration and active participation among the authorities responsible for these competencies, as well as the private sector and civil society.

6.5.3.2 Prescribed approach

In accordance with the global notion towards holistic thinking and integrated decision-making in natural resource management, water quality management in South Africa has also shifted to consider detailed aspects within a broader perspective (**FIGURE 100**).[442] Similarly, managing eutrophication now demands the consideration of multiple interconnected factors, including ecosystem complexities, socio-economic relationships and diffuse runoff from land, among others. This underscores the significance of collaboration and active management participation. Effective eutrophication management relies on successful collaboration to execute the eutrophication governance strategy, promoting enduring partnerships and mitigating potential conflicts.

Efforts to enhance eutrophication management within the DWS will focus on strengthening their structured matrix management systems. This entails improved internal coordination between Head Office and regional offices, and with CMAs, the appointment of Eutrophication Management Champions and the establishment of intra- and inter-departmental standing committees (**TABLE 49**). These mechanisms will aid in aligning decisions, improving performance, sharing information and clarifying roles and responsibilities. Integration of eutrophication management into wider water quality management is crucial, necessitating accountability across relevant departments and agencies under the IWQM Policy and Strategy. Creating an enabling environment and fostering suitable mechanisms, therefore, is crucial to encourage partnerships between public, private and community organisations, various government departments,

[442] Refer to **Section 2.2.2.2.2:** Integrated decision-making and integrated water resource management.

provincial and local authorities, non-governmental organisations, the private sector, civil society, shared river basin organisations and international governmental and aid organisations.[443]

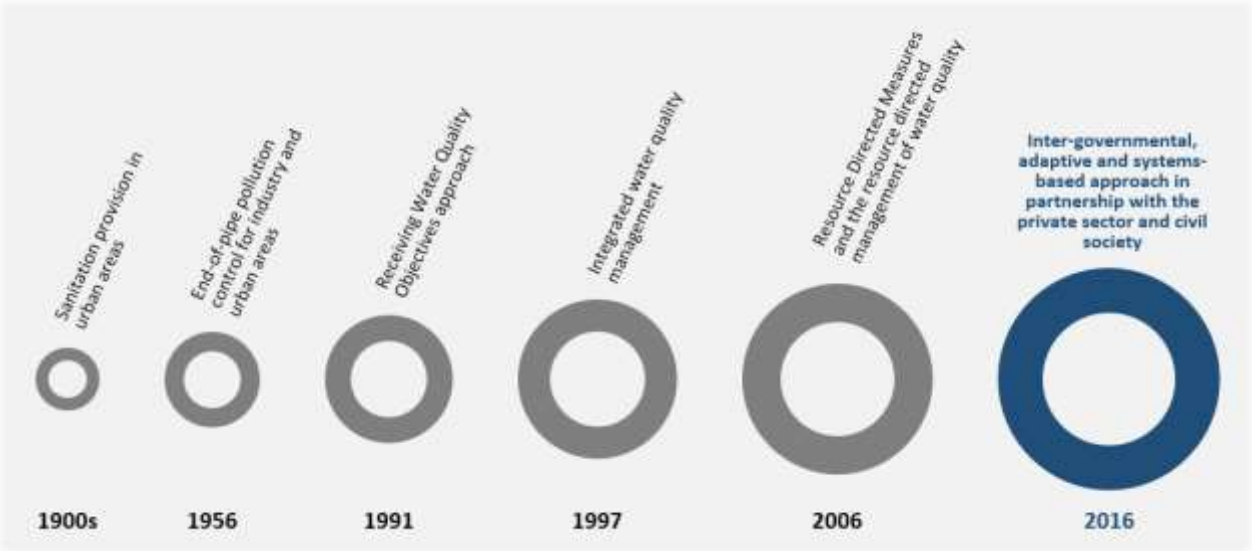

FIGURE 100: The management of eutrophication is part of a water quality management approach that, over time, has evolved into an *"inter-governmental, adaptive and systems-based approach that is executed in partnership with the private sector and civil society"* [DWS, 2017c:13].

TABLE 49: Intra- and inter-departmental water quality management standing committees to also serve as vehicles for addressing and improving the management of eutrophication [DWS, 2016a:33].

IWQM COMMITTEE	DESCRIPTION OF COMMITTEE AND POTENTIAL TO IMPROVE THE MANAGEMENT OF EUTROPHICATION [444]
Water Quality Functional Management Committee	This committee should be chaired by the Chief-Director: Water Use Compliance Monitoring and Enforcement and can consist of Chief Directors from the Branch: Water Resource Management; Branch: Regulation, Compliance and Enforcement, as well as Provincial Heads. Key line function Directors and Scientist Managers could be included in this committee to provide additional technical capacity and insights. This committee will have oversight over the IWQM function, **and will, therefore, also make recommendations with respect to eutrophication.**
Regional Water Quality Functional Management Committees	Within each DWS regional office this committee will pull together the various line functions that support IWQM within their respective WMAs. This committee will be chaired by the Director: Regulation. The participation will vary according to the structure of the DWS regional offices and would include CMAs, if established. **This committee will thus also aim to ensure eutrophication alignment in approach and coordination within the WMA.**
Inter-Governmental Task Teams	Typically established to resolve specific challenges, such as the current task team established for Mine Closure and Mine Water Management. These task teams provide the vehicle for cooperative government approaches and, as such, are largely advisory in nature, reporting back to parent Departments. Due to the nature of these task teams the chairing of these meetings should be rotated appropriately. **This task team will create awareness on eutrophication and promote collaboration and management cooperation among key government role-players.**

[443] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

[444] For the intra-departmental arrangements within the DWS, reference was made to the DWS organisational structure, as approved by the Hon. Minister S. Mchunu on 26 September 2022.

IWQM COMMITTEE	DESCRIPTION OF COMMITTEE AND POTENTIAL TO IMPROVE THE MANAGEMENT OF EUTROPHICATION [444]
National – Regional Water Quality Operational Committees *(National Water Quality Management Forum)*	This committee will provide a bridge between the DWS Head Office line functions and the regional offices/ CMAs and would replace what was previously the Water Quality Deputy-Director's meeting. The committee will be chaired by the Chief Director: Water Use Compliance Monitoring and Enforcement and will focus upon operational business matters, with a focus on ensuring strategic intent in WMAs, as part of the national drive to implement the IWQM Policy and Strategy (2017). A key focus will be on continual and adaptive improvement of approaches towards realising impacts in catchments. Hence, the focus of this committee would be upon the **operational dimensions of IWQM, which will include eutrophication**.
(Anti-Pollution Task Team - APTT)	The APTT will be chaired by the Chief Director: Water Use Compliance Monitoring and Enforcement and will co-ordinate and integrate immediate efforts for the improved management of water resource quality in South Africa, **with turn-around interventions for high-risk pollution hotpots and water use pollution activities**. The APTT will identify remedies to mitigate pollution caused by all water use sectors and must achieve its mandate by engaging other organs of state and water users.
(Water Quality Management Steering Committee)	The Water Quality Management Steering Committee will be chaired by the Chief Director: Water Use Compliance Monitoring and Enforcement and will deal with strategic matters, focusing on co-ordination and integration of water quality management and the **implementation of the IWQM Policy and Strategy (2017)**.
Integrated Water Quality Catchment Management Committees	Chapter 7 of the NWA (36:1998) and policy allow for the establishment of Catchment Management Committees, either based spatially; focused on a technical issue, such as IWQM; or in fact both. These provide a vehicle for on-the-ground operational management and involves a range of relevant or key stakeholders, together with officials. The modalities of these committees are very much in accordance with the needs for IWQM, **including the management of eutrophication**, at the local level. These committees will obtain strategic guidance from the Regional Water Quality Functional Management Committee, as well as more operational guidance from the National-Regional Water Quality Operational Committee.

Eutrophication management is best handled at a local and catchment scale, with Catchment Management Forums, Catchment Committees and Water User Associations playing crucial roles in participatory management. Goal setting,[445] visioning[446] and other planning-related activities[447] must be undertaken in a consensus-seeking manner to generate a sense of cohesion and common purpose amongst role-players with diverse interests in the water resource [DWAF, 2006c:3]. Delays in establishing CMAs impede participatory management efforts, underscoring the importance of engaging stakeholders through consensus-seeking processes. Building technical capacity[448] and developing regulatory frameworks[449] are essential to effectively manage eutrophication in a participatory and cooperative manner.

The DWS and CMAs will provide strategic guidance and leadership on transboundary eutrophication issues, engaging shared river basin organisations as needed. Business has a

[445] Refer to **Section 6.4.1.2.3**: Goal setting.

[446] Refer to **Section 6.4.1.2.2, [D]**: Visioning to propose levels for water resource protection.

[447] Refer to **Section 6.4.1:** The *"plan"* stage.

[448] Refer to **Section 6.5.1**: Technical capacity building to give impetus to eutrophication management.

[449] Refer to **Section 6.4.2**: The *"do"* stage.

corporate social responsibility and can contribute to mitigating eutrophication by adopting ethical practices or supporting volunteering efforts. Collaborations between civil society, corporate partners and focused, purpose-driven partnerships can be instrumental in improving the trophic status of water resources. Water stewardship should be promoted, as well as strengthening partnerships with civil society.

Establishing a *"community of practice"* for eutrophication governance involving academia, experts and practitioners will enhance knowledge sharing, collaboration, research[450] and knowledge development in this domain.

6.5.3.3 Spatial scale of implementation

Collaboration and management participation are vital at various levels of eutrophication governance, spanning from source-specific to local, regional or catchment levels, all the way up to national, transboundary and international scales.

6.5.3.4 Temporal scale of implementation

The collaboration and management participation interventions outlined in **TABLE 50** should be considered for implementation to enhance effective collaborative and cooperative eutrophication management:

TABLE 50: Supporting actions to strengthen collaboration and management participation.

SHORT TERM	
(1)	Participate and strengthen intra-departmental structures for IWQM to also address the management of eutrophication, including the National Water Quality Management Forum (NWQMF), the Anti-Pollution Task Team (APTT) and the Water Quality Management Steering Committee, to ensure efficient coordination and joint action, supported by regular reporting;
(2)	Nominate (an) Eutrophication Management Champion(s), preferably at both head and regional office levels;
(3)	Strengthen and foster strategic sector partnerships, and enable active participation of civil society; and
(4)	Establish and support Catchment Management Forums.
LONGER TERM	
(5)	Provide eutrophication support to Integrated Water Quality Catchment Management Committees, if established;
(6)	Provide eutrophication support to the Inter-Governmental Task Team on IWQM, once established;
(7)	Provide eutrophication support to the Regional Water Quality Functional Management Committees, once established; and

[450] Refer to **Section 6.5.2**: Research and technology development to address eutrophication-related challenges.

SHORT TERM	
(8)	Provide eutrophication support to the Water Quality Functional Management Committee, once established.

6.6 GOVERNANCE RESPONSIBILITIES

There are ongoing and anticipated significant changes in institutional arrangements, water governance and organisational responsibilities within the water sector. However, without clear definitions and reinforcement, especially concerning **roles and responsibilities**, the effectiveness of managing and making decisions about water resources and their quality could be severely compromised. This section focuses on identifying the key authorities with important roles that could impact the trophic status of water resources.

TABLE 51 is designed to outline mandates related to eutrophication governance, highlighting the importance of collaboration and management involvement.[451] Various competencies have been identified to map out the landscape of *"eutrophication governance"*. These competencies are listed alphabetically in **column 1**, linked to relevant authorities in **column 2** and contextualised from a eutrophication management perspective in **column 3**.

TABLE 51: Competencies (sectors), relevant authorities and their roles in eutrophication management.

COMPETENCY[452]	RELEVANT AUTHORITY	ROLE IN THE MANAGEMENT OF EUTROPHICATION
Agriculture	**(1)** *Department of Agriculture, Land Reform and Rural Development (DALRRD); and* **(2)** *Provincial departments of agriculture*	Are responsible for the implementation of the Conservation of Agricultural Resources Act, 1983 (Act No. 43 of 1983)[453] and for agricultural policy. Responsible for promoting agricultural practices that reduce water pollution, including anthropogenic eutrophication. In reviewing the CARA (43:1983), the DALRRD and provincial departments will consider the need to reduce excessive nutrient loading arising from current agricultural practices. The DALRRD and provincial departments will, in line with the approach outlined in the draft Policy on Sustainable Agriculture, promote sustainable agricultural practices that, amongst other things, will contribute to the reduction of nutrient loading arising from agricultural areas. The DALRRD and provincial departments will also ensure improved enforcement.
	(3) *Department of Water and Sanitation (DWS); and* **(4)** *Catchment Management Agencies (CMAs)*	Must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons. Are responsible for the authorisation of agricultural water use, including the regulation of agriculture-related industrial water use and intensive animal units, and, thus, must protect water resources against both agricultural point and diffuse impacts. The DWS must ensure that water resources remain fit for agricultural use.

[451] Refer to **POLICY STATEMENT 19**: Cooperative eutrophication management.

[452] The *"competencies"* listed in this column link to the competencies listed under the *"Authority"* headings, discussed in the individual strategies under Chapters 2, 3 and 4, to address the *"Who?"* that carries responsibility.

[453] Hereafter referred to as CARA (43:1983).

COMPETENCY[452]	RELEVANT AUTHORITY	ROLE IN THE MANAGEMENT OF EUTROPHICATION
	(5) *Department of Forestry, Fisheries and the Environment (DFFE); and* **(6)** *Provincial departments of environmental affairs*	Are responsible for the implementation of the NEMA (107:1998) and for conducting EIAs of listed activities. The DFFE must ensure, in consultation with DWS and CMAs, that water quality impacts, including excessive nutrient loading, are sufficiently dealt with in EIAs and through a co-ordinated compliance monitoring and enforcement approach with the DWS.
Disaster management	**(1)** *Department of Cooperative Governance and Traditional Affairs (CoGTA);* **(2)** *National Disaster Management Centre (NDMC)*	Supports inter-governmental cooperation. Must promote an integrated and co-ordinated system of disaster management, with a special emphasis on prevention and mitigation, by national, provincial and municipal organs of state, statuary functionaries, other role players and communities. Water pollution, including excessive nutrient loading and sewage spills, can cause disasters; a *"disaster"* being defined as: *"the progressive or sudden, widespread or localised, natural or human-caused occurrence which– causes or threatens to cause– death, injury or disease; damage to property, infrastructure or the environment; or disruption of the life of a community; and which is of a magnitude that exceeds the ability of those affected by the disaster to cope with its effects using their own resources"*.
	(3) *Department of Water and Sanitation (DWS)*	Must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons; Must ensure and maintain fitness-for-use of water resources; Responsible for the establishment of national monitoring systems to provide information to Water Management Institutions, the NDMC, water users and the public, *inter alia* for public safety and disaster management purposes.
Education	**(1)** *Department of Basic Education (DBE)*	Responsible for providing learner and teacher support materials; developing skills for a changing world; planning for the migration of the early childhood development function from the social development sector to the basic education sector; providing support to improve matric completion rates; preparing learners for jobs; and facilitating the increase in supply of quality teachers. Learning includes environmental awareness, which should also address aspects of eutrophication.
	(2) *Department of Higher Education and Training (DHET)*	Must develop capable, well-educated and skilled citizens who are able to compete in a sustainable, diversified and knowledge-intensive international economy, which meets the development goals of the country, by: reducing skills bottlenecks, especially in priority skills areas; improving participation rates in the system; correcting distributions in the shape, size and distribution of access to post-school education and training; and improving the quality and efficiency in the system, its subsystems and institutions. Additionally, DHET is over-all responsible for the harmonisation of education, training and skills development, across sectors, including the water sector, including skills to control and manage anthropogenic eutrophication.
	(3) *Energy and Water Sector Education and Training Authority (EWSETA)*	Is charged with the responsibility of coordinating and facilitating skills development and capacity building in the water sector, in accordance with the relevant national skills and human resource development strategies and agreements between government, business and labour.
	(4) *Department of Water and Sanitation (DWS);* **(5)** *Catchment Management Agencies (CMAs)*	DWS must provide the necessary sector leadership with respect to the building of technical water services and resource management capacity, including capacity to manage eutrophication. CMAs play a supporting and operational role.

COMPETENCY[452]	RELEVANT AUTHORITY	ROLE IN THE MANAGEMENT OF EUTROPHICATION
	"Research" authorities, such as: **(6)** *Water Research Commission (WRC);* **(7)** *Department of Science and Innovation (DSI);* **(8)** *Etc.*	Works closely, *inter alia* with other research and academic institutions and organisations to develop knowledge within the water sector, explore new thinking and to develop applied solutions to problems, including eutrophication knowledge development, thinking and addressing challenges.
Environment	**(1)** *Department of Forestry, Fisheries and the Environment (DFFE); and* **(2)** *Provincial departments of environmental affairs*	Are responsible for the implementation of the environmental management acts, including NEMA (107:1998), and for conducting EIAs for listed activities. The DFFE must ensure, in consultation with the DWS and CMAs, that water quality impacts, including excessive nutrient loading, are sufficiently dealt with in EIAs. DFFE, with DWS and other relevant regulators, are also responsible for a co-ordinated compliance monitoring and enforcement approach to enforce the SEMAs.
	(3) *South African National Biodiversity Institute (SANBI)*	Leads and coordinates research, and monitors and reports on the state of biological diversity in South Africa. The institute provides knowledge and information, gives planning and policy advice and pilots best-practice management models in partnership with stakeholders. Engages in ecosystem rehabilitation and restoration, leads the human capital development strategy of the biological diversity sector and manages the National Botanical and Zoological Gardens as 'windows' to South Africa's biological diversity for enjoyment and education. Eutrophication threatens biological diversity and must be controlled in a manner that promotes ecologically sustainable development.
	(4) *South African National Parks (SANParks)*	Responsible for inclusive nature conservation and to advance nature conservation policies in line with the National Development Framework for Sustainable Development and the National Development Plan. Eutrophication adversely affects *"nature"*, *i.e.,* aquatic ecosystems, biological diversity, etc.; sense of place; and tourism.
	(5) *Department of Water and Sanitation (DWS);* **(6)** *Catchment Management Agencies (CMAs)*	Must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons; Must ensure and maintain fitness-for-use of water resources, including fitness-for-use for the aquatic ecosystem. Must implement the Mitigation Hierarchy for eutrophication management. Must compile and publish sector offset guidelines for wetlands and water quality to enable the rolling out of offsetting for eutrophication management.
Health	**(1)** *Department of Health (DOH)* **(2)** *Provincial departments of health*	Have a critical role to play in epidemiological studies to understand the impacts of poor water quality, including eutrophication and the sub-standard treatment of wastewater, on human health.
	(3) *Department of Water and Sanitation (DWS);* **(4)** *Catchment Management Agencies (CMAs)*	Must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons; Must ensure and maintain fitness-for-use of water resources to *inter alia* protect human health and well-being. The Basic Human Needs Reserve constitutes a right and protects human health.

COMPETENCY[452]	RELEVANT AUTHORITY	ROLE IN THE MANAGEMENT OF EUTROPHICATION
Human settlements	**(1)** *Department of Human Settlements*	To facilitate the creation of sustainable human settlements and improve the quality of household life and to determine, finance, promote, communicate and monitor the implementation of housing and sanitation programmes.
	(2) *Department of Water and Sanitation (DWS);* **(3)** *Water Services Institutions*	To ensure that the country's water resources are protected, used, developed, conserved, managed and controlled by regulating and supporting the delivery of effective water supply and sanitation. This is done in accordance with the requirements of water-related policies and legislation that are critical in delivering on people's right to have sufficient food and water, growing the economy, and eradicating poverty.
Infrastructure	**(1)** *The Presidency*	The Presidential Infrastructure Coordinating Commission (PICC) was formed to provide for the facilitation and coordination of the National Infrastructure Plan which is of significant economic and social importance to the country; To ensure that infrastructure development is given priority in planning, approval and implementation; To ensure that the development goals of the State are promoted through infrastructure development; To improve the management of such infrastructure during all life-cycle phases, including planning, approval, implementation and operations.
	(2) *Department of Works and Infrastructure;* **(3)** *Provincial departments of public works;* **(4)** *Municipal Public Works*	Contributes to the national goals of job creation and poverty alleviation through public works programmes; Ensures the effective management of the state's immovable assets; The Constitution (108:1996) gives concurrent functions to municipalities for municipal public works, with either national or provincial government able to regulate how they exercise these functions in line with applicable norms and standards. Most municipalities carry out their own infrastructure planning and delivery functions in relation to the services they provide, such as water, sanitation, municipal roads and electricity distribution. The operation and maintenance of the WwTWs of many municipalities are currently unacceptable.
	(5) *Department of Cooperative Governance and Traditional Affairs (CoGTA);* **(6)** *Municipal Infrastructure Support Agent (MISA), an agent of CoGTA*	GoGTA supports inter-governmental cooperation. MISA provides technical support to targeted municipalities, which will improve infrastructure planning, implementation, as well as operations and maintenance. MISA also manages deployment of professional service providers to municipalities, ensuring that sufficient technical capacity is built within municipalities, which will result in effective and efficient service delivery in the long term. This includes all training administration activities, and provision of comprehensive generic strategic support to the technical support and capacity development programmes.
	(7) *Department of Water and Sanitation (DWS);* **(8)** *Catchment Management Agencies (CMAs)*	Must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons; Must provide sector support with respect to water purification and treatment and wastewater treatment infrastructure operation and maintenance.

COMPETENCY[452]	RELEVANT AUTHORITY	ROLE IN THE MANAGEMENT OF EUTROPHICATION
Land use and development planning	**(1)** *The Presidency*	The National Planning Commission was established to develop a long-term vision and strategic plan for South Africa. The main objective of the Commission is to rally the nation around a common set of objectives and priorities to drive development over the longer term. The Commission advises government on cross-cutting issues that influence the long-term development of South Africa.
	(2) *Department of Forestry, Fisheries and the Environment (DFFE); and* **(3)** *Provincial departments of environmental affairs*	Are responsible for the implementation of the environmental management acts, including NEMA (107:1998) and the Environmental Management Framework (EMF) regulations that aim to ensure that environmental limits to development are included in spatial planning. EMFs attempt to achieve the desired developmental and ecological balance by utilising early identification and mapping of sensitive ecosystems and resources to assist in pre-empting potential future land use conflicts. The EIA process provides an environmental instrument for local planning.
	(4) *Municipalities*	Municipalities are required to establish IDPs. An IDP is a plan for an area that gives an overall framework for development. It aims to co-ordinate the work of local, and other spheres of government, in a coherent plan to improve the quality of life for all the people living in that area. It considers the existing conditions and problems and resources available for development. It looks at economic and social development for the area as a whole. It is used by municipalities as a tool to plan short and long-term future development, including the water infrastructure.
	(5) *Department of Water and Sanitation (DWS);* **(6)** *Water Management Institutions; and;* **(7)** *Water Services Institutions*	To ensure that the country's water resources are protected, used, developed, conserved, managed and controlled by regulating and supporting the delivery of effective water supply and sanitation. The WSDP, as required by the WSA (108:1997), constitutes the water chapter of a municipality's IDP and deals with the long-term planning for the provision of water supply and sanitation services. Catchment Management Strategies, as required by the NWA (36:1998), deal with water resource management in WMAs. Catchment Management Strategies should influence development planning, and *vice versa*. Geographic water quality management strategies and thematic plans[454] provide content to Catchment Management Strategies and WSDPs
Mining	**(1)** *Department of Mineral resources and Energy (DMRE)*	DMRE promotes mining. Is responsible for approving Environmental Management Programme Reports (EMPRs) and for the regulation and control of mining waste. In exercising this responsibility, DMRE is required to ensure that the DWS and CMAs are involved throughout the process of mine authorisation, and that no authorisation for mining is given without a water use authorisation from the DWS, which will include stringent water quality management conditions. Additionally, DMRE is also required to involve DWS and DFFE in the process of mine closure to effectively address the potential long-term water quality impacts of mines.

[454] Refer to **Section 6.4.1.2.4, [F]**: Establishment of geographic water quality management strategies and thematic plans.

COMPETENCY[452]	RELEVANT AUTHORITY	ROLE IN THE MANAGEMENT OF EUTROPHICATION
	(2) *Department of Water and Sanitation (DWS);* **(3)** *Catchment Management Agencies (CMAs)*	Must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons. Blasting and the mining of *"nutrients"*, such as phosphorus-bearing rock, may contribute to excessive nutrient loading of water resources and to anthropogenic eutrophication. The mine-water management policy should be implemented, and mine water regulation and authorisation processes must address relevant eutrophication-related issues. DWS and DFFE/ provincial departments of environmental affairs will develop a co-ordinated and joint water quality compliance monitoring and enforcement system to optimise the use of government resources and to achieve maximum impact.
	(4) *Department of Forestry, Fisheries and the Environment (DFFE); and* **(5)** *Provincial departments of environmental affairs*	Are responsible for the implementation of the NEMA (107:1998) and for conducting EIAs for listed activities. The DFFE, in consultation with DWS and CMAs, must ensure that water quality impacts, including excessive nutrient loading, are sufficiently dealt with in EIAs and through a co-ordinated compliance monitoring and enforcement approach.
Monitoring and evaluation	**(1)** *The Presidency*	The Department of Planning, Monitoring and Evaluation (DPME) must facilitate the implementation of the NDP through the development of sector specific and outcome-specific medium-term plans and delivery agreements, and monitor and evaluate the implementation of these plans; ensure the alignment of departmental strategic and annual plans and budg*et al*locations with government's medium-term strategic framework; facilitate socio-economic impact assessments of legislation and regulations; monitor the performance of individual national and provincial government departments and municipalities, and related improvement plans, and facilitate targeted intervention programmes; monitor frontline service delivery; develop and implement the annual national evaluations plan and support the national evaluations system; and promote good planning, monitoring and evaluation practices in government.
	(2) *Department of Public Service and Administration (DPSA)*	To establish norms and standards to ensure that the state machinery functions optimally, and that such norms and standards are adhered to; implement interventions to maintain a compliant and functioning public service; promote an ethical public service through programmes, systems, frameworks and structures that detect, prevent and combat corruption; and contribute towards improved public administration. The DPSA is required to facilitate and support efforts that seek to, among others, improve service delivery quality and access; human resource management and development (Performance Management and Development System); business processes; systems and accountability management; anti-corruption and integrity; and effective public participation. Employee performance and corruption are aspects that relate to effective eutrophication management
	(3) *Department of Water and Sanitation (DWS)*	To ensure that the country's water resources are protected, used, developed, conserved, managed and controlled through oversight and supporting the delivery of effective water supply and sanitation. Establish monitoring systems for water resources and services with suitable and publicly available data and information.

COMPETENCY[452]	RELEVANT AUTHORITY	ROLE IN THE MANAGEMENT OF EUTROPHICATION
Research and development	**(1)** *Department of Water and Sanitation (DWS)*	The DWS, the DSI and the WRC are driving water research, development and innovation, nationally.
	(2) *Department of Science and Innovation (DSI);* **(3)** *Technology Innovation Agency (TIA)*	The DSI, the DWS and the WRC are driving water research, development and innovation, nationally.
	(4) *Water Research Commission (WRC)*	The WRC, the DWS and the DSI are driving water research, development and innovation, nationally.
	(5) *Science councils, such as the Council for Scientific and Industrial Research (CSIR); the Agricultural Research Council (ARC); etc.*	Have catalytic roles in establishing a strong and diverse science, engineering and technology base for South Africa; Maintain a stable pool of internationally informed workers and allow for advanced human capacity development; Support the innovation continuum from discovery to application; and often find integrated solutions to complex problems or emerging research areas.
	(6) *South African National Biodiversity Institute (SANBI)*	Leads and coordinates research, and monitors and reports on the state of biological diversity in South Africa. The institute provides knowledge and information, gives planning and policy advice and pilots best-practice management models in partnership with stakeholders. Engages in ecosystem rehabilitation and restoration, leads the human capital development strategy of the biological diversity sector and manages the National Botanical and Zoological Gardens as 'windows' to South Africa's biological diversity for enjoyment and education.
Water and Sanitation	**(1)** *Department of Water and Sanitation (DWS)*	DWS is the apex department in relation to water quality management and will lead the co-ordination, alignment and implementation of policy, strategy and legislation that address aspects of eutrophication. DWS will establish the necessary institutional arrangements under the Inter-Governmental Relations Framework Act, 2005 (Act No. 13 of 2005) to ensure a government-wide approach to IWQM, including the management of eutrophication. DWS and DFFE/ Provincial departments of environmental affairs will develop a co-ordinated and joint water quality compliance monitoring and enforcement system to optimise the use of government resources and to achieve maximum impact.
	(2) *Catchment Management Agencies (CMAs) and proto-CMAs*	Are agencies of the DWS with delegated functions under the NWA (36:1998). As such, they must act in alignment with the NWRS2 and the IWQM Policy of the DWS, and must ensure that, at the catchment scale, effective co-ordination of planning and implementation takes place between the relevant government departments. In line with the principles of subsidiarity, the management of water quality (including eutrophication) will be delegated to CMAs, with the DWS providing the necessary oversight, national strategic guidance, and control of transboundary matters. The CMAs will also build the necessary capacity to act under Section 19(3) to (6) of the NWA (36:1998), which is a responsibility allocated to them by the NWA (36:1998). The Catchment Management Committees, Catchment Management Forums (CMF) and other Water Management Institutions will be used, as appropriate, to manage or control eutrophication.

COMPETENCY[452]	RELEVANT AUTHORITY	ROLE IN THE MANAGEMENT OF EUTROPHICATION
	(3) *Department of Forestry, Fisheries and the Environment (DFFE); and* **(4)** *Provincial departments of environmental affairs*	Are responsible for the implementation of the NEMA (107:1998) and for conducting EIAs on development projects. The DFFE must ensure, in consultation with DWS and CMAs, that water quality impacts, including excessive nutrient loading, are sufficiently dealt with in EIAs and through a co-ordinated approach with the DWS to ensure compliance monitoring and enforcement. Waste is administered and managed under the National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008)[455] and should not cause nutrient loading of water resources.
	(5) *Department of Cooperative Governance and Traditional Affairs (CoGTA)*	Must improve cooperative governance across the three spheres of government, in partnership with institutions of traditional leadership, to ensure that provinces and municipalities carry out their service delivery and development functions effectively. CoGTA, *inter alia*, publishes information on municipal support and assists through capacity-building programmes.
	(6) *South African Local Government Association (SALGA)*	SALGA is the constitutionally mandated organisation responsible for local government oversight. As protector, SALGA robustly enforces the rights of the local government sector.
	(7) *Municipalities*	Municipalities have a regulatory role in relation to ensuring that by-laws regarding solid waste management and stormwater management systems reduce water pollution from municipal areas. In this regard, they carry part of government's responsibilities for preventing and reducing water pollution and must ensure that management and control of such forms of diffuse water pollution are clearly addressed in their WSDPs. At the same time, municipalities are responsible for sanitation provision and WwTWs, which are critical in improving the trophic conditions in water resources. In this regard, the DWS, working with the national and provincial departments of cooperative government, has a regulatory role to ensure that WwTWs are duly licensed under the NWA (36:1998), that Municipalities ensure that their WwTWs meet WDSs, and to take action to ensure compliance by municipalities. In this regard, the DWS will implement its internal protocol on engagement with municipalities, including taking legal action where necessary.
	(8) *Department of Finance; and* **(9)** *National Treasury (NT)*	To promote government's fiscal policy framework; Coordinate macroeconomic policy and inter-governmental financial relations; Manage the budget preparation process; Facilitate the Division of Revenue Act, 2013 (Act No. 2 of 2013) which provides for an equitable distribution of nationally raised revenue between national, provincial and local government; and monitor the implementation of provincial budgets. Financial resources are important and are needed to manage eutrophication. Involving NT officials at important stages of managing eutrophication will ensure a better understanding of challenges and needs, and *vice versa*.

6.7 CONCLUSION

Chapter 6 presented a comprehensive framework for the implementation of eutrophication governance in South Africa. This framework, developed in the form of a strategy, outlines the responsible authority (***"who?"***), the prescribed approach and actions (***"what and how?"***), and

[455] Hereafter referred to as NEMWA (59:2008).

the spatial (***"where?"***) and temporal (***"when?"***) scales of implementation. The eutrophication strategy was structured into three interrelated and mutually supporting strategy types, *viz.*:

- **Core strategies**, which focus on three aspects of eutrophication management, *viz.*, source-directed, resource-directed and remediation-directed management. These core strategies emphasised the connections between these different approaches;
- **Operational strategies**, which provide guidance on the day-to-day management of eutrophication. These strategies are based on the internationally recognised ***"Plan-Do-Check-Act"*** or P-D-C-A cycle, as outlined by Moen & Norman (2009:1-10); and
- **Supporting strategies**, which focus on measures that bolster eutrophication management. These include: *"Technical capacity building to give impetus to eutrophication management"*; *"Research and technology development to address eutrophication-related challenges"*; and *"Collaboration and management participation"*.

All these strategies and their components are interconnected, highlighting the need for an integrated and comprehensive approach to effectively address anthropogenic eutrophication in South Africa. It is essential that measures to manage eutrophication are implemented holistically and collaboratively, considering the requirements of IWQM.

Chapter 6 concluded with a focused discussion on governance responsibilities, encompassing the necessary competencies, relevant authorities and potential roles that contribute towards managing eutrophication.

Annexure J includes a one-page table for quick reference purposes to the eutrophication governance strategy for future use. In total, 111 short-term and long-term strategic actions have been identified to enhance eutrophication governance (**TABLE 52**). These actions must be carefully considered, prioritised and integrated into an implementation plan to translate strategy into actionable steps.

TABLE 52: Number of strategic actions that was identified to strengthen eutrophication management.

EUTROPHICATION MANAGEMENT STRATEGIES	NUMER OF STRATEGIC ACTIONS
CORE STRATEGIES	
Source-directed management	7
Resource-directed management	4
Remediation-directed management	8
Sub-total	***19***
OPERATIONAL STRATEGIES	
Plan stage	6
Do stage	22

EUTROPHICATION MANAGEMENT STRATEGIES	NUMER OF STRATEGIC ACTIONS
Check stage	22
Act stage	12
Sub-total	***62***
SUPPORTING STRATEGIES	
Technical capacity building	9
Research and technology development	13
Collaboration and management participation	8
Sub-total	***30***
TOTAL	**111**

The success of this strategy ultimately lies in the hands of those responsible for its roll-out and implementation. It is vital that the knowledge, policies and strategies outlined are transformed into tangible actions that enhance the well-being of water users and all South Africans.

THE RESEARCH CONTEXT OF CHAPTER 7

Chapter 7 is primarily a thesis-specific synthesis and critical reflection on the completed doctoral research. Its relationship with the EMSSA is mainly thematic, particularly with Part 4 (*The way forward*) and the implementation and concluding discussions elsewhere in the EMSSA [DWS, 2023b]. No material extended verbatim overlap with the EMSSA has been identified in this chapter; commonality principally concerns the implementation implications and future direction flowing from the same research findings.

The chapter performs academic functions specific to the doctoral thesis. It evaluates the extent to which each research objective was achieved, critically evaluates the advantages and limitations of the DPSIR framework, examines the influence of that framework on the policy and strategy responses, identifies the strategic and practical value of the research, states the knowledge contribution and develops future research and implementation perspectives. The corresponding EMSSA material, instead, concentrates on translating the policy and strategy into an implementation-oriented way forward. Chapter 7, therefore, provides scholarly closure to the doctoral research process, while the EMSSA's way-forward component frames the applied implementation process.

CHAPTER 7 RESEARCH FINDINGS AND WAY FORWARD

7.1 INTRODUCTION

FIGURE 101 positions the reader in terms of the high-level thesis structure, whereas **FIGURE 102** depicts the section content of Chapter 7 (this chapter).

FIGURE 101: High-level thesis structure (*You have arrived at Chapter 7*).

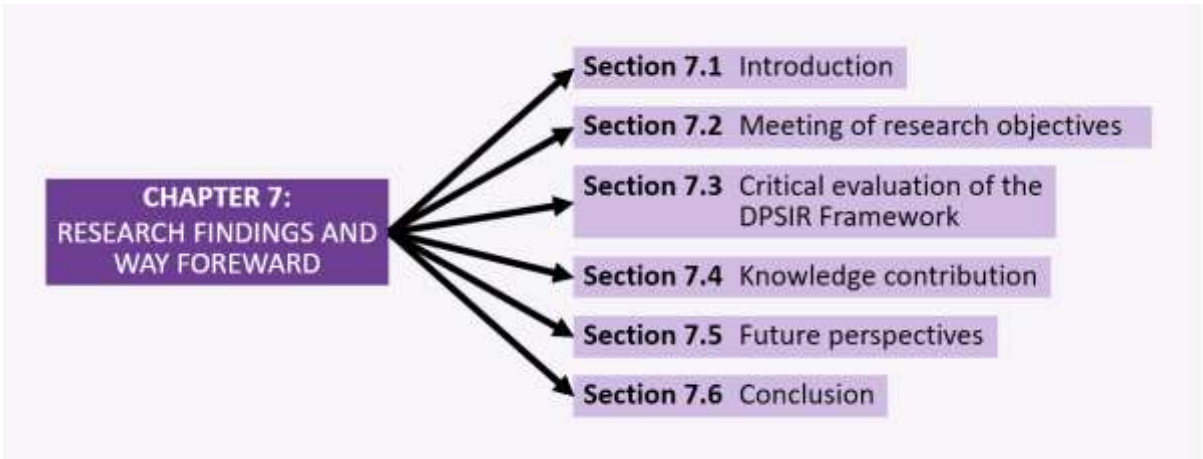

FIGURE 102: Section topics covered in Chapter 7.

Chapter 7 synthesises the insights and findings from previous chapters, providing a cohesive conclusion to the research. It distils key outcomes and reports on the achievement of research objectives. This chapter critically evaluates the DPSIR Framework, considering the value it adds

to the governance of eutrophication and assesses the knowledge contributed by the study. Finally, it presents perspectives on future directions and recommends practical steps to enhance the governance framework, outlining necessary actions for implementing the policy and strategies developed in this study.

7.2 MEETING OF RESEARCH OBJECTIVES

In **Chapter 1**, the study aimed to achieve the following three research objectives:

- **Research objective 1:** *"To design a framework for the evaluation of eutrophication governance in South Africa"*
- **Research objective 2:** *"To recommend a response in the form of eutrophication governance policy"*; and
- **Research objective 3:** *"To recommend a response in the form of eutrophication governance strategy" for implementation"*.

Sections 7.2.1, **7.2.2** and **7.2.3** summarise the research findings associated with each of these objectives and provide an account of how these objectives were met. For ease of comprehension, the evaluations under each of the three research objectives are presented in bullet points, each accompanied by descriptive narratives and closing with a finding and concluding remark.

7.2.1 Research objective 1: *"To design a framework for the evaluation of eutrophication governance in South Africa"*

- **Framework foundation and theoretical grounding:**

  In **Section 2.2**, the foundation for the framework designed to evaluate eutrophication governance in South Africa is firmly rooted in established theoretical constructs. The DPSIR Framework served as the primary analytical tool, ensuring that the evaluation is comprehensive and systematically covers all essential aspects of governance. This framework is referenced extensively throughout **Chapters 2** and **4**, where its application is discussed in detail to ensure it captures the multifaceted nature of eutrophication governance.

- **Data collection and integration:**

  The evaluation framework has drawn on data collected through a three-stage approach, incorporating literature research, a nationally conducted survey [456] and stakeholder

[456] The survey conducted by the DWAF during 2002 and 2003 was part of a departmental initiative focused on eutrophication control [Walmsley, 2003:11]. The findings from this survey [Walmsley, 2003:Annexures 3,4,5 and 6] were further analysed and provided crucial insights that were invaluable to this study.

engagement.[457] This holistic approach ensured that the framework for the evaluation of eutrophication governance in South Africa is not only based on a theoretical foundation but also supported by empirical evidence from diverse sources. This process is elaborated in **Chapter 2**, specifically in **Sections 2.3** and **2.4**, which outline how the data were integrated into the evaluation framework.

- **Causal chain analysis:**

  A crucial element of the evaluation framework is the causal chain analysis, which traces the relationships between various factors contributing to eutrophication. This analysis is essential for understanding how different drivers and pressures lead to changes in the state of waterbodies and their subsequent impacts. The outcomes of the causal chain analysis are discussed in **Chapter 4** where it served as the basis for evaluating current governance practices and identifying gaps.

- **Qualitative forecasting:**

  Another component of the framework for the evaluation of eutrophication governance in South Africa is qualitative forecasting, which was used to predict the future evolution of eutrophication governance in the country. This method relies on expert judgment and historical data to anticipate potential future scenarios and their implications for eutrophication governance. This aspect is addressed in **Chapter 4,** specifically **Section 4.3**, and was pivotal for the evaluation framework's forward-looking approach and perspective.

- **Integration of stakeholder insights:**

  The framework for the evaluation of eutrophication governance in South Africa placed significant emphasis on incorporating insights from various stakeholder groupings, including government agencies, NGOs and the private sector. Stakeholder engagement[457] is seen as critical for ensuring that the evaluation is grounded in the realities of those directly affected by eutrophication governance. This is highlighted in **Sections 2.3**, **4.2** and **4.5** , which detail the stakeholder engagement process and refer to outcomes.

- **Application of DPSIR Framework:**

  The DPSIR Framework was applied in evaluating current policies and strategies related to eutrophication governance. This application is detailed in **Chapter 4**, where the framework is used to identify weaknesses in existing governance structures and to propose improvements.

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[457] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

The evaluation framework's adaptability allowed it to address a wide range of issues, from regulatory gaps to the need for more robust enforcement mechanisms.

- **Evaluation of governance effectiveness:**

  The effectiveness of current governance measures was critically assessed using the evaluation framework, with a particular focus on how well these measures address the drivers and pressures identified in the causal chain analysis. This evaluation is presented in **Chapter 4** and forms the basis for subsequent policy and strategy recommendations.

- **Identification of gaps and challenges:**

  The evaluation framework's application revealed several gaps in the current governance of eutrophication in South Africa, including inadequate monitoring and enforcement, as well as insufficient coordination between different governmental and non-governmental entities. These challenges, among others, are discussed in detail in **Chapter 4**, emphasising the need for more integrated and comprehensive governance approaches.

- **Policy and strategy development:**

  The findings from the framework for the evaluation of eutrophication governance in South Africa were used to inform the development of new policy and strategies for eutrophication governance. This was a key outcome of the evaluation process, as discussed in **Chapters 5** and **6**, where the transition from evaluation to policy and strategy formulation is outlined.

- **Finding and concluding remark:**

  The first research objective, which is to design a framework for evaluating eutrophication governance in South Africa, was effectively met. The study employed the DPSIR Framework as the foundation for this evaluation. The **finding of the research** indicate that this model is well-suited for capturing the multifaceted nature of eutrophication governance, allowing for a comprehensive analysis that encompassed the root causes of eutrophication, the pressures on water resources and the resulting impacts. The framework was further validated through the integration of empirical data and stakeholder input[458], demonstrating its robustness and applicability to the South African context.

[458] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

7.2.2 Research objective 2: *"To recommend a response in the form of eutrophication governance policy"*

- **Policy development rationale:**

  The policy recommendations are grounded in the evaluation framework developed under the first research objective. These recommendations were designed to address the identified gaps and weaknesses in current governance approaches and structures, as highlighted in **Section 3.9** and outlined in **Chapter 4**. The policy proposals in **Chapter 5** aim to establish a more coherent and effective governance framework for managing eutrophication and introduce, for the first time, a pollutant-specific policy for South Africa.

- **Incorporation of stakeholder feedback:**

  Stakeholder feedback[459] played a pivotal role in shaping the recommended policy responses. The insights gathered from various stakeholders during the research process were used to ensure that the policy is both practical and reflective of the needs of those affected by eutrophication. This process is detailed in **Section 2.3**, and in **Chapter 5** where the stakeholder contributions are integrated into the policy formulation.

- **Visionary perspective:**

  The recommended governance policy is built on a clear vision, mission and goal for eutrophication management in South Africa. Eutrophication governance must align with the IWQM Vision and Mission and contribute to ensuring that water resources remain fit-for-use. This visionary perspective is discussed in **Section 5.3**, where it forms the foundation of the entire policy.

- **Technical policy statements:**

  The recommended governance policy consists of fourteen technical policy statements (**Chapter 5**), each addressing a specific aspect of eutrophication management. These statements are designed to be comprehensive, covering areas such as nutrient-load reduction, water quality monitoring and enforcement mechanisms. The technical nature of these statements ensures that they are actionable and aligned with best practices in environmental management.

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[459] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

- **Supporting policy statements:**

  In addition to the technical policy statements, five supporting policy statements are proposed in **Chapter 5**. These statements are broader in scope and address cross-cutting issues such as inter-agency coordination, public awareness, research and development. These supporting policy statements are intended to create an enabling environment for the successful implementation of the technical policy statements.

- **Alignment with national and international frameworks:**

  The recommended policy aligns with both national legislation and international best practices, as detailed in in **Section 3.11**. This alignment ensures that the policy is legally sound and consistent with global approaches to water resource management. This is especially important considering the transboundary nature of many waterbodies affected by eutrophication.

- **Focus on sustainability and long-term impact:**

  The policy recommendations emphasise the need for sustainable management practices that can provide long-term solutions to eutrophication. This includes promoting practices that reduce nutrient inputs into waterbodies and enhancing the resilience of aquatic ecosystems. Sustainability is a recurring theme throughout **Chapter 5**, where the long-term goals of the proposed policy are discussed.

- **Governance and institutional arrangements:**

  The proposed policy statements (**Sections 5.4.18** and **5.4.19**) include recommendations for strengthening governance structures and institutional arrangements. This involves clarifying the roles and responsibilities of different government agencies (**Section 6.6**), improving inter-agency coordination (**Section 6.5.3**) and enhancing the capacity of institutions responsible for water management (**Section 6.5.1**). These governance-related recommendations are critical for the effective implementation of the policy.

- **Monitoring and enforcement mechanisms:**

  Effective monitoring and enforcement are essential components of the proposed policy. The recommendations include the establishment of robust monitoring systems to track water quality and the implementation of enforcement mechanisms to ensure compliance with the policy. These aspects are thoroughly covered in **Chapter 5**, where the need for a strong regulatory framework is emphasised.

- **Public participation and awareness:**

  The proposed policy also highlights the importance of public participation and awareness in eutrophication management. Engaging the public and raising awareness about the causes and impacts of eutrophication are crucial for garnering support for the policy and ensuring successful implementation. **Chapter 5** discusses various approaches for increasing public involvement in eutrophication governance.

- **Finding and concluding remark:**

  The second research objective, to develop a governance policy response to the eutrophication challenges in South Africa, was successfully met. The **finding of the research** indicate that the policy recommendations are based on a comprehensive analysis of existing governance gaps and align with national and international best practices. The proposed policy emphasises sustainability, long-term impact and the need for an integrated approach to water resource management. It also incorporates feedback from key stakeholders,[460] ensuring that the policy is not only theoretically sound but also practically relevant. Despite these strengths, the effectiveness of the policy will ultimately depend on its implementation and the political will to enforce it across all relevant sectors.

7.2.3 Research objective 3: *"To recommend a response in the form of eutrophication governance strategy" for implementation"*

- **Strategic vision and goals:**

  The recommended governance strategy aligns with the policy and is founded on the same vision, mission, goal and objectives for eutrophication management in South Africa. This visionary perspective is detailed in **Section 5.3**, forming the foundation of the entire strategy, as explained in **Section 6.1**.

- **Priority actions and implementation plan:**

  The Strategy outlines a set of priority actions that need to be taken to achieve the eutrophication management goal. These actions are categorised into short, medium and long-term initiatives, ensuring that the Strategy is both actionable and time-bound. An implementation plan is also proposed to guide the execution of these actions, as discussed in **Chapter 6**.

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[460] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

- **Resource allocation and capacity building:**

  Effective implementation of the Strategy requires adequate resources and capacity building. The Strategy includes recommendations for allocating financial, human and technical resources to support the implementation of priority actions. Capacity building initiatives are also proposed to enhance the skills and knowledge of those involved in eutrophication management. These aspects are covered in **Chapter 6**, where the importance of resource mobilisation is emphasised.

- **Institutional roles and responsibilities:**

  Section 6.6 clearly defines the roles and responsibilities of various institutions involved in eutrophication governance. This clarity is essential for ensuring that all stakeholders are aware of their duties and can work together effectively. The Strategy also proposes mechanisms for improving inter-agency coordination, which is crucial for addressing the complex and cross-cutting nature of eutrophication.

- **Monitoring and evaluation framework:**

  Monitoring and evaluation are essential components of the Strategy, designed to track roll-out progress and measure the effectiveness of implemented actions. The monitoring and evaluation framework includes indicators for assessing the impact of the Strategy and mechanisms for reporting progress. **Chapter 6** provides a detailed overview of the monitoring and evaluation framework, highlighting its role in ensuring the Strategy's success.

- **Stakeholder engagement and communication:**

  The Strategy emphasises the need for ongoing stakeholder engagement and communication. This includes regular consultations with affected communities, NGOs and the private sector to gather feedback and ensure that the Strategy remains relevant and responsive to emerging challenges. **Section 6.5.3** discusses the various channels and methods for effective stakeholder engagement.

- **Integration with broader water resource management:**

  The recommended Strategy is designed to be integrated with broader water resource management initiatives in South Africa. This integration ensures that eutrophication governance is not treated in isolation but as part of a holistic approach to water governance. The Strategy's alignment with policy is discussed in **Chapter 6**, where the need for a coordinated approach is emphasised.

- **Adaptive management and flexibility:**

  The Strategy incorporates principles of adaptive management, allowing for adjustments to be made in response to changing conditions or new information. This flexibility is essential for dealing with the uncertainties associated with eutrophication management and ensuring that the Strategy remains relevant and effective over time. **Chapter 6**, specifically **Section 6.4** outlines the adaptive management approach and its application in the Strategy.

- **Finding and concluding remark:**

  The third research objective, which focuses on recommending a governance strategy for eutrophication, was comprehensively addressed in the study. The **finding of the research** indicate that the strategy developed is detailed and includes clear implementation steps, monitoring mechanisms and allowance for public engagement. This strategic approach is designed to be adaptive, allowing for adjustments based on ongoing monitoring and evaluation. The study's strategic recommendations are both actionable and aligned with the broader objectives of sustainable water resource management in South Africa. However, the successful implementation of this strategy will require sustained commitment and coordination among various stakeholders, as well as the necessary resources to support these efforts.

7.3 CRITICAL EVALUATION OF THE DPSIR FRAMEWORK

Section 7.3 expands on the discussions in **Section 7.2** by providing additional and specific details on the DPSIR Framework. It examines the various advantages and disadvantages encountered during the study, which are further explored in **Sections 7.3.1** and **7.3.2**, respectively. For ease of comprehension, the advantages and disadvantages are presented in bullet points, accompanied by descriptive narratives. The influence of the DPSIR Framework on the eutrophication governance policy and strategy responses, along with the strategic contribution and practical value derived from its use, is summarised in **Sections 7.3.3** and **7.3.4**, respectively.

7.3.1 Advantages

The following advantages of the DPSIR Framework (depicted in TABLE 22) were identified during study execution:

- **Versatility**

  The DPSIR Framework exceled in conceptualising and addressing eutrophication issues by systematically analysing causal chains. It has proven effective in selecting nutrient reduction measures and understanding the impact of factors such as urbanisation on nutrient loading.

- **Complexity handling**

  The DPSIR Framework has been instrumental in disentangling complex eutrophication management challenges by pinpointing root causes of failure, identifying key sectors that require action and formulating suitable responses to address excessive nutrient loading in water resources. Furthermore, this approach also highlighted unforeseen issues, such as the impact of vandalism on wastewater infrastructure due to criminality and socio-economic challenges present in South Africa, which underscored the need for interventions by law enforcement agencies like the South African Police Service (SAPS) in the management of eutrophication.[461]

- **Objectivity**

  The DPSIR Framework's systematically structured *"building block"* approach, which analyses causal factors in a step-by-step manner, significantly enhanced objectivity. The inclusion of empirical research and analysed water quality data further strengthened this objectivity. Moreover, different eutrophication management intervention options can be compared on a cost-benefit basis to facilitate informed decision-making and allow for tailoring responses to match specific catchment or local needs.

- **Solution oriented**

  The DPSIR Framework was utilised to connect eutrophication challenges with potential solutions – a pivotal aspect for developing effective governance policies and strategies for eutrophication. Additionally, it assisted in structuring policy and strategy responses based on their focus of application, *e.g.,* the *"strategic"*, *"operational"* and *"supporting"* focuses incorporated in the Strategy.

- **Scalability**

  The DPSIR Framework supported and guided the identification of eutrophication management responses at different geographical scales, from source-specific and local to sub-catchment, Water Management Area (WMA), national, transboundary and international levels. This flexibility enabled consideration of cumulative effects and the distribution of accountability across various catchment areas, governmental levels and political boundaries.

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[461] Responsibilities for eutrophication management extend beyond the DWS, as highlighted in the 2017 policy document [DWS, 2017c, p. 14], which emphasises that *"water quality management is a collective responsibility, involving entities beyond the DWS and national government"*.

- **Risk assessment**

  The DPSIR Framework provided a structured approach for ERA and the development of risk-based mitigation responses. Eutrophication hazards, affecting infrastructure, the economy, human health and aquatic ecosystems, pose significant risks. It is crucial to differentiate between natural features like undisturbed geology and anthropogenic hazards such as accelerated erosion from human activities. Risks from anthropogenic eutrophication, including unlawful wastewater discharges or urbanisation impacts, require governance responses to prevent adverse effects. Using the DPSIR Framework for risk-based assessment helped prioritise interventions and ensure efficient resource allocation[462] and implementation.

- **Performance monitoring**

  The DPSIR Framework established a basis for selecting performance indicators crucial for monitoring water quality improvements and the effectiveness of eutrophication management strategies, thereby facilitating ongoing refinement. Additionally, the SDG Programme's Target 6.3 on *water quality and wastewater* [UN, 2015b:20; UN Water, 2017:13] offers valuable metrics[463] for assessing *"the lawful discharge of wastewater"* and the *"fitness-for-use of water resources"*. Aligning these SDG indicators with metrics for eutrophication management is essential for promoting efficient management practices.

- **Sustainability**

  By analysing and understanding the complex causal relationships within eutrophication governance, the DPSIR Framework facilitated the development of policy positions and a governance strategy that balances ecological protection with socio-economic advancement. This approach ensures that while promoting economic benefits, such as optimised fertiliser use, it does not compromise downstream water users or aquatic ecosystems.

- **Confidence building**

  The scientifically grounded DPSIR Framework bolstered stakeholder[464] confidence by facilitating rigorous data collection and promoting participative engagement, which enhance the reliability of the analysis results.

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[462] Includes human, financial and other resources.

[463] Wording of Global SDG Indicators 6.3.1: *"Proportion of wastewater safely treated"* and 6.3.2: *"Proportion of bodies of water with good ambient water quality"*.

[464] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

- **Communication instrument**

  The DPSIR Framework doubled as a communication instrument, ensuring that technical content could be effectively conveyed through stakeholder engagement,[464] fostering a common understanding of eutrophication causal issues.

- **Integration of natural and social sciences**

  The DPSIR Framework enhanced interdisciplinary communication by bridging gaps between various natural and social scientific disciplines. Its structured approach linked root causes to ecological consequences and their societal effects, improving overall collaboration and understanding.

- **Training support**

  The DPSIR Framework was particularly effective in training diverse audiences during stakeholder participation,[464] helping them understand the causes and effects of eutrophication. This facilitated a shared understanding of management strategies across different disciplines.

7.3.2 Disadvantages

The following disadvantages of the DPSIR Framework (as represented by TABLE 22) became apparent during study execution:

- **Its application remains globally restricted**

  While the DPSIR Framework is increasingly utilised in environmental analyses, management and problem-solving, Tscherning, *et al.* (2012:104) notes that its application is primarily centred in Europe. Even so, the DPSIR Framework's use in this study as a tool for framing eutrophication problems and seeking solutions to inform policy and strategy development proved beneficial, despite occasional ambiguities in the terminology used during the analyses.

- **Terminology is ambiguous**

  This research revealed that there is some room for interpretation in the use of terminology, particularly in how the major components are understood. From the perspective of water resources and services management, variations in interpretation were especially evident concerning the *"Pressure"*, *"State"* and *"Impact"* components. For instance, the term *"Pressure"* was often used interchangeably with *"activity"* or *"driving force"*. Similarly, discussions around *"State"* change and *"Impact"* frequently focused on *"impacts on water resources"*, while *"Impact"* can also refer to the societal effects resulting from a change in the water resource *"State"*. However, this ambiguity was addressed by clearly defining how to attribute causal factors to the different components. Furthermore, the regular application of

the DPSIR Framework by practitioners will help standardise definitions and establish a more systematic approach for consistency, starting from concepts and advancing to assessments.

- **Biase towards the physical dimension of the environment**

  The research showed that the DPSIR Framework places greater emphasis on the physical aspects of water resource and service issues, such as human activities, effluent handling, physical effects and mitigation measures, while giving less focus to the societal dimension, which includes elements like knowledge generation, governance structures, resource allocation (both financial and human capital), awareness and the societal framing of problems.

  To address this imbalance, the study intentionally involved a diverse group of stakeholders[465] and considered all perspectives.[466] Several societal framing issues related to eutrophication that require attention include:

  - Skills development training and capacity building;
  - Appointment of staff with appropriate skills levels;
  - Research and technology development;
  - Creation of an informed, supportive and responsible public;
  - Facilitation of behavioural change and a sense of responsibility in communities; and
  - Management participation and cooperative governance.

- **Neglect of social justice and equity matters**

  Recognising that equity and social justice considerations are often overlooked in addressing environmental challenges, this research implicitly adhered to the slogan *"Water is life – Sanitation is dignity"*, which is relevant to eutrophication management. This emphasised that every individual in South Africa has the right to sufficient clean water and affordable basic sanitation services.[467] Through the policy and strategy, environmental justice was pursued to prevent vulnerable and disadvantaged groups from disproportionately facing adverse effects. The eutrophication governance policy and strategy support the essential goal of ensuring fair access to water resources, benefits and services to meet basic human needs and safeguard well-being.[468]

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[465] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

[466] The meeting records of all stakeholder engagements and the diverse views of the stakeholders, as recorded in a response register [DWS, 2023c] can all be viewed at: https://www.dws.gov.za/RDM/DocumentsSDS.aspx.

[467] With this right comes a responsibility not to abuse the right to free basic services and to pay for services where these are provided over and above a basic amount.

[468] These considerations for sustainable development constitute national environmental management principles, as per S.2(4)(c) and (d) of NEMA 107:1998.

- **Different skill sets are required**

  To uphold the integrity of the DPSIR Framework as both a problem framing and solution-seeking approach, it was essential to encourage contributions from a diverse group of stakeholders[469] with varied skill sets. The author's expertise being rooted in natural sciences posed a risk of bias towards the *"Pressure"* and *"State"* components, where natural scientists tend to delve into detailed analysis. Recognising this potential bias, the involvement of professionals from different backgrounds was deemed essential. This underscored the importance of employing the DPSIR Framework comprehensively as a unified instrument applicable to both human activities and water resource quality, serving as a bridge between natural and socio-economic systems.

- **Tends to oversimplify**

  The research viewed the DPSIR concept as a systematic sequence of cause-and-effect control events that outlines the progression from identifying the root causes of eutrophication to their management. However, despite its structured approach, the DPSIR Framework occasionally oversimplified eutrophication issues, often neglecting interconnected causal factors and the importance of adopting a systems thinking perspective. The individual components of the framework – *"Pressure"*, *"State"*, *"Impact"* and *"Response"* – were not always clearly distinct and exhibited strong interconnections. Specifically, certain *"Pressure"* and *"State"* components were closely linked, with pressures initiating various physical changes in the *"State"* that ultimately lead to biological transformations [Patrício, *et al.*, 2016:9].

  Moreover, the timescale of these changes varies; they can be chronic, developing subtly over extended periods, or acute, occurring instantaneously, particularly in terms of dose-response dynamics [Niemeijer & De Groot, 2008:89-106]. It is crucial to recognise the complexity inherent in catchment systems when applying the DPSIR Framework, as multiple concurrent activities can produce cumulative effects, with a single activity generating multiple pressures. Notably, a pressure does not always result in a change in state or impact, and the same pressure associated with different activities can produce varying effects with differing severity and potential for state change [Smith, *et al.*, 2016:12]. Consequently, an exclusive focus on one-to-one relationships, while disregarding the intricate interactions among various pressures, activities, water resources and societal factors, results in an oversimplified application of the DPSIR Framework [Niemeijer & De Groot, 2008:89-106].

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[469] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

7.3.3 Influence on the policy and strategy responses

The DPSIR Framework was instrumental in analysing eutrophication issues and guiding management interventions. Its benefits generally outweigh the manageable challenges, which can be mitigated by acknowledging its limitations and engaging diverse groups of stakeholders from social and natural sciences for broader perspectives.

The DPSIR Framework has effectively facilitated the systematic identification of several **human-induced activities and their effects on**–

- nutrient loading of waterbodies;
- the fitness-for-use of receiving water resources;
- downstream ecological infrastructure and their services;
- water user well-being and society; and
- the economy.

Human-induced activities, as outlined in the DPSIR Framework (**TABLE 22**), particularly the **drivers** and **pressures**, encompass several driving forces and sectors, including phosphate mining, coal-burning activities, piggeries, sewage treatment, irrigated golf courses, vandalism of wastewater infrastructure, poor government administration, urban runoff and climate variability, among others. These drivers and pressures lead to **state changes** that primarily result in negative impacts. **TABLE 23** provides a comprehensive inventory of the root causes associated with the **impacts** of excessive nutrient loading in South Africa.

The Framework in **TABLE 22** bridged the gap between natural and social sciences, connecting these fields with eutrophication governance policy and strategy **responses** that are focused on equity and inclusive development. This integration enhanced the policy and strategy processes by visualising the complex relationships between human activities, water environments and society, aiding communication, impact assessment and stakeholder engagement.[470]

According to Gabrielsen & Bosch (2003:10), the significance of the causal factors from different segments of the DPSIR Framework, also known as indicators, varies depending on the stage of the policy-strategy cycle to which they are applied (**FIGURE 103**). The authors note that environmental problems pass through a policy-strategy life cycle, with public awareness and policy-strategy attention initially increasing, followed by a decrease as the problem becomes more controlled. The horizontal bars, underneath the graph in **FIGURE 103**, illustrate the relative role

[470] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

of these indicators during the policy-strategy life cycle [Gabrielsen & Bosch, 2003:11; Smeets & Weterings, 1999:5].

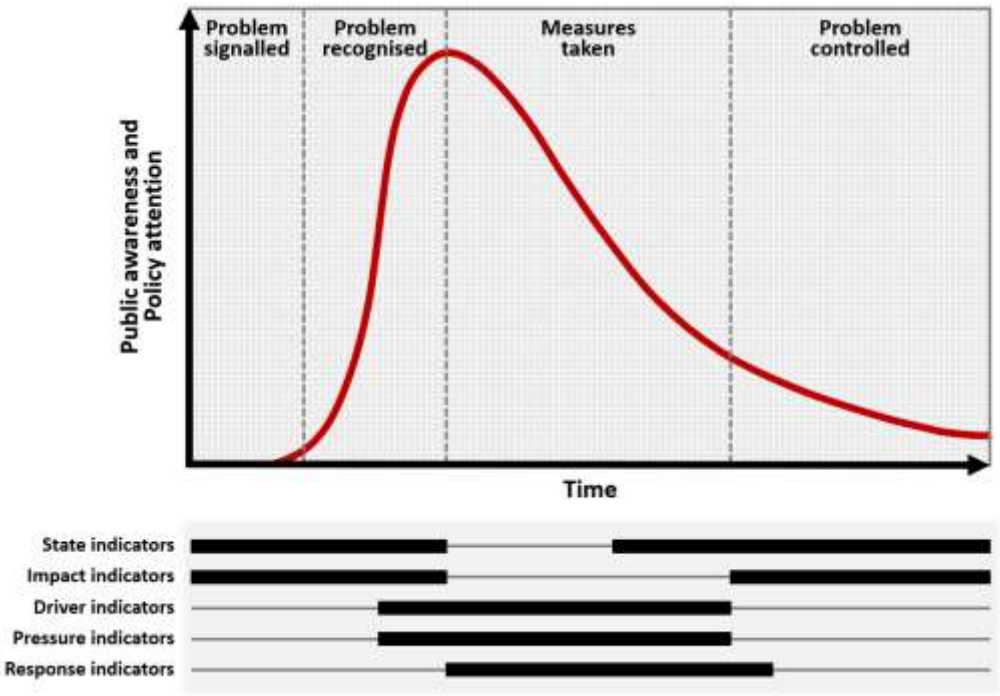

FIGURE 103: DPSIR indicators and the policy-strategy life cycle [Bassi, *et al.*, 2011:54].

The observations made by Gabrielsen and Bosch (2003:10-11), illustrated in **FIGURE 103**, are relevant to the development of the eutrophication governance policy and strategy in this study:

- Initially, indicators related to the ecological state of water resources, along with subsequent environmental and socio-economic impacts, were crucial in identifying the issue of eutrophication, raising awareness and establishing the need for interventions;
- As the governance policy was formulated and strategies developed, the focus shifted to elements that could be influenced, particularly societal drivers and anthropogenic pressures;
- During the implementation of the policy and strategies, emphasis is expected to remain on these elements - namely, societal drivers and anthropogenic pressures within the realm of influence;
- It is essential to establish management performance indicators to track changes in these drivers and pressures during these stages;[471] and
- Additionally, state and impact indicators become important again during the monitoring phases of the policy and strategy life cycle.[472]

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[471] Refer to **Section 6.4.3.2.3**: Management performance monitoring and reporting.
[472] Refer to **Section 6.4.3.2.2**: Domestic status and trends monitoring and reporting.

TABLE 53 summarises the societal **drivers** and anthropogenic **pressures** contributing to eutrophication in South Africa. The information in this table synthesises content from the populated DPSIR Framework in **TABLE 22**, showcasing the linkages established between the "*eutrophication problem"* and desired policy and strategy **responses**.

According to **TABLE 53**, various policy and strategy interventions were identified and categorised into a coherent structure based on analysed causal factors and stakeholder collaboration.[473] The populated DPSIR Framework in **TABLE 22** provided a solid foundation for policy formulation and strategy development. Additionally, it was observed that Source-Directed Controls for eutrophication management typically address drivers and pressures, while Resource-Directed Measures primarily focus on state changes and impacts, as outlined in the Framework.

[473] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

TABLE 53: National policy and strategy responses to the societal drivers and anthropogenic pressures that contribute to eutrophication.[474]

DRIVER [475]	PRESSURE [476]	NATIONAL RESPONSES [477]	
		Policy [478]	Strategy [479]
▶ Mining; ▶ Industry; ▶ Agriculture; ▶ Tourism; ▶ Human settlement areas; ▶ Other land uses; ▶ Local government; ▶ Poverty and criminality; ▶ Administrative and political instability; ▶ Population dynamics; and ▶ Climate variability and change.	▶ Blasting; ▶ Exposing of phosphorus-bearing rock; ▶ Disturbance of habitat and soil layers. ▶ Discharge of substandard wastewater; ▶ Atmospheric emissions of NH_3 and NO_2 affecting the nutrient content of precipitation; ▶ Atmospheric emissions of NO_2 and SO_2 generating acid precipitation; ▶ Habitat disturbance. ▶ Poor fertilising practices and over-fertilising causing fertiliser-laden diffuse runoff from agricultural fields; ▶ Prevalence of erosion, mobilising sediments on which chemical elements are adsorbed; ▶ Over-irrigation to satisfy leaching requirements;	**CHIEF IMPERATIVES:** ▶ Limit anthropogenic nutrient loading; ▶ Reduce excessive primary production; ▶ Protect aquatic ecosystems and their biological diversity; ▶ Secure water resources that are fit-for-use; and ▶ Support ecologically sustainable development and justifiable socio-economic growth. **COMPLEMENTING IMPERATIVES:** ▶ Resource eutrophication management (with money, people, etc); ▶ Promote research; ▶ Promote management cooperation; ▶ Promote transparency; and ▶ Facilitate capacity building and the empowerment of role-players.	**CORE APPROACHES:** **Source-directed management:** ▶ Improved regulation; ▶ Operationalising of the Receiving Water Quality Objectives Approach; and ▶ Integration across sectors. **Resource-directed management:** ▶ Determine RDMs; and ▶ Improved regulation. **Remediation-directed management:** ▶ Develop and implement a Remediation Strategy to address cases of legacy nutrient pollution; and ▶ Improved regulation.

[474] **TABLE 53** is based on **TABLE 22: An analysis of anthropogenic nutrient enrichment and the effects of eutrophication in South Africa, based on the DPSIR Framework.**

[475] Defined as the socio-economic or demographic developments, OR production or consumption practices that trigger *"pressures"*.

[476] Defined as the anthropogenic activities or consequences that disturb the *"state"* of ecosystems.

[477] Defined as the societal measures aimed at preventing, minimising or mitigating negative *"impacts"* by feeding back to the *"drivers"*, *"pressures"* and *"state"*.

[478] Colloquially, defined as the ground rules (for eutrophication management).

[479] Colloquially, defined as those approaches that must give effect to (the eutrophication management) policy.

DRIVER [475]	PRESSURE [476]	NATIONAL RESPONSES [477]	
		Policy [478]	Strategy [479]
	▶ Feedlot waste disposal and wastewater discharged; ▶ Habitat disturbance; ▶ Organic waste, food leftovers and excreta associated with aquaculture; ▶ Inadequate farm advisory and extension services; ▶ Poor farming practices. ▶ Fluctuating and increased waste and wastewater production; ▶ Fluctuating and increasing pressure on urban wastewater handling. ▶ Nutrient-laden diffuse runoff from built-up areas; ▶ Habitat disturbance. ▶ Fertiliser and nutrient-laden diffuse runoff from golf courses; ▶ Habitat disturbance. ▶ Inadequate operation and maintenance of offsite and onsite sanitation systems; ▶ Theft and vandalism of wastewater infrastructure; ▶ Discharge or loss of untreated and/or substandard wastewater; ▶ Poor waste practices; ▶ Inadequate investment in wastewater infrastructure. ▶ Washing in streams and in rivers;		**<u>OPERATIONAL APPROACHES</u>:** **<u>Plan</u>:** ▶ Holistic water resource system and catchment planning; ▶ Structured planning to ensure that WwTWs are timeously upgraded to not exceed design capacities; ▶ Validation and verification (V&V) of all water uses with a water quality impact potential; and ▶ Waste load accounting to be introduced as a planning instrument. **<u>Do</u>:** ▶ Integration of authorisation conditions with water resource requirements; ▶ Increased reuse and recycling of waste and water containing waste; ▶ Revision of nutrient discharge standards; ▶ Ensure that all water uses with a potential to contribute towards eutrophication are permissible, compliant and lawful; ▶ Improved water use authorisation and administration; ▶ Improved regulation; ▶ Enforcement of conservation agriculture; ▶ Enforcement of buffer zones and other best management practices; and ▶ Implementation of the WDCS.

DRIVER [475]	PRESSURE [476]	NATIONAL RESPONSES [477]	
		Policy [478]	Strategy [479]
	▶ Inappropriate onsite sanitation and bush-toileting; ▶ Theft and destruction of sanitation services infrastructure; ▶ Overflowing utility access holes caused by sewer system blockages and sabotage; and ▶ Discharge of untreated and/or substandard urban wastewater. ▶ Exceeding the design capacity of WwTWs; ▶ Destruction of water resource and services infrastructure; ▶ Failing operation and maintenance of water resource and services infrastructure; ▶ Discharge of untreated and/or substandard urban wastewater; ▶ Variety of upstream pollution sources; ▶ Operating rules for the water resource infrastructure that promote enrichment. ▶ Return flows becoming an increasingly important component of the country's water budget; ▶ Habitat disturbance; ▶ Increased urban waste production; ▶ The nutrient-loading character of wastewater is changing; ▶ Pressure on urban wastewater handling; ▶ Negative effect on the affordability of rural water services infrastructure, affecting operation and maintenance;		**Check:** ▶ Improved monitoring programmes and reporting for local and national government; ▶ Regular and targeted compliance monitoring; and ▶ Appropriate information management systems are in place. **Act:** ▶ Effective enforcement of big and regular offenders; ▶ Rehabilitation and restoration of ecological infrastructure; ▶ Rehabilitation of hard infrastructure; and ▶ Adequate maintenance of water resource and services infrastructure. **SUPPORTING APPROACHES:** ▶ Skills development training and capacity building; ▶ Appointment of employees, who possess appropriate skills levels, in technical positions; ▶ Research and technology development; ▶ Creation of an informed, supportive and responsible public; ▶ Behavioural change communication programmes to facilitate behavioural change and a sense of responsibility in

DRIVER [475]	PRESSURE [476]	NATIONAL RESPONSES [477]	
		Policy [478]	Strategy [479]
	▶ Altered flow and water quality regimes associated with the establishment of impoundments and related infrastructure; ▶ Lack of skilled water scientists and engineers; ▶ Inadequately capacitated water institutions. ▶ Changing water temperatures; ▶ Altered dilution capacity of water resources; ▶ Increasing levels of erosion; ▶ Altered flow and water quality regimes associated with the establishment of impoundments and related infrastructure; ▶ More frequent mixing of stratified layers and inversion of epilimnion and hypolimnion may lead to more regular recycling of nutrients from the anaerobic hypolimnion; and ▶ Exacerbated poor trophic conditions		communities aimed at limiting and preventing excessive nutrient loading; and ▶ Management participation and cooperative governance.

7.3.4 Strategic contribution and practical value

The **eutrophication governance policy and strategy developed using the DPSIR Framework is likely to be more effective** in reducing eutrophication than other approaches lacking this framework due to several key factors:

- Firstly, the DPSIR Framework provided a comprehensive and systematic approach to understanding and addressing the complex problem of eutrophication. By breaking down the process into distinct stages, *i.e.* into the *"Driver"*, *"Pressure"*, *"State"*, *"Impact"* and *"Response"* stages, this Framework ensured that the root causes of eutrophication are identified and addressed. Unlike other policies and strategies that might focus on symptoms or immediate pressures, the DPSIR approach digs deeper into the underlying drivers that contribute to nutrient loading in waterbodies. This deeper understanding allowed for more targeted interventions that are likely to be more effective.
- Secondly, the holistic nature of the DPSIR Framework facilitated the integration of various management strategies across different sectors. Eutrophication is a multifaceted problem *inter alia* involving agriculture, industry, urban planning and water management. The DPSIR Framework's ability to link these sectors through a common understanding of causes and effects enhances coordination and ensures that policies and strategies in one sector do not inadvertently exacerbate problems in another. This contrasts with more isolated approaches, where sector-specific policies and strategies might miss out on these crucial interconnections, leading to less effective overall outcomes.
- Another advantage of the DPSIR Framework is its emphasis on adaptive management. By continuously monitoring the state of waterbodies and the impacts of various pressures, the Framework allows for ongoing assessment and adjustment of policies and strategies. This adaptability is critical in dealing with the dynamic and often unpredictable nature of eutrophication, where environmental conditions and human activities can change rapidly. Policies and strategies developed without this framework might be less responsive to changing conditions, leading to lagging or outdated responses.
- The Framework also enhanced stakeholder engagement[480] and public awareness, which are critical components in addressing eutrophication. The clear structure of the DPSIR Framework makes it easier for stakeholders, including local communities, industries and government agencies, to understand the issues and their roles in addressing them. This transparency and inclusivity foster greater collaboration and commitment, which are essential for the successful

[480] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

implementation of any policy or strategy. In contrast, policies and strategies developed without such a structured approach might struggle with stakeholder buy-in, limiting their effectiveness.

- Finally, the DPSIR Framework aligns well with international best practices in environmental management, providing a robust and scientifically grounded basis for policy and strategy development. This alignment not only ensures that the policies and strategies are comprehensive and effective but also makes it easier to secure international support and funding for their implementation. Policies and strategies developed without this framework might lack this level of credibility and coherence, making them less attractive for international collaboration and support.

In conclusion, the eutrophication governance policy and strategy developed using the DPSIR Framework **are thus likely to be more successful in reducing eutrophication** due to their comprehensive, integrated, adaptive and participatory nature. These qualities make the DPSIR-based approach more effective in addressing the root causes of eutrophication and ensuring the sustainable management of water resources.

7.4 KNOWLEDGE CONTRIBUTION

The thesis presents a significant original contribution to new knowledge in the field of eutrophication governance, particularly within the South African context. This contribution is rooted in the development of a comprehensive and structured evaluation framework that addressed the complexities and challenges associated with eutrophication management. The research introduces a novel application of the DPSIR Framework, tailored specifically to the South African water governance context, which serves as a foundation for understanding and mitigating eutrophication.

One of the key contributions is the design of a framework for evaluating eutrophication governance. This evaluation framework is innovative in its integration of multiple dimensions of governance, including policy, strategy, implementation and stakeholder engagement. The framework is not only theoretical but also highly practical, offering a clear pathway for assessing the effectiveness of current governance practices and identifying areas for improvement. This aspect of the research directly addresses the gap in the literature where comprehensive governance frameworks for eutrophication, particularly in developing countries, are lacking.

Furthermore, the thesis recommends specific policy responses that are informed by the developed Framework. The policy responses are designed to be context-specific, addressing the unique challenges faced by South Africa, such as limited resources, political influence and the need for interdisciplinary collaboration. The policy recommendations emphasise the importance

of adaptive management and flexibility, ensuring that governance strategies can evolve in response to new data and changing environmental conditions.

The research also makes a significant contribution by proposing a governance strategy for the implementation of the eutrophication management policy responses. This Strategy includes detailed guidelines for the roles and responsibilities of various stakeholders, the spatial and temporal scales of implementation and the integration of public awareness and education campaigns. The emphasis on stakeholder engagement and the need for continuous monitoring and evaluation reflects a deep understanding of the complexities involved in managing eutrophication.

Another original contribution is the research's focus on building technical capacity and fostering innovation within the water governance sector. The thesis highlights the importance of research and technology development, proposing a coordinated national strategy for water quality research and innovation. The Strategy aims to bridge the gap between research and practical implementation, ensuring that scientific advancements translate into effective governance solutions.

Lastly, the thesis underscores the importance of philosophical and theoretical grounding in governance research. By incorporating concepts such as the tragedy of the commons, integrated decision-making and ecological infrastructure, the research offers a robust theoretical foundation that enhances the relevance and applicability of the proposed governance framework. This interdisciplinary approach not only contributes to the field of water governance but also provides valuable insights for broader environmental management practices.

7.5 FUTURE PERSPECTIVES

This section introduces future perspectives and offers a forward-looking view, focusing on recommendations for future initiatives that target water quality management in **Section 7.5.1** and recommendations for the practical application of the proposed eutrophication governance policy and strategy in **Section 7.5.2**.

7.5.1 Recommendations for future initiatives with similar aims, focusing on the development of water quality management-related policies and strategies

As our understanding of the interconnectedness between societies and natural systems grows, it is essential for management responses to adapt and incorporate new knowledge in both the ecological and social domains. Regulators, especially regarding eutrophication and water quality management, must act promptly and effectively on this new information. Carnohan, *et al.*

(2023:1) highlight that this necessity is heightened in the Anthropocene era, where rising demands for natural resources coincide with diminishing supplies, increasing the risk of irreversible harm to ecosystems. The authors stress the urgent need for enhanced communication and information exchange among the three **implementation pillars (or silos)**: *"Science"*, *"Policy"* and *"Society"* (**FIGURE 104**).

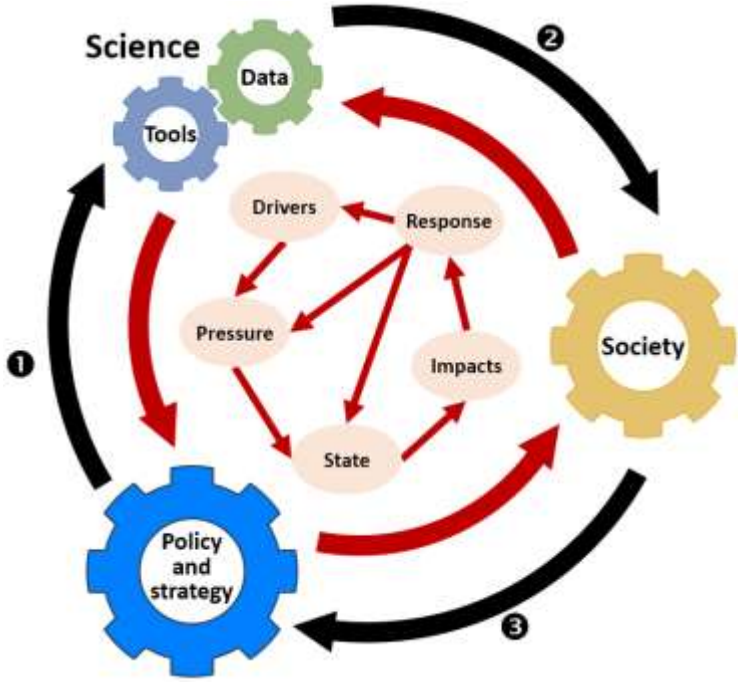

FIGURE 104: The DPSIR Framework links the three pillars of implementation, *viz.*, *"Science"*, *"Society"* and *"Policy"*, by creating interlinkages (red and black) [adapted from Carnohan, *et al.*, 2023:2].

Note, the reference numbers ❶, ❷ and ❸ in the figure are explained in the accompanying discussions, further down.

Science provides essential data, research and technical expertise necessary for developing effective management practices and informing policy and strategy decisions. **Policy and strategy** play crucial roles in supporting legislation and regulation that protects water resources, ensuring compliance with WDSs and setting limits of pollution. **Society** also plays a significant role in advocating for ecologically sustainable development through education, public awareness initiatives and individual actions.

A myriad of policies and strategies exists to protect our water resources, the environment and public health. For these measures to succeed, interventions and regulatory responses must address real-world complexities and the interactions among various factors. The DPSIR Framework is designed for this purpose. However, according to Carnohan, *et al.* (2023:3), the implicit focus on analytical and procedural aspects of the DPSIR Framework needs to be made explicit to facilitate coordination across the implementation silos, *"Science"*, *"Policy"* and *"Society"*. Those involved in water resource and environmental

protection should be cautious about continuously creating variations of the DPSIR Framework, as this could undermine its effectiveness. Emphasising the **analytical** and **procedural** aspects can enhance the impact of DPSIR analyses while maintaining flexibility.

According to Odume, *et al.* (2021:116), engaging the three silos, *"Science"*, *"Society"* and *"Policy"* is vital for implementing sustainable solutions to water resource and environmental challenges. The enhanced application of the DPSIR Framework is represented conceptually by the red feedback loop that acts across the entire system (**FIGURE 104**). This creates feedback linkages (depicted in black and red): ❶ from policy to science (and *vice versa*), ❷ science to society (and *vice versa*) and ❸ society to policy (and *vice versa*). While it is uncommon for all three feedback linkages to operate concurrently, activating them all during the DPSIR analysis ensures that essential information from within these sectors drives the implementation of sustainable solutions [Carnohan, *et al.*, 2023:3].

Carnohan, *et al.* (2023:3) propose **five key elements** vital for enhancing **water quality management policy and strategy development** using the DPSIR Framework.

- **Iteration**

  The iterative application of the DPSIR Framework is key to understanding causal factors, recognising consequences and identifying management responses. By promoting feedback among policy-strategy, science and society, it enhances collaboration and information sharing. As new information emerges, engaging researchers or practitioners from various fields and previously un-consulted stakeholders enhances confidence in suggested interventions.

- **Risk, uncertainty and analytical bias**

  The application of the DPSIR Framework should be transparent, addressing salience, credibility and legitimacy in communicating uncertainty and bias inherent in analytical techniques [Saltelli, *et al.*, 2020:482-484]. Information must be relevant to not only scientific and political stakeholders but also civil society and the private sector, where various definitions of risk and uncertainty have developed [Wassénius & Crona, 2022:35-43]. Integrating diverse perspectives is crucial for designing effective natural resource management solutions.

- **Flexible integration**

  To maintain the relevance of the DPSIR Framework, it should not be confined to specific analytical methods or techniques, as this could hinder the adoption of new approaches such as nature-based solutions [Escobedo, *et al.*, 2019:3-12]. Nature-based solutions address interconnected global societal challenges, enhancing socio-ecological adaptation and resilience.

- **Use of quantitative methods**

Simulation modelling is widely used to analyse various environmental aspects and impacts, aiding informed decision-making. Evidence suggests that these models often outperform expert judgement in prioritising management actions for ecological systems [Czaika & Selin, 2017:54-62]. These models predict impacts, simulate different scenarios and explore trade-offs.

- **Clear and standardised definitions for DPSIR analysis**

Understanding the definitions of the individual DPSIR components is crucial, as they underpin causal analyses and facilitate information connections within and among the three implementation silos – *"Science"*, *"Society"* and *"Policy"*. A summary of these definitions, derived from a meta-analysis by Oesterwind, *et al.* (2016:8-15) and applied in this study, is presented in **TABLE 54**.

TABLE 54: Definitions of the causal links (components) in the DPSIR Framework.[481]

DEFINITIONS PROPOSED BY Oesterwind *et al.* (2016:8-15)	SIMPLIFIED DEFINITIONS APPLIED IN THIS STUDY
Driver:	
A superior complex phenomenon governing the direction of the ecosystem change, which could be both of human and nature origin.	**The socio-economic or demographic developments, OR production or consumption practices that trigger *"pressures"*.**
Pressure:	
A result of a driver-initiated mechanism (human activity/natural process) causing an effect on any part of an ecosystem that may alter the environmental state.	**The anthropogenic activities or consequences that disturb the *"state"* of ecosystems.**
State:	
The actual condition of the ecosystem and its components established in a certain area at a specific time frame, that can be quantitatively-qualitatively described based on physical (*e.g.,* temperature, light), biological (*e.g.,* genetic-, species-, community-, habitat-levels) and chemical (*e.g.,* nitrogen level, atmospheric gas concentration) characteristics.	**The physical, chemical or biological condition of ecosystems that are associated with *"impacts"* on the environment.**

[481] Carnohan *et al.* (2023, p. 4) acknowledge that while some differences in interpretation are likely inevitable in future applications and updates to the Oesterwind *et al*. (2016, p. 9) definitions are anticipated, the work by Oesterwind *et al.* (2016, p. 9) nevertheless offers a solid foundation for DPSIR analyses.

DEFINITIONS PROPOSED BY Oesterwind *et al.* (2016:8-15)	SIMPLIFIED DEFINITIONS APPLIED IN THIS STUDY
Impact:	
Consequences of environmental state change in terms of substantial environmental and/or socio-economic effects which can be both, positive or negative.	**The effects on habitats, biota, ecosystem goods and services and ultimately society that require control, management and/or mitigation, through appropriate *"responses"*.**
Response:	
All management actions seeking to reduce or prevent an unwanted change or to develop a positive (desirable) change in the ecosystem.	**The societal measures aimed at preventing, minimising or mitigating negative *"impacts"* by feeding back to the "drivers", "pressures" and "state".**

By emphasising these key elements, the DPSIR Framework can transition from a mere reporting tool to a valuable aid for complex cause-and-effect response analyses, serving as a useful communication tool that supports the adoption of innovative practices and enhances the integration of scientific knowledge within society.

7.5.2 Recommendations for future eutrophication governance policy and strategy implementation

7.5.2.1 Implementation context

The umbrella IWQM Vision and Mission has been adopted for managing eutrophication in South Africa. In addition, a national goal for eutrophication management has been established, *viz.*: ***"To manage eutrophication effectively in order to protect aquatic ecosystems and secure water resources that are fit for use"***. Alongside this, a set of concomitant objectives has also been adopted. Together, these aspirational goals set forth a visionary and resolute guiding framework for the newly developed eutrophication governance policy and strategy.

The eutrophication governance policy consists of fourteen technical policy statements and five supporting policy statements that are more general and crosscutting in nature. These are considered highly relevant to eutrophication management in South Africa. Furthermore, the eutrophication governance strategy offers strategic guidance for policy implementation. While the Strategy facilitates implementation by specifying authority (*"who?"*), outlining approaches and actions (*"what and how?"*), and indicating spatial (*"where?"*) and temporal (*"when?"*) scales for implementation, there is a need to schedule strategy implementation with concrete deadlines and allocate resources in terms of human capital, budget and equipment, as required.

7.5.2.2 Towards the development of an Implementation Plan

Developing an Implementation Plan to translate strategy into action [DWS, 2017e:69] presents an opportunity to clearly outline how the eutrophication governance policy and strategy can be practically implemented. The Implementation Plan acts as a crucial catalyst for transitioning towards achieving full implementation. Key considerations for devising the Implementation Plan are presented in bullet points, accompanied by descriptive narratives:

- **A short to medium-term focus, in the context of longer-term aspirations for eutrophication management:**

  The NWA (36:1998) allows for the gradual development of the NWRS, mandating regular reviews every five years. This facilitates a long-term vision supported by short to medium-term actions and allows for adaptability through frequent updates.

  When it comes to the eutrophication governance strategy, which might be integrated into the NWRS in future, the emphasis should be on prioritising critical actions earmarked for short to medium-term implementation, while also keeping in mind the long-term goal for managing eutrophication in South Africa. The Implementation Plan should be designed to be practical, clear, concise and measurable, outlining specific yearly plans to track progress towards short to medium-term progress effectively.

- **Prioritising critical concerns for action, while ensuring that other issues are addressed through on-going management or monitoring for future prioritisation and action:**

  Addressing all eutrophication challenges simultaneously is not feasible due to resource limitations and constraints. Therefore, the Implementation Plan should concentrate on tackling prioritised challenges first. While ongoing work on other relevant areas continues, focusing on key challenges guides the allocation of resources.

- **Relevance at transboundary, national, catchment, local and source-specific scales, while ensuring alignment, at each spatial scale, across sectors:**

  For effective management of eutrophication, the eutrophication governance strategy must address vertical relevance across different spatial scales, *i.e.*, transboundary, national, WMA, catchment, local and source specific. It should also handle issues, horizontally at each spatial scale, specific to certain sectors or between sectors, despite presenting institutional and administrative challenges that are not easy to overcome, but that are critical to ensure effective eutrophication management.

  While the responsibilities of departments and organisations vary by scale and mandate, the catchment level is crucial for eutrophication management. The interfaces at this scale are vital

for water quality management, particularly for eutrophication. Therefore, CMAs play a key role in facilitating this, and developing CMSs becomes essential for strategic and adaptive management of nutrient loading and eutrophication. Hence, the Implementation Plan should prioritise interventions at the catchment level.

- **The inclusion of measurable targets for regular monitoring and evaluation:**

  Considering the complexities of managing eutrophication, which involve various aspects like water resource protection, planning, land and water use authorisation, regulation and monitoring, it is crucial to establish a purposeful framework for short and medium-term achievements leading to the long-term goal. Therefore, the Implementation Plan should focus on short to medium-term milestones and have a review cycle that aligns with Annual Performance Plans (APPs) (including operational planning and employee Performance Agreements) in government. It is essential to include SMART (Specific, Measurable, Agreed-upon, Realistic and Time-based) targets in the Implementation Plan to ensure clarity and accountability in achieving progress.

- **Adaptive responses, enabled by effective on-going monitoring and evaluation:**

  Effective management of complex socio-economic and ecological systems requires an adaptive approach. The successful implementation of the eutrophication governance strategy depends on the government's ability, especially at the catchment scale, to employ deliberate, systems-based adaptive management practices. This collaborative approach demands consistent engagement among government entities, the private sector and civil society to continually assess and modify policies and strategies. Adaptive management facilitates the adjustment of initiatives, such as resource reallocation upon reaching milestones or responding to unexpected outcomes. A well-rounded Implementation Plan should feature a robust monitoring and evaluation framework, especially at the catchment level, focusing on the trophic status of significant water resources.

  While South Africa is often viewed as a developing country, it shares some similarities with first-world nations, particularly in its strong water policies and legislation. However, implementation remains challenging due to factors such as decreasing sector capacity and leadership, corrupt practices, inadequate training and slow progress in establishing Water Management Institutions [Muller & Erasmus, 2020:47-62; Nepfumbada & Seetal, 2020:29] and CMSs. These challenges, both within and outside the eutrophication governance strategy's scope, require attention through effective leadership, coordination, collaboration and decisive action.

7.6 CONCLUSION

The proposed eutrophication governance policy and strategy is likely to succeed where previous approaches have failed due to its structured and comprehensive framework that addresses the root causes of nutrient loading rather than merely targeting symptoms. Unlike earlier approaches that often lacked coordination and targeted focus, the proposed policy and strategy for eutrophication governance in South Africa utilised the DPSIR Framework, ensuring that all elements contributing to eutrophication were systematically unpacked and addressed in the policy and strategy.

One key reason this policy and strategy can effectively tackle nutrient loading is their focus on integrated management and adaptive governance. They acknowledge the interconnectedness of ecological, social and economic factors in eutrophication governance, prioritising proactive over reactive interventions. By continuously monitoring and adjusting the strategy based on real-time data and evolving conditions, the policy is well-equipped to address the dynamic and complex nature of eutrophication – an area where previous approaches often struggled.

Moreover, the strategy's threefold focus on integrating source-directed, resource-directed and remediation-directed management tackles the problem from multiple angles. By regulating nutrient sources while protecting and rehabilitating affected waterbodies, the policy establishes a robust framework likely to yield tangible results. This holistic approach is particularly crucial in South Africa, where the complexity and scale of the eutrophication problem necessitate more than piecemeal solutions.

Beyond point source control, managing excessive diffuse nutrient loading offers a significant opportunity to improve the trophic status of many water resources. Innovative approaches include pioneering remediation for legacy pollution, elevating water quality planning to the level of strategic water supply and demand planning, developing waste load accounting methodologies and determining NLOs, establishing comprehensive BMPs and BMGs, expanding Green Drop certification and introducing LCA thinking. Additionally, certification schemes and eco-labelling with a public information component could indicate product compliance from a water resource protection perspective.

An evaluation of current legislation reveals that several underutilised provisions could enhance eutrophication management since the enactment of the NWA (36:1998). Urgent short-term actions include implementing these provisions, fully rolling out the WDCS, creating regulations under Section 26 of the NWA (36:1998), and enhancing RDMs. The outdated phosphorus standard of 1 mg/ℓ orthophosphate should be revised. Additionally, improving regulation and operationalising the Receiving Water Quality Objectives Approach is crucial. CMAs should be

established in all WMAs, and where CMAs do not exist, proto-CMAs should be empowered to accelerate catchment management and establish CMSs.

The inclusion of stakeholder engagement[482] and public awareness as key components of the strategy distinguishes it from many past interventions. By involving communities, industries and local government in the solution, the strategy is to foster a sense of ownership and responsibility among all parties. This collaborative approach is essential for ensuring long-term success, as it promotes the adoption of sustainable practices and enhances compliance with regulatory requirements.

As sector leader, the DWS recognises that managing water resources requires a collaborative, sector-wide approach, as highlighted in the NWRS. Addressing eutrophication necessitates broad engagement, fostering cooperation, partnerships and stewardship. Sustainable water use cannot be achieved by the DWS alone; it requires buy-in and support from the entire sector. A differentiated approach to engaging various government departments and sectors is essential and should be outlined in the Implementation Plan supporting the eutrophication governance strategy. The DWS will play a crucial role in developing and maintaining these stakeholder relationships.

Developing an Implementation Plan for strategy roll-out is the next step toward full implementation. The eutrophication governance strategy lays a solid foundation, particularly through the actions outlined in the *"core action"*, *"operational action"* and *"supporting action"* tables throughout **Chapter 6**. These include **TABLE 28**, **TABLE 29**, **TABLE 30**, **TABLE 33**, **TABLE 37**, **TABLE 44**, **TABLE 46**, **TABLE 47**, **TABLE 48** and **TABLE 50**, which should be transferred to, and expanded in the Implementation Plan(s) with defined scheduling and resource allocation. The DWS will oversee the monitoring and evaluation of the Implementation Plan(s). Success in protecting aquatic ecosystems and securing fit-for-use water resources will depend on appropriate resourcing, effective stakeholder participation and a commitment to improving water resource trophic conditions.

Although the proposed eutrophication governance strategy for South Africa is currently considered stable and ready for implementation, future revisions will likely be needed to keep pace with changing circumstances and priorities. Future revisions of the strategy may also explore collaboration with the DFFE to expand its scope to include coastal marine waters,

[482] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

enhancing integration and potentially resulting in a dual strategy that addresses both inland and coastal marine water eutrophication.

Finally, **TABLE 55** offers a concluding summary of the results from the assessment conducted to evaluate the achievement of the research objectives (see **Section 7.2** for detail):

TABLE 55: Summary of the research findings.

RESEARCH OBJECTIVE	RESEARCH FINDING
Research objective 1: *"To design a framework for the evaluation of eutrophication governance in South Africa"*	The study employed the DPSIR Framework as the foundation for evaluation. The resulting framework for the evaluation of eutrophication governance was well-suited for capturing the multifaceted nature of eutrophication governance, enabling a comprehensive analysis of the root causes of eutrophication, the pressures on water resources and the resulting impacts. The framework was further validated by integrating empirical data and stakeholder input [483], demonstrating its robustness and relevance to the South African context. **Consequently, the first research objective – *"to design a framework for the evaluation of eutrophication governance in South Africa"* – was effectively met.**
Research objective 2: *"To recommend a response in the form of eutrophication governance policy"*	The policy recommendations are grounded in a thorough analysis of existing eutrophication governance gaps and align with national and international best practices. The proposed policy emphasises sustainability, long-term impact and the need for an integrated approach to water resource management. It also incorporates feedback from key stakeholders,[483] ensuring that the policy is both theoretically sound and practically relevant. **Thus, the second research objective – *"to recommend a response in the form of eutrophication governance policy"* – was successfully met.**
Research objective 3: *"To recommend a response in the form of eutrophication governance strategy" for implementation"*	The developed strategy is detailed and includes clear implementation steps, monitoring mechanisms and opportunities for public engagement. The strategic approach is designed to be adaptive, allowing for adjustments based on ongoing monitoring and evaluation. The strategy's recommendations are both actionable and aligned with the broader objectives of sustainable water resource management in South Africa. **Thus, the third research objective – *"to recommend a response in the form of a eutrophication governance strategy for implementation"* – was comprehensively addressed.**

The research conducted in this thesis aimed *"to develop a critical understanding of eutrophication governance in South Africa"*. The outcomes of the research suggest that this aim was indeed achieved, as the study successfully bridged the theoretical framework with practical policy and strategy for implementation, offering valuable insights into addressing eutrophication challenges in South Africa.

In summary, the eutrophication governance policy and strategy are poised for success due to its comprehensive, integrated and adaptive approach. By addressing the root causes of eutrophication, involving relevant stakeholders and continuously adapting to changing conditions, the proposed policy and strategy offer a realistic pathway to reversing nutrient loading trends and effectively governing eutrophication in South Africa.

[483] The DWS conducted stakeholder engagement from 2020 to 2022 as part of developing South Africa's Eutrophication Management Strategy [DWS, 2023b:41]. Inputs gathered during the stakeholder engagement process [DWS, 2023d] were utilised in this study to enhance research outputs.

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ANNEXURE A

Department of Water and Sanitation copyright declaration letter

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

Private Bag X313, Pretoria 0001 / Sedibeng Building, 185 Francis Baard Street, Pretoria
Tel: 012 336 7500 / Fax: 012 323 4470 or 012 326 2715

Enquiries: P. Viljoen **Telephone:** 012 336 7514 **Reference:** P RSA 000/00/24123

To whom it may concern

COPYRIGHT DECLARATION

Mr Van Wyk was tasked with the responsibility to author the *Eutrophication Management Strategy for South Africa*. Additionally, Mr Van Wyk, at the time, expressed the wish to simultaneously conduct a Ph.D. study with similar focus and covering the same topic.

The simultaneous development and authoring of the *Eutrophication Management Strategy for South Africa*, and conducting of further studies, by Mr Van Wyk, presented a unique opportunity of mutual synergy. The Department supports continuous learning, talent development and capacity building of its employees. The in-tandem execution of these two initiatives, thus, was acceptable to the Department. As such, the Department acknowledges that Mr Van Wyk is the author of both documents and accepts that the document (referenced below) and his doctoral thesis, intrinsically, will share content.

The Department requires Mr Van Wyk to acknowledge the *Eutrophication Management Strategy for South Africa*, as referenced below, as source document in his doctoral thesis.

Yours sincerely

Viljoen

for DIRECTOR-GENERAL

Letter signed by: P. Viljoen
Designation: Scientist Manager: Water Quality Planning
(Supervisor of Mr Van Wyk)
Date: 9 May 2023

Full document reference:

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2030 NDP NATIONAL DEVELOPMENT PLAN
Our Future - make it work

ANNEXURE B

Human health and other effects of water resources that are unfit-for-use, with respect to some eutrophication-related water quality indicators (parameters) [Scherman, 2008; DWAF, 1996:Vol.1-7]

ALPHABETICALLY ARRANGED PARAMETERS	APPLICABLE CONCENTRATION RANGES	EXPECTED EFFECT CAUSED BY WATER RESOURCES WITH WATER QUALITY IN THE UNACCEPTABLE CONCENTRATION RANGE	MOST SENSITIVE RECEIVING WATER USER
Algae *[free floating green algae/ phytoplankton]*	***Aesthetics:*** **I: <=15 µg Chl-α/ℓ** **A: >15 to <=22.5 µg Chl-α/ℓ** **T: >22.5 to <=30 µg Chl-α/ℓ** **U: >30 µg Chl-α/ℓ**	Severe nuisance conditions may be encountered. Aesthetically unacceptable surface algal scums evident for much of the time. The composition and health of the fish population may be affected, depending on species. Rotting algae may cause severe odour problems. No health effects expected.	**Recreation: Full contact**
	Aesthetics: **I: <=20 µg Chl-α/ℓ** **A: >20 to <=25 µg Chl-α/ℓ** **T: >25 to <=30 µg Chl-α/ℓ** **U: >30 µg Chl-α/ℓ**	Severe nuisance algal blooms (scums) as well as other symptoms of eutrophication. Rotting algae may cause severe odour problems. No health effects expected.	**Recreation: Non-contact**
Algae *[blue-green algae/ cyanobacteria]*	***Human health:*** **I: <=50 colonies/mℓ** **A: >50 to <=14 000 colonies/mℓ** **T: >14 000 to <=42 000 colonies/mℓ** **U: >42 000 colonies/mℓ**	Significant risk of acute and chronic effects associated with the ingestion of the algae.	**Domestic**
	Human health: **I: <=6 blue-green algae units*** **A: -** **T: -** **U: >6 blue-green algae units**	Blue-green algae present in significant numbers and scum formation likely. Recreational users should increase their vigilance for algal scums and avoid all contact with scums. Notices warning users to avoid algal scums should be posted. Health effects likely with accidental ingestion of the scums and skin irritations likely with contact with the scums.	**Recreation: Full contact**

ALPHABETICALLY ARRANGED PARAMETERS	APPLICABLE CONCENTRATION RANGES	EXPECTED EFFECT CAUSED BY WATER RESOURCES WITH WATER QUALITY IN THE UNACCEPTABLE CONCENTRATION RANGE	MOST SENSITIVE RECEIVING WATER USER
	***Health of livestock*:** **I: <=12 colonies/mℓ; and <=2 000 Microcystis colonies/mℓ** **A: -** **T: >12 colonies/mℓ; and <=2 000 Microcystis colonies/ mℓ** **U: >12 colonies /mℓ; and >2 000 Microcystis colonies/ mℓ**	High risk of acute toxic effects. Do not allow livestock to drink from or have contact with the scum.	**Agriculture: Livestock watering**
Algae *[chlorophyll-α]*	***Aesthetics*:** **I: <=1 µg Chl-α/ℓ** **A: >1 to <=15 µg Chl-α/ℓ** **T: >15 to <=100 µg Chl-α/ℓ** **U: >100 µg Chl-α/ℓ**	Water has a distinct murky appearance, becoming increasingly green in colour. Significant taste and odour problems. Secondary growth of bacteria in the distribution system.	**Domestic**
Algae *[microcystins (hepatotoxins produced by algae)]*	***Human health*:** **I: <=0.8 µg/ℓ** **A: >0.8 to <=0.9 µg/ℓ** **T: >0.9 to <=1 µg/ℓ** **U: >1 µg/ℓ**	Possible acute hepatotoxic effects.	**Domestic**
Free ammonia *[NH_3]*	***Human health and Aesthetics*:** **I: <=1.0 mg N/ℓ (pH>8)** **A: >1.0 to <=2.0 mg N/ℓ (pH>8)** **T: >2.0 to <=10.0 mg N/ℓ (pH>8)** **U: >10.0 mg N/ℓ (pH>8)**	Unacceptable in domestic water. Danger of formation of nitrite. Likelihood of fish deaths in aquaria. Chlorination is severely compromised.	**Domestic**

ALPHABETICALLY ARRANGED PARAMETERS	APPLICABLE CONCENTRATION RANGES	EXPECTED EFFECT CAUSED BY WATER RESOURCES WITH WATER QUALITY IN THE UNACCEPTABLE CONCENTRATION RANGE	MOST SENSITIVE RECEIVING WATER USER
	Aquatic ecosystem health: **I: <=15.0 µg N/ℓ (pH>8)** **A: >15.0 to <=72.5 µg N /ℓ (pH>8)** **T: >72.5 to <=100 µg N /ℓ (pH>8)** **U: >100 µg N /ℓ (pH>8)**	The toxicity of ammonia and ammonium salts to aquatic organisms is directly related to the amount of free ammonia in solution. At low to medium pH values, the ammonium ion dominates, but as pH increases free ammonia is formed, the latter being considerably more toxic to aquatic organisms. Free un-ionised ammonia affects the respiratory systems of many animals, either by inhibiting cellular metabolism or by decreasing oxygen permeability of cell membranes. Acute toxicity to fish may cause a loss of equilibrium, hyper-excitability, an increased breathing rate, an increased cardiac output and oxygen intake, and in extreme cases convulsions, coma and death. Chronic effects include a reduction in hatching success, reduction in growth rate and morphological development, and pathological changes in tissue of gills, liver and kidneys.	**Aquatic ecosystem**
Clarity	***Human health & Aesthetics:*** **I: >=3.0 m (Secchi depth)** **A: <3.0 to >=1.5 m (Secchi depth)** **T: <1.5 to >=1.0 m (Secchi depth)** **U: <1.0 m (Secchi depth)**	Unsuitable for swimming. However, if lack of clarity (or turbidity) is the only consideration preventing the use of a waterbody for swimming, then it may be allowed, provided all subsurface, potential hazards are removed and signs indicating water depth are clearly posted. Risk of disease transmission by organisms associated with particulate matter increases, but this cannot solely be determined based on clarity measurements. There may be some depreciation in aesthetic quality and enjoyment of the waterbody.	**Recreation: Full contact**
Dissolved Oxygen *[DO]*	***Aquatic ecosystem health:*** **I: >=80%** **A: <80% to 70%** **T: <70% to 60%** **U: <60% *(7 day mean)*; and <40% *(1 day minimum)***	The 7-day mean minimum and the 1-day minimum should apply together. Violation of these minimum values is likely to cause acute toxic effects on aquatic biota.	**Aquatic ecosystem**
Dissolved Organic Carbon *[DOC]*	***Human health:*** **I: <=5 mg C/ℓ** **A: >5 to <=10 mg C/ℓ** **T: >10 to <=20 mg C/ℓ** **U: >20 mg C/ℓ**	Aesthetic effects (taste, odour, colour) and formation of trihalomethanes (THMs) during chlorination. Marked health effects, depending on the composition of the DOC.	**Domestic**

ALPHABETICALLY ARRANGED PARAMETERS	APPLICABLE CONCENTRATION RANGES	EXPECTED EFFECT CAUSED BY WATER RESOURCES WITH WATER QUALITY IN THE UNACCEPTABLE CONCENTRATION RANGE	MOST SENSITIVE RECEIVING WATER USER
Nitrate/Nitrite *[NO_2^-/NO_3^-]*	***Human health:*** **I: <=6 mg N/ℓ** **A: >6 to <=10 mg N/ℓ** **T: >10 to <=20 mg N/ℓ** **U: >20 mg N/ℓ**	Upon absorption, nitrite combines with the oxygen-carrying red blood pigment, haemoglobin, to form methaemoglobin, which is incapable of carrying oxygen. This condition is termed methemoglobinemia. The reaction of nitrite with haemoglobin can be particularly hazardous in infants under three months of age and is compounded when the intake of Vitamin C is inadequate. Occurrence of mucous membrane irritation in adults.	**Domestic**
	Health of livestock: **I: <=100 mg N/ℓ** **A: >100 to <=200 mg N/ℓ** **T: >200 to <=400 mg N/ℓ** **U: >400 mg N/ℓ**	Adverse chronic effects, such as restlessness, frequent urination, dyspnoea, cyanosis associated with methemoglobinemia and decreased feed and water intake associated with adverse palatability effects may occur, but can be tolerated if- ▶ feed concentration is normal; ▶ there is adequate carbohydrate intake; and ▶ exposure is short term. Acute effects such, as severe gastroenteritis in non-ruminants and acute methemoglobinemia in ruminants (severe dyspnoea and cyanosis) may occur. May be tolerated under certain conditions, depending on site-specific factors such as nutritional carbohydrate levels, TDS and sulphate concentrations in the water, and the type of micro-organisms present in the rumen.	**Agriculture: Livestock watering**
Nitrogen (inorganic) *[TIN]*	***Crop yield and Groundwater:*** **I: <=0.5 mg total N/ℓ** **A: >0.5 to <=5 mg total N/ℓ** **T: >5 to <=30 mg total N/ℓ** **U: >30 mg total N/ℓ**	Most crops are affected. A limited range of crops can utilise the nitrogen applied. Severe restrictions are placed on the utilisation of these waters. Increasingly serious likelihood of ground water contamination.	**Agriculture: Irrigation**
	Irrigation equipment: **I: <=0.5 mg total N/ℓ** **A: >0.5 to <=2.5 mg total N/ℓ** **T: >2.5 to <=10 mg total N/ℓ** **U: >10 mg total N/ℓ**	Hypertrophic conditions. Almost continuous growth of nuisance plants and blue-green algal blooms in irrigation structures in the absence of other growth-limiting factors.	**Agriculture: Irrigation**

ALPHABETICALLY ARRANGED PARAMETERS	APPLICABLE CONCENTRATION RANGES	EXPECTED EFFECT CAUSED BY WATER RESOURCES WITH WATER QUALITY IN THE UNACCEPTABLE CONCENTRATION RANGE	MOST SENSITIVE RECEIVING WATER USER
	***Aquatic ecosystem health*:** **I: <=0.25 mg total N/ℓ** **A: >0.25 to <=1.00 mg total N/ℓ** **T: >1.00 to <=4 mg total N/ℓ** **U: >4 mg total N/ℓ** **(1)** *Inorganic nitrogen concentrations should not be changed by more than 15 % from that of the waterbody under local unimpacted conditions at any time of the year; and* **(2)** *The trophic status of the waterbody should not increase above its present level, though a decrease in trophic status is permissible; and* **(3)** *The amplitude and frequency of natural cycles in inorganic nitrogen concentrations should not be changed.*	Hypertrophic conditions; usually very low levels of species diversity; usually very highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae, often including species which are toxic to man, livestock and wildlife.	**Aquatic ecosystem**
Odour	***Aesthetics*:** **I: <=1 TON** **A: >1 to <=5 TON** **T: >5 to <=10 TON** **U: >10 TON**	The odour of water becomes stronger and increasingly objectionable	**Domestic**
Orthophosphate (soluble) *[PO_4]*	***Aquatic ecosystem health*:** **I: <=0.01 mg P/ℓ** **A: >0.01 to <=0.03 mg P/ℓ** **T: >0.03 to <=0.13 mg P/ℓ** **U: >0.13 mg P/ℓ**	Hypertrophic conditions; usually very low levels of species diversity; usually very highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae, often including species which are toxic to man, livestock and wildlife.	**Aquatic ecosystem**

ALPHABETICALLY ARRANGED PARAMETERS	APPLICABLE CONCENTRATION RANGES	EXPECTED EFFECT CAUSED BY WATER RESOURCES WITH WATER QUALITY IN THE UNACCEPTABLE CONCENTRATION RANGE	MOST SENSITIVE RECEIVING WATER USER
Phosphorus (inorganic) *[TP]*	***Aquatic ecosystems*:** **I: <=5 µg total P/ℓ** **A: >5 to <=25 µg total P/ℓ** **T: >25 to <=250 µg total P/ℓ** **U: >250 µg total P/ℓ** **(1)** *Inorganic phosphorus concentrations should not be changed by >15 % from that of the waterbody under local, unimpacted conditions at any time of the year; and* **(2)** *The trophic status of the waterbody should not increase above its present level, though a decrease in trophic status is permissible; and* **(3)** *The amplitude and frequency of natural cycles in inorganic phosphorus concentrations should not be changed.*	Hypertrophic conditions; usually very low levels of species diversity; usually very highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae, often including species which are toxic to man, livestock and wildlife.	**Aquatic ecosystem**
Turbidity	***Human health and Aesthetics*:** **I: <=1 NTU** **A: >1 to <=5 NTU** **T: >5 to <=10 NTU** **U: >10 NTU**	Severe aesthetic effects (appearance, taste and odour). Water carries an associated risk of disease due to infectious disease agents and chemicals adsorbed onto particulate matter. A chance of disease transmission at epidemic level exists at high turbidity.	**Domestic**

ALPHABETICALLY ARRANGED PARAMETERS	APPLICABLE CONCENTRATION RANGES	EXPECTED EFFECT CAUSED BY WATER RESOURCES WITH WATER QUALITY IN THE UNACCEPTABLE CONCENTRATION RANGE	MOST SENSITIVE RECEIVING WATER USER
Nuisance water plants	***Swimming:***	The growth of aquatic vascular plants in waterbodies used for full-contact recreation should be limited to ensure that entanglement of swimmers does not occur and that plants do not obscure visibility. Excessive plant growth should not occur in full-contact recreational areas. The presence of floating masses of detached plants which may obstruct water users are aesthetically objectionable and provide a habitat for the growth of nuisance and vector organisms (for example insects, fungi and bacteria) and should be limited as far as possible.	**Recreation: Full contact**
	Intermediate contact recreation:	Since activities involving intermediate-contact recreation may include occasional full-body immersion, the criteria given above should be used and the extent of contact should be considered. Where water contact is slight or infrequent, the criteria may be applied less stringently. Plant growth should also be limited to prevent possible entanglement of boats, water skiers and boardsailors.	**Recreation: Intermediate contact**
	No contact recreation:	Aquatic plant growth should not detract from the aesthetic aspects of waterbodies used for non-contact recreation. Hence, water should not be completely covered, plant growth should not be unsightly or cause unpleasant odours, and there should be no adverse effects on other aquatic organisms.	**Recreation: Non-contact**

*** Key:**

- **I**=Ideal; **A**=Acceptable; **T**=Tolerable; and **U**=Unacceptable; and
- *"Blue-green algae units"* refers to the number of blue-green units (colonies and filaments) counted in a two-minute scan of 0.5 mℓ of water at x200 magnification.

ANNEXURE C

Survey Questionnaire developed to assess the status of eutrophication and its management in the country [Walmsley, 2003:1-21 + Annexure 3]

SURVEY QUESTIONNAIRE

on the status of eutrophication and its management

The survey is designed so that you do not have to supply statistics or complicated information. We hope that it will not take you more than 20 minutes to complete.

INSTITUTIONAL DETAILS:

Organisation/ Name of Water Management Area:	
Post Office Box:	
City/ Town:	
Postal Code:	
Contact Person:	
Designation:	
Telephone:	
Fax:	
E-mail:	

GENERAL QUESTIONS:

(1) Based on the complaints received by you from water users and communities, how do you rate eutrophication as a water resource problem in your management area?

RATING	INSERT X
Extreme problem	
Medium problem	
Low problem	
No problem at all	
Cannot provide an opinion	

(2) Is routine eutrophication monitoring and reporting carried out by your office?

SELECTION	INSERT X
Yes	
No	

If yes, please specify where and how frequently in what in the space below:

(3) Do you feel that your staff are fully conversant with the topic of eutrophication and its management?

SELECTION	INSERT X
Yes	
No	

(4) Would your staff like to receive more information or training on eutrophication and its management?

SELECTION	INSERT X
Yes	
No	

If yes, please specify any topics of special interest in the space below:

(5) Do you think that the current national policy and strategy for management of eutrophication requires revision?

SELECTION	INSERT X
Yes	
No	

If yes, please specify where and how frequently in what in the space below.

(6) Would your region/ institution be prepared to participate in the development of a national strategy?

This will involve commenting on draft documentation, and possibly participating in a workshop:

SELECTION	INSERT X
Yes	
No	

(7) Do you have any comments that you would like the Department of Water Affairs and Forestry to take note of?

If so, please provide these below:

AREAS WHERE EUTROPHICATION PROBLEMS OCCUR:

(8) In the table below, please indicate where eutrophication problems occur, (8.1) the level of intensity, (8.2) the type of problems (immediate causes) and (8.3) the possible underlying causes. (8.4) Where severe eutrophication problems occur, provide details of any eutrophication management actions that have been implemented.

Please extend the table by adding more rows if necessary.

SYSTEM #1	8.1 LEVEL OF PROBLEM #2	8.2 TYPE OF PROBLEM #3	8.3 PRINCIPLE CAUSE #4	8.4 ACTION IMPLEMENTED
e.g. Pienaars River	*e.g.* Persistently severe	*e.g.* Algae, weeds, water chemistry	*e.g.* Sewage discharges	*e.g.* Aeration, nutrient removal at Baviaanspoort WwTWs

***Note*:**

#1 = Name of the aquatic ecosystem;

#2 = Use the scale description as either persistently severe or infrequently severe;

#3 = Indicate whether the problem is caused either/or/and by algae, aquatic weeds, water chemistry etc.; and

#4 = Please indicate whether the principal cause is either/or/and sewage effluent discharges, agricultural practices or other practices.

Thank you for your cooperation.

ANNEXURE D

Record of survey participation [Walmsley, 2003:1-21 + Annexure 4]

ORGANISATION/ WATER MANAGEMENT AREA	CONTACT PERSON	ADDRESS	TEL/ FAX	EMAIL
DWAF Head Office	[redacted] Acting Deputy Director	Private Bag X313 Pretoria 0001	Tel: [redacted] Fax: [redacted]	[redacted]
	[redacted] Assistant Director WQM: Management Systems	Private Bag X313 Pretoria 0001	Tel: [redacted] Fax: [redacted]	[redacted]
	[redacted] Deputy Director: Water Utilisation	Private Bag X313 Pretoria 0001	Tel: [redacted] Fax: [redacted]	[redacted]
(2) Luvuvhu –Letaba	[redacted] District Manager	PO Box 2503 Thohoyandou 0950	Tel: [redacted]	
(3) Crocodile-Marico	[redacted]	Private Bag X995 Pretoria 0001	Tel: [redacted] Fax: [redacted]	[redacted]
	[redacted]	Hartbeespoort Office Private Bag X352 Hartbeespoort 0216	Tel: [redacted] Fax: [redacted]	
	[redacted] Surface water quality specialist	City of Johannesburg PO Box 30733 Braamfontein 2017	Tel: [redacted] Fax: [redacted]	[redacted]
	[redacted] Surface water quality specialist	City of Johannesburg PO Box 30733 Braamfontein 2017	Tel: [redacted] Fax: [redacted]	[redacted]

ORGANISATION/ WATER MANAGEMENT AREA	CONTACT PERSON	ADDRESS	TEL/ FAX	EMAIL
(4) Olifants (middle to lower)	[redacted] Assistant Director	Private Bag X11259 Nelspruit 1200	Tel: [redacted] Fax: [redacted]	[redacted]
(5) Inkomati	[redacted]	Private Bag X11259 Nelspruit 1200	Cell: [redacted] Fax: [redacted]	[redacted]
(6) Usutu to Mhlatuze	[redacted] Principal Water Pollution Control Officer	Private Bag X 2015 Dundee 3000	Tel: [redacted] Fax: [redacted]	[redacted]
	[redacted] Acting Director: Water Quality Management	P.O. Box 1018 Durban 4000	Tel: [redacted] Fax: [redacted]	[redacted]
(7) Thukela	[redacted] Acting Director: Water Quality Management	P.O. Box 1018 Durban 4000	Tel: [redacted] Fax: [redacted]	[redacted]
(8) Upper Vaal	[redacted] Deputy Director	Private Bag X995 Pretoria 0001	Tel: [redacted] Fax: [redacted]	[redacted]
(9) Middle Vaal	[redacted] Head Hydrobiology	Rand Water P.O. Box 3526 Vereniging 1930	Tel: [redacted] Fax: [redacted]	[redacted]
	[redacted] Scientist	Rand Water P.O. Box 3526 Vereniging 1930	Tel: [redacted] Fax: [redacted]	[redacted]
(10) Lower Vaal	[redacted] Assistant Director	Private Bag X6101 Kimberley 8300	Tel: [redacted] Fax: [redacted]	[redacted]
	Jurgen Streit Deputy Regional Director	Private Bag X6101 Kimberley 8300	Tel: [redacted] Fax: [redacted]	[redacted]

ORGANISATION/ WATER MANAGEMENT AREA	CONTACT PERSON	ADDRESS	TEL/ FAX	EMAIL
(11) Mvoti to Umzimkulu	[redacted] Principal Scientist Hydrobiology	Umgeni Water P.O. Box 9 Pietermaritzburg 3200	Tel: [redacted] Fax: [redacted]	[redacted]
	[redacted] Acting Director: Water Quality Management	P.O. Box 1018 Durban 4000	Tel: [redacted] Fax: [redacted]	[redacted]
(12) Mzimvubu to Keiskamma	[redacted] Assistant Director	P.O. Box 7019 East London 5200	Tel 1: [redacted] Tel 2: Fax: [redacted]	[redacted]
(13) Upper Orange	[redacted] Water Pollution Control Officer	P.O. Box 528 Bloemfontein 9300	Tel: [redacted] Fax: [redacted]	[redacted]
	[redacted] Water Pollution Control Officer	P.O. Box 528 Bloemfontein 9300	Tel: [redacted] Fax: [redacted]	[redacted]
	[redacted] Plant Superintendent	Bloem Water P.O. Box 146 Selosesha 9783	Tel: [redacted] Fax: [redacted]	[redacted]
(15) Fish to Tsitsikamma	[redacted] Water Pollution Control Officer	Private Bag X6041 Port Elizabeth 6000	Tel: [redacted] Fax: [redacted]	[redacted]
(16) Gouritz	[redacted] Deputy Town Engineer	Mossel Bay Municipality Private Bag X 29 MOSSEL BAY 6500	Tel: [redacted] Fax: [redacted]	[redacted]
(17) Olifants/Doorn	[redacted], Water Pollution Control Officer	Private Bag X 16 Sanlamhof 7532	Tel: [redacted] Fax: [redacted]	[redacted]

ORGANISATION/ WATER MANAGEMENT AREA	CONTACT PERSON	ADDRESS	TEL/ FAX	EMAIL
(18) Breede	[redacted] Principal Water Pollution Control Officer	Private Bag X16 SANLAMHOF 7532	Tel: [redacted] Fax: [redacted]	[redacted]
	[redacted] Int. Deputy Director: Operational Services	Theewaterskloof Municipality P.O. Box 24 CALEDON 7230	Tel: [redacted] Fax: [redacted]	[redacted]
(19) Berg	[redacted] Asst. Dir. Water Quality Management	Private Bag X 16 Sanlamhof 7532	Tel: [redacted] Fax: [redacted]	[redacted]

Note: Contact names, contact numbers and email addresses were redacted for privacy purposes.

ANNEXURE E

Record of survey results [Walmsley, 2003:1-21 + Annexure 5]

Replies to Survey Questions 1 to 6 (fixed-response option questions):

REPLIES TO SURVEY QUESTIONS 1 TO 6 (FIXED-RESPONSE OPTION QUESTIONS)	DWAF Head Office	1. Limpopo	2. Luvuvhu-Letaba	3. Crocodile-Marico	4. Olifants (middle to lower)	5. Inkomati	6. Usuthu to Mhlatuze	7. Thukela	8. Upper Vaal	9. Middle Vaal	10. Lower Vaal	11. Mvoti to Umzimkulu	12. Mzimvubu to Keiskamma	13. Upper Orange	14. Lower Orange	15. Fish to Tsitsikamma	16. Gouritz	17. Olifants/Doorn	18. Breede	19. Berg
1. **Based on the complaints received by you from water users and communities, how do you rate eutrophication as a water resource problem?** E = Extreme problem; M = Medium problem; L = Low problem; 0 = No problem; Blank = No reply *(Number of respondents)*	E M L 0 0 2 0 0	E M L 0 - - - -	E M L 0 0 0 1 0	E M L 0 2 1 0 0	E M L 0 0 0 1 0	E M L 0 0 1 0 0	E M L 0 0 0 2 0	E M L 0 0 1 0 0	E M L 0 0 1 0 0	E M L 0 0 1 0 0	E M L 0 0 1 1 0	E M L 0 0 2 0 0	E M L 0 0 1 0 0	E M L 0 0 1 1 1	E M L 0 - - - -	E M L 0 0 1 0 0	E M L 0 0 0 1 0	E M L 0 0 0 1 0	E M L 0 0 1 0 0	E M L 0 1 0 0 0
2. **Is routine eutrophication monitoring and reporting carried out by your office?** Y = Yes; N = No; N/A = Not applicable; Blank = No reply *(Number of respondents)*	Y N N/A 0 2 1	Y N N/A - - -	Y N N/A 1 0 0	Y N N/A 3 0 0	Y N N/A 0 1 0	Y N N/A 0 1 0	Y N N/A 0 2 0	Y N N/A 0 1 0	Y N N/A 0 1 0	Y N N/A 1 0 0	Y N N/A 1 1 0	Y N N/A 1 1 0	Y N N/A 1 0 0	Y N N/A 1 2 0	Y N N/A - - -	Y N N/A 1 0 0	Y N N/A 0 1 0	Y N N/A 0 1 0	Y N N/A 0 1 0	Y N N/A 1 0 0
3. **Do you feel that your staff are fully conversant with the topic of eutrophication and its management?** Y = Yes; N = No; N/A = Not applicable; Blank = No reply *(Number of respondents)*	Y N N/A 0 2 1	Y N N/A - - -	Y N N/A - - -	Y N N/A 1 2 0	Y N N/A 0 1 0	Y N N/A 0 1 0	Y N N/A 0 2 0	Y N N/A 0 1 0	Y N N/A 0 1 0	Y N N/A 1 0 0	Y N Y 1 1 0	Y N N/A 1 1 0	Y N N/A 1 0 0	Y N N/A 0 2 0	Y N N/A - - -	Y N N/A 0 1 0	Y N N/A 1 0 0	Y N N/A 1 0 0	Y N N/A 1 0 0	Y N N/A 1 1 0
4. **Would your staff like to receive more information or training on eutrophication and its management?** Y = Yes; N = No; Blank = No reply *(Number of respondents)*	Y N 1 2	Y N - -	Y N - -	Y N 3 0	Y N 1 0	Y N 1 0	Y N 2 0	Y N 1 0	Y N 1 0	Y N 1 0	Y N 2 0	Y N 2 0	Y N 1 0	Y N 3 0	Y N - -	Y N 1 0	Y N 1 0	Y N 1 0	Y N 1 0	Y N 1 0
5. **Do you think that the current national policy & strategy for management of eutrophication requires revision?** Y = Yes; N = No; ? = Could not provide an opinion Blank = No reply *(Number of respondents)*	Y N ? 2 1 0	Y N ? - - -	Y N ? - - -	Y N ? 1 0 1	Y N ? 0 0 1	Y N ? 0 0 1	Y N ? 2 0 0	Y N ? 1 0 0	Y N ? 1 0 0	Y N ? 0 1 0	Y N ? 0 1 0	Y N ? 1 1 0	Y N ? 0 0 1	Y N ? 0 0 1	Y N ? - - -	Y N ? 1 0 0	Y N ? 0 0 1	Y N ? 1 0 0	Y N ? 1 0 0	Y N ? 1 0 0
6. **Would your region/institution be prepared to participate in developing a national strategy?** Y = Yes; N = No; Blank = No reply *(Number of respondents)*	Y N 2 1	Y N - -	Y N - -	Y N 3 0	Y N 1 0	Y N 1 0	Y N 2 0	Y N 1 0	Y N 1 0	Y N 1 0	Y N 2 0	Y N 2 0	Y N 1 0	Y N 3 0	Y N - -	Y N 1 0	Y N 0 1	Y N 1 0	Y N 1 0	Y N 1 0

Replies to Survey Questions 2, 4, 5, 7 and 8 (written representations):

QUESTION 2: *"IS ROUTINE EUTROPHICATION MONITORING AND REPORTING CARRIED OUT BY YOUR OFFICE?"*	
2 Luvuvhu-Letaba	▶ Once a month, checking upstream and downstream of the discharge point of the effluent.
3 Crocodile-Marico	▶ Done by IWQS - Caren van Ginkel (IWQS). ▶ Johannesburg Municipality - Chlorophyll is monitored at impoundment outlets monthly. Results are incorporated into a water quality index calculated on a quarterly basis. The results are reported to Council, Johannesburg Water, other stakeholders in the CoJ water quality monitoring programme and distributed at the catchment management forums. Specific eutrophication reporting is not done.
6 Usutu to Mhlatuze	▶ Not by Durban Office, but will be performed soon as part of requirement for inclusion of Lake Mzingazi and Godertrouw Dam into NEMP. This needs to be expanded to other coastal lakes too (*e.g.* Cubhu, Nsezi, Eteza, Kosi, Nhlabane, Sibaya, St. Lucia, etc.). ▶ Dundee - Not routine, during follow-up where the pollution still exist another set of samples is taken to persist with supported request to improve the existing water quality management.
8 Upper Vaal **9 Middle Vaal**	▶ Whole catchment of interest to Rand Water (Upper Vaal Dam Catchment, Vaal Dam, Vaal River Barrage catchment). Depending on the situation, twice a month or monthly.
11 Mvoti to Umzimkulu	▶ Umgeni Water has a large and diverse monitoring programme covering several hundred sites. Frequency varies from weekly to annually depending on the site. Many of the sites are now done for DWAF on a contractual basis, while others are done for Umgeni Water's purposes. Details of these sites can be provided separately if required.
12 Mzimvubu to Keiskamma	▶ In all the catchments, 2 monthly; for chlorophyll, nitrates & o-phosphates.
13 Upper Orange	▶ Only just started – as part of IWQS programme. Still in implementation phase. The following impoundments have been identified by us to start eutrophication monitoring: Gariep; Vanderkloof; Krugersdrift; Rustfontein; Groothoek; Knellpoort; Welbedacht; Allemanskraal; Erfenis; Koppies; Rietspruit. For these impoundments we have already contacted people who will help to take samples twice a month. These samples will be sent to IWQS for analysis for amongst other things: TP, Chl-α, turbidity etc. Blooms will also be sampled and send for identification.
15 Fish to Tsitsikamma	▶ All river samples taken monthly are tested from time to time for Nitrogen, Phosphorus and Potassium.
19 Berg	▶ Monthly to six-weekly monitoring of final effluent from sewage works and river systems as part of normal compliance and catchment monitoring.

QUESTION 4: *"WOULD YOUR STAFF LIKE TO RECEIVE MORE INFORMATION OR TRAINING ON EUTROPHICATION AND ITS MANAGEMENT?"*
▶ General management info. ▶ Prevention (especially diffuse nutrient source reduction). ▶ Affects reduction (algae bloom minimisation). ▶ Can it be reversed / mitigated? ▶ The causes of eutrophication. ▶ The Water Quality Status of the Hartbeespoort Dam. ▶ The environmental management of Hartbeespoort Dam. ▶ What is currently available? I am not aware of anything. ▶ Aquatic weeds. Algae and algal blooms. Management of local authority infrastructure and the need to reduce nutrient input. Nutrient budgeting for reservoirs. ▶ With the high staff turnover training new officers are important but time to achieve this is restrictive and the priority ranks eutrophication down. ▶ Explain the process and monitoring. How does it affect river health? ▶ Practical short- and long-term management options of eutrophication. ▶ Estimation of the cost implications of eutrophication. ▶ General eutrophication overview. ▶ Algae and eutrophication. ▶ Overall training on the nature of eutrophication problems. ▶ Implementation of monitoring programmes. ▶ Biomonitoring. ▶ Water quality monitoring. ▶ Interpretation of water chemistry data. ▶ Toxicity testing. ▶ How to combat the above proliferation of algae. ▶ How is eutrophication detected? How do I test for eutrophication? ▶ Causes and negative effects of different species of algae in the dam, and info on algae removal. ▶ Nutrients reduction as a principal means to control and manage eutrophication. ▶ Management options in the spirit of co-operative governance.

QUESTION 5: *"DO YOU THINK THAT THE CURRENT NATIONAL POLICY & STRATEGY FOR MANAGEMENT OF EUTROPHICATION REQUIRES REVISION?"*

- I'm not aware of any dedicated eutrophication policy. Various levels of strategy apply. At the lower-level strategy must be verified and reviewed more frequently. Policy is needed to specify DWAF's/ Government's intent with respect to nutrient management.
- Communication of policy is essential. A fair question is *"What policy?"* Most WQM staff know nothing of eutrophication, it is causes or consequences. As with this questionnaire, it is priority. Line function, staff turnover, training new staff continuously and looking for personal advancement are higher priorities, and will continue to be unless professional technical staff are free to concentrate on work issues, such as eutrophication. Unless all strategies and policies are complementary, effort in any area will be diluted.
- Unless staff at grassroots level are involved and committed, any policy development will be a waste of time.
- I have not seen this document – when last was it revised/ would have helped if this was made available with this questionnaire.
- Better legislation and how to enforce it. More departmental awareness. Input from the Regions.
- The above *"no"* is based on the new Eutrophication Monitoring Programme that has been espoused by DWAF. As this is a new programme, a revision is not appropriate although improvements are probably possible.
- Eutrophication of rivers has not received as much focussed attention as that of dams.
- We may need to extend the Special Phosphate Std to other areas, especially near impoundments.
- I have not seen this policy and do not know what the document looks like.
- More information is required to know the link of eutrophication related algae with aquatic ecosystems particularly for cases when it can result in fish kills.
- Point source pollution management instruments are lacking.
- I am not aware of a formal national eutrophication policy or strategy in place at the moment, so it would be good to know what is available and how it could be implemented and improved.

QUESTION 7: *"DO YOU HAVE ANY COMMENTS THAT YOU WOULD LIKE THE DEPARTMENT OF WATER AFFAIRS AND FORESTRY TO TAKE NOTE OF?"*

- The positioning of the proposed policy within the evolving hierarchy of Water Quality Management policies and strategies is important. This includes the relationship and integration of the proposed policy with other policy.
- Uncertainty around restructuring makes questions difficult if not impossible to answer.
- Crocodile-Marico - Extremely serious problem in this region. This office initiated an *"action group"* recently to start addressing the problem. Assistance to this group is required. External stakeholder members of this group are prepared to provide assistance and committed to in obtaining funds, should it be required in managing the eutrophication in the Roodeplaat Dam. Should an impoundment be identified for the purpose of a case study, the Roodeplaat will be an ideal option. This Dam is close to the IWQS, Head Office and the Regional Office.
- More information regarding the sustainable management of our water resources should be made available to the public. Public awareness campaign urgently needed.
- Johannesburg Metropolitan Municipality **-** Please send copy of policy and strategy document and keep us informed of developments.
- I am aware that Mr H.H. Bosman from the Department's Water Utilisation Section has been involved in some monitoring activities.
- Please note that staff turnover is a major problem, there is no point training staff who will not stay to work. See KwaZulu-Natal Water Quality Management staff turnover details to understand the severity of the problem. Further training will also increase staff requirements to complete line-function duties. At this stage if one staff member leaves, the entire capacity to

appreciate eutrophication collapses. The capacity to run forums and maintain contact with local authorities and academic institutions will be severely hampered by the leaving of a recently trained staff member.

- Provide a career in Water Quality Management for staff. Jobs are not enough, and you cannot grow knowledge and experience if you only provide *"a job"* as is currently the case. Refer to recent Water Quality Management Deputy Director's meetings for a description of the severity of the problem. Additional loading of work onto loyal senior Assistant Directors & Water Pollution Control Officers is not the answer to increasing workload – more workers are needed; not more professional students being carried to their next job.
- Holistic progressive training of career Water Quality Management staff. Currently training concentrates on the flavour of the month. Unless staff understand water treatment processes, they will not grasp the need for eutrophication management, algal blooms, chemical quality problems, etc. Ditto dam water quality, ecology, biodiversity etc.
- Eutrophication monitoring needs to be undertaken throughout the WMA. When algal blooms reach severe status, the solutions and management should have been implemented 10 years previously. Thus, at best there is a reactive approach, and lip service at best is only paid to the precautionary principle. Ecology responds to drivers at levels far below the detection limits of instruments, and more attention needs to be paid to the early warning signs which we do not yet even know that we are missing. Similar policy/ strategy needs to be developed for wetlands and estuaries, to name but 2 important categories of the water resource. Currently little is known about the system functioning or importance of individual components by Regional DWAF staff, nor why we should protect them.
- Integration between various tiers of Government must be facilitated and driven. Currently it is *ad hoc* and poor. Individual officers are left to devise, organise and run cost-effective local environmental training courses to facilitate and clarify roles. Line-function work must be rescheduled in order to accommodate this, so that time may be saved at a later date in order to prevent fruitless expenditure of resources.
- The control of effluents released by for example WwTWs must receive urgent attention.
- The control of runoff from informal settlements must receive urgent attention.
- The profile or importance of minimising eutrophication should be rolled-out to all role-players, especially the main contributors to eutrophication.
- Eutrophication of rivers should not be separated from that of dams.
- A biological response monitoring system is imperative to assess the real impact of poor water chemistry.
- Eutrophication is a real problem that water quality management is faced with, but without a legal leg to stand on with regards to sewerage works that overflow and that are over capacity (in the light of co-operative governance), etc. We are wasting our time and your money.
- It will take a long while to have any system in place in the Port Elizabeth Office as capacity is low, the office is without an Assistant Director, POLMON is not actively utilised in the office and WMS is not up and running yet. Water Quality Monitoring programmes must include eutrophication on a regular basis, especially for essential waterbodies like big dams.

QUESTION 8: ***"IN THE TABLE BELOW PLEASE INDICATE WHERE EUTROPHICATION PROBLEMS OCCUR, (8.1) THE LEVEL OF INTENSITY, (8.2) THE TYPE OF PROBLEMS (IMMEDIATE CAUSES) AND (8.3) THE POSSIBLE UNDERLYING CAUSES. (8.4) WHERE SEVERE EUTROPHICATION PROBLEMS OCCUR, PROVIDE DETAILS OF ANY EUTROPHICATION MANAGEMENT ACTIONS THAT HAVE BEEN IMPLEMENTED."***

WATER RESOURCE SYSTEM	8.1 LEVEL OF PROBLEM	8.2 IMMEDIATE CAUSES	8.3 UNDERLYING CAUSES	8.4 ACTIONS IMPLEMENTED
DWAF HEAD OFFICE				
In the seven catchments that DWAF identified many years ago PLUS others, *i.e.*: (1) Vaal River upstream and inclusive of the Bloemhof Dam; (2) Pienaars and Crocodile Rivers upstream of their confluence; (3) Great Olifants River upstream and inclusive of the Loskop Dam; (4) Umgeni River upstream of the influence of tidal water; (5) Umlaas River upstream of its point of discharge into the sea; (6) Buffels River upstream and inclusive of the Bridle Drift Dam; (7) Berg River upstream of the influence of tidal water.	It is a major problem.	Mostly related to algae, smell, etc.	Originating from sewage spills, malfunctioning WwTWs and industrial wastewaters.	On an *ad hoc* basis, however, no formal legal systems yet to systematically address the causes, *e.g.,* additional phosphate standards.
Hartbeespoort Dam.	Persistently severe.	Algae, weeds, etc.	Sewage discharges.	*"Treating the symptom"*: *i.e.* initiation of an awareness creation campaign, in collaboration with the Regional Office, for the users of the reservoir.
	Severe.	Algal Water hyacinth.	Industrial pollution.	
Pienaars River Roodeplaat Dam.	Severe.	Red water fern Water hyacinth Algal and water grass.	Baviaanspoort Zeekoeigat.	
Apies River Bon Accord/ Leeukraal.	Severe.	Algal Water hyacinth.	Johannesburg Metropolitan North.	

WATER RESOURCE SYSTEM	8.1 LEVEL OF PROBLEM	8.2 IMMEDIATE CAUSES	8.3 UNDERLYING CAUSES	8.4 ACTIONS IMPLEMENTED
Sterkspruit Hammersdale Dam.	Severe.	Water hyacinth.	Stutterheim sewage Works.	
Kubusi/Cunnikala Wruggleswade Dam.	Medium.	Algal Water hyacinth.	Industrial and farming.	WQM - East London.
Swartkopsriver Uitenhage.	Severe.	Algal Water hyacinth.	Pretoria Daspoort sewage works. Rooibank sewage works	
Buffalo/ Yellow Woods Laing Dam.	Severe.	Algal Water hyacinth.	King Williams Town and rural areas Farming activities enroute.	
1. LIMPOPO				
No reply to questionnaire.	No reply to questionnaire.	No reply to questionnaire	No reply to questionnaire	No reply to questionnaire.
2. LUVUVHU –LETABA				
Mandzoro River.	Infrequently severe.	Weeds.	Sewage discharges Malamule sewage works (Maturation ponds).	No action implemented.
3. CROCODILE-MARICO				
Pienaars River (Roodeplaat Dam).	Persistently severe.	Algae, weeds, water chemistry and bacteriological. Constant algae with severe blooms in autumn, weeds, water chemistry.	Sewage discharges and diffuse sources (sewer leakages, overflowing manholes and feedlots) Difficult to quantify.	Strict nutrient removal standards at Baviaanspoort and Zeekoeigat sewage treatment works. General source reduction management actions in catchment including instant response to sewer leakages, overflows and pollution prevention at feedlots.
Apies River (Bon Accord Dam).	Persistently severe.	Same as for Pienaars River – although impact smaller. Same as for Roodeplaat, but the Apies River experience filamentous algae problems as well.	Same as for Pienaars River.	Nutrient Removal at Daspoort and Rooiwal Sewage Treatment Works.

WATER RESOURCE SYSTEM	8.1 LEVEL OF PROBLEM	8.2 IMMEDIATE CAUSES	8.3 UNDERLYING CAUSES	8.4 ACTIONS IMPLEMENTED
Hartbeespoort Dam Catchment Area.	Persistently severe – the problem becomes excessive in the presence of other environmental factors such as low rainfall and warm, windless weather.	Algae and waterweeds such as hyacinth.	Loads of plant nutrients (phosphates and nitrogen) commonly found in fertilisers, industrial wastewater, sewage effluent and products such as soap and washing powder.	Nutrient removal at all sewage works of the surrounding developments and the eradication of the aquatic weeds (Biocontrol and manual removal).
Blue Dam, Klipspruit.	Ranges from oligo- to hypertrophic with average in the hypertrophic range.	Water chemistry, nuisance plants.	Sewage.	Reporting of sewage spills to Johannesburg Water.
Bruma Lake, Upper Jukskei River.	Ranges from eutrophic- to hypertrophic with average in hypertrophic range.	Water chemistry, algae.	Sewage.	Bioaugmentation, chemical treatment, inspection of sewer network. Reporting of sewage spills to Johannesburg Water.
Emmarentia Dam, Braamfonteinspruit.	Ranges from meso- to eutrophic with average in the mesotrophic range.	Water chemistry.	Occasional sewage.	Reporting of sewage spills to Johannesburg Water.
Rhodes Park, Upper Jukskei.	Ranges from oligotrophic to Eutrophic with average in the eutrophic range,	Water chemistry.	Occasional sewage, Bird life?	Reporting of sewage spills to Johannesburg Water.
Westdene Dam, Braamfonteinspruit.	Ranges from oligotrophic to eutrophic with average in the mesotrophic range.	Water chemistry.	Sewage.	Reporting of sewage spills to Johannesburg Water.
Wemmerpan, Natalspruit.	Oligo to mesotrophic with average in the oligotrophic range.	Water chemistry.	Sewage.	Reporting of sewage spills to Johannesburg Water.
Zoo Lake, Braamfonteinspruit.	Meso- to hypertrophic with average in the hypertrophic range.	Water chemistry.	Sewage.	Biochemistry. Reporting of sewage spills to Johannesburg Water.
Florida Lake, Klipspruit.	Meso- to hypertrophic with average in the hypertrophic range.	Water chemistry.	Occasional sewage, bird life?	Reporting of sewage spills to Johannesburg Water.
Moroka Dam, Klipspruit.	New point – one sample indicates eutrophic status.	Water chemistry.	Sewage.	Reporting of sewage spills to Johannesburg Water.

WATER RESOURCE SYSTEM	8.1 LEVEL OF PROBLEM	8.2 IMMEDIATE CAUSES	8.3 UNDERLYING CAUSES	8.4 ACTIONS IMPLEMENTED
4. OLIFANTS (MIDDLE TO LOWER)				
Bronkhorstspruit Dam.	Intermittently medium to low significance.	Algae, weeds.	Sewage discharges.	Issuing of licenses for small sewage works – setting water quality limits monitoring.
Loskop Dam.	Becoming a problem of late – in canals from dam.	Algae, weeds, in canals.		Not attended to yet – will attend as soon as new officers appointed.
Various smaller dams on tributaries of the Middle Olifants River System that receives runoff from dense settlements.	Persistent – medium.	Algae, weeds, water chemistry.	Poor sanitation facilities.	As soon as capacity must co-operate Local Govt to attend to sanitation problems.
Lower Olifants River.	Low flow periods.	Algae.	Sewage discharges and effect of concentration at low flow.	
5. INKOMATI				
Kaap River.	Infrequently.	Hyacinth.	????	There is a committee together with Working with Water investigating the problem.
Crocodile Below the inflow of the Kaap.	Infrequently.	Hyacinth.	????	
6. USUTU TO MHLATUZE				
Wit Umfolozi River Vryheid (W211).	Infrequently severe if given the necessary attention Frequently severe if just left as is and below average rain.	Water chemistry Parrot feather weed development. Algae have developed in the past.	Sewage discharge, no phosphate removal in place.	Correspondence referring to attached photographs and sample results requesting the necessary attention.
Pongola canal system & River (W440).	Animal count in unit low, infrequently severe Unit full, frequently severe but also depending on other conditions for increased development.	Higher COD & faecal coli, strep and Clostridium counts, possible algae.	Cattle feedlot & sewage.	Same.
Upper Pongola River (W421).	Infrequently severe.	Higher COD & bacterial counts following unnecessary / careless and unauthorised discharges.	Intensive piggery & dairy units.	Same.

WATER RESOURCE SYSTEM	8.1 LEVEL OF PROBLEM	8.2 IMMEDIATE CAUSES	8.3 UNDERLYING CAUSES	8.4 ACTIONS IMPLEMENTED
Upper Bivane river (W410).	Infrequently severe.	Higher COD & bacterial counts following unnecessary / careless and unauthorised discharges.	Intensive piggery & dairy units.	Same, upper Bivane no improvement facing possible prosecution 29-11-2002 (court date) first hearing September 2001.
Umhlathuze.	Infrequently severe in specific areas *e.g.*, Lake Mzingazi – seasonal algal bloom.	Algae, weeds, water chemistry. Mzingazi - Seasonal algal bloom (at turnover in spring), Water chemistry, Water treatment (Geosmin & 2-MIB).	Sewage discharges from infrastructure, urban runoff, also dense settlements, inadequate/inappropriate sanitation for area, agrochemicals.	Institution of Mzingazi Lake Forum. Problem experienced due to trained staff member now leaving – capacity problem and capacity building. Lack of commitment from local authorities – lack of appreciation of problem, capacity, etc. Needs to be expanded to all the coastal lakes. Stakeholder fatigue. Umhlathuze Catchment Forum. Lack of appreciation of problem and legal requirements (they think water hyacinth does a fine job of pretreating suspended solids). Application currently being formulation for inclusion of Goedertrouw Dam into NEMP, as disturbing amounts of benthic algae noted (relatively undeveloped catchment). Intention is to include all DWAF dams into NEMP in due course in this WMA.
All coastal lakes and estuaries.	Infrequently severe, potential grows *e.g.*, Lodge development around Kosi, becoming persistently moderate, will soon be persistently severe.	Algae, weeds, water chemistry, change in species/abundance.	Sewage discharges from infrastructure, also dense settlements and agrochemicals.	
General – farm dams and all water courses.	Infrequently severe.	Algae, weeds, water chemistry.	Non-point sources: agriculture, especially agrochemicals. Soil erosion contributes.	

WATER RESOURCE SYSTEM	8.1 LEVEL OF PROBLEM	8.2 IMMEDIATE CAUSES	8.3 UNDERLYING CAUSES	8.4 ACTIONS IMPLEMENTED
General – all watercourses.	Infrequently severe.	Algae, weeds, water chemistry.	Point sources: agriculture, including dairies, piggeries, feedlots, etc.	Water quality management actions as and when necessary (reactive)
7. THUKELA				
Tugela (Bushmans at Weenen).	Infrequently severe.	Algae, weeds, water chemistry.	Agricultural return flows/over-irrigation-low flow. Rarely (but dramatically) Sewage discharges from infrastructure (Estcourt municipality).	
Tugela (Mooi River area).	Infrequently severe.	Algae, weeds, water chemistry. Particularly benthic algae in flowing water (filamentous).	Agricultural return flows/over-irrigation-low flow. Rarely (but dramatically) Sewage discharges from infrastructure.	
Mgeni (via inter-basin transfer into Midmar catchment).	Same as immediately above, but oligotrophic system – major change.	Same as immediately above, but oligotrophic system – major change.	Same as immediately above, but oligotrophic system – major change.	Actions undertaken by Umgeni Water in conjunction with DWAF and local authorities.
General – farm dams and all water courses.	Infrequently severe. My impression is that the problem is growing (slowly, but unmonitored) more severe.	Algae, weeds, water chemistry.	Non-point sources: agriculture, especially agrochemicals. Soil erosion contributes nutrients bound to particles.	
General – all watercourses.	Infrequently severe.	Algae, weeds, water chemistry.	Point sources: agriculture, including dairies, piggeries, feedlots, etc.	Water quality management actions as and when necessary (reactive).
8. UPPER VAAL				
Upper Klip River.	Persistently severe.	Algae, weeds.	Sewage discharge.	Special phosphate level of 1mg/l.
Vaal River at Villiers.	Infrequently severe.	Algae, water chemistry.	Sewage discharge.	Special phosphate level of 1mg/l.
Vaal Dam.	Infrequently severe (Low to moderate).	Blue green algae.	Agriculture and sewage discharge.	Reporting of spillages to DWAF Assist with the management of WwTWs.
Golf courses and urban impoundments.	Persistent severe (Moderately to high).	Algae and macrophytes.	Sewage discharge and informal settlements, general run-off, contaminated ground water.	
Klein Blesbokspruit.	Low problem.	Algae.	Sewage discharge.	Special phosphate level of 1mg/l.

WATER RESOURCE SYSTEM	8.1 LEVEL OF PROBLEM	8.2 IMMEDIATE CAUSES	8.3 UNDERLYING CAUSES	8.4 ACTIONS IMPLEMENTED
Blesbokspruit.	Low problem.	Weeds.	Agriculture practice.	Special phosphate level of 1mg/l.
Rivers including Klip River, Blesbokspruitt.	Persistent severe (Moderately to high).	Macrophytes.	Sewage discharge and informal settlements high intensity farming.	
Boksburg Lake.	Persistently severe.	Algae, water chemistry.	Sewage discharge.	sample for phosphate.
Vaal River at inflow from Bophelong.	Persistently severe.	Algae, hyacinth.	Stormwater from Bophelong.	
Rietspruit.	Persistently severe.	Algae, weeds.	Sewage discharge.	Special phosphate level of 1mg/l.
Vaal River Barrage.	Persistent severe (Moderate to high).	All algae and macrophytes.	Sewage discharge and informal settlements high intensity farming.	Physical removal of invader plants; Barley straw Reporting of spillages to DWAF Assist with the management of WwTWs.
9. MIDDLE VAAL				
Vaal River at Parys.	Persistently moderate.	Algae and hyacinth.	Sewage discharges and diffuse pollution from agriculture.	Special phosphate level of 1mg/l.
Vaal River at Potchefstroom.	Persistently moderate.	Algae and hyacinth.	Sewage discharges and diffuse pollution from agriculture.	Special phosphate level of 1mg/l.
10. LOWER VAAL				
Harts River.	Seasonal. Moderate.	Algae and Water Chemistry.	Sewage discharges, surface runoff, irrigation backflow.	
Spitskop Dam.	Moderate to extreme.	Algae and Water Chemistry.	Sewage discharges, surface runoff, and irrigation backflows.	Not yet in place as the Dam is not extensively used in the area.
Lower Vaal River.	Low to moderately.	Algae, water chemistry.	Upstream pollution.	
11. MVOTI TO UMZIMKULU				
Baynespruit.	Persistently severe.	Impacted biota, water chemistry	Oil industry and sewer discharges	
uMsunduze River.	Severe.	Impacted biota and excessive benthic diatom growth, water chemistry, weeds.	Run off from Pietermaritzburg and outlying towns, wastewater discharge, industrial discharge.	Ongoing catchment management, reducing pollution inputs, improved management of Darvill wastewater works.

WATER RESOURCE SYSTEM	8.1 LEVEL OF PROBLEM	8.2 IMMEDIATE CAUSES	8.3 UNDERLYING CAUSES	8.4 ACTIONS IMPLEMENTED
uMgeni River (upper)	Infrequently severe.	Impacted biota, water chemistry.	Wastewater works discharges from Howick.	Umgeni Water plans to take over Howick wastewater works and upgrade operation. Also improve operation of Mphophomeni sewage. DWAF - Actions undertaken by Umgeni Water in conjunction with DWAF and local authorities.
Lower uMgeni River.	Severe.	Impacted biota, weeds, water chemistry.	Run-off from townships, wastewater discharges, some industrial effluent.	Influence on wastewater works, working with others to eradicate weeds.
Nagle Dam.	Infrequently severe.	Algae, water chemistry.	Upstream water quality.	Ongoing catchment management.
Inanda Dam.	Infrequently severe.	Algae, water chemistry.	Upstream water quality.	Ongoing catchment management and zero-tolerance of hyacinth in upstream river as well.
Upper uMlazi River.	Severe.	Impacted biota, weeds.	Agricultural run-off, meat processing, wastewater discharges.	
Sterkspruit (uMlazi).	Persistently severe.	Impacted biota, weeds, water chemistry, algae.	Wastewater works discharge.	
Shongweni Dam.	Persistently severe.	Weeds, water chemistry.	Upstream wastewater works discharges.	Ongoing catchment management, reducing pollution inputs, improved management of Hammarsdale wastewater works.
Lower uMlazi River.	Persistently severe.	Weeds, water chemistry, impacted biota.	Wastewater discharges, township run-off.	Ongoing catchment management, reducing pollution inputs, improved management of Hammarsdale wastewater works.
uMbilo River.	Persistently severe.	Water chemistry, impacted biota.	Industrial and wastewater discharges.	Ongoing catchment management – no real responsibility by Umgeni Water.

WATER RESOURCE SYSTEM	8.1 LEVEL OF PROBLEM	8.2 IMMEDIATE CAUSES	8.3 UNDERLYING CAUSES	8.4 ACTIONS IMPLEMENTED
uMhlatuzane River.	Persistently severe.	Water chemistry, impacted biota.	Industrial and wastewater discharges.	Ongoing catchment management – no real responsibility by Umgeni Water. Dense settlements project. Expanded to other areas on a continuous basis as needed.
Amanzimtoti, Little Amanzimtoti.	Infrequently severe.	Algae, weeds, water chemistry.	Sewage discharges from infrastructure, urban runoff, also dense settlements.	
All coastal estuaries.	Infrequently severe.	Algae, weeds, water chemistry.	Sewage discharges from infrastructure, also dense settlements.	
General – farm dams and all water courses.	Infrequently severe.	Algae, weeds, water chemistry.	Non-point sources: agriculture, especially agrochemicals. Soil erosion contributes nutrients bound to particles.	
General – all watercourses.	Infrequently severe.	Algae, weeds, water chemistry.	Point sources: agriculture, including dairies, piggeries, feedlots, etc.	Water quality management actions as and when necessary (reactive).
12. MZIMVUBU TO KEISKAMMA				
Buffalo River.	Infrequently severe.	Algae & water hyacinth.	Sewage discharges.	Laing Dam & Bridle Drift Dam - Special Std applies. Have tried to spray the aquatic weeds. Special Std applies.
Nahoon River.	Infrequently severe.	Algae.	Agricultural activities Abattoir problems.	Addressing abattoirs by issuing authorisations.
Kubusie River.	Persistently severe.	Water hyacinth.	Diffuse in nature.	Wriggleswade Dam - Have tried to spray and introduce the bug (beetle).
13. UPPER ORANGE				
Gariep Dam.	Start of warmer weather, severe for about a month.	Blue-green algal blooms.	Possibly due to sewerage from Venterstad/ Oviston discharged into dam.	

WATER RESOURCE SYSTEM	8.1 LEVEL OF PROBLEM	8.2 IMMEDIATE CAUSES	8.3 UNDERLYING CAUSES	8.4 ACTIONS IMPLEMENTED
Sometime also in Vanderkloof Dam).	Start of warmer weather, severe for about a month.	Blue-green algal blooms.	Possibly due to sewerage from Venterstad/ Oviston discharged into dam.	
Rustfontein	Unknown (2-3 times a year).	Relatively small amounts of algae, lots of fish kills.	Bloem Water purification works close-by. Cause: unknown.	
Krugersdrift Dam.	Start of warmer weather, persisted for nearly 2 months	Blue-green algal blooms.	Unknown.	
Allemanskraal Dam.	Start of warmer weather, persisted only 2 weeks.	Blue-green algae.	Unknown.	
Renosterspruit: Bishops Glen Weir.	2-3 times a year.	Algae – lots of fish kills.	Possibly due to dairy farm upstream ??	
Rustfonteindam.	Persistently.	Algae.		Some "Reps" busy with analysis.
14. LOWER ORANGE				
No reply to questionnaire.	No reply to questionnaire.	No reply to questionnaire.	No reply to questionnaire.	No reply to questionnaire.
15. FISH TO TSITSIKAMMA				
Zwartkops River.	Persistently severe.	Water Hyacinth and weeds.	Sewage, industry and Agriculture.	Systematic identification of polluters. Application of mitigating measures.
16. GOURITZ				
Hartenbos.	Algae in September months.	Algae.	Beyond sewage works, agricultural.	
17. OLIFANTS/DOORN				
Verlorenvlei.	Low level.		Natural.	Natural self-cleansing in the valley.
18. BREEDE				
Lower Breede River.	Persistently medium.	Water hyacinth.	Accumulated impacts from developments upstream.	Spraying of water hyacinth.
Middle Breede river.	Persistently medium.	Algae in irrigation canals and under low flows in the river.	Accumulated impact from upstream developments.	

WATER RESOURCE SYSTEM	8.1 LEVEL OF PROBLEM	8.2 IMMEDIATE CAUSES	8.3 UNDERLYING CAUSES	8.4 ACTIONS IMPLEMENTED
19. BERG				
Diep River & tributaries.	Severe in summer.	Algae, weeds – hyacinth & reeds, water chemistry.	Sewage discharges, run-off from informal settlements & agriculture.	Aims to reduce inputs of nutrients at source.
Eerste River & tributaries.	Bad in summer.	Algae, weeds, water chemistry.	Sewage discharges, run-off from informal settlements & agriculture.	Aims to reduce inputs of nutrients at source.
Salt River & tributaries.	Severe in summer.	Algae, weeds – hyacinth & reeds, water chemistry.	Sewage discharges, run-off from informal settlements.	Aims to reduce inputs of nutrients at source.
Sand River.	Severe in summer.	Algae, weeds – hyacinth & reeds, water chemistry.	Sewage discharges, run-off from informal settlements &agriculture.	Aims to reduce inputs of nutrients at source.
Lotus River.	Severe in summer.	Algae, weeds – hyacinth & reeds, water chemistry.	Sewage discharges, run-off from informal settlements &agriculture.	Aims to reduce inputs of nutrients at source.
Sir Lowry's Pass River.	Severe in summer.	Algae, weeds – hyacinth & reeds, water chemistry.	Sewage discharges, run-off from informal settlements &agriculture.	Aims to reduce inputs of nutrients at source.
Wildevoëlvlei wetlands.	Severe in summer.	Algae, weeds – hyacinth & reeds, water chemistry.	Sewage discharges, run-off from informal settlements.	Drastic actions by City of Cape Town *e g.* dumping of salt etc.

Responses to Survey Question 8 were codified and further summarised in the table below for statistical analysis purposes:

Totals	Water Management Area and associated water resource systems	Question 8.1 Level of the problem, as defined by respondents.		Question 8.2 Immediate causes of eutrophication in Water Management Areas, as identified by respondents.				Question 8.3 Underlying causes of eutrophication in Water Management Areas, as identified by respondents.					Question 8.4 Actions taken to address eutrophication in Water Management Areas, as identified by respondents.								
		Systems labelled as "persistently severe"	Systems labelled as "infrequently severe"	Algae, including blue-green algae	Aquatic weeds and macrophytes	Biodiversity change and/or habitat destruction	Water chemistry	Domestic Wastewater Treatment Works	Industrial Wastewater Treatment Works	Agricultural practices	Run-off from dense settlements	Variety of up-stream pollution sources	Regulatory responses, including enforcement action	Cooperative governance and technical support	Stakeholder- and participative management approaches	Bio-remediation and nature-based solutions	Spraying and physical water plant removal	Catchment management	Water quality monitoring	Other actions	No action, or no capacity to take action
1. Limpopo																					
TOTAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2. Levuvhu-Letaba																					
TOTAL	1	0	1	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1
3. Crocodile-Marico																					
TOTAL	12	5	7	4	5	0	0	11	1	3	0	0	4	0	0	5	1	0	0	0	0
4. Olifants (middle to lower)																					
TOTAL	4	2	2	4	3	0	1	3	0	1	0	0	1	0	0	0	0	0	1	0	3
5. Inkomati																					
TOTAL	2	0	2	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
6. Usutu to Mhlatuze																					
TOTAL	8	0	8	4	3	1	6	1	0	1	1	0	4	0	0	0	0	8	0	0	0
7. Thukela																					
TOTAL	5	0	4	2	2	1	2	2	0	4	0	0	0	0	0	0	0	4	0	0	0
8. Upper Vaal																					
TOTAL	11	7	4	9	7	0	2	9	0	4	4	0	8	1	2	1	1	0	1	0	2
9. Middle Vaal																					
TOTAL	2	2	0	2	2	0	0	2	0	2	0	0	2	0	0	0	0	0	0	0	0
10. Lower Vaal																					
TOTAL	3	1	2	3	0	0	3	2	0	2	2	1	0	0	0	0	0	0	0	0	3
11. Mvoti to Umzimkulu																					
TOTAL	16	8	8	8	9	9	15	12	4	3	5	2	5	1	0	0	3	7	0	0	6
12. Mzimvubu to Keiskamma																					
TOTAL	3	1	2	3	2	0	0	1	1	2	1	0	2	0	0	1	2	0	0	0	0
13. Upper Orange																					
TOTAL	7	1	6	7	0		0	2	1	5	0	0	0	0	0	0	0	1	0	0	6
14. Lower Orange																					
TOTAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15. Fish to Tsitsikamma																					
TOTAL	1	1	0	1	1	0	0	1	1	1	0	0	0	0	0	0	1	1	0	0	0
16. Gouritz																					
TOTAL	1	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1
17. Olifants/Doorn																					
TOTAL	1	0	1	1	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0
18. Breede																					
TOTAL	2	2	0	1	1	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	1
19. Berg																					
TOTAL	7	0	6	6	6	0	6	6	0	5	6	0	5	0	0	0	0	0	0	1	0
GRAND TOTAL	86	30	54	57	42	11	45	55	8	36	19	5	31	2	12	6	9	21	2	1	24

ANNEXURE F

The roles of the National Water Act, 1998 (Act No. 36 of 1998) and the Water Services Act, 1997 (Act No. 108 of 1997) in eutrophication management

NATIONAL WATER ACT, 1998 (ACT NO. 36 OF 1998):

Although no mention is made of nutrient enrichment in the NWA (36:1998), there are several features to the Acts that merit the inclusion of eutrophication considerations. These include:

- **The National Water Resource Strategy:** The NWA (36:1998) requires the progressive development, after consultation with society at large, of a NWRS. The NWRS provides the framework for the integrated water resource management for the country as a whole. It also provides the framework within which water will be managed at regional or catchment level, in defined WMAs. The NWRS, which must be formally reviewed in five yearly cycles, is binding on all authorities and institutions exercising powers or performing duties under the Act. Nutrient management considerations should form part of the NWRS.
- **Catchment Management Strategies:** The NWA (36:1998) devolves responsibility to CMAs to progressively develop Catchment Management Strategies (CMSs) for the water resources within their jurisdiction. All CMSs must be in harmony with the NWRS and set principles for allocating water to existing and prospective users, taking into account all matters relevant to integrated water resource management in a particular WMA. Nutrient management strategies should form part of all CMSs.
- **A national Water Resource Classification System:** The NWA (36:1998) calls for the development of a system to classify the nation's water resources and, thus, requires guidelines and procedures for determining different classes of water resources. The system for classifying water resources may establish guidelines and procedures for determining different classes of water resources; establish procedures for determining the Reserve; establish procedures which are designed to satisfy the water quality requirements of water users, as far as is reasonably possible, without significantly altering the natural water quality characteristics of the resource; set out water uses for instream or land-based activities which activities must be regulated or prohibited in order to protect the water resource; and provide for such other matters relating to integrated water resource management. Government is required to classify all, or part of, water resources considered to be significant. Once a MC has been determined, it is binding on all authorities and institutions, when exercising any power or performing any duty under the Act. Since anthropogenic eutrophication is an impediment to achieving the MC,

due consideration should be given to nutrient enrichment and the trophic status of specific waterbody types (*e.g.,* rivers, wetlands, reservoirs, lakes and estuaries).

- **The Reserve:** This is a volume of water that needs to be maintained for two purposes. The basic human needs reserve provides for the essential needs of individuals served by the water resource in question and includes water for drinking, for food preparation and for personal hygiene. The ecological reserve relates to the water required to protect the aquatic ecosystems of the water resource. The Reserve refers to both the quantity and quality of the water in the resource, and will vary depending on the MC of the water resource. Government is required to determine the Reserve for all or part of any significant water resource. Once the Reserve has been determined for a water resource it is binding on all authorities and institutions, when exercising any power or performing any duty under the Act. Eutrophication issues should form a strong consideration on the assessment of the Reserve.
- **Resource Quality Objectives:** Government is required to determine Resource Quality Objectives (RQOs) for all, or part of, water resources considered to be significant. The RQOs will vary depending on the MC of the water resource. The purpose of RQOs is to establish clear goals relating to the quality of the relevant water resources. Once RQOs have been determined they are binding on all authorities and institutions, when exercising any power or performing any duty under the Act. RQOs should give due consideration to nutrient enrichment and the trophic status of specific waterbody types (*e.g.,* rivers, wetlands, reservoirs, lakes and estuaries).
- **Pollution prevention:** The NWA (36:1998) deals with pollution prevention, and in particular the situation where pollution of a water resource occurs or might occur as a result of activities on land. The person who owns, controls, occupies or uses the land in question is responsible for taking measures to prevent pollution of water resources. If these measures are not taken, the CMA concerned may itself do whatever is necessary to prevent the pollution or to remedy its effects, and to recover all reasonable costs from the persons responsible for the pollution. Anthropogenic eutrophication, amongst others, is the result of nutrient pollution, and its management should be incorporated into pollution control considerations.
- **Water use authorisation:** The NWA (36:1998) requires all water uses to be permissible and to comply with the conditions of the entitlement, including any WDSs that may relate to the combating of eutrophication, specified in Municipal Approvals, if relevant; or an Authorisation issued prior to 20 August 1996 to an ELU; or the applicable GA; or the water use Licence in question; or an alternative authorisation, if dispensing with the requirement for a licence to be issued under the NWA (36:1998). Additionally, the Act also enables the publication of several water quality management related regulations, which includes prescribing WDSs.
- **Regulations:** As enabling legislation, the NWA (36:1998) supports the development and publication of a variety of regulations, which deals with a range of aspects that may or should

be related to the management of eutrophication (**Annexure G**). These provisions include prescribing the extent of water use; the monitoring, measurement and recording of water use; various requirements in relation to waterworks; regulation or prohibiting activities in order to protect water resources; waste standards; management practices; procedures for the allocation of water by means of public tender; and procedures, and the contents of assessments of the likely effect of proposed licences on resource quality.

- **Water pricing:** The NWA (36:1998) acknowledges the polluters-pay principle and, through the application of a system of waste discharge charges, including charging for nutrients, aims to-
  - promote the ecologically sustainable development and efficient use of water resources;
  - promote the internalisation of environmental externalities by impactors;
  - create financial incentives for dischargers to reduce waste and use water resources in a more optimal way; and
  - recover the costs of mitigating the impacts of waste discharges on water quality.
- **Water resource information management systems:** The NWA (36:1998) requires government to establish national information systems on the quantity and quality of all water resources. Eutrophication management issues and indicators should be included on any such developed information system(s) at both national and WMA (or sub-catchment) levels.

WATER SERVICES ACT, 1997 (ACT NO. 108 OF 1997)

Overlap between the WSA (108:1997) and the NWA (36:1998) exists to some extent, principally to ensure seamless integration, albeit that cooperative governance challenges frequently exist. Although mention of nutrient enrichment is not made in the WSA (108:1997) either there are also several features to the WSA (108:1997) that merit the inclusion of eutrophication considerations.

- **National norms and standards:** The WSA (108:1997) enables the Minister of Water and Sanitation to prescribe national standards, *inter alia,* relating to-
  - the provision of water services;
  - the quality of water discharged into any water services or water resource system;
  - the effective and sustainable use of water resources for water services;
  - the nature, operation, sustainability, operational efficiency and economic viability of water services; and
  - requirements for persons who install and operate water services works.
- **Water Services Development Plans:** As part of the process of preparing IDPs, the WSA (108:1997) compels WSAs to develop WSDPs for the water resources and services within their area. The contents of the WSDP*, inter alia,* relates to existing and expected future

industrial effluent disposal; water sources to be used and the quantity of water to be discharged into each source; and the estimated capital and operating costs associated with the operation, maintenance, repair and replacement of existing and future infrastructure. Poorly operated and maintained WwTWs are sources of excessive nutrient enrichment. Nutrient management strategies should form part of all WSDPs.

- **Municipal approvals:** In terms of the WSA (108:1997), no person may dispose of industrial effluent in any manner other than that approved by the Water Services Provider (WSPs), nominated by the WSA having jurisdiction in the area in question. Additionally, the Act also enables the publication of compulsory national standards, *inter alia*, relating to– the quality of any wastewater being discharged into any water services or water resource system; and the effective and sustainable use of water resources for water services. Anthropogenic eutrophication, amongst others, is the result of nutrient pollution, and its management should be incorporated into pollution control considerations.
- **Water services information management systems:** The WSA (108:1997) requires government to establish national information systems on water services. Eutrophication management issues and indicators should be included on any such developed information system(s).

ANNEXURE G

Enabling provisions in the National Water Act, 1998 (Act No. 36 of 1998) and Water Services Act, 1997 (Act No. 108 of 1997) for making regulations or for prescribing compulsory national standards, which can be employed to enhance the control and management of anthropogenic eutrophication

NATIONAL WATER ACT, 1998 (ACT NO. 36 OF 1998):

In cases where the enabling legislation allows for the making of regulations that could assist with the management of anthropogenic eutrophication, but such regulations do not exist, consideration must be given to the development and publication of such regulations.

In cases where regulations do exist, a re-evaluation can be considered of the suitability and/or effectiveness of those measures that relate to the management of anthropogenic eutrophication – specifically also their suitability to assist with the realisation of the eutrophication management goal.

The table below lists those regulations under Section 26 of the NWA (36:1998), which could, or should be employed to enhance the control and management of anthropogenic eutrophication. Other provisions for making regulations under the NWA (36:1998), which are of a more general nature, or which mostly relate indirectly to the management of eutrophication, were not further considered here.

Regulations that are made under Section 26 of the NWA (36:1998) may-

- differentiate between different water resources and/or different MCs;
- differentiate between different geographical areas; and
- create offences and prescribe penalties.

When making regulations, the following must be considered:

- to promote the economic and sustainable use of water;
- to conserve and protect water resources or, instream and riparian habitats;
- to prevent wasteful water use;
- to facilitate the management of water use and waterworks;
- to facilitate the monitoring of water use and water resources; and
- to facilitate the imposition and recovery of charges.

Relevant provisions, as per the National Water Act, 1998 (Act No. 36 of the 1998):	
Section/ Provision	**Context and potential application to enhance the efficacy of eutrophication management**
S.26(1) The Minister of Water and Sanitation may make regulations–	
(a) ***"limiting or restricting*** *the purpose, manner or extent of* ***water use"***;	*Context* To **regulate (limit or restrict) particular water uses**, including the discharge of water containing waste or the disposal of waste, with respect to purpose, manner of use and extent.
	Application ▶ This provision can be utilised to apply limiting or restrictive measures to water uses that potentially contribute to anthropogenic eutrophication; ▶ It may be possible to apply this provision to improve the regulation of ELUs, as an alternative to compulsory licensing; and ▶ A draft regulation was published under the NWA (36:1998) [GN R.1188, 2006]: Draft regulations for the use of water for rec*reational purposes, generally and in respect of a government waterworks and surrounding state-owned land*.
(d) *"prescribing the* ***outcome or effect which must be achieved*** *by the installation and operation of any* ***waterwork"***;	*Context* To **prescribe performance criteria for any waterwork**, including a government waterwork, *i.e.,* any borehole, structure, earthwork or equipment installed or used for, or in connection with water use.
	Application ▶ The performance targets can be selected and formulated to benefit eutrophication management and to improve the trophic status of selected receiving reservoirs and/or other water resources; ▶ A waterwork may include WwTWs; and ▶ No such regulations have been published.
(e) *"regulating the design,* ***construction****, installation, operation and maintenance of any* ***waterwork****, where it is necessary or desirable to monitor any water use or to protect a water resource"*;	*Context* To **prescribe minimum requirements for the establishment, operation and maintenance of any waterwork**, including a government waterwork, *i.e.,* any borehole, structure, earthwork or equipment installed or used for, or in connection with water use.
	Application ▶ The minimum requirements can be selected and formulated to benefit eutrophication management and to improve the trophic status of selected receiving reservoirs and/or other water resources; ▶ A waterwork may include WwTWs; and ▶ No such regulations have been published.

Section/ Provision	Context and potential application to enhance the efficacy of eutrophication management
(f) *"requiring **qualifications** for and registration of persons authorised to design, construct, install, operate and maintain any **waterwork**, in order to protect the public and to safeguard human life and property"*;	*Context*: To **prescribe minimum qualifications for persons, in connection with the establishment, operation and maintenance of any waterwork**, including a government waterwork, *i.e.,* any borehole, structure, earthwork or equipment installed or used for, or in connection with water use. *Application*: ▶ This provision can be utilised to prescribe minimum qualifications for persons that establish, operate and maintain WwTWs. These qualifications can be selected and formulated to benefit eutrophication management; ▶ [GN R.2834, 1985]: Regulations for the erection, enlargement, operation and registration of water care works, published under Section 26 of the WA (54:1956), or any relevant regulation meant to replace it, published under the WSA (108:1998) or NWA (36:1998); and ▶ Refer to S.9(1)(e), WSA (108:1997).
(g) ***"regulating or prohibiting** any **activity** in order to protect a water resource or instream or riparian habitat"*;	*Context*: To **regulate or prohibit land and/or water use activities** in order to protect the resource quality and to give effect to RDMs. *Application*: ▶ This provision can be utilised to regulate (see S.26(1)(a) above) and/or to prohibit activities that can cause excessive nutrient loading in sensitive or stressed areas; ▶ [GN R.704, 1999]: Regulations on the use of water for mining and related activities, aimed at the protection of water resources, exist, and is currently being revised; and ▶ A draft regulation was published under the NWA (36:1998) [GN R.1188, 2006]: Draft regulations for the use of water for recreational purposes, generally and in respect of a government waterworks and surrounding state-owned land.
(h)*** *"prescribing **waste standards** which specify the quantity, quality and temperature of waste which may be discharged or deposited into or allowed to enter a water resource"*;	*Context*: To **prescribe uniform WDSs**, which specify nutrient loads and/or concentrations in waste disposed of and water containing waste discharged to surface water resources. *Application*: ▶ This provision can be utilised to prescribe updated uniform WDSs for nutrients, which inter alia give effect to RDMs; ▶ Although draft regulations have been prepared, no such regulations have been finalised or published; and ▶ [GN R.991 in GG 9225 of 18 May 1984]: General and Special Standards for the purification of Wastewater or Effluent, published under the previous Act, have not been repealed.

Section/ Provision	Context and potential application to enhance the efficacy of eutrophication management
(i)*** *"prescribing the outcome or effect which must be achieved through **management practices** for the treatment of waste, or any class of waste, before it is discharged or deposited into or allowed to enter a water resource"*;	*Context*: To **prescribe BMPs, BPGs or portions thereof**, which stipulate intermediate and/or end-results that must be achieved before waste is disposed of, or before water containing waste is discharged, or before point and/or diffuse sources of pollution are allowed to enter water resources. *Application*: ▶ This provision can be utilised to prescribe eutrophication management practices; and ▶ [GN R.704, 1999]: Regulations on the use of water for mining and related activities aimed at the protection of water resources exists and is currently being revised.
(j)*** *"requiring that **waste discharged or deposited** into or allowed to enter a water resource be **monitored** and analysed, and prescribing methods for such monitoring and analysis"*;	*Context*: To **require monitoring**, and to prescribe methods for monitoring and analysis, of waste being disposed of, or water containing waste being discharged into, or allowed to entering, water resources. *Application*: ▶ This provision can be utilised to compel water users, who contribute to excessive nutrient loading, to monitor the quality of their waste and/or water containing waste, and to regularly enter such data into a common information management system, such as IRiS. The availability of such e-data will make it possible to easily analyse information that can help with the management of eutrophication; and ▶ No such regulations have been published.
(n) *"prescribing procedures for the **allocation of water** by means of public tender or auction"*; and	*Context*: To **prescribe methodologies for the allocation of water quality** on the open market. *Application*: ▶ This provision can be considered for allocating available water quality for nutrients on the open market; and ▶ No such regulations have been published for water quality.
(o) *"prescribing– (i) procedures for obtaining; and (ii) the required contents of, **assessments** of the likely **effect which any proposed licence may have** on the quality of the water resource in question"*.	*Context*: To **prescribe assessment methodologies** that must be followed by proponents who are applying for water use authorisations in order to quantify the expected impacts on resource quality. *Application*: ▶ This provision can be utilised to compel water users to investigate and report on the potential effects, associated with the disposal of waste and/or discharge of water containing waste, as proposed. This may include an assessment of available water quality, nutrient loading and whether effect will be given to RDM and/or RWQOs/ WQPLs; and ▶ No such regulations have been published.

***** Regulations may contain general provisions applicable to all waste; and/or specific provisions applicable to waste with specific characteristics.**

In cases where the enabling legislation allows for the making of regulations or for prescribing compulsory national standards that could assist with the management of anthropogenic eutrophication, but such regulations or compulsory national standards do not exist, consideration must be given to the development and publication of such regulations or compulsory national standards.

In cases where regulations and or compulsory national standards do exist, evaluation of the suitability and/or effectiveness of those measures can be considered in relation to the management of anthropogenic eutrophication – specifically also their suitability to assist with the realisation of the eutrophication management goal.

The table below lists those compulsory national standards that can be prescribed under Section 9(1) of the WSA (108:1997), which could, or should be employed to enhance the control and management of anthropogenic eutrophication. Other provisions for making regulations under the WSA (108:1997), which are of a more general nature, or which mostly relate indirectly to the management of eutrophication, were not further considered here.

The compulsory national standards that are prescribed under Section 9(1) of the WSA (108:1997) may differentiate between–

- different users of water services; and
- different geographic areas, taking into account among other factors the socio-economic and physical attributes of each area.

In prescribing compulsory national standards, the Minister of Water and Sanitation must consider–

- the need for everyone to have a reasonable quality of life;
- the need for equitable access to water services;
- the operational efficiency and economic viability of water services;
- any norms and standards for applicable tariffs for water services;
- any other laws or any standards set by other governmental authorities;
- any guidelines recommended by official standard-setting institutions;
- any impact which the water services might have on the environment; and
- the obligations of the National Government as custodian of water resources.

Relevant provisions, as per the Water Services Act, 1997 (Act No. 108 of the 1997):	
Section/ Provision	**Context and potential application to enhance the efficacy of eutrophication management**
S.9(1) The Minister of Water and Sanitation may prescribe compulsory national standards relating to–	
S.9(1)(a) *"the **provision of water services**"*;	*Context*: To **prescribe compulsory national standards for the provision of water supply services,** *i.e.,* the abstraction, conveyance, treatment and distribution of potable water, water intended to be converted to potable water, or water for commercial use, but not water for industrial use, **and sanitation services,** *i.e.,* the collection, removal, disposal or purification of human excreta, domestic wastewater, sewage, and effluent resulting from the use of water for commercial purposes**.** *Application*: ▶ This provision can be utilised to apply specific standards to the provision of sanitation services, including controlling objectionable substances, grey water disposal and the use of effluent return flows, that may affect anthropogenic eutrophication; and ▶ A regulation was published under the WSA (108:1997) [GN R.509, 2001]: Regulations relating to compulsory national standards and measures to conserve water.
S.9(1)(b) *"the **quality of water** taken from or **discharged into any water services or water resource system**"*;	*Context*: To **prescribe compulsory national standards for return-flow water**, being discharged into any water services or water resource system. *Application*: ▶ Water Services Authorities (WSAs) can also exercise control over the quantity and quality of effluent, including industrial effluent being discharged to water resources or to municipal sewer network systems; ▶ A regulation was published under the WSA (108:1997) [GN R.509, 2001]: Regulations relating to compulsory national standards and measures to conserve water.
S.9(1)(c) *"the **effective and sustainable use of water resources** for water services"*;	*Context*: To **balance the need to protect water resources with the need to use water resources** for the purpose of water services provision. *Application*: ▶ In order to conserve and to protect water resources, this provision can be utilised to promote water conservation, water demand management, water and effluent balance analysis and the determination of water losses, as well as wastewater recycling and reuse strategies, and to avoid, prevent and minimise water pollution; ▶ A regulation was published under the WSA (108:1997) [GN R.509, 2001]: Regulations relating to compulsory national standards and measures to conserve water.

Section/ Provision		Context and potential application to enhance the efficacy of eutrophication management
S.9(1)(d)	*"the **nature, operation, sustainability, operational efficiency** and economic viability of water services"*;	*Context*: To **ensure that water services related practices are sustainable, viable and efficient.** *Application*: ▶ This provision can be utilised to prescribe compulsory national standards for basic sanitation, for basic water supply, for interruptions in the provision of water services, the quality of potable water, the repair of leaks, and the reporting of non-compliance; and ▶ A regulation was published under the WSA (108:1997) [GN R.509, 2001]: Regulations relating to compulsory national standards and measures to conserve water.
S.9(1)(e)	*"**requirements for persons who** install and **operate water services works**"*; and	*Context*: **To prescribe minimum qualifications for persons, in connection with the installation and operation of any water services works**, *i.e.,* of any reservoir, dam, well, pumphouse, borehole, pumping installation, purification work, sewage treatment plant, access road, electricity transmission line, pipeline, meter, fitting or apparatus built, installed or used by a water services institution to provide water services; water for industrial use; or to dispose of industrial effluent**.** *Application*: ▶ This provision can be utilised to prescribe minimum qualifications for persons, in connection with the installation and operation of any sewage treatment plant to provide sanitation services or to dispose of industrial effluent. These qualifications can be selected and formulated to benefit eutrophication management; ▶ [GN R.2834, 1985]: Regulations for the erection, enlargement, operation and registration of water care works, published under Section 26 of the WA (54:1956), or any relevant regulation meant to replace it, published under the WSA (108:1998) or NWA (36:1998); and ▶ Refer to S.26(1)(f), NWA (36:1998).
S.9(1)(f)	*"the **construction and functioning of water services works and consumer installations**"*.	*Context*: **To prescribe compulsory national standards for the establishment, operation and maintenance of any water services work,** *i.e.* for a reservoir, dam, well, pumphouse, borehole, pumping installation, purification work, sewage treatment plant, access road, electricity transmission line, pipeline, meter, fitting or apparatus built, installed or used by a water services institution to provide water services; water for industrial use; or to dispose of industrial effluent; and **any consumer installations,** *i.e.* a pipeline, fitting or apparatus installed or used by a consumer to gain access to water services and includes a meter attached to such pipeline, fitting or apparatus. *Application*: ▶ This provision can be utilised to prescribe compulsory national requirements for the measurement or control of water that is supplied, for consumer installations other than meters, for pressure in reticulation system, etc.; and ▶ A regulation was published under the WSA (108:1997) [GN R.509, 2001]: Regulations relating to compulsory national standards and measures to conserve water.

ANNEXURE H

Potential legislative amendments, necessary to improve eutrophication management

The following potential legislative amendments and reviews are proposed in this document. These changes are regarded as necessary to address anomalies or shortcomings, or to improve and strengthen certain statutory provisions:

RECOMMENDED LEGISLATIVE AMENDMENT	NOTES	REFERENCE *(page #)*
(1) Amendment to allow re-classification of the MC.	If the receiving water resource does not have enough allocable water quality to assimilate waste without exceeding the RQOs, and if there are major socio-economic drivers behind a proposed new waste discharge, there may be a case to be made for re-classification of a water resource. In this case, it needs to be investigated whether a lower MC, which might allow for socio-economic development opportunities to be implemented, may be more appropriate. In such a case, the full procedures required under the legislation for the determination of a MC, RQOs and Reserve, including stakeholder consultation, will be applied. The converse is also true, that is, if the MC is found to be inadequate for any reason, a higher MC might be applied, after appropriate investigation and consultation.	**189**
(2) Amendment to allow for the declaration of protected water source areas	Currently, the NWA (36:1998) allows for only the prohibition of activities in a water source area. A legislative amendment would allow the Minister of DWS to declare a high yield water source area as protected. This would ensure that certain areas receive full protection. This may be required for an area to recover and rehabilitate itself or it may simply be required for ecological protection.	**201**
(3) Amendment to extend the financial provisioning clause to all high-risk polluting sectors	The financial provisioning for site rehabilitation should extend to all industries that are deemed *"high-risk"* polluters. This will ensure that provision is made, whilst the industry is operational, and it will aid to avoid *post facto* actions, with the State carrying the risk.	**241**
(4) Amendments as part of the development of a Non-Point Source (NPS) Strategy	Legislative amendments may be required and need to be investigated, as part of the development of a NPS Strategy for South Africa. These may relate to amendments of the definition of water use, the authorisation process; monitoring requirements; and the addition of provisions to allow for the identification of P and N vulnerable zones; and provisions requiring several diffuse source related interventions.	**290**
(5) Amendments to allow for pollution taxes	The ambitions of the WDCS will be extended by the introduction of pollution taxes on *"input products"*, such as on herbicides and pesticides in line with **POLICY STATEMENT 6**: A life cycle view on nutrient loading.	**291**

RECOMMENDED LEGISLATIVE AMENDMENT	NOTES	REFERENCE *(page #)*
(6) Amendment to allow for the categorisation of polluting industries, based on risk	There are limited human and financial resources available within government. In order to use these resources most effectively and to achieve the greatest impact, a targeted risk-based approach should be adopted. Under this approach, the potential significance of the impact of water pollution must inform the level of response or intervention from the state. Thus, areas of particular sensitivity will receive heightened attention, as will activities from which the pollution potential is of a particularly hazardous nature and areas where pollution is already extremely high.	**292**
(7) Amendment to allow for the publication of a Water Polluter Register	The publication of information is a useful tool towards incentivising responsible behaviour. In the South African context, the Green Drop certification system for municipalities has proven the regulatory value of the reporting and disclosure of information. A Water Polluter Register should be introduced to extend this reporting beyond municipalities to incentivise polluters to reduce their pollution. In this register, enterprises that are meeting best practice standards should be recognised, as should non-compliance by enterprises.	**294**
(8) Amendment to allow for the promulgation of a Money Bill for the Waste Discharge Levy	The WDCS is based on the Polluter-Pays Principle and aims to promote the sustainable development and efficient use of water resources; internalise the environmental and social costs of using water; create financial incentives for water users to reduce waste and use water resources more optimally, and recover costs associated with impacts of waste discharges. It consists of two charges: a Waste Discharge Levy and a Waste Mitigation Charge. The Waste Mitigation Charge, provided for by the NWA (36:1998), is intended to cover the quantifiable administrative costs of implementing measures to mitigate the negative impacts of waste related discharges. The Waste Discharge Levy provides a disincentive to the discharge of wastewater and will be based on the rate of water utilisation as a means of disposing of waste. In order for the Waste Discharge Levy to be introduced, an amendment to the NWA (36:1998) is required to give the Minister permission to promulgate a Money Bill.	**293**
(9) Amendments to allow for eco-labelling	The introduction of an eco-labelling scheme that acknowledges the water pollution related life cycle of goods and products will stimulate innovation as more sustainable products are invented; develop markets that cater to evolving consumer interests; create opportunities for education; create new value chains by establishing new networks of production; monitor water resource claims; influence consumer behaviour towards more water resource friendly products; promote economic efficiency in response to predefined standards; muster economic support for sustainability; and reallocate the costs of improving the trophic status of receiving water resources.	**295**

RECOMMENDED LEGISLATIVE AMENDMENT	NOTES	REFERENCE *(page #)*
(10) Amendment to allow for administrative penalties	Currently South Africa relies on criminal prosecution for addressing water quality violations, but such processes are slow and difficult, particularly in an overburdened criminal justice system. Criminal prosecution is dependent on evidence that proves the case beyond reasonable doubt, and the support of the South African Police Service and National Prosecuting Authority. Many of the players in the criminal justice system do not fully understand water legislation or the seriousness of environmental crimes, with the result that such violations do not draw serious penalties. This is a common problem in many countries, and as a result, many countries are moving towards administrative or civil penalty systems for environmental violations, with a criminal enforcement option retained for the worst environmental crimes. Certain activities that result in water pollution will still follow the criminal prosecution route, such as acts of vandalism.	**325**

ANNEXURE I

Quick Reference Table: Eutrophication governance policy

STATEMENT #	POLICY STATEMENT	REFERENCE *(page #)*
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POLICY STATEMENT 3	The Differentiated Approach for the control of excessive nutrient loading	189
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POLICY STATEMENT 5	The Receiving Water Quality Objectives Approach applied to eutrophication management	192
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ANNEXURE J

Quick Reference Table: Eutrophication Governance Strategy

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OPERATIONAL STRATEGIES		
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	Goal setting	257
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SUPPORTING STRATEGIES					
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