RESTORATION OF ESTUARIES USING A SOCIO-ECOLOGICAL SYSTEMS FRAMEWORK

Report to the Water Research Commission

by

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EXECUTIVE SUMMARY

The South African National Biodiversity Assessment 2019 indicated that our estuaries are under severe pollution pressure and that improvement of water quality as a key intervention would lead to significant improvement in estuary health and associated benefits that society derive from them. Innovative approaches are needed to remove wastewater inputs from estuaries to improve estuary health because both general and special standards result in high nutrient input and eutrophication. The research focused on the restoration of estuary water quality using the Swartkops Estuary as a case study. The objective of the project was to develop a socio-ecological systems framework for the restoration of estuaries. The research addressed the objectives of the United Nations Decade of Ecosystem Restoration (2021-2030) using the Society for Ecological Restoration (https://www.ser.org/) principles. Restoration is the process of assisting the recovery of damaged, degraded, or destroyed systems. Restoration occurs along a continuum and ranges from reducing impacts to remediation, rehabilitation, and ecological restoration.

The Swartkops Estuary was chosen as the study site as it is nationally important. It is one of few permanently open estuaries with large intertidal salt marshes and available nursery habitat for fish. Swartkops Estuary is also recognised internationally as an IBA (Important Bird and Biodiversity Area). Despite the estuary's importance it is highly impacted. There are however opportunities to improve its health from a D (highly modified) to a C (moderately modified) present ecological status category. Additionally, there are several different water quality issues that need addressing, including industrial discharges, input to the river from three wastewater treatment works, stormwater runoff, and agricultural return flow. The research investigated innovative methods for water quality improvement such as sustainable drainage systems, artificial wetlands, as well as the role of salt marsh, seagrass, and phytoplankton as pollutant filters. Enhancing and protecting their ecological role as phytoremediators is crucial for restoring estuary health. In recent years, the high pollution levels in the estuary have negatively influenced various social and cultural activities such as the Redhouse River Mile swimming event, cleansing ceremonies by traditional healers, and baptisms by the Zion Church. The estuary is also close to the Nelson Mandela University, providing opportunities for student training and continual interaction with stakeholders.

The study had the four main objectives:

1. Investigate innovative methods for water quality improvement
2. Determine the role of primary producers as pollutant filters
3. Assess the benefits of water quality improvement on estuary health
4. Develop a socio-ecological systems framework for the restoration of estuaries

All these objectives were achieved. Although the study site was the Swartkops Estuary, the socio-ecological framework developed for the restoration of estuaries is applicable to all estuaries.

Innovative methods for water quality improvement

South African estuaries are polluted because of increased inputs of stormwater run-off, agricultural return flows, and wastewater treatment plant effluent discharges. The nutrient loads from these sources have resulted in numerous South African estuaries experiencing harmful algal blooms (HABs) and nuisance macroalgal growth. Pollutant uptake and cycling are essential ecosystem services that need to be maintained and innovative solutions are required to reduce pollution pressure and improve estuary health.

Inputs were also made on how to optimise the functioning of the artificial wetland at Motherwell Canal. This small artificial wetland adjacent to the Motherwell Canal was not coping with the volume of water entering from the canal and thus alternative solutions needed to be found. The diversion of canal water to the nearby abandoned Redhouse saltpan was proposed to improve water quality and reduce the input of polluted water to the Swartkops Estuary. A network of 14 stormwater drains into the Motherwell Canal transporting litter, debris and frequently raw sewage. The canal enters the middle reaches of Swartkops Estuary and is a major source of pollution in the form of nitrogen (ammonium), trace metals and faecal bacteria.

Research on the inorganic nutrient removal efficiency of the Motherwell constructed wetland before discharging into the eutrophic Swartkops Estuary was completed (Lemley et al., 2022b). Results showed that the constructed wetland removed a negligible amount of Dissolved Inorganic Nitrogen (DIN 5% uptake) and acted as a source of Dissolved Inorganic Phosphorus (DIP 68% efflux) to the estuary. Flow volume to the wetland has increased 10-fold since 2016, thus resulting in low water residency.

The existing artificial wetland is too small (0.8 ha) to cope with the volume of water coming down the canal. The wetland surface area would need to be increased to 46 ha to cope with current daily inputs (ca. 6300 m^3 d^{-1}), but unfortunately there is no space at the site due to surrounding steep hills. Recommendations were made to improve the functioning of the artificial wetland which include regular harvesting of bulrush and sediment removal. This would remove nutrients from the system. The stormwater volume entering the Motherwell Canal needs to be reduced by fixing upstream water leaks and blocked household sewerage systems. Solid waste, plastics and algal growth are also a problem as this clog up the system and prevents the water from flowing into the artificial wetland.

Innovative methods for estuary water quality improvement were investigated in a specialist workshop in June 2021 (Appendix 5). Methods identified include practical solutions for stormwater management, using Sustainable Drainage Systems (SuDS), biomimicry, algal ponds, and artificial wetlands. The three main sources of polluted water to the middle reaches of the Swartkops Estuary are the Markman Canal, Motherwell Canal, and Chatty River. A treatment train (SuDS) was installed at Markman Canal where local communities were consulted and involved (Mmachaka 2022 – Appendix 4). SuDS (sustainable drainage systems) are globally accepted practices for managing the water quality of stormwater and effluent, discharged into urban rivers and estuaries. The treatment train consisted of five separate tanks for sedimentation, sand filtration, stone filtration, biodegradation and a floating wetland tank. Stormwater meant for the Markman Canal was diverted and sequentially pumped into each of the tanks. The treatment train reduced macronutrient concentrations by 76%, trace elements by 74% and faecal bacteria counts by 80%. This serves as a case study to upscale and roll out such interventions at urban estuaries.

Research also investigated the use of the abandoned salt pans for the treatment of stormwater run-off from the Motherwell Canal (Wasserman 2021 – Appendix 4). The pollution contribution of the Chatty River was measured, and recommendations provided to improve its water quality through the inclusion of SuDS (Matalanga – Appendix 4). SuDS are designed to minimise the impact of development on stormwater quality while maximising amenity and biodiversity through a suite of interventions designed to manage stormwater in a way that mimics nature. These are novel applications for estuaries in South

Africa. These interventions investigated in this study can be used to inform the restoration of estuaries and improvement of water quality at other sites.

Role of primary producers as pollutant filters

The role of primary producers in estuaries as natural bio-accumulators and nutrient filters was investigated (Whitfield 2022 – Appendix 4). Estuaries occur at the interface between the terrestrial and marine environment and, as such, act as the last 'filtering' mechanism prior to polluted waters entering the adjacent ocean. This study focused on the Swartkops Estuary which is eutrophic and requires the removal of nutrients. The role of phytoplankton as nutrient filters and storage of nutrients by seagrass and salt marsh was investigated. This study found that phytoplankton temporarily took up a large percentage of dissolved inorganic nitrogen (max. 99%) and dissolved silica (max. 76%) and limited amounts of dissolved inorganic phosphorus (max. 18%). The amount of carbon, nitrogen, and phosphorus stored by the salt marsh species *Spartina maritima* and *Salicornia tegetaria* and the seagrass species *Zostera capensis* were determined. It was found that the salt marsh grass *Spartina maritima* stored the most nutrients, and the salt marsh succulent *Salicornia tegetaria* the least. The macrophytes were able to store nutrients for longer periods and thus prevent these nutrients from being exported into the adjacent ocean. On the contrary, phytoplankton uptake was temporary as the nutrients are released once the bloom decays. Macrophyte decay and subsequent mineralisation can increase nutrient concentrations but this was not investigated.

An assessment of data from 11 water quality and phytoplankton surveys showed that for 64% of the sampling dates, the Swartkops Estuary was in an undesirable state characterised by phytoplankton blooms of *Heterosigma akashiwo* and the diatom *Cyclotella atomus.* Although phytoplankton play an important role in taking up nutrients this comes with costs associated with HABs. Management interventions are needed to prevent HABs as they cause oxygen extremes and produce mucilage that impact fish and invertebrates. Without intervention there will be an increase of HABs and associated fish kills in the eutrophic Swartkops Estuary. Nutrient input from upstream wastewater treatment works, canals, and stormwater run-off must be reduced. Conservation and management of the seagrass and salt marsh habitats is essential to ensure the long-term storage of nutrients and their role as a pollutant filter.

Nutrient inputs from upstream wastewater treatment works have introduced high levels of nutrients into the Swartkops Estuary. The upper reaches of the estuary at Perseverance are eutrophic and characterised by extensive mats of invasive alien aquatic plants (IAAPs). Water hyacinth (*Pontederia crassipes*) is dominant. The nutrient storage capacity of water hyacinth was measured (Lakane 2022, Appendix 4). Water hyacinth was collected at the upper tidal limit of the estuary (Perseverance) at different temporal scales (i.e. weekly, and monthly). Aerial images were used to map the cover of IAAPs on each sampling trip, while the collected hyacinth samples were sorted into leaves, stems, and roots to determine total phosphorus (TP) and total nitrogen (TN) concentrations. Average plant nutrient concentrations indicated consistent TP levels during the high (0.31 ± 0.24 g m^{-2}) and low flow season (0.29 ± 0.16 g m^{-2}).

Conversely, average TN concentrations were greater (0.75 ± 0.48 g m^{-2}) during low flow periods compared to the high flow season (0.58 ± 0.54 g m^{-2}). Additionally, tissue nutrient concentrations were highest in the stems compared to other plant parts. From a temporal perspective, water hyacinth displayed maximum cover (>30% of water surface) and nutrient storage (TN and TP > 650 kg) during the summer months at Perseverance. The study showed how water hyacinth can be used as a phytoremediator to take up nutrients before they enter the estuary. They play a similar role in other aquatic ecosystems such as dams.

Benefits of water quality improvement on estuary health

An important first step in restoration is understanding a system's health or Present Ecological Status. A project workshop was completed in June 2021 that assessed the health of the Swartkops Estuary (Adams et al. 2021). Restoration of estuary health and resilience to future climate change impacts was considered as well as the effects of water quality improvement on estuary health and ecosystem services. There was immediate knowledge transfer from this study as the results were included in the Estuary Management Plan that was being revised by the Province of the Eastern Cape, Economic Development, Environmental Affairs & Tourism; a requirement of the National Environmental Management: Integrated Coastal Management Act (Act No. 24 of 2008).

Our research has shown a deterioration in health of the Swartkops Estuary. Previously, the Estuarine Health Index (EHI) score was 53 and this study reported an EHI score of 47. However, the estuary remains in a Present Ecological Status (PES) of Category D indicating a largely modified estuary. Because of the national importance of the estuary, it should be managed as a Category C and thus restoration activities were identified to improve health. There has been a loss in the marine state of the estuary due to persistent input of nutrient rich baseflow from three upstream WWTWs. This results in eutrophic conditions indicated by HABs in the estuary and extensive mats of IAAPs (e.g. water hyacinth) in the upper estuary reaches. Bait collection and overfishing were also major pressures on the estuary and there has been a loss of birds due to drying of salt pans and human disturbance. Habitat restoration as well as removal of all inputs from upstream WWTWs would be needed to improve the health of the estuary to a PES of C (moderately modified).

Two worst case future scenarios were considered, i.e. Scenario 1 represents a climate change scenario where there would be warmer conditions and an increase in floods and Scenario 2 represents a 60% increase in wastewater input aligned with the projected population growth for 2050. The restoration scenarios were Scenarios 3 and 4 that represent a decrease in wastewater input and Scenario 5 habitat restoration. In the EHI assessment, responses are averaged across the different components and the two worst case scenarios keep the estuary in a Category D. Under restoration Scenario 3, removal of 75% of wastewater input, keeps the estuary in a Category D which only improves to a C/D when 100% of the wastewater input is removed in Scenario 4. This indicates the significant impact of the WWTW input to the estuary as well as the influence of other multiple pressures. Besides reducing WWTW input, habitat restoration will also need to take place to improve the health of the Swartkops Estuary. There was a 4-point improvement from the present state (score of 47) to Scenario 5 (score of 51). If this improvement occurs in addition to the water quality scenario (Scenario 4) the estuary health score would be 63 with a C ecological category (61-75 = C = moderately modified). Changes in ecosystem services were described for different scenarios compared with the present state. The benefits of water quality improvement on estuary health were identified. A conclusion from the study was that the poor health of the Swartkops Estuary is a result of multiple pressures that need to be addressed to improve present status.

Water quality improvement is a priority; other actions identified for immediate action were:

- Remove all wastewater input to the estuary from the river through measures such as recycling and artificial wetlands,
- Add water to the Redhouse salt pan from Motherwell Canal,
- Restore riparian habitat by removal of alien plants from the middle & upper estuary reaches,
- Reduce fishing pressure and,
- Reduce destructive bait collection through compliance monitoring & protected areas.

Socio-ecological systems framework for the restoration of estuaries

The health of marine ecosystems is deteriorating globally due to anthropogenic activities (e.g. urbanisation, industrial, agricultural, sea level rise). This is a concern as estuaries are ecologically important systems that support and maintain a range of flora and fauna while also providing humans with a diverse range of services. In trying to solve this problem, a socio-ecological system (SES) approach for estuary restoration was developed in this study. The concept of socio-ecological systems is an important approach for managing natural resources as it emphasises that human populations and coastal ecosystems are interlinked, and that interdependent relations should not be taken for granted when managing these ecosystems.

This study tested the socio-ecological systems framework for the restoration of estuaries using the Swartkops Estuary as a case study. The condition of the Swartkops Estuary was assessed using the Estuary Health Index to understand the present ecological state (PES) of the estuary following from the last assessment completed in 2013/2014. The Estuary Health Index is a nationally accepted method of measuring the health of South African estuaries. The state of the societal system was assessed through field observations, engagements with estuary users on-site, insights provided by the Zwartkops Conservancy, and from recent literature.

This study showed that the health of the Swartkops Estuary is on a negative trajectory. The main pressures are water quality deterioration (e.g. WWTWs, stormwater canals) along with habitat loss and resource exploitation. Fishing, bait collection, recreation and the use of spiritual sites are the dominant ecosystem services provided by the estuary. Through the assessment of the state of the societal system, the estuary was highlighted to be a major food source for many people living close by through subsistence fishing and bait collection for selling to recreational fishers. The estuary is also a health hazard to the very same people that depend on it for survival because of the high bacterial loads and high metal inputs from past and present nearby industrial activities.

Removing WWTW inputs, adding water to the Redhouse salt pan, restoring riparian habitat by removing alien vegetation, reducing fishing pressure and reducing bait collection pressures were identified as priority restoration activities needed at the Swartkops Estuary. WWTW inputs need to be removed as even the general standards for wastewater discharge cause downstream estuary eutrophication. An assessment of salt marsh restoration options highlighted that disturbed areas in the supratidal salt marsh habitat were not significantly different from the undisturbed areas in terms of carbon storage. However, the disturbed plots were found to be unsuitable for salt marsh growth due to hypersalinity and remedial actions will need to be taken for future salt marsh growth to occur. Hypersalinity occurred in abandoned salt pan areas as well as supratidal habitats where evaporation and low rainfall resulted in sediment salinisation.

This research has developed and tested a socio-ecological systems framework for the restoration of estuaries (Adams et al., 2020b; Tsipa 2022). A socio-ecological systems approach to estuary restoration is vital in addressing the gap between legislation, governance, implementation, and social commitment. The framework was tested for saltpan restoration at Swartkops Estuary and salt marsh in South Africa (Adams et al. 2021). Given that best practice was used in this study, the information can be used to inform restoration of estuaries and improvement of water quality at other sites. The restoration of complex systems such as the St Lucia Estuary should use a socio-ecological systems approach.

Restoration plans need to be communicated with all the relevant stakeholders including local communities and estuary users. Implementation of restoration plans in conjunction with the implementation of the Estuary Management Plan will lead to improved ecosystem service delivery and simultaneously improve societal health. This research is timely considering that we are in the UN Decade of Ecosystem Restoration (2021-2031). Research of this nature will also help achieve various objectives of the Sustainable Development Goals. Employing a SES framework for the restoration of estuaries helps managers and policymakers to make informed environmental management decisions that consider both ecological and socio-economic factors.

Key findings

- Estuary restoration should take place using a socio-ecological systems framework.
- Innovative methods can improve estuary water quality.
- Abandoned salt pans can be used for the treatment of stormwater run-off.
- Sustainable urban drainage systems can improve water quality as shown for the Chatty River and treatment train implemented in the Markman Canal.
- The size of an artificial wetland must be large enough to cope with the volume of stormwater inflow, otherwise the wetland can act as a source of nutrients (e.g. Motherwell Canal).
- Estuary primary producers act as important bio-accumulators of metals and nutrient filters.
- Environmental flow and restoration scenarios were used to show the improvement in estuary health following restoration interventions.

The users and beneficiaries of the research were:

- **Scientific community** - the Estuary Health workshop and ecological water requirement study provided training for a wide group of scientists and postgraduate students. Following this workshop, a study in collaboration with UCT Engineering was initiated on the Chatty River catchment with a MSc study funded.
- **Postgraduate students** benefitted from a multi-disciplinary and multi-institutional research approach.
- **Local communities** – the Aloes community living near the Markman Canal are directly influenced by poor water quality. They were involved with the design and construction of the treatment train (SuDS) at this site to ensure sustainability and maintenance of the system.
- **Eastern Cape Department of Economic Development, Environmental Affairs (DEDEAT) and Tourism and Department of Forestry, Fisheries and Environment (Oceans and Coasts) (DFFE).** Input provided on the revision of the Swartkops Estuary Management Plan – collaboration with national & provincial government as well as local authorities i.e. Nelson Mandela Bay Metro.
- **DFFE** – Working for Wetlands programme – input was provided on the prioritisation of estuary sites on a national scale for restoration. This serves as a precursor to a National Estuarine Restoration Programme.
- **Department of Water and Sanitation (DWS)** – implementation of treatment train and identification of sites for SuDS. Input on water quality management of Swartkops Estuary. The research would also provide input to a revised EWR (Ecological Water Requirements/ reserve) study.
- **Input to Zwartkops Conservancy (NGO)** on estuary management issues including rehabilitation of the Redhouse and Bar None salt pans, water quality and Harmful Algal Blooms.
- Data and results from this study provided input to an **Estuary Ecosystem Accounting** project with Swartkops Estuary as a case study. This is in line with UN's System for Environmental-Economic Accounting (SEEA) that aims to gather and organise environmental information consistently and enable its integration with socio-economic information, such as Systems of National Accounts.
- The local communities, general public and users of the Swartkops Estuary benefitted from interaction on the project's activities. In particular members of the Zwartkops Conservancy act

as citizen scientists. **Estuarine users** with access to healthier ecosystem services and creation of new partnerships to address human health.
- Knowledge transfer – this study has informed a new research project on the Knysna Estuary where innovative methods for water quality improvement and the role of seagrass as a pollutant buffer will be measured.

Capacity building

This research contributed to human capital development in the water and science sectors as the primary researchers were Honours, MSc, and PhD students. Over 50% of the research team consisted of woman and previously disadvantaged persons. The training of several interns (Zolani Ntsata, Chuene Lakane, Shulamy Ntsoeu) also took place. Thandi Mmachaka completed her PhD part-time while working at the Department of Water and Sanitation, and the results from her research have been immediately incorporated into the Department's programme of work on the water quality management of the Swartkops River and estuary. This includes the implementation of Sustainable Drainage Systems. Research activities were multi-disciplinary and inter-institutional through collaboration in research symposia and workshops. This approach ensured high quality training of postgraduate students that secures critical and scarce skills for our country. Students interacted with the end-users of the research ensuring transfer of knowledge across the science - policy - practice continuum, particularly concerning the conservation and management of estuaries.

Research outputs

Research outputs were:

- One report on environmental flow requirements and restoration options for the Swartkops Estuary.
- Eight journal articles, four popular articles, and 11 conference presentations.
- Trained postgraduate students: seven Honours studies, six Masters studies, one PhD study.

Conclusions and management recommendations

There is an urgent need to develop an "Integrated Estuarine Restoration Strategy" to coordinate and direct estuary restoration at national, provincial, or even municipal levels. Local communities are essential for the effective and successful conservation and restoration of estuaries. Policies and actions must be inclusive and equitable. Some critical government responses are summarised that were developed in parallel to this project in a study on blue carbon sinks in South Africa.

Actions needed to address the ongoing decline of estuary ecosystem services include:

- Developing an integrated Estuarine Restoration Strategy to coordinate and direct estuary restoration at national, provincial, or even municipal levels.
- Implementing restoration at an estuary level through Estuary Management Plans under the National Estuarine Management Protocol (2021) and formally include restoration guidelines in the DFFE Guidelines for the Development and Implementation of Estuarine Management.
- Improving estuary protection status. This can be done by applying for example the IUCN Red Listing of Ecosystems criteria to salt marsh to determine their overall threat status and ensure increased legislative protection.
- Reducing pressures to promote estuary restoration, for example:
    - Reinstate freshwater flows to estuaries, prevent over-abstraction and lowering of the groundwater table.

- Reduce the volume of effluent from WWTWs into estuaries (or immediately upstream of estuaries).
- Improve water quality of return flow from agriculture in catchments.
- Control and reduce urban stormwater runoff into estuaries by for example using sustainable drainage systems (SuDS).
- Remove poorly planned low-lying infrastructure in the Estuary Functional Zone so that unnecessary artificial breaching of estuaries, e.g. for poor water quality is avoided.

Recommendations for future research

South Africa needs a National Estuary Restoration and Research programme to prioritise key sites and allocate resources. Site- and context-specific research studies (living laboratories) can guide restoration through the implementation of Estuary Management Plans. Priority sites for estuary and salt marsh restoration have been identified. Action research is needed to establish best methods and practices; for example on how to convert agricultural lands back to salt marsh. Action research includes a learning-by-doing approach and provides input to via strategic adaptive management.

Restoration research provides opportunities for innovation through transdisciplinary approaches. Research can harmonise links between disciplines in a co-ordinated and coherent whole that focuses on “real-world” system problems. The involvement of stakeholders and communities is essential.

Restoration research provides opportunities for postgraduate training across disciplines. By celebrating conservation successes, we will ignite hope and inspire the next generation of thinkers and change-makers (#oceanoptimism, #GenerationRestoration). It is important to communicate the message that individuals can make a difference.

The interaction between climate change and restoration activities in estuaries needs greater understanding. High-resolution digital elevation models are required to assess the influence of sea level rise on coastal habitats at the national scale. Coastal squeeze could result in the loss of estuarine habitats or in some cases could allow expansion if there is available land. Remote sensing is also a tool that can be used in South African estuaries to track progress of estuary restoration, assess water quality, as well as determine the standing biomass of plants and carbon stocks. The extent of estuarine habitats (Blue Carbon Sink Register) needs to be updated every five years to reflect the change in the area of salt marsh, mangroves and seagrass ecosystems to report on restoration and protection progress. A register can be used to also track the threats and trajectory of pressures. There is also scope for research geared towards investigating the link between water quality and human health.

The monetary worth of ecosystem services was not addressed in this study, but this can be easily achieved now that the major ecosystem services have been identified. Research can identify opportunities for carbon trading, restoration, and payment for ecosystem services.

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Project site visit 2021

LIST OF ABBREVIATIONS

CMR	Institute for Coastal & Marine Research
CPUT	Cape Peninsula University of Technology
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DEDEAT	Eastern Cape Department of Economic Development, Environmental Affairs and Tourism
DFFE	Department of Forestry, Fisheries and Environment
DIN	Dissolved inorganic nitrogen
DIP	Dissolved inorganic phosphorus
DSS	Decision Support System
DWS	Department of Water and Sanitation
EbA	Ecosystems-based Adaptation
EHI	Estuarine Health Index
EMP	Estuary Management Plan
EPWP	Expanded Public Works Programme
ES	Ecosystem Services
HAB	Harmful algal bloom
IAAP	Invasive alien aquatic plant
IBA	Important Bird and Biodiversity Area
ICM	Integrated Coastal Management
IWRM	Integrated Water Resources Management
MEA	Millennium Ecosystem Assessment
MPA	Marine Protected Area
MPB	Microphytobenthos
NEM:ICM Act	National Environmental Management: Integrated Coastal Management Act (Act No. 24 of 2008)
NGOs	Non-governmental organisations
NPOs	Non-profit organisation
PRA	Participatory Rural Appraisal
PRS	Pollution Incident Reporting System
PES	Present Ecological Status
RU	Rhodes University
SAIAB	South African Institute for Aquatic Biodiversity
SAEON	South African Environmental Observation Network
SANBI	South Africa National Biodiversity Institute
SES	Socio-ecological Systems
SER	Society for Ecological Restoration
SDGs	Sustainable Development Goals
SuDS	Sustainable drainage systems
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
UCT	University of Cape Town
UFS	University of the Free State
UN	United Nations
UNDP	United Nations Development Programme
WfWs	Working for Wetlands
Wits	University of the Witwatersrand
WRC	Water Research Commission

WUSS	Water Use Screening System
WW	Wastewater
WWTP	Wastewater Treatment Plant
WWTW	Wastewater Treatment Works

CHAPTER 1: DEVELOPMENT AND APPLICATION OF A SOCIO-ECOLOGICAL SYSTEMS FRAMEWORK FOR ESTUARY RESTORATION

Restoration is the process of assisting the recovery of an ecosystem that has been damaged, degraded, or destroyed. Restoration occurs along a continuum (Figure 1), and ranges from reducing impacts to remediation, rehabilitation, and ecological restoration. Nine principles have been identified for ecosystem restoration by the Society for Ecological Restoration (https://www.ser.org/; Figure 2); all of these are applicable to estuary restoration in South Africa. Rehabilitation relates to the repairing of ecosystem function and initiating native recovery whereas restoration would refer to a recovering natural ecosystem (Figure 2).

This research was aligned with the UN Decade of Ecosystem Restoration that runs from 2021 through 2030, which is also the deadline for the Sustainable Development Goals and the timeline scientists have identified as the last chance to alleviate catastrophic climate change. Ecosystem restoration will increase food and water security, contribute to climate change mitigation, alleviate the pressures of conflict and migration, and slow further loss of species. "Nature-based Solutions are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits" (IUCN, 2016)

By restoring, conserving, and wisely using our wetlands, we can contribute towards achieving the Sustainable Development Goals (SDGs). For example, SDG 14.2 (Life below Water) states "*By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans*

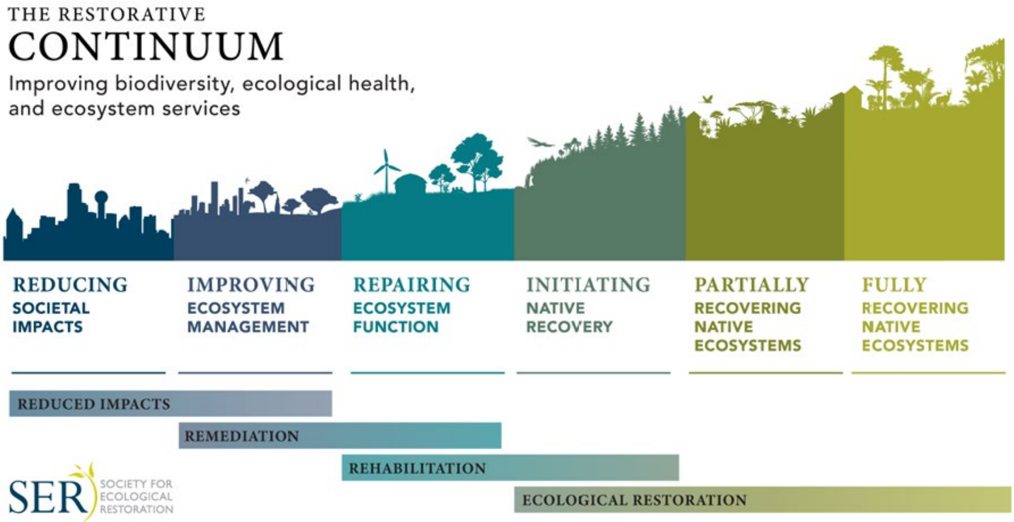
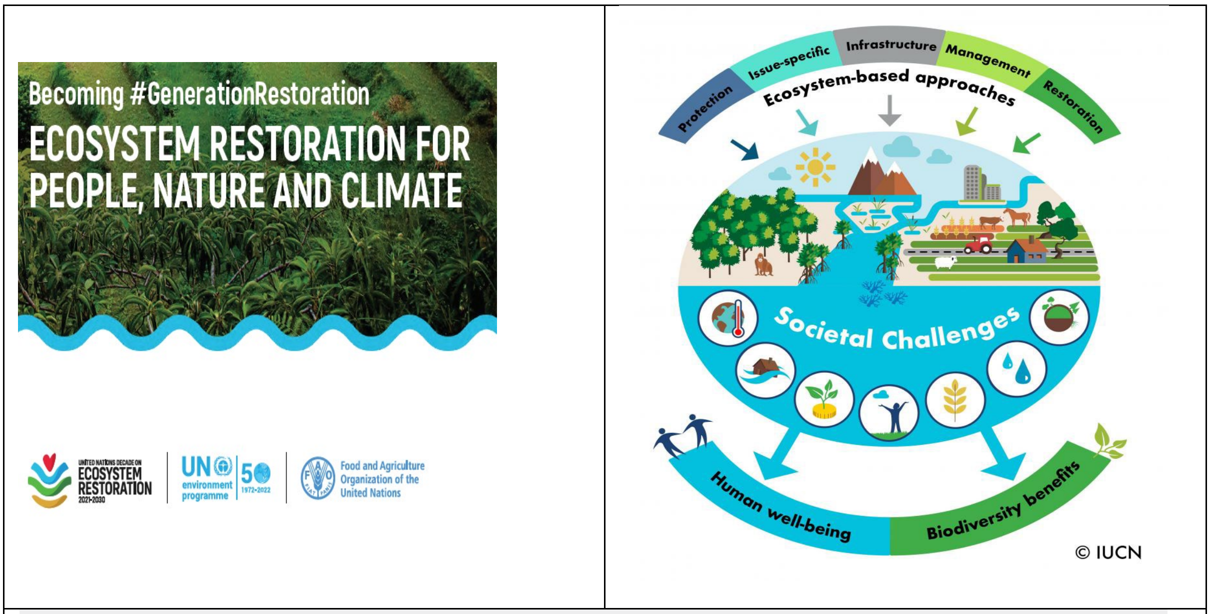


Figure 1: The Restorative Continuum as illustrated by the Society for Ecological Restoration (https://www.ser.org/).



Box 4.1 Guiding principles for the UN Decade on Ecosystem Restoration

Common principles are critical for a shared vision of ecosystem restoration. Towards this end, the FAO-led Task Force on Best Practices, the Society for Ecological Restoration, and IUCN's Commission on Ecosystem Management led an expert consultation process. Based on a synthesis of published principles for restorative activities, the process resulted in nine proposed principles that underpin ecosystem restoration throughout the UN Decade and across sectors, biomes and regions. The final wording and full descriptions of these principles will be developed collaboratively during 2021 to support effective restoration efforts around the world.

Ecosystem restoration:

PRINCIPLE 1	PRINCIPLE 2	PRINCIPLE 3
Promotes inclusive and participatory governance, social fairness and equity, from the start and throughout the process and outcomes.	Includes a continuum of restorative activities.	Aims to achieve the highest level of recovery possible for ecosystem health and human wellbeing.
PRINCIPLE 4	**PRINCIPLE 5**	**PRINCIPLE 6**
Addresses drivers of ecosystem degradation.	Incorporates all types of knowledge and promotes their exchange throughout the process.	Is tailored to the local context, while considering the larger landscape or seascape, and social-ecological and cultural settings.
PRINCIPLE 7	**PRINCIPLE 8**	**PRINCIPLE 9**
Is based on well-defined short- and long-term ecological and socioeconomic objectives and goals.	Plans and undertakes monitoring, evaluation, and adaptive management throughout the lifetime of the project or program.	Integrates policies and measures to ensure longevity, maintain funding and, where appropriate, enhance and scale up interventions.

Figure 2: Ecosystem approaches and the nine guiding principles for ecosystem restoration (https://www.ser.org/).

Restoration of estuaries and coastal wetlands in the Anthropocene needs to balance considerations of ecology, economy, and indigenous rights. These complex and interactive needs require adaptive management in the context of a changing climate, as sea level rise, changing precipitation patterns, and storm erosion compound with the consequences of increasing land use change and anthropogenic freshwater demands. Globally, many coastal wetlands are experiencing stress linked to freshwater supply due to low precipitation, freshwater diversion, or drought conditions. Estuaries are especially vulnerable to loss and degradation, as increasing coastal urbanisation and climate change are rapidly exacerbating freshwater supply stressors. These systems present unique management challenges, necessitating the development of novel restoration approaches and success metrics.

South African estuaries are at the interface of increasing human pressures and climate change. The country is experiencing an increase in the duration and frequency of droughts and devasting effects of large floods. There is an increase in sea level and sea storms causing loss of estuary habitat due to erosion. In terms of estuarine area, 78% is impacted by overfishing, 60% by artificial breaching, 40% by land use development, 34% experience severe pollution pressure, 15% are subject to severe flow modification, while alien or translocated fish occur in 35% of all estuaries (Van Niekerk et al. 2022).

The restoration of environmental flows is essential for maintaining the ecological health and socio-economic benefits of estuaries. Environmental flow requirement and classification studies of the Department of Water and Sanitation has prevented the issuing of further licenses in stressed catchments. There is a national deterioration in estuary water quality due to agricultural return flow, stormwater, and WWTW inputs (Adams et al., 2020). Failing or overloaded WWTW facilities result in raw sewage entering many aquatic ecosystems, often culminating in the increased occurrence of mass fish kills, HABs, and IAAPs.

There are only a few examples of restoration in South Africa. For example, at the Orange Estuary, part of the causeway / road located at the mouth was removed to re-instate tidal flow from the estuary into the desertified and salinised salt marsh area. Seeds were transported passively into this area and brackish salt marsh colonised the fresher area (Shaw et al. 2008, Bornman et al. 2010). At the Zandvlei Estuary, the City of Cape Town artificially breaches the estuary mouth to maintain water level and salinity conditions. Increased salinity and flushing of the estuary have prevented the occurrence of HABs (Lemley et al. 2019). Zandvlei is an example of an urban estuary that is managed as a novel ecosystem for the provision of certain ecosystem services, such as improved water quality and recreational use.

The National Estuary Management Protocol provides a blueprint for estuary management and restoration in South Africa (Figure 3). Clean water is crucial for human health, social, and cultural benefits. Water is considered polluted when it is no longer fit for the intended use and can have far-reaching impacts on, for example, the economy, recreational activities, and fishing sectors. An environment that is not harmful to health or well-being is a constitutional right for South Africans according to the Constitution of the Republic of South Africa (No. 108 of 1996). Furthermore, it is a constitutional right that the environment is protected by reasonable legislative and other methods which prevent pollution and ecological degradation for the benefit of both present and future generations.

Globally, legislation that addresses restoration of estuaries include the Clean Water Act and the Estuary Restoration Acts in the USA, and the Water Framework Directive and the Marine Strategy Framework Directive in the European Union. The economic impact of estuary and salt marsh degradation can be used as an incentive to protect and restore the resources they provide.

VISION: The estuaries of South Africa are managed in a sustainable way that benefits the current and future generations

- To conserve, manage & enhance sustainable economic & social use without compromising the ecological integrity & functioning of estuarine ecosystems;
- To maintain or restore ecological integrity of SA estuaries through ecological interactions between estuaries/estuaries & catchments/estuaries & other ecosystems;
- To manage estuaries co-operatively through all spheres of government; and to engage the private sector/ entities and civil society;
- To protect a representative sample of estuaries to meet biodiversity targets;
- To promote awareness, education & training;
- To minimise the potential detrimental impacts of predicted climate change.

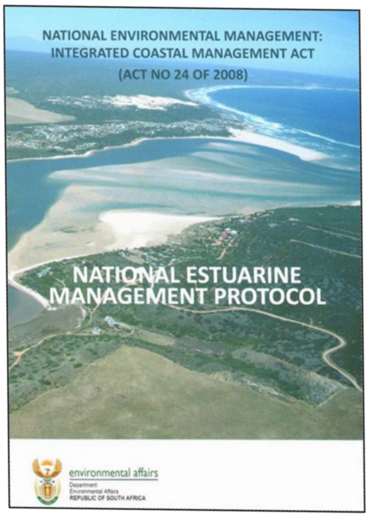


Figure 3: Objectives for estuary management as identified in the National Estuary Management Protocol.

Water pollution has diverse and far-reaching effects on the economy, impacting tourism, property values, fishing, recreation, businesses, and many other sectors. The water quality focus for this research was on nutrients, bacteria, and metals as this is where our expertise lies. Persistent phytoplankton blooms and nuisance macroalgal growth, associated with nutrient enrichment, have recently been described for a number of estuaries (e.g. Snow et al. 2000; Kotsedi et al. 2012; Kaselowski 2013; Nunes and Adams 2014; Human et al 2016; Lemley et al. 2017, Adams et al., 2020; Lemley et al. 2019; Lemley et al. 2021; Lemley et al. 2022a).

Looking towards the future it is evident that a socio-ecological systems (SES) approach, which obliges cooperation between all role players and data on a wide array of ecological processes, is desirable for South African estuaries. Scientific knowledge must be better integrated with the societal systems and show the links between ecosystem functioning and the well-being of humans so that it can guide meaningful and implementable management and restoration interventions. Knowledge exchange between scientists from different disciplines, decision makers, and stakeholders can then take place through a shared understanding of terms, such as 'sustainability' and 'ecosystem services' (Hossain et al. 2017). A SES approach is in line with the One World – One Health concept, which recognises that no-one lives in isolation, that the actions of one affect all, and that health security requires a global crosscutting perspective that integrates humans, ecosystem health, and biodiversity (Hristovski et al. 2010, Destoumieux-Garzon et al. 2018).

Existing socio-ecological systems were identified and critically assessed for the best approach for South African estuaries. A framework was developed as part of this study (Figure 5); a socio-ecological systems approach for the research, restoration, and management of estuaries and published in Adams et al. (2020b). This SES framework was "applied" to the Swartkops Estuary. The SES framework was based on Ostrom (2009), the millennium ecosystem assessment approach (MEA, 2005) and other available literature. This framework was composed of components from various international restoration frameworks. The key ecosystem services that need to be considered when setting restoration objectives for estuaries include fisheries and nursery habitats, carbon storage, erosion control and coastal protection, nutrient sequestration and cycling, habitat for invertebrates, and resting areas for migratory birds (Adams et al., 2021).

A SES approach will require adaptive capacity to cope with perturbations, a willingness to learn from mistakes, and to engage in collaborative decision making with a diversity of people and institutions. An understanding of the relationships between complex estuarine ecosystem functioning and ecosystem services is key because it provides the link between nature and human well-being. Estuary State can be measured using the Estuarine Health Index (Van Niekerk et al. 2013, 2019; Figure 5), whereas the State of the Social System can be measured through uses and vales that contribute towards Human Wellbeing (Figure 5). To facilitate SES in South Africa, Roux et al. (2020) have organised annual meetings to promote dialogue and the advancement of research and practices to address approaches to research and the interfaces between humans and nature.

Within the SES paradigm, restoration and estuary management take place in an adaptive management cycle where objectives are set, actions implemented and then monitored. Outcomes are analysed and objectives adapted, if necessary, in a learn-by-doing approach (Figure 4). The success of restoration interventions is measured against the restoration objectives (or targets), which should include ecosystem and social targets, and indicate the desired endpoint of a restoration project. Monitoring data are analysed and reported on to see if the restoration objectives have been achieved. The management actions and restoration objectives are adapted accordingly, and the learning captured and shared. As emphasised by the following statement, education and communication is key: "*If the science and technology underlying restoration are not understood by the general public, implementation will fail for lack of public support*" (Cairns 2000).

Figure 4: Implementing restoration in an adaptive management cycle.

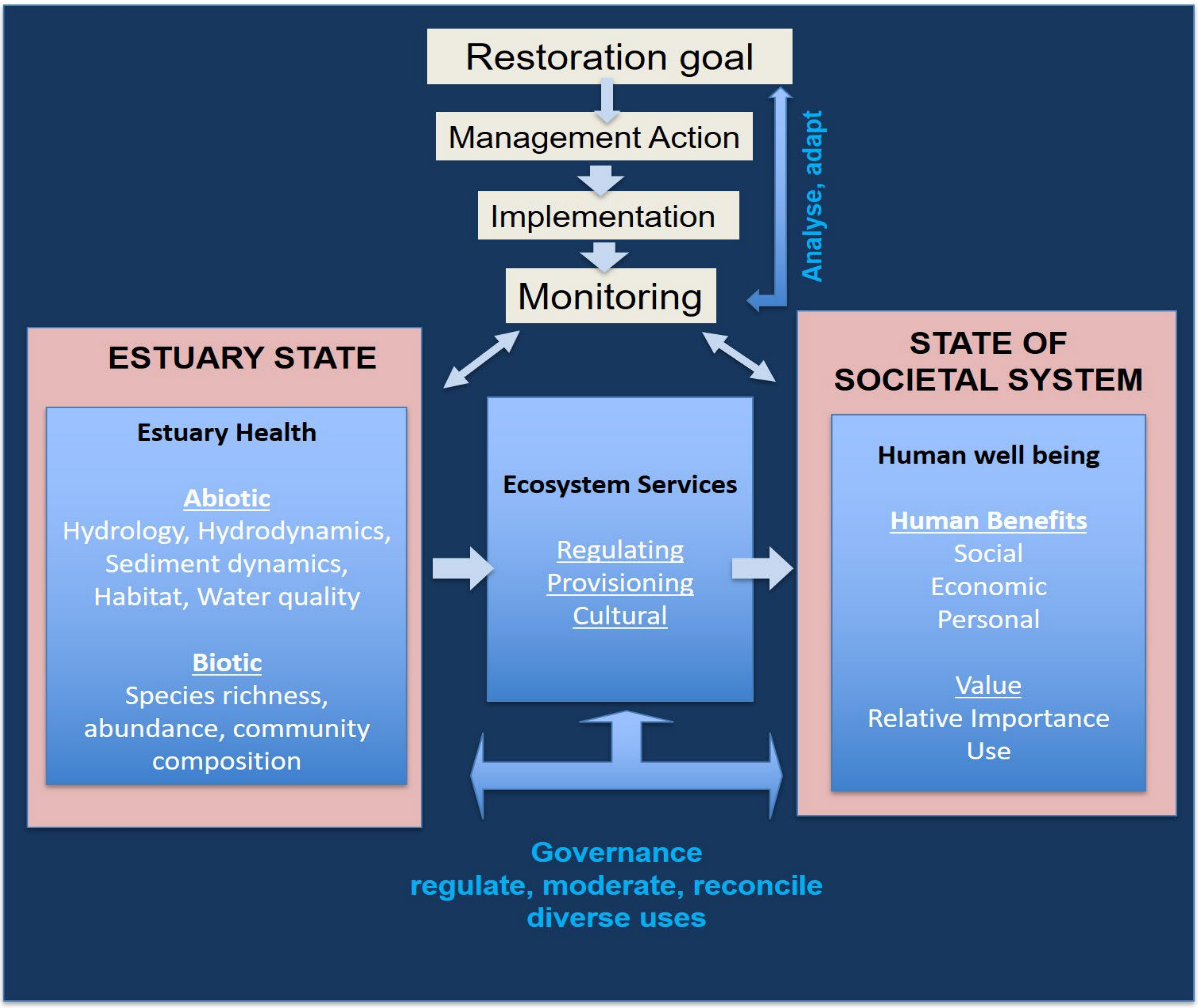


Figure 5: The socio-ecological systems framework for estuary restoration.

CHAPTER 2: APPLICATION OF A SOCIO-ECOLOGICAL SYSTEMS FRAMEWORK FOR RESTORATION OF THE SWARTKOPS ESTUARY

2.1 INTRODUCTION

The health of marine ecosystems is deteriorating globally due to anthropogenic activities (e.g. urbanisation, industrial, agricultural, sea level rise) (Van Niekerk et al., 2019). This is a concern as estuaries are ecologically important systems that support and maintain a diverse range of flora and fauna while also providing humans with a diverse range of services. Erosion control, habitat provision, water purification, climate regulation, and cultural benefits are among these services (Barbier et al., 2011).

South African estuaries are under severe pollution pressure and improving water quality as a primary intervention would result in considerable improvements in estuary health and the associated societal benefits (Adams et al., 2019). South Africa is rich in several types of estuaries due to the broad range of geological, climatic, and oceanographic factors. Some estuarine plant species and ecosystem types exist only in South Africa, with some species limited to a few estuaries (Van Niekerk et al., 2019). To limit further deterioration in health, fundamental changes in estuary management and restoration approaches are essential. Ecological restoration initiatives cover social, ecological, and economic elements of the environment, and they often include a diverse group of stakeholders (Adams et al., 2020a).

Recognising the importance of preserving or maintaining estuaries for long-term use has become crucial for managers and politicians who are progressively making challenging decisions related to population growth and urbanisation of coastal areas around them. Frameworks, theories, and models help researchers to structure concepts that expose key interdependencies (Nilsen et al., 2015).

The Swartkops Estuary is a warm temperate, predominantly open estuary in the Nelson Mandela Bay. It is considered one of South Africa's most ecologically important estuaries in terms of its size, habitats, and biodiversity (Turpie et al., 2002). The vision for the Swartkops Estuary as stated in the Estuary Management Plan is that the "*Swartkops Estuary and the Swartkops Valley and Aloes Nature Reserves are unique national assets that are rich in biodiversity and must be restored and protected to a level (Category B/C) that will attract visitors, uplift our spirits, sustain our livelihoods, and preserve our natural, cultural and recreational heritage".* However, the estuary is influenced by various anthropogenic pressures as it is proximal to heavily urbanised and industrialised areas of Nelson Mandela Bay. These pressures include wastewater and stormwater runoff, boating, baiting, and pollution (Adams, 2016).

There are three wastewater treatment works (KwaNobuhle, Kelvin Jones, and Despatch WWTWs) discharging upstream of the estuary and three stormwater canals (Chatty River, Motherwell and Markman) that drain directly into the estuarine functional zone , all of which cause excessive nutrient loading (Adams et al., 2019). This has resulted in a strong longitudinal nutrient gradient within the estuary – with higher concentrations observed upstream versus at the estuary mouth – and the middle to upper reaches of the estuary are in a persistently eutrophic condition, evidenced by HABs, IAAPs, oxygen depletion, and occasional fish kill events (Adams et al., 2019; Lemley et al. 2022a). Thus the estuary has a low present ecological status of D (highly degraded).

The increasing deterioration in estuary health highlights that there is a critical need for restoration measures to be implemented. Marine habitats are closely related to coastal human communities which reciprocally affect each other (Abelson et al., 2020). Therefore, restoration efforts in estuaries must consider the link between people and the coastal environment. The aim of this study was to develop a socio-ecological framework for the restoration of the Swartkops Estuary by testing the framework by Adams et al., (2020a). This is essential because it will aid the awareness, future analyses, and interpretations of the complex socio-ecological systems that exist in coastal and marine areas. Additionally, this will promote the importance of considering the three pillars of sustainability (i.e. social, environmental, and economic) as an approach to coastal management that is effective and sustainable because often the social aspect of sustainability is not given much attention, yet human communities play a significant role in the well-being of natural ecosystems. This addresses our understanding of the connectivity between land, water, people, preparedness for and responses to global change.

This research is relevant as the United Nations Decade of Ecosystem Restoration (2021-2030) provides an opportunity to highlight the efforts of Southern Africa to preserve and rewild estuaries, as it offers hope for conservation and securing important ecosystem services for people (Adams et al., 2020a).

The commitment emphasises the significance of developing capacity and cooperating, including exchanging experiences and best practices, to gain traction and scale up ecosystem restoration to meet the demands of a changing climate (Maher et al., 2021). A specific SES framework was developed for the Swartkops Estuary by updating the present ecological state of the estuary using the Estuarine Health Index (EHI), describing, and understanding the state of the societal system, identifying important ecosystem services that link societal and estuarine health and by identifying restoration goals, actions, and monitoring for the estuary. A step-by-step approach was used that can be implemented at other estuaries.

2.2 METHODS

2.2.1 Estuary health: Present Ecological State (PES) and the Estuarine Health Index (EHI)

The Present Ecological Status (PES) of the Swartkops Estuary was assessed using the Estuarine Health Index (EHI) with a group of specialists (Adams et al. 2021) in a workshop environment. The Present Ecological Status (PES) of the Swartkops Estuary, which is the measured state of the estuary, provides the point of departure for the development of any management objectives. The health assessment offers a description of the characteristics and functioning of all major abiotic and biotic aspects of the system and their relationships to one another, as well as flow- and non-flow related pressures and impacts on the system (Turpie et al., 2002). For the abiotic component, sections studied included hydrology, water quality, hydrodynamics, mouth condition, and physical habitat alteration. In terms of the biotic component, estuarine flora (microalgae and macrophytes) and fauna (invertebrates, fish, and birds) were assessed. For each of the components (abiotic and biotic), the change in condition is estimated as a percentage (0-100%) of the natural state. Scores are weighted (25% for each abiotic and 20% for each biotic component) and aggregated (50:50) to provide an overall score that reflects the present health of the system as a percentage of that under natural conditions (Van Niekerk et al., 2013).

For each biotic group, health is scored in terms of (a) species richness and (b) abundance and community composition. The EHI is an assessment that establishes the PES of an estuary using a simple scale of A (unmodified, natural) to F (extremely degraded). Assessment of the health of an estuary involves (a) estimating what the estuary was like in its natural condition (the Reference condition) in terms of physical/biological characteristics and processes, (b) scoring the present condition relative to this estimated Reference state using the Estuary Health Index (score out of 100), and (c) converting the score to its Present Ecological Status category (Turpie et al., 2012). To inform an assessment of the estuary's PES, a literature evaluation of all recent research was undertaken for the Swartkops Estuary. In addition to the literature review, existing datasets were evaluated to detect any changes over time. Literature and data on both biotic and abiotic components were analysed and used in this study.

2.2.2 Ecosystem Services

Ecosystem Services (ES) were described for the Swartkops Estuary as defined by the Millennium Ecosystem Assessment using available literature and expert knowledge. Ecosystem services were assessed according to their impact on human benefits and well-being. The effect of different future scenarios on ecosystem services were described. The approach described by Valesini et al. (2019) was used to illustrate environmental change, estuary response, and socio-economic change in the Swartkops Estuary. This is important because to begin to understand the future of this complex socio-ecological system, it is necessary to understand its past development (Valesini et al., 2019). Ecosystem Services of the Swartkops Estuary were identified with their associated benefits and human well-being (Table 4). Fortunately, there is a lot of available information for the Swartkops Estuary in terms of ecosystem services. In an ecosystem where there is limited data, ecosystems services provided by the estuary can be investigated through field observations and qualitative collection of data from estuary users and nearby residents.

2.2.3 Human well-being: the state of the societal system

The constituents of well-being were described according to the Millennium Ecosystem Assessment descriptors. Security, basic material for good life, health, good social relations, and freedom of choice and action were indicators used from MEA (2005). The relationship between ecosystem services and human wellbeing is critical for the sustainable future of ecosystems and human systems alike. To identify the state of the societal system, the ecosystem approach described by Millennium Ecosystem Assessment was applied. The Ecosystem Approach is a method for integrated land, water, and living resource management that promotes equitable conservation and sustainable use. The method is based on the use of appropriate scientific methodologies focused on biological organisational levels, which include the essential structure, processes, functions, and interactions between organisms and their surroundings (MEA, 2005). Input on the state of the societal system was obtained from available literature and Hartmann's (2021) study that aimed to co-develop a novel, transformative management system with stakeholders through action research. Participatory Rural Appraisal (PRA) principles were applied as part of the action research through a mixed method approach using both qualitative and quantitative research methods.

The constituents of well-being were rated on a 'Good', 'Fair', and 'Poor' basis using available information. 'Good' indicated little threat to well-being, 'Fair' indicated some threat, and 'Poor' indicated a major threat to wellbeing. In the case of the Swartkops Estuary, there was data available for analysis. However, in an estuary where there is limited data, an understanding of the constituents of well-being can be sourced using qualitative and quantitative data from estuary users, residents near the estuary, relevant government officials, and any other relevant stakeholders.

2.2.4 Restoration activities for the estuary

Restoration goals focused on two main components: improvement of water quality and restoration of estuary habitat including the salt marshes. Alternative innovative methods for water quality improvements were also investigated from existing literature and recommendations were made for the Swartkops Estuary. The historic disturbances in salt marshes were identified from the past and present vegetation maps and other non-spatial records of area change. Areas denoted as "Developed" are those where natural land cover (e.g. salt marsh) has been completely removed and replaced with hard infrastructure. Areas classified as "Degraded" are those where revegetation or restoration to natural land cover is possible, i.e. grassed recreational areas that could be converted back to supratidal, or floodplain salt marsh given the correct environmental conditions. Sea-level rise would accelerate this process in some systems, particularly if physical processes and substrates are largely still intact.

2.2.5 SES restoration framework for Swartkops Estuary

A critical assessment was completed of all restoration activities in South African estuaries, including international practices. This entailed reviewing existing socio-ecological systems and applying recommendations from the literature regarding restoration of estuaries. This study adapted the framework for a socio-ecological systems approach for the research, restoration, and management of estuaries proposed by Adams et al. (2020b). This SES framework was applied to the Swartkops Estuary. In addition, environmental and socio-economic change were linked using the Valesini et al. (2019) framework.

2.3 RESULTS AND DISCUSSION

2.3.1 Ecological Health of the Swartkops Estuary

The current EHI score for the Swartkops Estuary in its present state is 47, i.e. 47 % similar to natural condition (Table 1). This converts into a Present Ecological Status of D which indicated that the estuary is largely modified. The health score has declined from 53 to 47 since it was previously assessed in 2014 (Van Niekerk et al., 2014). There is a persistent input of nutrient rich freshwater from three upstream WWTWs that has caused a loss in the marine state in the estuary due to an increase in baseflow. This has led to an increase in eutrophication and deterioration in health of macrophytes due to extensive mats of IAAPs that are fast growing because of high nutrient input (Table 1). Bait collection and overfishing are major pressures in the estuary. There has been a decline in birds due to the drying of the salt pans. Estuarine health under different future scenarios was assessed (Table 2) and indicated that there was a further decrease in EHI scores to 45 and 43 under Scenarios 1 and 2, respectively (worst-case scenarios), yet the estuary remained in a D category. Improvement in estuary health only occurs under Scenarios 3, 4, and 5, with the most notable improvement in Scenario 4, with an overall EHI score of 59 (Table 2).

2.3.2 Ecosystem Services for the Swartkops Estuary

Ecosystem services (ES) specific to the estuary were classified according to the Millennium Ecosystem Assessment (MEA). The provision of specific ecosystem services was identified for the different scenarios set out for the estuary. A summary of how the different scenarios will affect the provision of ecosystem services is provided (Tables 3 and 4). The worst-case scenarios (i.e. Scenarios 1 and 2) have lower ES value than the present state. Improving the water quality (Scenarios 3 and 4) provides the highest ES values and benefits. Nutrient cycling and phytoremediation as an ecosystem service were not considered as this is not sustainable. Larger bodies of water can assimilate nutrients but not constricted estuaries. For example, the ocean has some resilience to take up nutrients without having detrimental consequences. Threats to ecosystem service provision were summarised (Table 5). An understanding of these threats assists with prioritising restoration objectives.

2.3.3 Value of Estuary Ecosystem Services

A summary of the main environmental, estuary response, and socioeconomic changes in the Swartkops Estuary, from past to present, are shown in Figure 6. This figure serves to graphically illustrate some of the results from this research. This study has not provided a monetary value for ecosystem services; however, this is an important task that should be completed by a resource economist. Quantification of ecosystem services is expressed in monetary units derived from cost-benefit analyses and macroeconomic indicators. Turpie and Clark (2007) conducted an economic valuation of the ecosystem services provided by the Swartkops Estuary (Table 6), however, such an undertaking needs to be revised and applied to future restoration scenarios. Recommendations of other aspects that can be included in future evaluation are provided. Returns on investment in restoration are not immediate, but have a delay as the ecosystem re-establishes; this needs to be considered in valuation studies.

Table 1: Present Ecological State of the Swartkops Estuary assessed in this study (2021)

Variable	Weight	Score	Description
Hydrology	25	44	Increase in stormwater and WW inputs have increased baseflow to the estuary. Major floods are largely untransformed.
Hydrodynamics and mouth condition	25	56	There has been a complete loss of marine dominated conditions due to an increase in baseflow from WWTWs.
Water quality	25	46	Three WWTWs discharge just upstream of the estuary and additional polluted runoff also enters through Motherwell and Markman canal and Chatty River.
Physical habitat alteration	25	50	Land use change and disturbance have decreased physical habitat.
Habitat health score		**49**	
Microalgae	20	39	An increase in nutrients, stratification, and turbidity from reference conditions have decreased microalgal health.
Macrophytes	20	35	Macrophyte health has decreased due to an increase in salinity, invasive species, sedimentation and salt marsh disturbance.
Invertebrates	20	50	There has been a decrease in benthos abundance due to disturbance and harvesting.
Fish	20	40	Decline in abundance due to fishing pressure and overexploitation. Additional loss of abundance due to HABs, low oxygen and fish kills.
Birds	20	60	Disturbance and habitat modification have reduced the overall water bird abundance
Biotic health score		**45**	
ESTUARY HEALTH SCORE Mean (Habitat health, Biotic health)		**47**	
PRESENT ECOLOGICAL STATUS (PES)		**D**	
OVERALL CONFIDENCE		**M/H**	

Table 2: EHI score under present and future scenarios

Variable	Weight	Scenario					
		Present	**1**	**2**	**3**	**4**	**5**
Hydrology	25	44	33	42	50	54	45
Hydrodynamics and mouth condition	25	56	50	55	60	67	56
Water quality	25	46	45	44	60	70	46
Physical habitat alteration	25	50	50	50	50	50	60
Habitat health score	**50**	**49**	**45**	**48**	**55**	**60**	**50**

Variable	Weight	Scenario					
		Present	1	2	3	4	5
Microalgae	20	39	37	27	60	63	39
Macrophytes	20	35	35	33	37	39	45
Invertebrates	20	50	50	45	55	60	55
Fish	20	40	50	35	55	60	45
Birds	20	60	55	55	65	70	72
Biotic health score	**50**	**45**	**46**	**39**	**54**	**58**	**51**
ESTUARY HEALTH SCORE		**47**	**45**	**43**	**55**	**59**	**51**
ECOLOGICAL CATEGORY / PES		**D**	**D**	**D**	**D**	**C/D**	**D**

Table 3: Main changes in the estuary for future scenarios.

Scenarios	Description of changes
1. Climate change	Warmer conditions and an increase in floods cause a slight decline in estuary health (EHI score 45)
2. Increase in WW	A further decline in estuary health due to increased nutrients resulting in eutrophication (EHI score 43)
3. Decrease WW by 75%	Removal of 75% of wastewater input keeps the estuary in a Category D even though health improves (EHI score 55)
4. Decrease WW by 100%	Estuary health improves to a C/D (EHI score 59). Nutrient rich baseflow input is reduced improving eutrophic conditions, additionally reducing the occurrence of HABs and invasive species.
5. Habitat improvement	There would be improvement to a score of 51 following successful habitat restoration. Supratidal habitat would be restored and riparian zone improvement through removal of alien plants.

Table 4: Summary of change of Ecosystem Services for different scenarios for the Swartkops Estuary.

Ecosystem Services	Scenario responses
Bait collection	*Scenario 1* small reduction in ES due to flooding, *Scenario 2* loss due to HABs, *Scenario 3 & 4* some improvement in bait availability. Metal pollution influencing prawns and demand for this resource. *Scenario 5* restoration of banks and riparian habitat increase available habitat for bait.
Fishing	*Scenario 1* small reduction due to flooding. *Scenario 2* loss due to HABs and increase in freshwater alien invasive species, *Scenarios 3, 4, 5* some improvement. Fishing is influenced by pollution although people continue to fish despite this pressure. Lesions on fish from pollution can make this a less attractive resource. This ES does not track the fish EHI score as this also includes benthic fish species that are not targeted as a fishing resource. Many people still fish so as an ES the decline in the score due to pressures is not the same dramatic response as it is for the EHI fish abundance score. Intensive subsistence and recreational fishing still take place in the estuary. More effort is taking place though to catch a fish compared with the reference condition.

Ecosystem Services	Scenario responses
Fish nursery habitat	The proxy for this ES was considered as an average of fish health score and climate refugia score (abundance of the seagrass *Zostera capensis*). *In Scenario 1* flooding would provide cues for fish and increase upstream connectivity and food availability. HABs have an effect but only in the upper reaches.
Climate refugia	Vegetated habitats controlling ocean acidification; during upwelling events fish will use the estuary to escape temperature extremes. Seagrass bed extent was used to track this ES i.e. *Zostera capensis* cover. *Scenario 1 and 2,* reduction in seagrass cover due to smothering by IAAPs, *Scenarios 3 and 4* improvements. *Scenario 5* some restoration of banks will stabilise sediment, reduce turbidity, and improve seagrass cover. HABs upper estuary not available as a refugia. Shallow creeks and salt marsh habitats also important as a thermal refugia. Closest next large seagrass estuaries are Kromme, Bushmans and Kariega.
Carbon storage	Proxy score is macrophyte abundance and area cover. Improvements only in *Scenario 5.*
Flood regulation	Proxy score is EHI flood value. Most of the floods were similar to the present (85%).
Bank protection	Score proxy is intertidal area; >80 % of the banks are transformed. A decrease in *Scenario 1* due to intense flooding eroding the bank. Slight improvement in *Scenario 5* due to likelihood of increased vegetation.
Scenic views & vistas	Extent of development, building rubble, pathways, disturbance, alien vegetation all removes the property value of scenic views and vistas. *Scenario 1* increase in flood debris. *Scenario 2* eutrophic blooms, fish kills, smells, loss of aesthetic appeal. *Scenario 3 and 4* some improvement. Scenario 5 improvement through habitat restoration zone ~10%.
Cultural / Spiritual sites	*Scenario 1*, flooding and deepening of the estuary may improve water quality at Perseverance site. *Scenario 2* poses a health risk due to deterioration of water quality. People walk into the water but do not drink it. If there are IAAPs little available open water area for use. Aesthetics and health of people is relevant. *Scenarios 3 & 4* improvements. *Scenario 5* little effect.
Recreation	Contact and non-contact. People want access, aesthetics are important. For contact recreation, water quality is the main driver and therefore improvements only seen in *Scenarios 3 and 4*. For non-contact, improvements in *Scenarios 3 and 4* due to improvement of water quality. Very low scores for the contact recreation based on the assumptions of high *E. coli* levels from stormwater and wastewater inputs. Microalgae abundance is used as a proxy score. However, it should be noted that the dilution effect would be different to that of nutrients. Zones are influenced by diffuse sources that provide inputs above the recreational limits for bacterial counts. A separate study is needed to assess this.
Bird watching	*Scenario 5* significant improvement due to rewetting of salt pan. *Scenario 3 and 4* slight improvements due to enhanced water quality and increased likelihood of marine-dominated state. External factor is safety due to theft, this has decreased the value of this ES, a loss of 10%. The proxy for this

Ecosystem Services	Scenario responses
	score is community composition as bird watchers are attracted by unusual species.

Table 5: Major threats to Ecosystem Services of the Swartkops Estuary

Ecosystem Service	Threat	Reference
Provisioning services		
Food (fishes)	Overfishing	Nel 2014; Adams & Riddin 2020
	Heavy metal contamination	Nel et al. 2015
Bait collection	Overharvesting	Fielding 2014; Pretorius 2015; Adams & Riddin 2020
Supporting services		
Nursery habitat	Lack of protection/restriction	Nel et al. 2018
	Climate change	Adams 2020
	Alien species invasion	Adams et al., 2019b
Regulating services		
Carbon storage	Habitat development	Adams et al., 2019a
Cultural services		
Spiritual	Water quality deterioration	Pretorius 2015; Adams and Riddin 2020
Recreational	Water quality deterioration	Pretorius 2015; Adams and Riddin 2020

Table 6: Available (Turpie and Clark, 2007) and some suggested future economic value estimates (shaded) for the Swartkops Estuary.

Type of value	Value provided by the estuary
Subsistence	Ranked 1st amongst temperate systems; value of R808 953 per annum
Property	Ranked 19th amongst temperate systems in terms of property value related to estuaries with a value of R155 million
Tourism	Ranked 7th amongst temperate systems in terms of tourism value attributed to estuaries with a value of R50 million per year.
Nursery for fish	Ranked 5th amongst temperate systems; value of R32.8 million per annum
Existence	Does not rank amongst the top 40 temperate estuaries. This is the value of simply knowing that an estuary and its biodiversity are protected.
Future considerations : Carbon storage, Fishing, Bird watching, Medicinal plant harvesting	

2.3.4 State of the Societal System

The state of the societal system at the Swartkops Estuary were classified as either Good, Fair, or Poor based on available information (Table 7).

Table 7: Summary of the state of the societal system at the Swartkops Estuary.

Constituents of well-being	Rating	Description
Security	Poor	Crime in the area is a threat to human well-being. Property crime, violent crime and robberies are the leading crimes compromising the security of users and residents of the estuary.
Basic material for good life	Fair	The estuary assists in poverty alleviation through subsistence fishing and bait collection.
Human health	Poor	Poor water quality and persistent pollutants are a threat to human health.
Social relation	Fair	Littering by estuary users creates conflict with people living near the estuary. The deterioration in water quality has affected recreational activities.
Freedom of choice and action	Fair	Freedom of choice is curtailed by poverty, access to decision making, declining resources (e.g. fish and bait) and poor water quality. Lack of compliance monitoring at the estuary has led to people doing as they please and having no respect for the environment.

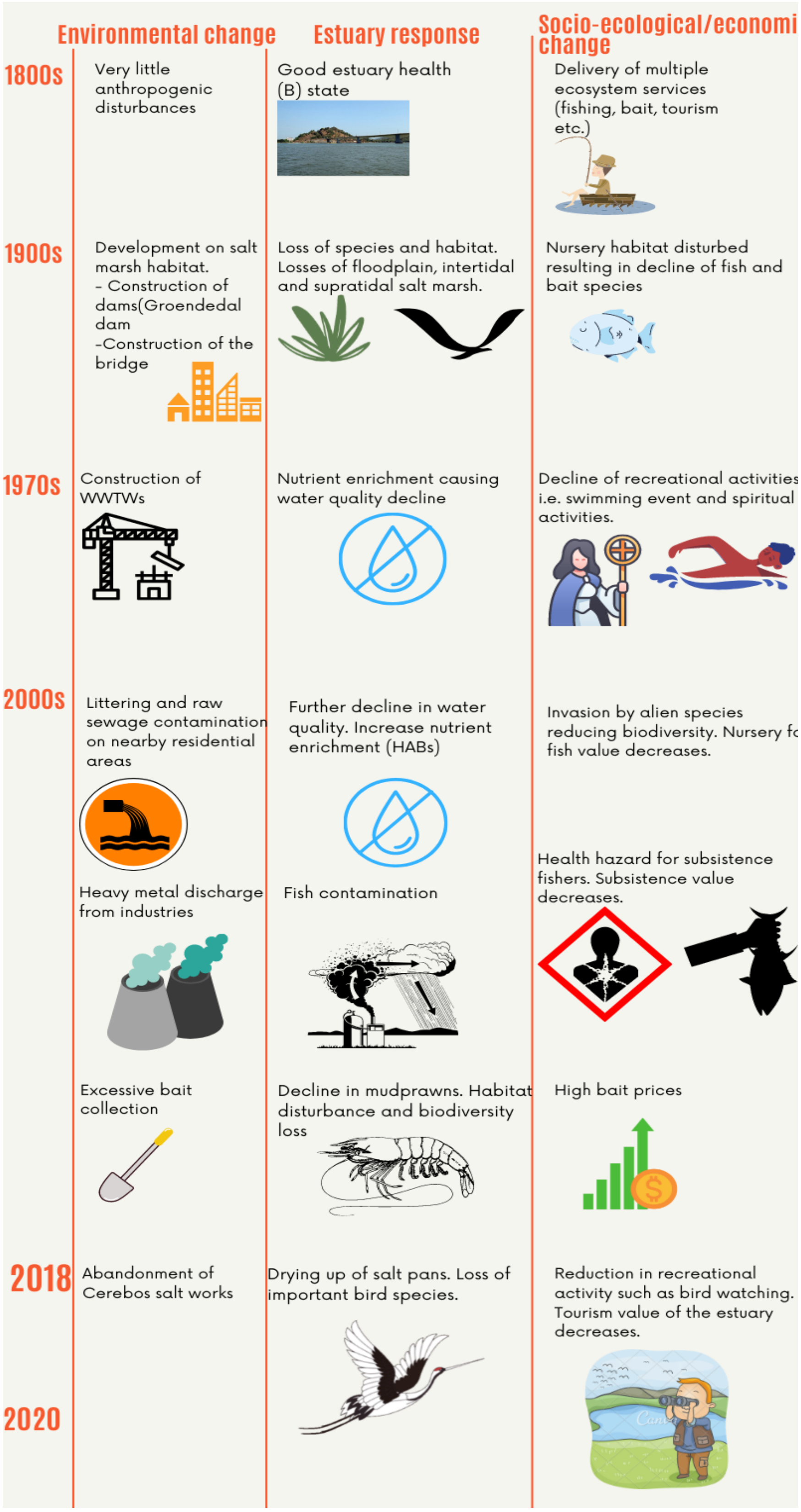


Figure 6: Summary of socio-economic changes in the Swartkops Estuary Currently in category "D" from category "A/B" in the 1800s (Compiled by V. Tsipa 2022).

2.3.4.1 Security

An assessment of security considers personal safety and secure resource access. Using a rating system of Good, Fair, and Poor in relation to the 'threat to human well-being,' security can be considered 'Poor' for the area (Table 7). In a study conducted by Masuku (2003), 10 of the 17 police stations in the metro experienced higher than average crime levels. In 2018, vandalism and theft led to the abandonment of the saltpan operation at the estuary where Cerebos used to conduct saltworks. Crime in the area is a threat to human well-being and recreational activities. Vehicle and truck thefts and the illegal trading in non-ferrous metal, have been declared priority crimes for the Swartkops police station area. Night-time bait collection has also increased crime in the area as the collectors become target of robberies.

From the observations done by the Zwartkops Conservancy, the Swartkops Village next to the estuary is said to be the crime hotspot in the area. That is where poachers and drug dealers are believed to stay. The two nature reserves have also become a hotspot for crime due to lack of restrictions on access. Thieves hide in the bushes and then rob fishermen and people walking in the reserves.

2.3.4.2 Basic material for a good life

Basic material for good life considers adequate livelihoods, sufficient nutritious food, shelter, and access to goods. This can be considered to be in a 'Fair' state for the Swartkops Estuary (Table 7). In a study by Magobiane (2011), the majority of participants were not satisfied by the municipality's effort in maintaining good water quality for recreational and commercial activities. This is a major concern as the respondents felt that the recreational activities provided by the estuary were extremely important. A substantial number of respondents appreciated the role of the estuary in poverty alleviation. Additionally, most outlined that it was important that those who were underprivileged were able to use the estuary for subsistence activities.

People living close to the estuary use the estuary differently. However, the most preferred use is bird watching and fishing (Hartmaan, 2021). Fishing activities are primarily done as a means of survival. Other than survival, users also visit the estuary for peace and calmness. Between 1992 and 1993, the Swartkops Estuary attracted an average of 148 fisherman per day on weekends and 46 on weekdays (Baird et al., 1996). The spotted grunter (*Pomadasys commersonnii*) was chosen by the majority of responders (77%) as the favourite species in the Swartkops and Sundays estuaries, followed by dusky kob (*Argyrosomus japonicus*). These fish species are good to eat and interesting to capture, hence explaining why they are preferred. This shows how popular recreational and subsistence angling is in the estuary. However, many fishermen choose to fish in the Sundays Estuary because of its comparatively clean surroundings, as compared to the highly urbanised and industrialised environment of the Swartkops Estuary (Baird et al., 1996). The vast number of subsistence fishermen in the Swartkops Estuary is a result of the large number of people who live along the river's banks and rely directly on the river for food.

2.3.4.3 Human health

Human health considers strength, feeling well, access to clean air and water. This is considered 'Poor' for the Swartkops Estuary as poor water quality and persistent pollutants are a threat to human well-being (Table 7). Odours from the surrounding WWTWs and industries are also strong. The Swartkops Estuary experiences heavy metal pollution due to anthropogenic and industrial activities nearby (Binning and Baird, 2001; Nel, 2014; Nel, 2020). Heavy metal contamination in fish species poses a health hazard for the subsistence fishers in the estuary. Mercury, chromium, vanadium, cobalt, and zinc were elements identified in Kelp Gull eggs and eggshells (van Aswegen et al., 2019). Some heavy metal concentrations found in the fish exceeded the food guidelines and may in turn pose a threat for subsistence users of the estuary (Nel, 2014). These were found in the liver, muscle, and fat of spotted grunter, dusky kob, and garrick (*Lichia amia*). These species are among the preferred species of fishers at the estuary.

In a study by Hartmann (2021), residents near the estuary revealed that children often get sores and skin rashes from swimming and playing in the estuary. In the Aloes community, which is situated next to the estuary, the Markman Canal carries industrial waste and sewage passes right in front of many houses. Just opposite the canal is the children's playground and church. Residents of the Aloes community cross through the canal when going to church and when the kids go to the playground. This is the shortest access route. There is no designated pathway to cross, and residents have put up stones to step on when crossing. This is a great health hazard as kids occasionally play in the water and when it overflows the smell enters their houses.

Residents depend on estuarine fauna as both a means of survival by selling bait and also as a source of protein by fishing. The main fishing spot used by the residents is just next to the outlet of the Markman Canal in the estuary. Despite all these living conditions, there is no health facility nearby for the residents, with the closest clinic being some distance away in Wells Estate. Children occasionally have intense rashes as a result of playing in the canal and some still have black marks. There is currently no sewage system in the community, and they make use of chemical toilets. Occasionally when the toilets are full, residents use the bucket system and dump their waste into the canal in front of their houses. The smoke from Algoa Bricks also gets intense and they need to close windows to breathe properly.

2.3.4.4 Social relations

Social relations consider social cohesion, mutual respect, and the ability to help others. This can be rated 'Fair' for the area (Table 7). Heavy industry, informal settlements, upper-middle-class residential neighbourhoods, a national highway, a railway, and multiple stormwater outlet pipes surround the estuary (Hasler and Munro 2007). The majority of residents in the area are Xhosa speaking, with some using Afrikaans and English as a native language (Schell, 2011). Bait collection is a key form of survival for the communities bordering the estuary with KwaZakhele being home for most of the bait collectors (Zungu, 2008; Schell, 2011). Most bait collectors are unskilled, and as a result, 75% of the collectors are dependent on the income generated from selling bait (Kariem, 2005). Subsistence collectors were not allowed to collect in the estuary during the Apartheid regime. It was only after the implementation of the Marine Living Resource Act (No. 18 of 1998) that subsistence bait collectors were formally recognised. However, this was subject to permit conditions.

The Swartkops small scale fishery struggles with complying to laws and regulations governing the fishery. Hauck (2009) argues that the non-compliance is caused by behaviour and attitude. The laws regulating the fishery have mainly been from the economic perspective, often neglecting the fishers' social aspect of the system. This oversight explains some of the non-compliance behaviour of fishers (Hauck, 2009). Fishers and other stakeholders complain of lack of involvement in the management of the fishery. This causes increasing conflict between the compliance staff and the subsistence fishers (Schell, 2011).

The deterioration in water quality has affected recreational activities in the area. For example, the Redhouse River Mile swimming event was moved to the Sundays River due to the high faecal coliform bacteria counts in the water. Traditionally an important site for baptisms in the Zion Christian Church and for traditional healers to perform cleansing ceremonies, the water quality at Swartkops Estuary is now too poor for recreational purposes although these ceremonies continue (Pretorius, 2015; Adams 2019). There is some conflict between residents of Amsterdamhoek and non-residents of the area. This is largely due to restrictions and restricted access in the area. Non-residents make use of the residents' private property (e.g. slipways and jetties). Residents cannot stop people from using their property because, according to the municipality, everyone has the right to the estuary despite residents having built the jetties and slipways. This is a problem for safety reasons and also pollution. The fishermen litter around the area and leave it for the owners to tidy up. To prevent access by perlemoen poachers, slipways have been chained.

2.3.4.5 Freedom of choice and action

In terms of freedom of choice and action, there are some obstacles to individuals being able to achieve what they value doing and being. This can be rated as ‘Fair’ as there is some threat to human well-being (Table 7). Freedom of choice is curtailed by poverty, access to decision making, declining resources (e.g. fish and bait), and poor water quality. The Swartkops Estuary lacks a physical boundary, such as a fence, and is therefore easily accessible. The nature of the surroundings makes it near impossible to exclude people. This leads to the estuary constantly faced with the risk of free-riders and opportunistic behaviours (Hartmann, 2021). Users of the estuary feel excluded in the decision-making processes involving the estuary, yet some use it as part of their livelihoods. The Swartkops Estuary is in the immediate proximity of Gqeberha (formerly Port Elizabeth) which makes it easily accessible to large numbers of people, especially over weekends and during holidays (Marais and Baird, 1980).

There is little compliance monitoring at the estuary which has led to people doing as they please and having no respect for the environment. The fishermen leave a lot of litter lying around which is then collected by the Zwartkops Conservancy. The reserves are also used as a source of firewood due to lack of compliance monitoring and enforcement.

2.3.4 Restoration activities for the Swartkops Estuary to improve delivery of ecosystem services

In this study, restoration activities were considered for the Swartkops Estuary and are summarised in Tables 8 and 9. Priority actions are identified (Table 8), as well as specific activities (Table 9) for each component of the Estuary Health Index. Management actions, associated legislation, and an assessment on the extent to which the legislation is applied is provided in Table 10. ‘Good’ implies some implementation, ‘Fair’ little implementation, and ‘Poor’ little to no implementation. Restoration activities considered for the Swartkops Estuary were also informed by the estuary management plan and these are summarised in Table 11. Further detail is provided on two main activities: (1) water quality and (2) habitat improvement.

Table 8: Priority actions to improve estuary health (increase Ecological Category from a D to C).

Action	Approach
Remove wastewater input to the estuary from the river	Recycle, artificial wetlands
Add water to the Redhouse salt pan	From Motherwell canal & estuary
Restore riparian habitat through removal of alien plants	In middle & upper estuary reaches
Reduce fishing pressure	Compliance monitoring & protected areas
Reduce bait collection	

Table 9: Detailed restoration actions to improve estuary health (increase Ecological Category from a D to C).

Variable	Restoration activity
Hydrology	Remove nutrient rich baseflow that enters the estuary from WWTWs through recycling and reuse. Install a flow gauge / low flow weir closer to the head of the estuary to better quantify freshwater inflow. Reduce stormwater input and polluted flows from Motherwell, Markman canals and Chatty River.
Water quality / microalgae	Remove nutrient rich baseflow that enters the estuary from WWTWs and restore hydrodynamic variability and the marine dominant state. Improve water quality by preventing inputs of urban run-off, raw sewage and increased stormwater input. This would reduce nutrient, toxin and bacterial inputs. Reduced nutrient input would prevent HABs and general eutrophication indicated by water hyacinth and other invasive floating macrophyte abundant in the upper estuary reaches. Other activities outlined in management plan.
Physical habitat / macrophytes	Restore abandoned dry salt pan habitats to encourage the return of high bird numbers. Motherwell Canal water can be used to rewet the Redhouse pans. This would promote macrophyte growth in the bare saltpan areas.

Variable	Restoration activity
	Restore connectivity with the river by removal of rubble and invasive aquatic macrophytes once the water quality improves. Restore riparian vegetation where removed and disturbed. Remove alien invasive trees such as gums. Restore supratidal salt marsh lost due to development and disturbance (556 ha). Target salt marsh areas for restoration for blue carbon storage for possible trading and climate change mitigation. This includes both the plants and sediment stocks and nationally important blue carbon registered salt marsh areas in urgent need of restoration.
Invertebrates	Control exploitation in terms of bait digging through protected areas. No spades to limit disturbance to seagrass. Prevent trampling of intertidal and supratidal salt marsh.
Fish	Introduce methods to prevent overfishing such as a night ban on fishing. Protected areas as indicated in the Estuary Management Plan, REI zone and Tippers Creek. Water quality and habitat restoration as indicated in Scenarios 3-5 will benefit fish. Implement the Marine Living Resources Act and compliance monitoring in terms of bag limits and closed seasons. There are opportunities for compliance training through FishFORCE Academy, Nelson Mandela University. Enhance larval and juvenile recruitment through habitat restoration and ecosystem engineering for concrete structures particularly in the lower reaches.
Birds	Restoration of habitat and food sources will increase abundance & diversity of birds.

Table 10: Management actions and associated legislation needed to ensure and maintain estuary health.

Restoration activity	Management action	Relevant legislation	Rating	Supporting evidence
Development and implementation of estuarine management plans.	Gazetting of the Estuary Management Plan	Integrated Coastal Management Act	Good	The EMP has been gazetted; next phase is implementation.
Determine the classes of water resources and the resource quality objectives.	Gazetting of Resource Quality Objectives	Requirement of the National Water Act	Poor	Implementation of Water Resource Quality Objectives for the estuary
Limit and reduce the volume of effluent from WWTWs into estuary.	Monitoring of WWTW and discharge licenses	National Water Act	Poor	Daily flow amounts exceed the daily capacity at the Kelvin Jones, Despatch and KwaNobuhle wastewater treatment works.

Enforce compliance legislation	Implement estuary management plan activities, employ law enforcement officers, control bait collection, promote catch and release, protect sensitive salt marsh areas through an improved zonation plan.	Integrated Coastal Management Act	Poor	No monitoring is being done at the estuary.
Continuous compliance monitoring	Implement a monitoring programme	ICM Act and Water Act	Fair	Water Affairs does some monitoring
Improve protection status				
Consideration of the Swartkops Estuary as a Ramsar site	Implement restoration activities and EMP activities.	Wetland of international importance as designated by the Ramsar Convention	Poor	No legally binding requirements in place.
Establishment of the estuary as a formally protected area.	Include Swartkops Estuary in the extension of the Algoa Bay Marine Protected Area	Biodiversity Act, Living Marine Resources Act (No 18 of 1998), National Water Act	Poor	Estuary not formally protected
Prohibit development of new infrastructure in low-lying areas.	Regulate all activities within 100 m of the high-water mark. Promote agricultural practices that avoid and minimise erosion	National Water Act 36 of 1998. Marine Living Resources Act	Poor	No regulation of activities occurs.

2.3.4.1 Improvement of estuary water quality

Methods for water quality improvement were recommended for the Swartkops Estuary (Table 11) as it is a major pressure that requires intervention. For each method recommended, there is an associated restoration goal, management action, and implementation plan. Restoration also needs to be supported by a detailed monitoring plan. Innovative methods proposed to improve water quality at the Swartkops Estuary include sustainable urban drainage systems (SuDS), algal ponds, artificial wetlands, and the use of saltpans as stormwater retention ponds. Detailed monitoring indicators and plans would need to be developed for each restoration goal.

Table 11: Summary of restoration activities to improve estuary water quality.

Water quality improvement method	**Restoration goal**	**Management Action**	**Implementation**
Sustainable Drainage Systems	Reduce urban inputs	Manage flow rates and treat pollution	Introduce stormwater treatment trains in hotspot areas
Algal Ponds	Treat municipal domestic wastewater effluent	Design or construction of an algal pond	Place the algal ponds in the outlets of the three WWTWs.
Artificial Wetlands and Biomimicry	To facilitate nutrient stripping and heavy metal uptake	Wetland maintenance including harvesting to remove nutrients and metals from the system.	Identify a suitable site with enough space next to a hotspot area (i.e. next to Markman Canal).
Salt pans as stormwater retention ponds	Treat urban stormwater and provide breeding grounds for various shorebird species	Regulation of the hydrological regime	Identifying sites to fill with water

Large quantities of stormwater runoff, and the management thereof, are a serious issue at the Swartkops Estuary. Sustainable urban drainage systems (SuDS) provide a means of addressing this issue as they are designed to control flow rates, reduce pollution, and improve water quality by managing runoff in proximity to where rainfall occurs (Kirby, 2005). SuDS recreate natural hydrological processes that have been lost as a result of urbanisation, impervious surfaces, and pipe-based drainage. These system components aid in flood mitigation by temporarily holding water, filtering pollutants at the source, and encouraging stormwater infiltration into the ground (Hoang and Ferner, 2016).

A stormwater treatment train, in line with those designed by Woods-Ballard et al., (2007), is being employed at the Markman Canal (Mmachaka, 2020). The train is designed to remove nutrients by sedimentation, biodegradation, precipitation, and denitrification, to name a few. Photolysis and ozonation are used to eliminate microbes, while biodegradation, photolysis, filtration, and adsorption are used to eliminate hydrocarbons. Metals are removed through sedimentation, adsorption, filtration, precipitation, and plant absorption mechanisms, whereas organic matter is removed through filtration, sedimentation, and biodegradation. In addition to the Markman Canal, other hotspot areas that could be considered for SuDS in the Swartkops Catchment include areas adjacent to the Kat Canal and Motherwell Canal.

The use of specific algae to treat urban domestic wastewater effluent offers a new way to improve the water quality effluent of current rural pond systems in Southern Africa (Oberholster et al., 2019). The reduction of nutrients from wastewater treatment plant (WWTP) effluents, particularly phosphorus, is critical for minimising eutrophication and improving water quality and reuse (Oberholster et al. 2013, 2019). The Council for Scientific and Industrial Research (CSIR) developed algae wastewater treatment technology that has been successful in both inland (Sekhukhune District Municipality, Limpopo) and coastal (Mossel Bay Local Municipality, Western Cape) regions of South Africa. This technology employs low-cost phyto-remediation techniques that do not require electricity or a qualified crew and remove nutrients from domestic wastewater using a consortium of algae that have been specifically bred to extract nutrients from the water column. Furthermore, algal biomass can be used as a biofuel, feedstock, or fertiliser for agriculture (Molazadeh et al., 2019). Considering that the Swartkops Estuary receives effluent input from three upstream WWTWs, exploration of this kind of treatment option might be worthwhile.

Urgent interventions are needed at the estuary to improve water quality. These are some of the techniques that can be employed in an attempt to improve water quality. However, further research and planning still need to be done to identify the method that would work best at the Swartkops Estuary.

Innovative methods for improving estuary water quality included the implementation of a treatment train at Markman Canal and studies on the use of abandoned salt pans for the treatment of stormwater run-off from the Motherwell Canal. Both of these are novel applications for estuaries in South Africa. Inputs were also made on how to optimise the functioning of the artificial wetland at Motherwell Canal. Results from this study can be used to inform restoration of estuaries and improvement of water quality at other sites (i.e. use of artificial wetlands, treatment trains, sustainable drainage systems).

2.3.4.2 Improvement of estuary habitat condition

The degraded salt marsh in Figure 8 below is some of the area available for restoration, i.e. improvement of estuary habitat. If 50% of the degraded salt pan could be restored back to salt marsh this would improve habitat extent by 314 ha. Similarly, if 50% of the disturbed salt marsh habitat could be restored this would increase salt marsh extent by 87.4 ha (Adams et al., 2021).

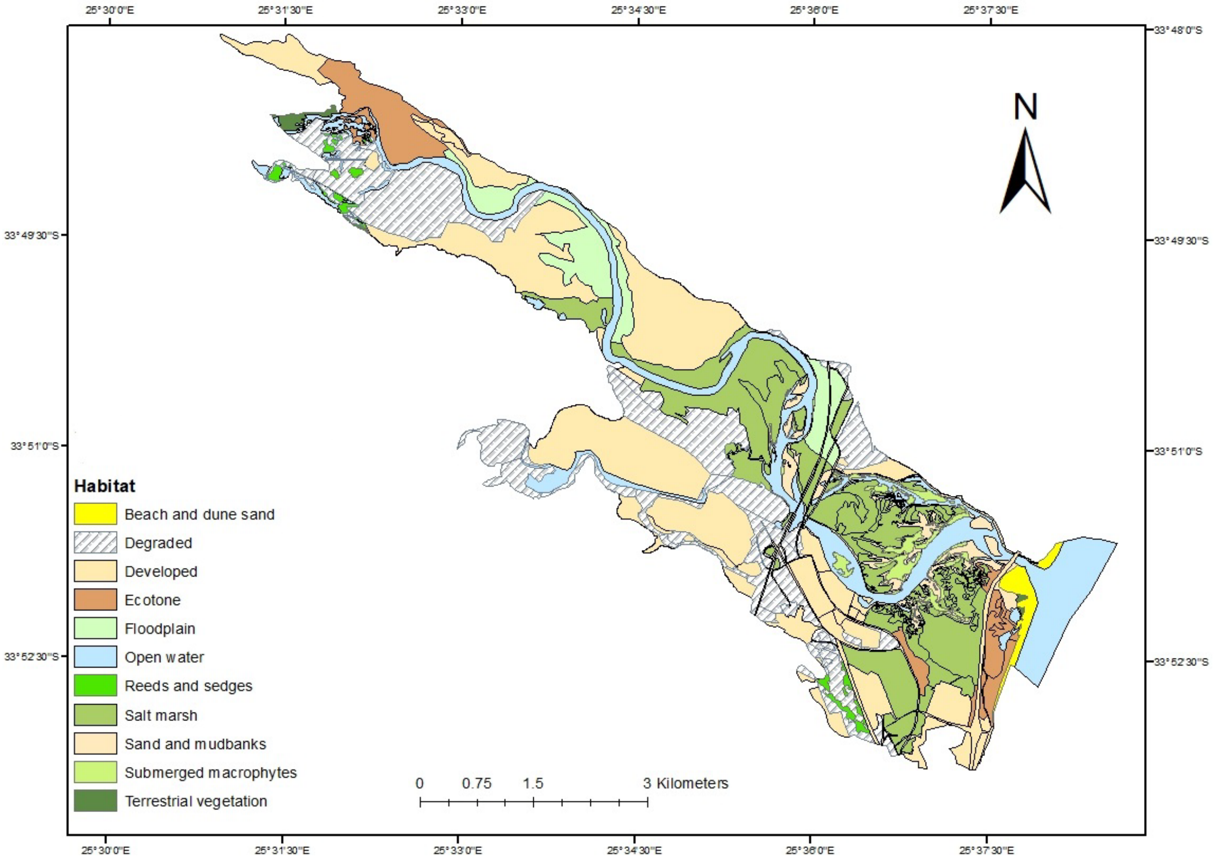


Figure 8: Areas available for salt marsh restoration at the Swartkops Estuary.

Restoration of habitat for carbon storage is important. Salt marsh restoration at the Swartkops Estuary can lead to sustained accumulation of carbon, in large part due to CO_2 uptake and carbon accumulation by salt marsh plants growing on saturated soils. Plant diversity increases soil organic carbon storage hence vegetated salt marshes are important (Chen et al., 2018). Other studies have found a similar trend (Fenstermacher et al., 2016; Byun et al., 2019) of undisturbed vegetated salt marsh habitats capturing more carbon than the disturbed unvegetated salt marsh. However, many of the disturbed sites at the Swartkops Estuary are currently not suitable for salt marsh growth due to hypersalinity (Tsipa 2022).

2.3.4.3 Rehabilitation of salt pans

The Motherwell Canal drains the large Motherwell development area. A network of 14 stormwater drains transport litter, debris and frequently raw sewage. The canal enters the middle reaches of Swartkops Estuary (Figure 9) and dispenses a daily volume of water equivalent to a medium sized wastewater treatment works. The canal is a major source of nitrogen (ammonium), trace metals and faecal bacteria and contaminates the middle reaches of the estuary. There is a small experimental wetland that 90% of the water is diverted through before reaching the estuary but the small wetland cannot cope with the load. Motherwell Canal water was therefore diverted to the nearby abandoned salt works. This provided an opportunity to restore waterbird habitat and improve water quality at relatively low cost. This would also provide societal benefits as people use the estuary for cultural activities such as cleansing ceremonies and baptisms. Water quality deterioration poses a risk to human health and thus any improvement would provide a safer environment for these activities. Multiple ecosystem services were restored through a single action and this restoration case study can be presented in a socio-ecological systems framework (Figure 10).

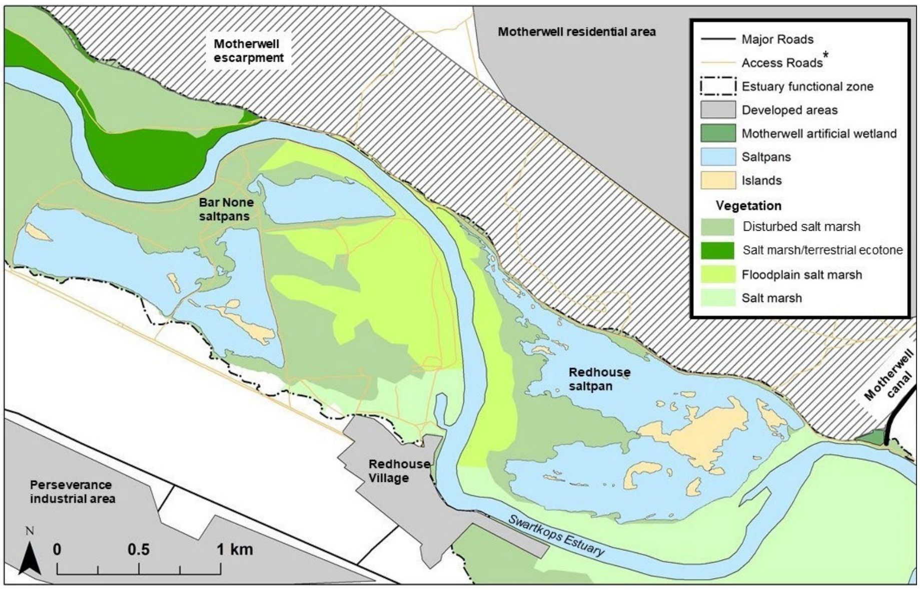


Figure 9: Map of the abandoned salt pans at the Swartkops Estuary with associated degraded salt marsh (Adapted from Wasserman 2021)

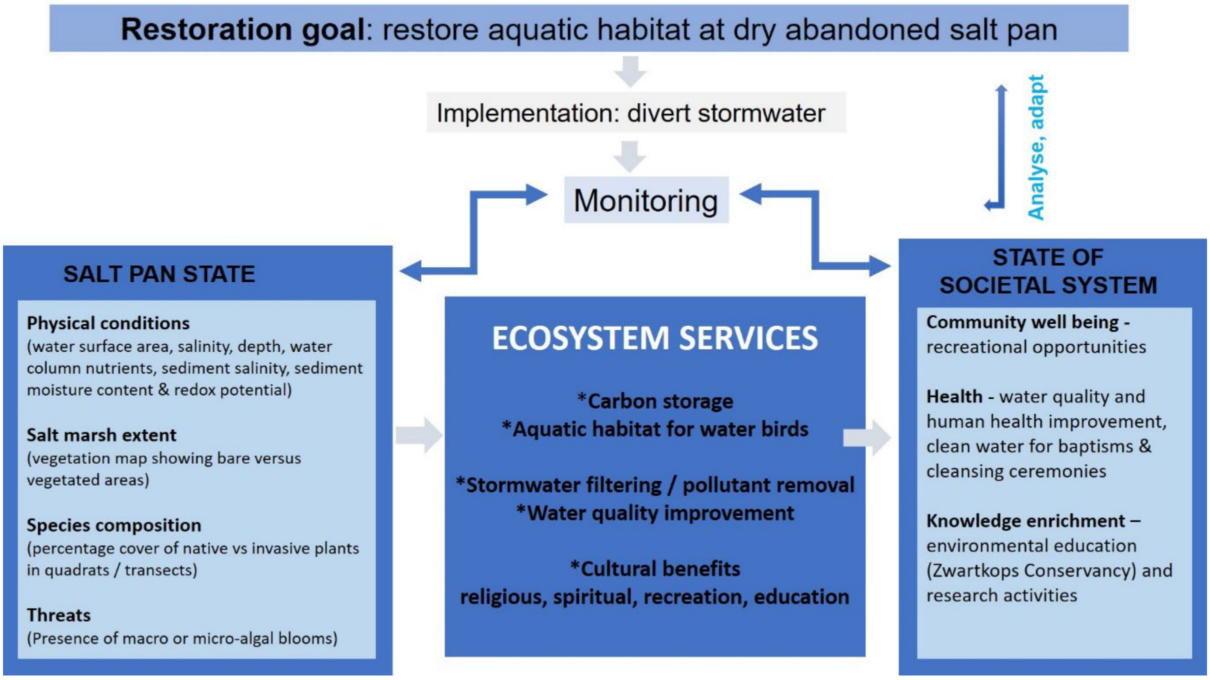


Figure 10: Restoration of the salt pans represented in a socio-ecological systems framework.

The saltpans were abandoned by Cerebos in 2018 due to the high cost of security to prevent vandalism and theft of pumps. The saltpans were left to dry and thousands of waterbirds usually found there disappeared. While operational, the saltworks was an important component of the Swartkops Estuary-Redhouse and Chatty Salt Pans Important Bird and Biodiversity Area (IBA). Because of proximity to the Motherwell Canal water was diverted to the Redhouse saltpan (33°50'10"S 25°35'E) situated on the northern bank, in the middle reaches of the estuary (Figure 9). At approximately 98.6 ha in size, the Redhouse saltpan was the primary evaporation pan during saltpan production; water was pumped into the Redhouse saltpan from the Swartkops River at the pumphouse. Islands at Redhouse have previously been considered as the most important mainland breeding site in the Eastern Cape for Caspian terns and kelp gulls. Previously, aquatic vegetation that were present within the saltpan were the macrophytes *Enteromorpha* spp. and *Ruppia spiralis* (Martin and Randall 1987). These plants grew again when the salt pans were rewetted.

The Bar None saltpans (33°49'16"S 25°33'42"E) lie on the southern bank of the estuary and comprise three saltpans: upstream, downstream, and river pan each sized at 33.2 ha, 21.9 ha and 14.7 ha respectively (69.8 ha total) (Wasserman 2021). When the salt pans were operational water was pumped from the Redhouse saltpan under the Swartkops River to the smaller pan of Bar None (Pan 3). The larger pans (Pan 1 and 2) were both consecutively gravity fed. Thereafter, water was pumped back to the Northern side of the river and up the escarpment to the final saltpan adjacent to Motherwell Canal where salt extraction occurred (P Martin pers. comm. 2022).

Wasserman (2021) investigated possible rehabilitation interventions in collaboration with the Zwartkops Conservancy (Figure 11). Restoring abandoned dry salt pan habitats is important to encourage the return of high bird numbers, promote salt marsh growth and blue carbon storage in the bare saltpan areas (Wasserman et al. 2022). The Redhouse saltpan was rewetted with freshwater from the nearby Motherwell Canal as of late October 2021 (Table 12). A manmade trench was dug to link the Motherwell Canal with the salt pan area. Monitoring of changes in the physico-chemical conditions of the salt pans started bi-weekly from 24 November 2021. The aim of recreating a wetland was targeted at the

Redhouse saltpan to restore its value as a waterbird habitat. Benjamin (2022) assessed the changes in waterbirds. Long term bird data was provided by Dr Paul Martin who has been monitoring the birds in the area for the past 30 years. Overall, waterbird abundance was highest during the active saltpan period whereafter abundance decreased after saltpan decommissioning. An increase in abundance was observed during the rewetted state. Rewetting of the Redhouse saltpan revealed higher waterbird abundance compared to the abandoned saltpans of Bar None. However future management should ensure that part of the Bar None saltpans remain dry to provide overall biodiversity and habitat diversity for birds. Diverse microhabitats with exposed muds and sandbanks for feeding are important. A heterogenous landscape could be achieved by creating a combination of islands that are either shallow or deep water, therefore, accommodating a more diverse waterbird community.

Summarised rehabilitation plan for the Swartkops Estuary salt pans (Wasserman, 2021).
The scope and current condition of the abandoned saltworks, the vision for the rehabilitated site, and the implementation and monitoring measures necessary to achieve the vision.
Study site: An abandoned saltworks at Swartkops Estuary (Eastern Cape, South Africa) comprised of four saltpans covering a total area of 163 ha.

Conditions in 2021: Since the pumping of estuary water into the saltworks has ceased in 2018, the area has been left dry. The site is now characterised by vast expanses of hypersaline sediment with sparse patches of halophytic vegetation and hypersaline pools that occasionally form after rainfall. The once abundant and diverse birdlife of the site has all but disappeared.

Vision: The creation of four wetlands at the Redhouse and Bar None saltpans with a salinity gradient ranging from brackish to marine conditions. The wetlands will provide a regionally important mainland breeding ground for various shorebird species throughout most of the year and provide a foraging habitat for Palearctic migrant waterbirds over summer. Additionally, the Redhouse saltpan will be transformed into an extension of the Motherwell artificial wetland in order to effectively treat urban stormwater that is currently impacting water quality in the nationally important Swartkops Estuary.

Ecological targets

- Saltpans to host breeding waterbird colonies and Palearctic migrant species increasing over summer
- ≥ 80% of the saltpans' area inundated from February to October, decreasing to ≥ 60% from November to January to maximise habitat value for waterbirds
- Maintain a salinity gradient throughout the saltpans
- Presence of various primary producer functional groups (phytoplankton, microphytobenthos, submerged macrophytes and floating macroalgae)
- Absence of harmful algal blooms

Implementation of rehabilitation measures

Option 1: Fill the Redhouse and Bar None saltpans with estuary water; OR
Option 2: Redhouse saltpan filled with stormwater from the outlet of the Motherwell artificial wetland and the Bar None saltpans filled with estuary water.

Monitoring: Monitoring is to be carried out over three temporal scales.
Tier 1 : Monthly for the first year. Frequency in following years contingent on the findings of the first year, but minimum biannually.
Tier 2: Biannually – once in summer and once in winter.
Tier 3: Following any major storm events or reported sewage spills at the MWC for Redhouse saltpan only.

Figure 11: Summarised rehabilitation plan for the Swartkops Estuary salt pans (Wasserman 2021).

Table 12: Dates indicating changes in the operation of the Redhouse saltpans.

2018 – salt pans abandoned and dry out
September 2019 – dry hypersaline conditions as shown in Google Earth image

October 2021 – filled with water from Motherwell canal
July 2022 – high water level with filamentous green macroalgal growth as visible in GE image below.

October 2022: Motherwell Canal closed off, water evaporates to create habitat for birds and facilitate egg laying and breeding.
1 December 2022: Motherwell Canal reconnected to Redhouse salt pans due to low water level in pan, higher temperature and winds lead to rapid evaporation.

CHAPTER 3: A SOCIO-ECOLOGICAL SYSTEMS RESTORATION FRAMEWORK FOR THE RESTORATION OF THE SWARTKOPS ESTUARY

Following the application of the framework by Adams et al. (2020b), Figure 12 is the restoration framework for the Swartkops Estuary. From the proposed restoration goals (Table 9), feasible restoration actions need to be identified for the Swartkops Estuary. This can be done based on ease of implementation or available budget. These plans then need to be communicated with all the relevant stakeholders including community and estuary users. Implementation of restoration plans, in conjunction with the EMP, will lead to improved ecosystem service delivery and simultaneously improve societal health. Continuous monitoring and engagement with stakeholders are required throughout the restoration process. Steps to follow when implementing the framework are outlined in Figure 13, with associated methodology presented in brackets.

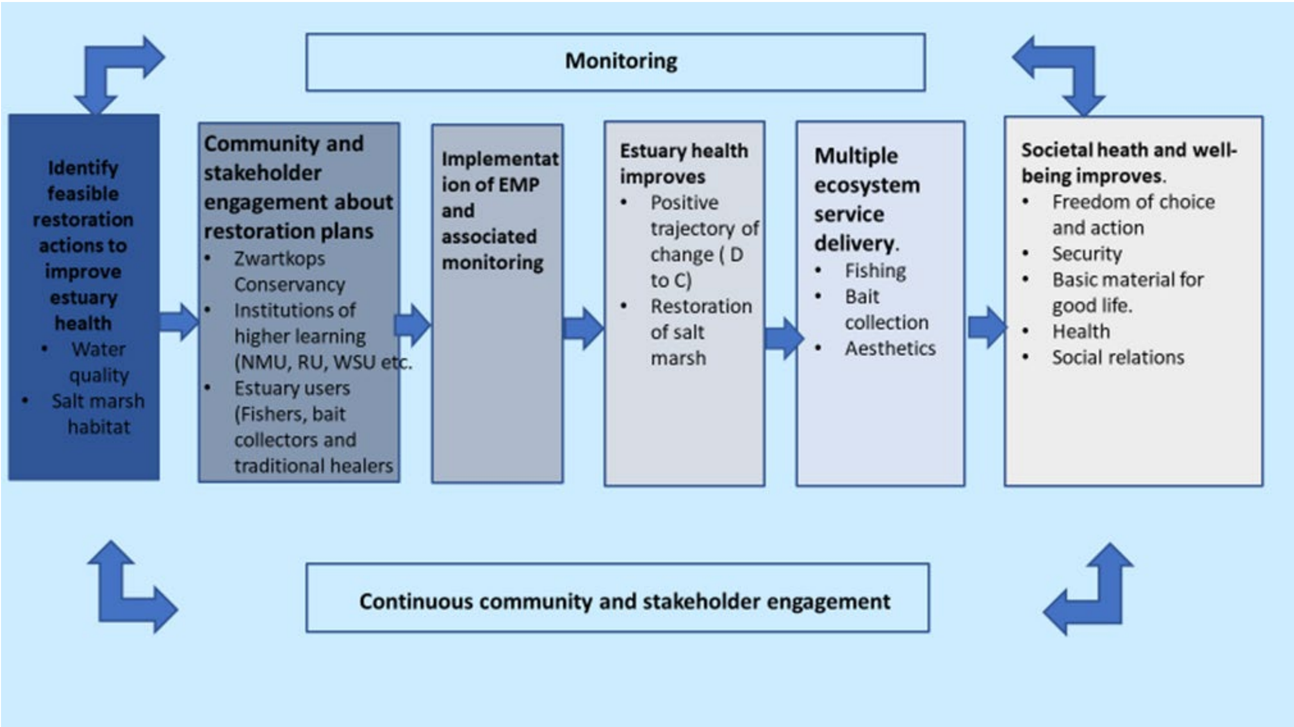


Figure 12: Proposed SES restoration framework for the restoration of the Swartkops Estuary to be implemented as part of the Estuary Management Plan by the metro and provincial government in collaboration with all stakeholders.

The restoration goal for Swartkops Estuary is to improve its Present Ecological State from a D (largely modified) to a C (moderately modified) estuary. Ideally, the Swartkops Estuary should be in the A or B category as it is rated as “Highly Important”, and it is a designated as a desired protected area in the Biodiversity Plan for the National Biodiversity Assessment. However, since the estuary is highly urbanised and subject to extensive anthropogenic pressures, an A or B category is not attainable (Turpie et al., 2012). It would be impossible to return the estuary to an A category due to the large loss of natural habitat stemming from significant urban development. Additionally, the disturbance of biota due to over-fishing, bait digging, and habitat destruction have all reduced ecosystem health (Adams et al., 2019b).

This goal is in line with the vision of the EMP for the Swartkops Estuary and Swartkops Valley and Aloes Nature Reserves which was set out as: *The Swartkops Estuary and the Swartkops Valley and Aloes Nature Reserves are unique national assets that are rich in biodiversity and must be restored and* *protected to a level (Category B/C) that will attract visitors, uplift our spirits, sustain our livelihoods, and preserve our natural, cultural and recreational heritage*.

The application of the proposed framework for the restoration of estuaries is aligned with various Sustainable Development Goals (e.g. SDGs 1, 2 and 11) as it has great potential for job creation. There is potential to create jobs for pollution monitors, waste recycling, artificial wetland installation, riparian zone maintenance, community workers, extension officers, environmental education officers, tourism guides, social and natural scientists, engineers, environmental consultants, and water quality managers.

The conservation of the Swartkops Estuary and its biodiversity is vital for the economic outputs and human welfare of current and future generations. Using a SES framework highlights the relationships between human and natural systems more clearly and openly, allowing us to develop better policy targets and indicators that meet the complex nature of ES supply (Reyers et al., 2013). As a result, employing a SES framework for the restoration of estuaries enables managers and policymakers to keep in mind that environmental management decisions have the potential to not only alter the ecological components of the system, but also the supply of ecosystem services, and, thus, the human benefits associated with them. As a result, by integrating biophysical factors to social elements and reflecting what people truly value, we might improve our ability to predict the complexity of ecosystem services (Pouso et al., 2018). Therefore, this will lead to improved ecosystem management and better policy design.

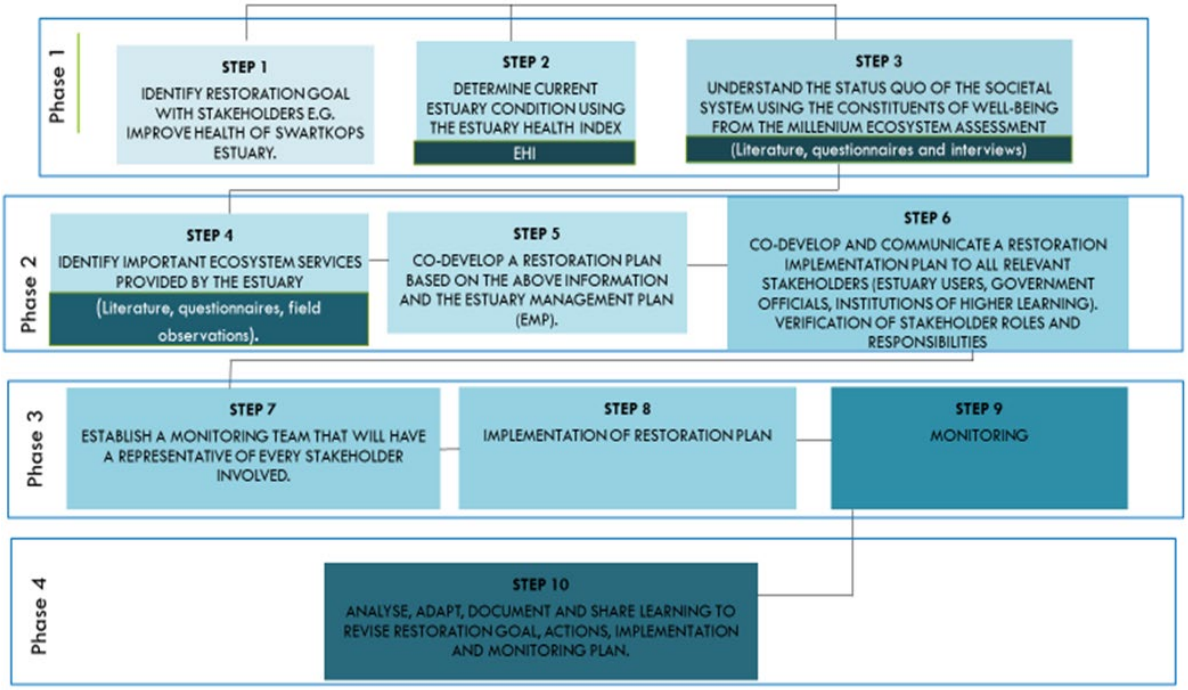


Figure 13: Steps to follow when implementing SES restoration at the Swartkops Estuary. Cost-benefit analysis also important to include as rehabilitation is resource intensive.

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

A socioecological systems approach is important for restoration, as it connects ecologists, society, government and practitioners. There is future scope for a living labs transdisciplinary research approach to analyse the ecological and social effects of restoration activities as they occur (Fischer et al., 2021; Adams et al., 2021). A socioecological systems framework was developed to connect the state of the ecosystem to the state of the societal system through ecosystem services. The key ecosystem services that need to be considered when setting restoration objectives for estuaries include fisheries and nursery habitats, carbon storage, erosion control and coastal protection, nutrient sequestration and cycling, habitat for invertebrates, and resting areas for migratory birds. Restoration takes place in an adaptive management cycle, where objectives are set, actions are implemented, and then monitored. Restoration outcomes are analysed, and objectives are adapted in a learning-by-doing approach. The success of restoration interventions is measured (using indicators) against S.M.A.R.T restoration objectives, which should include ecological and social targets.

Restoration of South African estuaries is urgent due to an increase in human and climate change pressures. For example, cities such as Cape Town and Gqeberha have come close to 'Day Zero' where there is no water. This is primarily due to prolonged drought conditions, yet consistent failure of infrastructure is a contributing factor that requires a large investment to improve the situation. Moreover, the accelerating frequency and magnitude of climate change consequences such as droughts and floods that act as a "double whammy" that creates shifting baselines for estuary management. Conservation efforts have not sufficiently protected estuaries and ecological restoration has become a necessity to preserve these ecosystems. Climate change impacts, such as sea-level rise and freshwater flow modification are driving habitat loss and coastal squeeze.

Salt marshes and the ecosystem services they provide are rapidly being lost globally. In parallel to this study on the Swartkops Estuary, a salt marsh restoration framework was outlined and seven estuaries in South Africa were recommended as high priority for salt marsh restoration (Adams et al. 2021). Specific restoration actions were identified based on the pressures known to occur at these estuaries and salt marsh sites. The next step would be to apply the SES restoration framework to the seven estuaries identified as priorities for salt marsh. This would link ecosystem functioning and the well-being of humans to guide meaningful and implementable management and restoration interventions. Recognising the economic value of salt marshes should accelerate restoration activities. For example, protecting salt marshes for carbon storage provides important opportunities for climate change mitigation (IPCC 2021; Adams et al., 2021).

Systems are in place to initiate an estuary restoration programme and track change. The Estuarine Health Index can be used to track improvement in estuary health in response to restoration interventions, which, can subsequently be linked to societal benefits through a socio-ecological system. Restoration must be considered as a complex socio-ecological system. Accordingly, adoption of a catchment-to-coast approach to estuary restoration is needed to reduce all pressures. Additionally, environmental flows for estuary restoration requires an integrated water resources management (IWRM) approach with an emphasis on cooperation, co-ordination, and commitment amongst all stakeholders. More specifically, the management of water resources should consider aspects such as water reuse, recycling, rainwater harvesting, and desalination. This process requires a circular economy approach that considers nature-based solutions that addresses the Green and Blue economy initiatives.

This study addressed some of these approaches by researching the use of abandoned salt pans for stormwater treatment, role of wetlands and use of SuDS.

The overall aim of this study was to develop a socio-ecological systems framework for restoration using the Swartkops Estuary as the case study. This involved understanding the estuary state which was assessed using the national Estuary Health Index and provided an updated Present Ecological Status assessment of the estuary. The state of the societal system was understood by using existing data, assessing estuary use, and engagement with the Zwartkops Conservancy. This is important because effective estuary management requires incorporation of scientific knowledge with an understanding of how these ecosystems influence the well-being of various people and groups in society.

The deteriorating health of the Swartkops Estuary as observed by past studies (Pretorius, 2015; Lemley et al., 2017 and Adams et al., 2019b), and also confirmed in this study, is of concern as most people use the estuary for survival. Poor management of the estuary has led to unsustainable use of the estuary's resources, threatening human health and livelihoods. The direct relationship between estuary health and ecosystem service provision in the Swartkops Estuary was highlighted in this study. Due to eutrophication numerous mass fish kills have been reported that negatively affects fishing activities and subsistence use. Also, the deteriorating water quality has led to church congregants carrying their own water for baptisms and some groups like the ZCC have relocated to another site for baptisms.

This study investigated possible innovative methods that can be used at the Swartkops Estuary for water quality improvement. The recommended restoration activities to improve water quality include Sustainable Urban Drainage Systems, Algal Ponds, Artificial Wetlands, Biomimicry, and Saltpans as stormwater retention ponds. Restoration of the salt pans through stormwater input from the Motherwell Canal showed that through a single restoration action multiple ecosystem services would be achieved. Application of the framework requires identifying the ecosystem services that have been lost or those that could be enhanced through holistic restoration. Ecosystem service provisioning also depends on ecological conditions that control habitat type and distribution.

The SES framework for the restoration of estuaries highlights that everyone has a role to play, and that positive results in estuary health will be seen when everyone participates. The collaboration among estuary users, government officials, NPOs and NGOs on the ground, and academics will facilitate the transfer of both knowledge and resources in addition to promoting complex problem-solving in policy and management. Local stakeholders can be crucial actors in the implementation of ecosystem-based mitigation and adaptation strategies. As a result, local populations' opinions and knowledge should be considered when establishing integrated planning processes to ensure effective implementation. Integrated managements strategies are needed to bring together often siloed management of estuaries, coasts and ocean together as an interconnected SES, from policy, to practice.

Socio-ecological frameworks are necessary for engaging stakeholders in decision making. This is important as participation of local communities ensures that social benefits are achieved. In South Africa, the Expanded Public Works Programmes have played an important role in freshwater wetland restoration in a way that has created jobs to reduce local unemployment, particularly in rural areas.

However, a new policy is urgently needed that addresses estuary restoration to coordinate efforts and link to existing programs. Effective SES restoration can only be carried out at national scales under suitable legislation and proper implementation. In the South African context, restoration at the national level directed at priority estuaries can be coordinated by the lead department mandated with estuary management (i.e. Department of Forestry, Fisheries and Environment). There are national projects (e.g. coastal clean-up/restoration through EPWP programmes) that can be useful for estuary restoration. This can be a precursor for a 'Working for Estuaries' programme, a similar programme to the existing Working for Wetlands programme but dedicated to estuaries. Actions to restore the Swartkops Estuary were identified in this study and should be implemented as soon as possible because restoration occurs over a continuum. Implementation of these restoration actions also has the potential to facilitate job creation, including pollution monitors, waste recycling, artificial wetland installation, riparian zone maintenance, community workers, extension officers, environmental education officers, tourism guides, social and natural scientists, engineers, environmental consultants, and water quality managers.

Climate change poses a threat to future restoration efforts. For example, salinisation and an increase in unvegetated salt marsh in response to reduced rainfall and freshwater input results in a loss of ecosystem services (Osland et al., 2014, 2016). The conservation, restoration, and long-term usage of blue carbon ecosystems can help mitigate climate change while also preserving many other benefits, such as fisheries support and coastal protection, which are vital for climate adaptation (Alongi et al., 2016). This is a perfect time to implement the proposed framework for the restoration of the Swartkops Estuary as the United Nations (UN) recently declared 2021 to 2030 the Decade on Ecosystem Restoration.

Restoration of environmental flows should also take place in a socio-ecological systems framework. For example, one of the ways in which environmental flows can be provided in through water releases from dams (Figure 14; Adams et al. in press). Hydrological connectivity is key to restoration of estuary habitats; whether this is connectivity to freshwater inflow or tidal flows as both are needed to maintain the salinity gradients in these ecosystems. The type of restoration actions to improve connectivity and estuary health include the removal of causeways to ensure tidal connectivity or removal of upstream weirs / farm dams to restore freshwater connectivity. Restoring tidal connectivity to desiccated salt marshes can improve carbon storage, enhance nutrient removal, and provide support to fisheries through increasing biodiversity and nursery habitats. Carbon storage for climate change mitigation is a key issue globally.

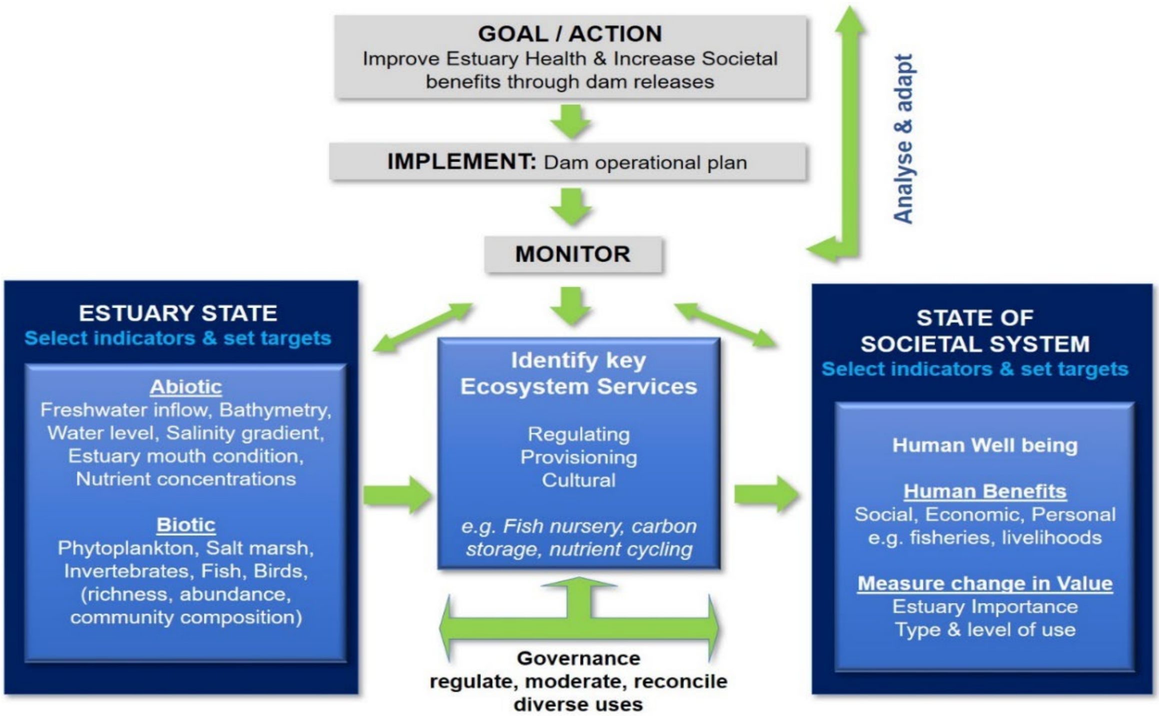


Figure 14: Restoration of environmental flows to estuaries from upstream dams presented in a socio-ecological systems framework.

CHAPTER 5: RECOMMENDATIONS FOR FUTURE RESEARCH

Action research is needed where the recommended restoration activities from this study will be implemented and tested. These studies should involve human geographers and social scientists that have expertise on qualitative data collection and analysis. Research can harmonise links between disciplines in a co-ordinated and coherent whole that focuses on “real-world” system problems. The involvement of stakeholders and communities is essential.

Action research is needed to establish best methods; for example, converting agricultural lands back to salt marsh. Action research includes a learning-by-doing approach and providing input to strategic adaptive management is recommended. Restoration research provides opportunities for innovation through transdisciplinary approaches. Restoration research also provides opportunities for postgraduate training across disciplines. By celebrating conservation successes, we will ignite hope and inspire the next generation of thinkers and change-makers (#oceanoptimism, #GenerationRestoration). It is important to communicate the message that individuals can make a difference.

The monetary worth of ecosystem services was not addressed in this study, but this can be easily achieved now that the major ecosystem services have been identified. Following Turpie and Clark's (2007) assessment, an update of the ecosystem service economic evaluation of the Swartkops Estuary is required. There is a risk that insufficient financial resources and capacity will be made available to safeguard ecosystem services if their full worth is not understood. The value of preserving and increasing these resources, and the ecosystems that provide them, can be demonstrated through the valuation of ecosystem services. Ecosystem service valuation is a means of integrating ecological knowledge with economic concerns to correct the conventional neglect of ecosystem services in policy decisions. This is important because it also has potential to unlock opportunities for carbon trading, restoration, and payment for ecosystem services.

The socio-ecological systems approach developed in this study can be applied to other estuaries to identify the unique features that characterise different sites. There are opportunities to consider the restoration of biodiversity from a functional point of view. For example, investigating the nursery function or storm protection function. The effect of water quality on these functions can also be pursued further for by example understanding the effects of nutrients/metals on iconic, abundant and/or exploited estuarine species.

The interaction between climate change and restoration activities in estuaries needs greater understanding. High-resolution digital elevation models are required to assess the influence of sea level rise on coastal habitats at the national scale. Coastal squeeze could result in the loss of estuarine habitats or in some cases could allow expansion if there is available land. Remote sensing is also a tool that can be used in South African estuaries to track progress of estuary restoration, assess water quality, as well as determine the standing biomass and carbon stocks. The extent of estuarine habitats (Blue Carbon Sink Register) needs to be updated every five years to reflect the change in the area of salt marsh, mangroves and seagrass ecosystems to report on restoration and protection progress. A register can be used to also track the threats. There is also scope for research geared towards investigating the link between water quality and human health.

Future studies are needed to fill in the gaps highlighted by the carbon storage map produced in this study. Such research will provide comprehensive carbon storage data for the Swartkops Estuary and also allow for the investigation of appropriate methods to restore the disturbed salt marsh habitats. An assessment of groundwater salinity and depth to groundwater would have greatly assisted in assessing the potential for future salt marsh restoration, as these are important determinants for the survival of supratidal and floodplain salt marsh.

Future research can provide detail on societal health using a system to track this (e.g. Society for Ecological Restoration wheel). A better rating assessment of the constituents of well-being is needed when additional data becomes available so that both ecological and societal indicators can be incorporated into restoration efforts. For a transition to a circular economy, and to meet the challenges of the UN Decade on Ecosystem Restoration, social indicators of ecosystem restoration must be included in policies and activities. Nationally restoration efforts need to build climate resilience and sustainable food systems. Socio-cultural and socio-political research that uses transdisciplinary approaches, for co-management and inclusive benefitting is necessary.

Research can be conducted on reducing the inputs of wastewater from WWTWs into estuaries through the use of a sewerage recycling plant. Preliminary use of these plants has been conducted in Namibia and the concept thereof is being introduced to Cape Town. These sewerage recycling plants will have a two-fold benefit. Firstly, they can reduce the need to discharge nutrient rich wastewater into our natural ecosystems and secondly, they can aid in solving the water scarcity crisis which South Africa is currently facing.

CHAPTER 6: REFERENCES

Abelson, A., Reed, D.C., Edgar, G.J., Smith, C.S., Kendrick, G.A., Orth, R.J., Airoldi, L., Silliman, B., Beck, M.W., Krause, G. and Shashar, N., 2020. Challenges for restoration of coastal marine ecosystems in the Anthropocene. *Frontiers in Marine Science*, *7*, p.544105.

Adams, J.B., 2016. Distribution and status of *Zostera capensis* in South African estuaries—a review. *South African Journal of Botany*, *107*, pp.63-73.

Adams, J.B., Pretorius, L. and Snow, G.C., 2019. Deterioration in the water quality of an urbanised estuary with recommendations for improvement. *Water SA*, *45*(1), pp.86-96.

Adams, J.B., Taljaard, S., Van Niekerk, L. and Lemley, D.A., 2020. Nutrient enrichment as a threat to the ecological resilience and health of South African microtidal estuaries. *African Journal of Aquatic Science*, *45*(1-2), pp.23-40.

Adams, J.B., Tsipa, V. and Wasserman, J., 2020a. Community and governance considerations play an important role in the restoration of estuaries and blue carbon habitats. In: The WIOMSA Magazine – People & the environment, Issue 11, September 2020. pp, 22-25.

Adams, J.B., Whitfield, A.K. and Van Niekerk, L., 2020b. A socio-ecological systems approach towards future research for the restoration, conservation and management of southern African estuaries. *African Journal of Aquatic Science*, *45*(1-2), pp.231-241.

Adams, J.B. and Riddin, T. 2020. State of knowledge: Conservation and management of the Swartkops Estuary. Benguela Current Convention Report September 2020. Institute for Coastal and Marine Research, Nelson Mandela University, Port Elizabeth, South Africa.

Adams, J.B., Raw, J.L., Riddin, T., Wasserman, J. and Van Niekerk, L., 2021. Salt marsh restoration for the provision of multiple ecosystem services. *Diversity*, *13*(12), p.680.

Adams, J.B., Taljaard, S. and Van Niekerk, L. Water releases from dams improve ecological health and societal benefits in downstream estuaries. *Estuaries and Coasts* (under revision)

Alongi, D.M., Murdiyarso, D., Fourqurean, J.W., Kauffman, J.B., Hutahaean, A., Crooks, S., Lovelock, C.E., Howard, J., Herr, D., Fortes, M. and Pidgeon, E., 2016. Indonesia's blue carbon: a globally significant and vulnerable sink for seagrass and mangrove carbon. *Wetlands Ecology and Management*, *24*, pp.3-13.

Baird, D., Marais, J.F.K. and Daniel, C., 1996. Exploitation and conservation of angling fish in two South African estuaries. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *6*(4), pp.319-330.

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C. and Silliman, B.R., 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs*, *81*(2), pp.169-193.

Benjamin, S. 2022. Changes in multi-decadal waterbird biodiversity and abundance on the Swartkops Estuary: a case-study of saltpan restoration. Zoology Department, Nelson Mandela University. Gqeberha. 45 pp.

Binning, K. and Baird, D., 2001. Survey of heavy metals in the sediments of the Swartkops River Estuary, Port Elizabeth South Africa. *Water SA*, *27*(4), pp.461-466.

Bornman, T.G. and Adams, J.B., 2010. Response of a hypersaline salt marsh to a large flood and rainfall event along the west coast of southern Africa. *Estuarine, Coastal and Shelf Science*, *87*(3), pp.378-386.

Byun, C., Lee, S.H. and Kang, H., 2019. Estimation of carbon storage in coastal wetlands and comparison of different management schemes in South Korea. *Journal of Ecology and Environment*, *43*(1), pp.1-12.

Cairns Jr, J., 2000. Setting ecological restoration goals for technical feasibility and scientific validity. *Ecological Engineering*, *15*(3-4), pp.171-180.

Chen, Y., Li, Y., Thompson, C., Wang, X., Cai, T. and Chang, Y., 2018. Differential sediment trapping abilities of mangrove and saltmarsh vegetation in a subtropical estuary. *Geomorphology*, *318*, pp.270-282.

Destoumieux-Garzón, D., Mavingui, P., Boetsch, G., Boissier, J., Darriet, F., Duboz, P., Fritsch, C., Giraudoux, P., Le Roux, F., Morand, S. and Paillard, C., 2018. The one health concept: 10 years old and a long road ahead. *Frontiers in Veterinary Science*, p.14.

Emanuel, B.P., R.H. Bustamante, G.M. Branch, S. Eekhout and F.J. Odendaal., 1992. A zoogeographic and functional approach to the selection of marine reserves on the west coast of South Africa. *South African Journal of Marine Science,* 12(1), pp. 341-354.
Fenstermacher, D.E., Rabenhorst, M.C., Lang, M.W., McCarty, G.W. and Needelman, B.A., 2016. Carbon in natural, cultivated, and restored depressional wetlands in the mid-Atlantic coastal plain. *Journal of Environmental Quality*, *45*(2), pp.743-750.
Fielding, P.J., 2014. Stock assessment of bait organisms in the Swartkops Estuary, Eastern Cape. Comparison with bait organism stocks of 2008 and 1980. Report prepared for: Zwartkops Conservancy.
Fischer, J., Riechers, M., Loos, J., Martin-Lopez, B. and Temperton, V.M., 2021. Making the UN decade on ecosystem restoration a social-ecological endeavour. *Trends in Ecology & Evolution*, *36*(1), pp.20-28.
Hasler, R. and Munro, L., 2007. Co-management Project NORSA 3 Pilot Sites: Preliminary Socio-Economic Assessment of Swartkops Bait Fishery, Environmental Evaluation Unit, University of Cape Town, South Africa.
Harrison, T.D., 2002. Preliminary assessment of the biogeography of fishes in South African estuaries. Marine and Freshwater Research, 53(2), pp.479-490.
Hartmann, N.R., 2021. Social-ecological systems approaches to integrated estuarine governance: the Swartkops Estuary. PhD thesis. Development Studies, Nelson Mandela University, South Africa.
Hauck, M., 2009. Rethinking Small-scale Fisheries Compliance: from criminal justice to social justice. PhD thesis. University of Cape Town, South Africa.
Hoang, L. and Fenner, R.A.A., 2016. System interactions of stormwater management using sustainable urban drainage systems and green infrastructure. *Urban Water Journal*, *13*(7), pp.739-758.
Hristovski, M., Cvetkovik, A., Cvetkovik, I. and Dukoska, V., 2010. Concept of one health-a new professional imperative. *Macedorian Journal of Medical Sciences*, *3*(3), pp.229-232.
Human, L.R.D., Adams, J.B. and Allanson, B.R., 2016. Insights into the cause of an *Ulva lactuca* Linnaeus bloom in the Knysna Estuary. *South African Journal of Botany*, *107*, pp.55-62.
International Panel on Climate Change (IPCC). 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Cambridge University Press: Cambridge, UK.'

IUCN, 2016. Nature-based Solutions to address global societal challenges. Cohen-Shacham, E., Walters, G., Janzen, C. and Maginnis, S. (eds.) Gland, Switzerland

Kariem, S., 2005. Identification of Alternative Economic/Livelihood Opportunities for the Swartkops Fishery, Final Report by Sustainable Coastal Development (SCD), South Africa.
Kaselowski, T., 2013. Not so pristine-characterising the physico-chemical conditions of an undescribed temporarily open/closed estuary. *Water SA*, *39*(5).
Kirby, A., 2005, June. SuDS—innovation or a tried and tested practice? In *Proceedings of the Institution of Civil Engineers-Municipal Engineer* (Vol. 158, No. 2, pp. 115-122). Thomas Telford Ltd.
Kotsedi, D., Adams, J.B. and Snow, G.C., 2012. The response of microalgal biomass and community composition to environmental factors in the Sundays Estuary. Water SA, 38(2), pp.177-190.
Lakane, CP. Quantifying nutrient storage capacity of invasive aquatic plants in the upper Swartkops Estuary. MSc (under examination). Department of Botany, Nelson Mandela University, Gqeberha.
Lemley, D.A., Adams, J.B. and Taljaard, S., 2017. Comparative assessment of two agriculturally-influenced estuaries: similar pressure, different response. *Marine Pollution Bulletin*, *117*(1-2), pp.136-147.
Lemley, D.A., Adams, J.B., Rishworth, G.M. and Bouland, C., 2019. Phytoplankton responses to adaptive management interventions in eutrophic urban estuaries. *Science of the Total Environment*, *693*, p.133601.
Lemley, D.A., Lamberth, S.J., Manuel, W., Nunes, M., Rishworth, G.M., Van Niekerk, L. and Adams, J.B., 2021. Effective management of closed hypereutrophic estuaries requires catchment-scale interventions. *Frontiers in Marine Science*, *8*, p.688933.

Lemley, D.A., Human, L.R., Rishworth, G.M., Whitfield, E. and Adams, J.B., 2022. Managing the Seemingly Unmanageable: Water Quality and Phytoplankton Dynamics in a Heavily Urbanised Low-Inflow Estuary. Estuaries and Coasts, pp.1-16.
Lemley, D.A., Lakane, C.P., Taljaard, S. and Adams, J.B., 2022b. Inorganic nutrient removal efficiency of a constructed wetland before discharging into an urban eutrophic estuary. *Marine Pollution Bulletin*, *179*, p.113727.
Magobiane S., 2011. Willingness to Pay for Water Quality Changes in the Swartkops Estuary. MSc Dissertation. Department of Economics, Nelson Mandela Metropolitan University, Port Elizabeth.
Marais, J.F.K. and Baird, D., 1980. Analysis of anglers' catch data from the Swartkops Estuary. *African Zoology*, *15*(2), pp.61-65.
Martin, A.P. and Randall, R.M., 1987. Numbers of waterbirds at a commercial saltpan, and suggestions for management. *South African Journal of Wildlife Research*, *17*(3), pp.74-81.
Masuku, S., 2003. Finding local solutions: Crime prevention in the Nelson Mandela Metro. *South African Crime Quarterly*, (5).
MEA, 2005. Ecosystems and human well-being: wetlands and water. *World Resources Institute*. Island Press: Washington, DC, USA,2005; pp. 92–101.

Mmachaka, T. 2020. Smart catchment management and application in Swartkops River. PhD Thesis, Proposal, Department of Botany, Nelson Mandela University, South Africa.
Molazadeh, M., Ahmadzadeh, H., Pourianfar, H.R., Lyon, S. and Rampelotto, P.H., 2019. The use of microalgae for coupling wastewater treatment with CO_2 biofixation. *Frontiers in Bioengineering and Biotechnology*, *7*, p.42.
Nel, L., 2014. *Presence, levels and distribution of pollutants in the estuarine food web: Swartkops River Estuary, South Africa* (Doctoral dissertation, North-West University).
Nel, L., Strydom, N.A. and Bouwman, H., 2015. Preliminary assessment of contaminants in the sediment and organisms of the Swartkops Estuary, South Africa. *Marine Pollution Bulletin*, *101*(2), pp.878-885.
Nel, L., Strydom, N.A. and Adams, J.B., 2018. Habitat partitioning in juvenile fishes associated with three vegetation types in selected warm temperate estuaries, South Africa. *Environmental Biology of Fishes*, *101*(7), pp.1137-1148.
Nel, M.A., Rubidge, G., Adams, J.B. and Human, L.R., 2020. Rhizosediments of Salicornia tegetaria indicate metal contamination in the intertidal estuary zone. *Frontiers in Environmental Science*, *8*, p.572730.
Nel, M.A. 2022 Seasonal changes of metals in the salt marsh and seagrass beds of the Swartkops Estuary. MSc Dissertation, Department of Botany, Nelson Mandela University, Gqeberha.
Nilsen, E., Rosenbauer R.J., Fuller, C.C., Jaffe, B.J., 2015. Sedimentary organic biomarkers suggest detrimental effects of PAHs on estuarine microbial biomass during the 20th century in San Francisco Bay, CA, USA. *Chemosphere*. 119. pp. 961-970.
Nunes, M. and Adams, J.B., 2014. Responses of primary producers to mouth closure in the temporarily open/closed Great Brak Estuary in the warm-temperate region of South Africa. *African Journal of Aquatic Science*, *39*(4), pp.387-394.
Oberholster, P.J., Botha, A.M., Chamier, J. and de Klerk, A.R., 2013. Longitudinal trends in water chemistry and phytoplankton assemblage downstream of the Riverview WWTP in the Upper Olifants River. *Ecohydrology & Hydrobiology*, *13*(1), pp.41-51.
Oberholster, P.J., Cheng, P.H., Genthe, B. and Steyn, M., 2019. The environmental feasibility of low-cost algae-based sewage treatment as a climate change adaption measure in rural areas of SADC countries. *Journal of Applied Phycology*, *31*(1), pp.355-363.
Osland, M.J., Enwright, N. and Stagg, C.L., 2014. Freshwater availability and coastal wetland foundation species: ecological transitions along a rainfall gradient. *Ecology*, *95*(10), pp.2789-2802.
Osland, M.J., Enwright, N.M., Day, R.H., Gabler, C.A., Stagg, C.L. and Grace, J.B., 2016. Beyond just sea-level rise: Considering macroclimatic drivers within coastal wetland vulnerability assessments to climate change. *Global Change Biology*, *22*(1), pp.1-11.

Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*(5939), pp.419-422.
Pouso, S., Uyarra, M.C. and Borja, Á., 2018. Recreational fishers' perceptions and behaviour towards cultural ecosystem services in response to the Nerbioi estuary ecosystem restoration. *Estuarine, Coastal and Shelf Science*, *208*, pp.96-106.
Pretorius, L. 2015. Spatial and temporal variability in water quality characteristics of the Swartkops Estuary. Department of Botany, Nelson Mandela Metropolitan University. South Africa.
Reyers, B., Biggs, R., Cumming, G.S., Elmqvist, T., Hejnowicz, A.P. and Polasky, S., 2013. Getting the measure of ecosystem services: a social–ecological approach. *Frontiers in Ecology and the Environment*, *11*(5), pp.268-273.
Roux, D., Clements, H., Currie, B., Fritz, H., Gordon, P., Kruger, N. and Freitag, S., 2020. The GRIN Meeting: A'third place'for managers and scholars of social-ecological systems. *South African Journal of Science*, *116*(3-4), pp.1-2.
Schell, N., 2011. *Small-scale fisheries in South Africa: stakeholder's understandings and perceptions of co-management.* Master's thesis, University of Cape Town, South Africa.
Shaw, G.A., Adams, J.B. and Bornman, T.G., 2008. Sediment characteristics and vegetation dynamics as indicators for the potential rehabilitation of an estuary salt marsh on the arid west coast of South Africa. *Journal of Arid Environments*, *72*(6), pp.1097-1109.
Snow, G.C., Adams, J.B. and Bate, G.C., 2000. Effect of river flow on estuarine microalgal biomass and distribution. *Estuarine, Coastal and Shelf Science*, *51*(2), pp.255-266.
Tsipa, V., 2022. *Developing a socio-ecological framework for the restoration of estuaries using the Swartkops Estuary as a case study.* Master's thesis, Nelson Mandela University, South Africa.

Turpie, J.K., Beckley, L.E., Katua, S.M., 2000. Biogeography and the selection of priority areas for conservation of South African coastal fishes. *Biological Conservation.* 92(1). pp.59-72.
Turpie, J.K., Adams, J.B., Joubert, A., Harrison, T.D., Colloty, B.M., Maree, R.C., Whitfield, A.K., Wooldridge, T.H., Lamberth, S.J., Taljaard, S. and Van Niekerk, L., 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation. *Water SA*, *28*(2), pp.191-206.
Turpie, J. and Clark, B., 2007. Development of a conservation plan for temperate South African estuaries on the basis of biodiversity importance. *Ecosystem Health and Economic Costs and Benefits-Final Report (CAPE Regional Estuarine Management Programme 2007)*.
Turpie, J.K., Taljaard, S., van Niekerk, L., Adams, J., Wooldridge, T., Cyrus, D., Clark, B. and Forbes, N., 2012. The Estuary Health Index: a standardised metric for use in estuary management and the determination of ecological water requirements. WRC Report No. 1930/1/12
Valesini, F.J., Hallett, C.S., Hipsey, M.R., Kilminster, K.L., Huang, P. and Hennig, K., 2019. Peel-Harvey Estuary, Western Australia. *Estuaries and Coasts* pp. 103-120.
Van Aswegen, J.D., Nel, L., Strydom, N.A., Minnaar, K., Kylin, H. and Bouwman, H., 2019. Comparing the metallic elemental compositions of Kelp Gull Larus dominicanus eggs and eggshells from the Swartkops Estuary, Port Elizabeth, South Africa. *Chemosphere*, *221*, pp.533-542.
Van Niekerk, L., and Turpie, J.K., 2012. National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. CSIR Report Number CSIR/NRE/ECOS/ER/2011/0045/B. Council for Scientific and Industrial Research, Stellenbosch.
Van Niekerk, L., Adams, J.B., Bate, G.C., Forbes, A.T., Forbes, N.T., Huizinga, P., Lamberth, S.J., MacKay, C.F., Petersen, C., Taljaard, S. and Weerts, S.P., 2013. Country-wide assessment of estuary health: An approach for integrating pressures and ecosystem response in a data limited environment. *Estuarine, Coastal and Shelf Science*, *130*, pp.239-251.
Van Niekerk, L., Adams, J., Stephen, L., MacKay, F., Taljaard, S., Jane, T. and Weerts, S., 2019. South African National Biodiversity Assessment 2018: Technical Report. Volume 3: Estuarine Realm CSIR report number CSIR/SPLA/EM/EXP/2019/0062/A.
Van Niekerk, L., Taljaard, S., Lamberth, S.J., Adams, J.B., Weerts, S.P. and MacKay, C.F., 2022. Disaggregation and assessment of estuarine pressures at the country-level to better inform

management and resource protection–the South African experience. *African Journal of Aquatic Science*, pp.1-22.
Wasserman, J., 2021. Recreating a wetland at an abandoned saltworks: towards a rehabilitation plan (MSc dissertation). Department of Botany, Nelson Mandela University, Port Elizabeth, South Africa.
Wasserman, J., Lemley, D.A. and Adams, J.B., 2022. Saltpan primary producer and inorganic nutrient dynamics in response to inundation with nutrient-rich source waters. *Journal of Experimental Marine Biology and Ecology*, *551*, p.151723.
Whitfield, E.C. 2022. Uptake and storage of nutrients by primary producers in the Swartkops Estuary. MSc dissertation, Department of Botany, Nelson Mandela University, Gqeberha.
Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R. and Shaffer, P., 2007. *The SUDS Manual* (Vol. 697). London: Ciria.
Zungu, V., 2008. 'Swartkops Bait Fishery Co-management Project: a NORSA case study', Environmental Evaluation Unit, University of Cape Town.

APPENDICES

APPENDIX 1: Project Deliverables

APPENDIX 2: Capacity Building Report

APPENDIX 3: Project Outputs

APPENDIX 4: Summary of Postgraduate Studies

APPENDIX 5: Workshop Overview - Innovative Methods for Estuary Water Quality Improvement

APPENDIX 6: Draft Discussion Document – Restoration case studies towards the development of a National Estuarine Restoration Programme (submitted to Umesh Bahadur, Director Working for Wetlands, DFFE – August 2021)

APPENDIX 7: Restoration measures needed to improve estuary condition and productivity

APPENDIX 1: PROJECT DELIVERABLES

Project Objective	Developing a socio-ecological systems framework for estuaries using the Swartkops Estuary as a case study
Deliverable 1 (11/2020)	Innovative methods for estuary water quality improvement Report with detail on artificial wetlands, treatment trains, sustainable drainage and other approaches for improving water quality.
Deliverable 2 (11/2020)	Artificial wetland optimisation plan - Motherwell Canal wetland optimisation and use of salt pans
Deliverable 3 (11/2021)	Harmful Algal Blooms, seagrass and salt marsh as heavy metal bio accumulators and nutrient filters
Deliverable 4 (6/2022)	Conference presentations and articles submitted for publication
Deliverable 5 (11/2022)	Final report - A socio-ecological systems framework for the restoration of estuaries including the benefits of water quality improvement on estuary health

APPENDIX 2: CAPACITY BUILDING REPORT

Honours studies

Completed

Priscah Lakane. 2020. Investigating the nutrient removal efficiency of the Motherwell Artificial Wetland before discharging to the Swartkops Estuary. Honours project 1. Department of Botany, Nelson Mandela University. (Supervisors Adams, Lemley)

Priscah Lakane. 2021. Testing a water screening model for the Swartkops Estuary. Honours project 2. Department of Botany, Nelson Mandela University. (Supervisors Lemley, Adams)

Asiphe Ndoto. 2020. Trait-based analysis of dominant invasive aquatic plants found in South African estuaries. Honours project 1. Department of Botany, Nelson Mandela University.

Asiphe Ndoto. 2021. Abundance and cover change of the floating invasive plants in the upper reaches of the Swartkops Estuary. Honours project 2. Department of Botany, Nelson Mandela University.

Christo Tripodis. 2020. The nutrient composition of Typha capensis grown in the Motherwell Artificial Wetland, Swartkops Estuary, South Africa. Honours project 1. Department of Botany, Nelson Mandela University. (Supervisors Lemley, Adams)

Christos Tripodis. 2020. Artificial wetlands and biotechnology as a tool to remediate the urbanised Swartkops Estuary. Honours project 2. Department of Botany, Nelson Mandela University. (Supervisors Adams, Lemley)

Saudiqa Benjamin. Changes in multi-decadal waterbird biodiversity and abundance on the Swartkops Estuary: a case-study of saltpan restoration. Zoology Department, Nelson Mandela University, South Africa. 45 pp (supervisors Rishworth, Adams, Martin)

MSc studies

Completed:

Johan Wasserman. 2021. Recreating a wetland at an abandoned saltworks: towards a rehabilitation plan. MSc Dissertation. Department of Botany, Nelson Mandela University, South Africa. pp. 141. (*funded by WRC)*

Marele Nel. 2022. Seasonal changes of metals in the salt marsh and seagrass beds of the Swartkops Estuary. MSc Dissertation, Department of Botany, Nelson Mandela University, South Africa. 151 pp. (*aligned with this research but not funded by WRC)*

Vusumzi Tsipa. 2022. Developing a socio-ecological framework for the restoration of estuaries using the Swartkops Estuary as a case study. MSc Dissertation. Department of Botany, Nelson Mandela University, South Africa. 172 pp. (*funded by WRC)*

Emily Whitfield. 2022. Uptake and storage of nutrients by primary producers in the Swartkops Estuary. MSc dissertation, Department of Botany, Nelson Mandela University, South Africa. pp. 120. (*funded by WRC)*

Ongoing:

Priscah Lakane. Quantifying nutrient storage capacity of invasive aquatic plants in the upper Swartkops Estuary. MSc dissertation, Department of Botany, Nelson Mandela University, South Africa.

Anabel Matalanga. Investigation of hydrological variability and the pollutant contribution of sub-catchments in the Chatty River Catchment. MSc Engineering. University of Cape Town.

Completed PhD study

Mmachaka, T. 2022. Smart catchment management and application in the Swartkops River and Estuary. PhD thesis, Botany Department, Nelson Mandela University. 276 pp.

APPENDIX 3: PROJECT OUTPUTS

Journal articles

- Adams, J.B., Whitfield, A.K. and Van Niekerk, L. 2020a. A socio-ecological systems approach towards future research for the restoration, conservation and management of southern African estuaries. *African Journal of Aquatic Science* 45: 231-241. DOI: 10.2989/16085914.2020.1751980.
- Adams, J.B. and Van Niekerk, L. 2020b. Ten principles to determine environmental flow requirements for temporarily closed estuaries. *Water* 12: 1944. DOI: 10.3390/w12071944.
- Adams, J.B., Taljaard, S., Van Niekerk, L. and Lemley, D.A. 2020c. Nutrient enrichment as a threat to the ecological resilience and health of South African microtidal estuaries. *African Journal of Aquatic Science* 45: 23-40. DOI: 10.2989/16085914.2019.1677212.
- Adams JB, Raw JL, Riddin T, Wasserman J and Van Niekerk L. 2021. Salt marsh restoration for the provision of multiple ecosystem services. *Diversity* 2021, 13, 680. https://doi.org/10.3390/ d13120680. Supplementary document: https://www.mdpi.com/article/10.3390/d13120680/s1
- Lemley DA, Human LRD, Rishworth GM, Whitfield E and Adams JB. 2022. Managing the seemingly unmanageable: Water quality and phytoplankton dynamics in a heavily urbanised low-inflow estuary. Estuaries and Coasts. DOI: https://doi.org/10.1007/s12237-022-01128-z
- Lemley DA, Lakane CP, Taljaard S, and Adams JB. 2022. Inorganic nutrient removal efficiency of a constructed wetland before discharging into an urban eutrophic estuary. Marine Pollution Bulletin 179: 113727.
- Wasserman J, DA Lemley and JB Adams. 2022. Saltpan primary producer and inorganic nutrient dynamics in response to inundation with nutrient-rich source waters. *Journal of Experimental Marine Biology and Ecology* 551: 151723.
- Wasserman J, Lemley DA and Adams JB. 2022. Investigating the potential for saltpan restoration for the provision of multiple ecosystem services. *African Journal of Aquatic Science,* 47(4): 436-446.

Presentations

- Adams, JB. 2022. Codesign: estuary conservation and management. Plenary Talk for the OSM Networking Session on Co-Design of Science – at the innovative panel session at the OSM2022 (28 February 2022). http://www.oceansciencesmeeting.org.
- Adams, JB. 2022. Restoration of coastal water quality. Invited presentation for Institute for Nanotechnology and Water Sustainability (iNanoWS) – College of Science, Engineering and Technology. UNISA, Pretoria, South Africa. April 2022.
- Adams JB. 2022. Source to sea: estuaries at the pressure interface. Keynote lecture at the 2022 conference of the Southern African Society of Aquatic Scientists. 59th conference meeting. Conference theme: Valuing our river systems: source to sea. (Brandfort, Free State): 26-30 June 2022.
- Adams, JB. 2022. Environmental Flows for Estuary Restoration. 17th South African Marine Science Symposium. Conference theme: Marine Science for the Future South Africa. 20-24 June 2022.
- Adams, JB. 2021. Urban estuaries provide global opportunities for restoration. Estuarine Coastal Shelf Sciences Association (ECSA), University of Hull, UK. September 2021.

- Adams, JB and C Olisah. 2021. Restoration of coastal water quality. Presentation at The Community of Practice in Marine Spatial Planning Research meeting 21 October 2021, online with zoom.
- Adams, JB. Time to learn from experience: Addressing the UN Decade on Ecosystem Restoration, approach and lessons. Presentation at International Impact Working Group. One Ocean Hub. 1 December 2021.
- Lakane, CP. 2021. Quantifying nutrient storage capacity of invasive alien aquatic plants. Presentation for South African Society of Aquatic Scientists (Online) (03 November 2021)
- Lakane, CP. 2022. Quantifying nutrient storage capacity of invasive alien aquatic plants in the upper Swartkops Estuary. Conference presentation at 17th SAMSS: Marine Science for the Future of South Africa. Durban, South Africa. 22 June 2022.
- Lemley, DA. 2022. Managing the seemingly unmanageable: Water quality and phytoplankton dynamics in a heavily urbanised low-inflow estuary. Conference presentation at 17th SAMSS: Marine Science for the Future of South Africa. Durban, South Africa. 22 June 2022.
- Whitfield, E. 2022. Phytoplankton as nutrient filters in an urbanized and eutrophic estuary. Conference presentation at 17th SAMSS: Marine Science for the Future of South Africa. Durban, South Africa. 22 June 2022.

Popular articles

- Adams J.B. and McGwynne, L. 2020. Restoration of a salt marsh in a semi-arid Ramsar site. In: The WIOMSA Magazine - People & the environment, Issue 12, December 2020. pp. 6-7. https://www.wiomsa.org/wp-content/uploads/2020/12/WIOMSA-Magazine-Issue-12_December2020.pdf
- Adams, J.B., Tsipa, V. and Wasserman, J. 2020. Community and governance considerations play an important role in the restoration of estuaries and blue carbon habitats. In: The WIOMSA Magazine – People & the environment, Issue 11, September 2020. pp. 22-25. https://www.wiomsa.org/wp-content/uploads/2020/09/WIOMSA-Magazine-Issue-11_September2020.pdf
- Human, L.R.D., Nel, M., Rubidge, G. and Adams, J.B. 2020. Spotlight on Salicornia tegetaria and its role in heavy metal localisation. SAEON eNews, Issue 2, 2020. https://enews.saeon.ac.za/issue-02-2020/spotlight-on-salicornia-tegetaria/
- Olisah C, Rubidge G, Human LRD, Adams JB. 2022. The sequestration of organophosphate pesticides in common reed growing in an agricultural estuarine environment. SAEON Elwandle Node. SAEON eNews. #01/2022. https://enews.saeon.ac.za/issue-01-2022/the-sequestration-of-organophosphate-pesticides-in-common-reed-growing-in-an-agricultural-estuarine-environment/

Reports

- Adams JB, D Hughes, N James, R Kibble, D Lemley, G Rishworth, T Riddin, N Strydom, S Taljaard, V Tsipa and L Van Niekerk. 2021. Swartkops Estuary: Present Ecological Status and Future Restoration Scenarios. Institute for Coastal & Marine Research Report No. 48, Nelson Mandela University, South Africa. 167 pp.

Other related research articles not funded by WRC

- Nel MA, Human LRD, Adams JB, Rubidge G. 2022. Contributions of wetland plants on metal accumulation in sediment. *Sustainability* 14: 3679. https://doi.org/10.3390/su14063679
- Olisah C, Rubidge G, Human LRD and Adams JB. 2021. A translocation analysis of organophosphate pesticides between surface water, sediments and tissues of common reed *Phragmites australis. Chemosphere 284: 131380.* https://doi.org/10.1016/j.chemosphere.2021.131380
- Olisah C, Rubidge G, Human LRD, Adams JB. 2021. Organophosphate pesticides sequestered in tissues of a seagrass species - *Zostera capensis* from a polluted watershed. *Journal of Environmental Management* 300: 113657
- Olisah, C., Adams, J.B. & Rubidge, G. 2021. The state of persistent organic pollutants in South African estuaries: A review of environmental exposure and sources. *Ecotoxicology and Environmental Safety* 219: 112316. DOI: 10.1016/j.ecoenv.2021.112316
- Raw, JL, Adams JB, Bornman TG, Riddin T, Vanderklift MA. 2021. Vulnerability to sea-level rise and the potential for restoration to enhance blue carbon sequestration in salt marshes of an urban estuary. *Estuarine Coastal & Shelf Science* 260: 107495.
- Taljaard S, Adams JB. 2021. Coastal management – working towards the UN's Decade of Ocean Science for Sustainable Development (2021–2030). *South African Journal of Science*: 117(9/10): 8857. https:// doi.org/10.17159/sajs.2021/885

This research informed the following studies:

- Raw J, Tsipa V, Banda S, Riddin T, Van Niekerk L, Adams, JB. 2021. Scoping Study: A Blue Carbon Sinks Assessment for South Africa. Project 83360258 funded by GIZ: Deutsche Gesellschaft für Internationale Zusammernarbeit GmbH for the Department of Environment Forestry and Fisheries, South Africa.

- Van Niekerk L, Adams JB, Raw JL, Chauke O, Mbatha H, Mthembu N, Moyo L, Silinda Z, Browan A, Cilliers G. 2021. Draft Policy Brief. Climate Protection through the Conservation and Restoration of Blue Carbon Ecosystems. Department of Environment, Forestry and Fisheries, South Africa. (funded by funded by GIZ: Deutsche Gesellschaft für Internationale Zusammernarbeit GmbH, Project 83360258).

- Taljaard, S, Van Niekerk L, Adams JB, Riddin T and Lamberth SJ. 2021. Communities of Practice in the Western Indian Ocean: Ocean Accounts Framework. Ecosystem Accounting for the Estuaries in Algoa Bay (Physical accounts). CSIR Research Report CSIR/SPLA/SECO/ER/2022/0017/A. Stellenbosch, South Africa.

APPENDIX 4: SUMMARIES OF POSTGRADUATE STUDIES

Anabel Matalanga

MSc Engineering ongoing. University of Cape Town. Investigation of hydrological variability and the pollutant contribution of sub-catchments in the Chatty River Catchment. (Supervisor: Prof Neil Armitage)

The Chatty River, located in Gqeberha, South Africa, is the largest tributary feeding into the Swartkops Estuary and is among the three significant sources of pollution that enters Swartkops Estuary within the Estuarine Functional Zone (EFZ), the other two being the Motherwell Canal and the Markman Canal. The Chatty River catchment (Figure 1) is mainly occupied by low-income residential areas resulting in pollution from stormwater runoff, litter, and raw sewage discharge. There are growing informal settlements and limited agriculture.

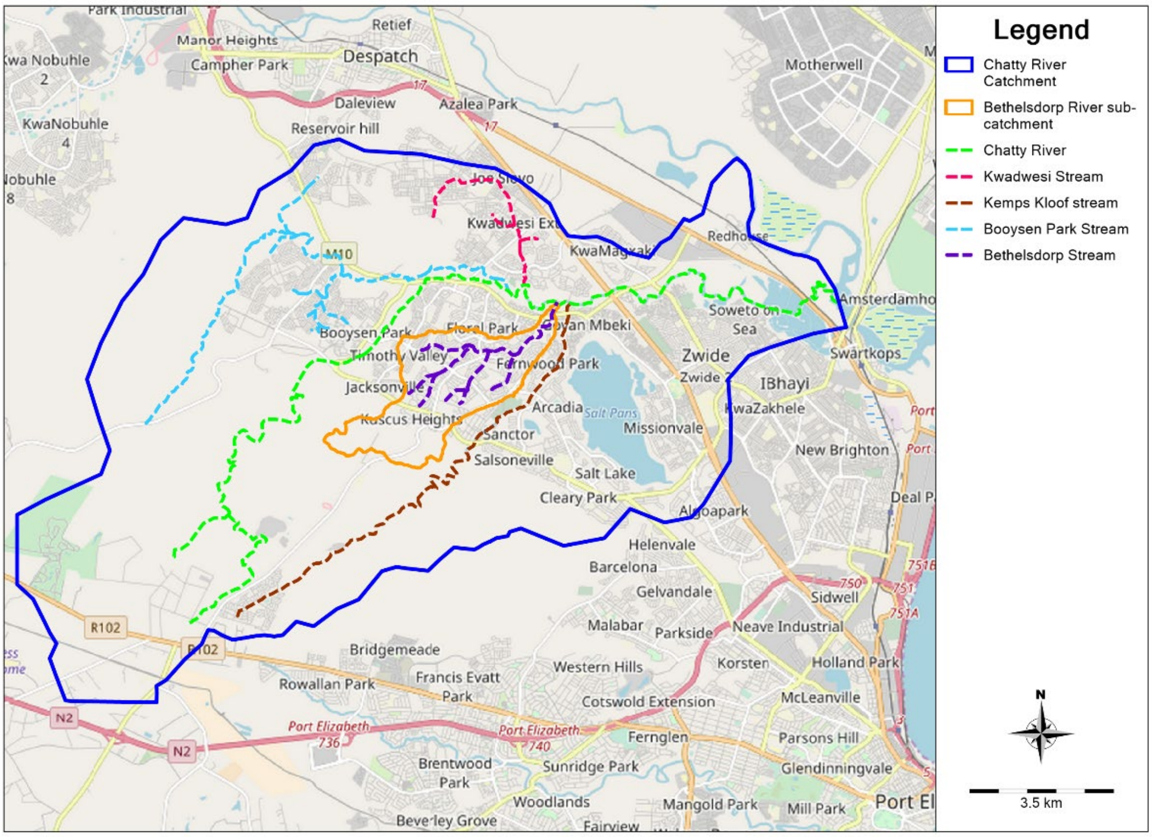


Figure 1: Chatty River Catchment Locality Map

In recent years, the high pollution level in the Swartkops Estuary has led to the reduction and even halting of various social and cultural activities such as the Redhouse River Mile swimming event, cleansing ceremonies by traditional healers, and baptisms by the Zion Church. This study sought to understand the pollution contribution of the Chatty River and provide recommendations to improve its water quality through the possible inclusion of Sustainable Drainage Systems (SuDS). SuDS are designed to minimise the impact of development on stormwater quality while maximising amenity and biodiversity through a suite of interventions designed to manage stormwater in a way that mimics nature.

The Chatty River's physical, nutrient, and microbiological characteristics were assessed through water quality sampling and historical data review to identify pollutant hotspots. The high mean dissolved inorganic phosphorus (DIP concentrations, in the form of orthophosphate, indicate eutrophic and hypertrophic conditions in most sections of the Chatty River. The mean nitrogen concentrations, in the form of dissolved inorganic nitrogen (DIN), on the other hand, were below the eutrophic threshold in most sections of the Chatty River. Microbiological pollutant analysis indicated high gastrointestinal health risks to any residents in the catchment who utilised the water for domestic and recreational use.

Overall, no consistent relationship was established between pollutant concentrations and rainfall. This could possibly be because of point pollution. The extent of pollution highlighted by the water quality sampling (Table 1) indicated the need for mitigation measures.

Table 1: Summary findings of the Chatty River Catchment water quality analysis

Pollutant parameter	**Maximum concentration**	**Mean concentration**	**Minimum concentration**
DIP (mg $ℓ^{-1}$)	0.64 ± 0.23	0.37 ± 0.22	0.02 ± 0.01
DIN (mg $ℓ^{-1}$)	5.57 ± 5.03	2.61 ± 0.97	2.02 ± 0.82
TSS (mg $ℓ^{-1}$)	87.7 ± 84.5	32.0 ± 25.7	12.8 ± 6.6
E.coli (cfu/100 m ℓ)	11 000 000	1 940 000	239

Hydraulic and hydrological models were constructed in PCSWMM, a stormwater management modelling software developed by Computational Hydraulics International (CHI) using the USEPA SWMM model as the ‘engine.’ Both the Chatty River Catchment as a whole, as well as the Bethelsdorp River sub-catchment located within the Chatty River Catchment, were modelled to test the potential benefits of SuDS inclusion. Various scenarios were tested including: the current situation (‘As-is’); the likely Pre-Development situation representing the state before the influence of anthropogenic activities; and various retrofitted SuDS interventions. DIN, DIP, and total suspended solids (TSS) were the pollutant indicators tracked in the model. DIN and DIP were used to assess the risk of eutrophication.

TSS is a good measure of pollution as pollutants such as heavy metals attach to suspended particles. The SuDS interventions included: a constructed wetland, a retention pond, and various infiltration practices. Six scenarios (Table 22 and Figure 2), were explored, including various individual interventions, some regional controls and finally, the combination of all the interventions.

Pollutant reduction from the different scenarios ranged from 13-80% (Figure 3). Restoring the wetlands appeared to offer the most significant impact with a mean reduction of 30%. However, a combination of all the interventions had the highest pollutant removal when functioning efficiently of 72% and 80% for DIP and TSS, respectively. This is within the range of treatment required by the City of Cape Town (2009) *Management of Urban Stormwater Impacts Policy* which was used in the absence of a Gqeberha-specific guideline. Installing a treatment train of multiple SuDS interventions is seen as the most effective strategy to adequately improve water quality in the catchment to meet the standards presented by various guidelines.

Table 2: Summary of SuDS scenarios

Scenario	SuDS Intervention	Aim
Scenario 1	Constructed wetland	Addition of a wetland in an existing ponded open area to reduce the pollutant load in the catchment's middle reaches of the urbanised area.
Scenario 2	Restored wetlands	Restoration of channelled valley-bottom wetland areas, altered in shape, size and functioning due to urbanisation.
Scenario 3	Retention Pond	Utilisation of open space beside the outlet point for water quality improvement before water enters the main river channel.
Scenario 4	Infiltration Practices	Management of runoff as close to the source as possible and at the neighbourhood level. Source and local controls which reduce pollutant load through the infiltration of runoff, for example, soakaways, bioretention areas, filter strips, permeable pavements, and infiltration trenches, were simulated.
Scenario 5	Regional controls	Combination of Scenarios 1,2, and 3 to evaluate the management of pollutant load in the large catchment through regional controls.
Scenario 6	All the interventions	Application of a treatment train, complete with source, local and regional controls.

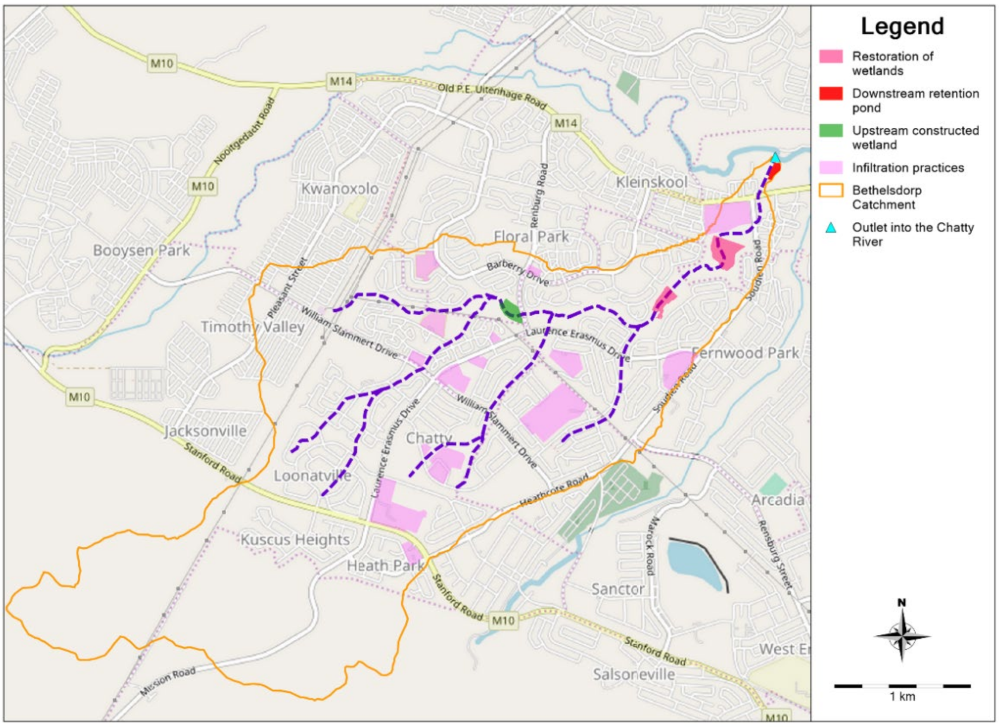


Figure 2: Proposed SuDS interventions in the Bethelsdorp River sub-catchment

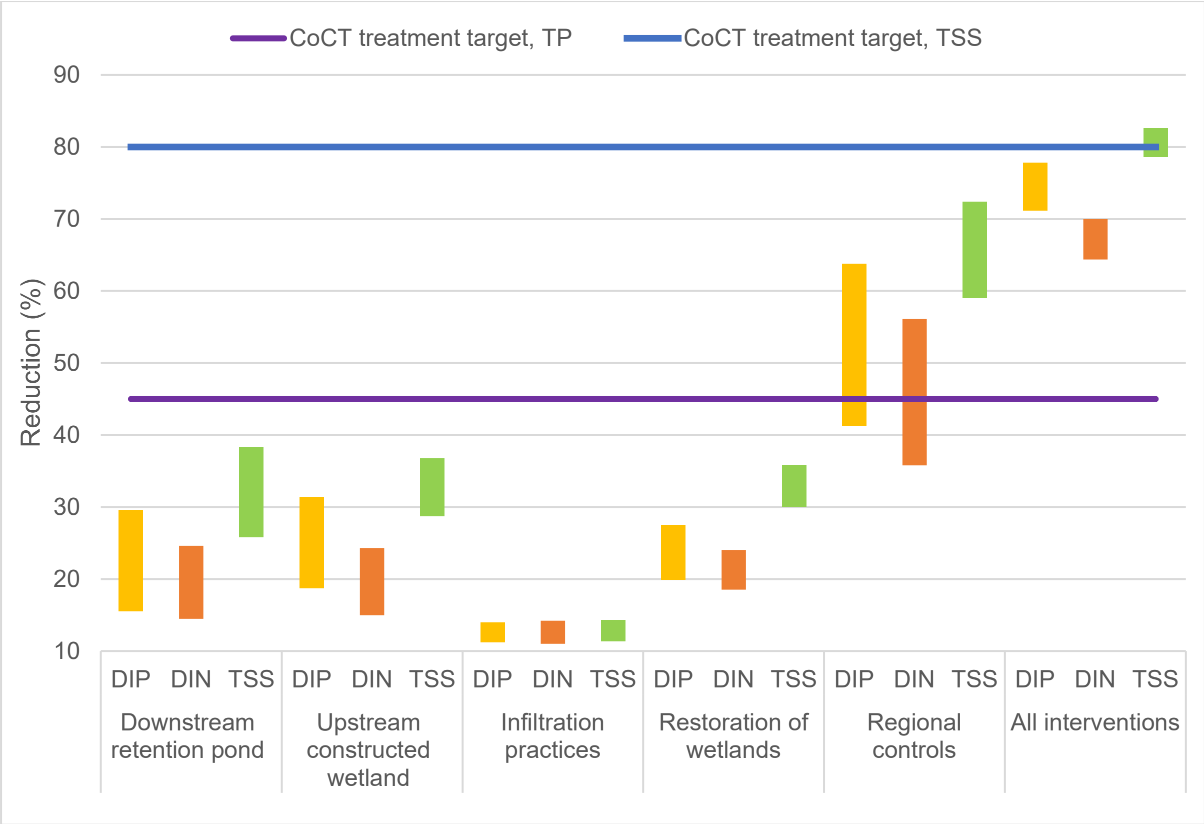


Figure 3: Indicator removal percentages over the 9.5-year modelling period

Thandi Mmachaka 2022
Smart catchment management and application in the Swartkops River and Estuary. PhD thesis, Botany Department, Nelson Mandela University. 276 pp. (Supervisors: Prof Bernadette Snow & Prof Janine Adams)

The influence of urbanisation and industrialisation on natural resources results in complex water resource management. In South Africa, there has been escalating rural-urban migration, a growing population in urban areas, and the mushrooming of informal settlements in cities over the last five decades. In the pursuit of protecting water resources, these contextual realities create a significant challenge to policymakers, planners, and implementers. Due to rapid population growth, climate change, recent droughts, and growing competition among agricultural, industrial, commercial, environmental, and domestic sectors, water resources are presently under severe stress in South Africa. This situation necessitates the effective management of water resources.

This study completed a situational assessment for the Swartkops Catchment to examine the extent of pollution, mapped sources of pollution, investigated water quality governance, and identified hot spot areas to provide the foundation for effective and efficient catchment management. To determine the current water quality status of the Swartkops Catchment, this current study investigated spatial and temporal variation in physico-chemical parameters, nutrients, and faecal bacteria. This study applied a mixed-method research design using semi-structured interviews and focus group discussions as data collection methods to investigate the water quality governance of the Swartkops Catchment. Following the situational assessment of the Swartkops Catchment, the effectiveness of applying innovative smart catchment practices to improve water quality was investigated. The word “smart” in this context refers to innovative mechanisms that will ensure effective and efficient water resources management. The PHP scripting language (Hypertext Preprocessor), Android studio, Wampserver, and JavaScript were used to develop the Water Use Screening System (WUSS) and Pollution Incident Reporting System (PRS).

In South Africa, stormwater infrastructure suffers from unsustainable utilisation. Stormwater systems discharge into many of the country’s rivers and estuaries, including Swartkops, leading to water quality degradation. To improve the Recommended Ecological Category (REC) of the Swartkops Estuary to Category C, drivers that contribute to poor water quality must be understood to inform appropriate management interventions. Results from sampling in Markman Canal were compared with historical water quality data. The present study showed that the Markman Canal contributed faecal bacteria, nutrients, and trace metals to the Swartkops Estuary. The Markman Canal was the greatest source of trace metals to the Swartkops Estuary compared to the other point sources entering the estuary. The results show that arsenic and mercury levels in the Markman Canal and the Swartkops Estuary were higher than that previously measured. Iron and copper concentrations were higher in the Markman Canal, whereas only copper increased in the Swartkops Estuary.

The results further showed increasing trends in nutrient concentrations especially in the middle reaches (near Despatch) of the Swartkops River due to stormwater discharges and effluent from the WWTWs and the Brak River (i.e. subject to KwaNobuhle WWTW discharges). Faecal bacteria counts remain high in the river and estuary showing no improvement since earlier studies. As a result, faecal bacteria and nutrients continue to harm the Swartkops Catchment's ecological functioning and health. Stormwater outlets discharging into the Swartkops River and Estuary have been identified as the greatest sources of pollution in the catchment. The study identified unlawful water use activities that are likely to impact or contribute to the deteriorating water quality in the Swartkops Catchment. Those included abattoirs in the middle reaches of the catchment.

The results revealed that water quality governance of the Swartkops Catchment is considered weak and can thus be considered unsuccessful and an indication of failure when assessing the current catchment management practices discussed with the participants. Stakeholders are not aware of the catchment managers responsible for water quality management. They are also not aware of the protocol or where to report pollution incidents. This is a concern because the regulators do not have a tool that reports pollution incidents and rely on the water users to report such incidents as and when they occur. As water users are not aware of the correct protocol for reporting pollution incidents to the appropriate department, these are not effectively addressed and enforcement actions that inform transgressors to take rectification measures do not occur.

The WUSS and PRS were successfully applied and tested with participants who found the Decision Support System (DSS) to be user-friendly, easy to navigate, and met the intended purpose. The WUSS offers regulators and water users in South Africa a novel system to screen water use activities and to sensitise water users on water use requirements in terms of the National Water Act of 1998 (Act No. 36 of 1998) to curb unlawful water use activities. The PRS provides an effective platform for reporting pollution incidents to efficiently implement Section 19 of the National Water Act, 1998 (Act No. 36 of 1998) that addresses pollution prevention.

The data indicate the necessity for remedial actions to reduce the pollutants loads to protect and manage the Swartkops Estuary. The present study applied the biomimicry concepts comprising of Sustainable Drainage System (SuDS) options to design and implement a treatment train to manage industrial runoff water from the Markman Canal that was identified as the greatest source of trace metals to the Swartkops Estuary. The SuDS treatment train employed in this study comprised sedimentation, filtration, bioremediation, and plant uptake treatment options. The findings showed that on average, the SuDS treatment train reduced total suspended solids concentrations by 83%, nutrient concentrations by 80%, trace metals by 70%, and faecal bacteria by 80%. The SuDS treatment train was effective in managing polluted stormwater and the treated wastewater could be reused for irrigation purposes. The use of SuDS is recommended as a potential management option to treat industrial wastewater due to relatively high sediments, nutrients, trace metals and organic matter removal efficiency.

This study made an original contribution to the knowledge field by addressing smart catchment management and application in the Swartkops catchment. Decision support tools were developed for stakeholders to report pollution incidents and query water use license applications. Innovative methods for water quality improvement were identified. This is the first study in the country to design and test a SuDS treatment train for the reduction of pollution inputs into an estuary. These findings have been integrated in the Department of Water and Sanitation management practices and assist with the implementation of the Swartkops Estuary management plan. Recommendations were made for improved water quality monitoring and governance.

Marele Nel 2022

Seasonal changes of metals in the salt marsh and seagrass beds of the Swartkops Estuary. MSc Dissertation, Department of Botany, Nelson Mandela University, South Africa. 151 pp. (Supervisors: Dr Lucienne Human, Prof Janine Adams & Dr Gletwyn Rubidge)

Estuaries are historically convenient places to build industries, as it was deemed a suitable place to dispose of large quantities of urban and industrial waste into the ocean. At the time it was judged to be appropriate, as rivers can transport and deposit waste into the ocean, which was considered so vast that it is insurmountable. Therefore, metal pollution in estuaries is a well-known occurrence. Coastal wetlands play an important role in the cycling of metals, and act as effective metal sinks. They provide an important ecosystem service acting as accumulators and phytostabilisers, which make toxic levels of the metals unavailable to the rest of the food chain. The overall aim of this study was to assess the metal pollution in the salt marsh (*Salicornia tegetaria* and *Spartina maritima*) and seagrass (*Zostera capensis*) of the heavily developed Swartkops Estuary. Assessing the metals in the estuary will provide information on effective environmental management strategies. Metal concentrations were measured in the rhizosediment of the three wetland plants, bare sediment, and in the tissues (leaves, shoots, and roots) of the selected plant species. Sampling occurred during one seasonal cycle (2019-2020), and in 5 sites along the middle and lower reaches of the estuary.

Metal concentrations were not the highest closest to the point sources in the middle reaches, but the metals rather accumulated downstream in Site 3 (Tiger Bay launch site close to the WwTW) and Site 4 (Tippers' Creek), which were depositional sites. Although these two sites generally displayed the highest metal concentrations, they also had the most seasonal fluctuations in their metal concentrations and sediment characteristics. Flushing events in spring/summer were likely the determining factor of these fluctuations. The mouth of the estuary (Site 5) consistently had much lower metal concentrations, with distinctly more sandy, low organic content sediment, due to marine-influenced flushing.

Thus, spatial differences were distinct in the estuary, however seasonal differences did not play an important role in the metal concentrations, indicating that seasonal sampling was not as important as sampling in different sites. Assessing the metal concentrations in different rhizosediment gave important insights on intertidal accumulation and contrasted with the unvegetated (bare) sediment. The metals generally accumulated more, higher up the intertidal range, due to less frequent tidal inundation and flushing — so that metal accumulated in the vegetation in the following order: *Z. capensis* > *S. maritima* > *S. tegetaria.*

Moreover, unvegetated (bare sediment) showed much lower metal concentrations compared to the rhizosediment, indicating that the vegetation trapped small particles, and changes the physical environment to concentrate metals in their rhizosphere. Lastly, the plant species all displayed good accumulation of metals in their roots, while *Z. capensis* also showed remarkable uptake to its leaves. The study identified *S. maritima* and *S. tegetaria* as good phytostabilisers, particularly the latter with its high metal stocks and slow root turnover rate. The compartmentalisation in these plants were unique to each species, corroborating previous assessments that compartmentalisation cannot be compared between similar life forms and genera.

These results contribute to local and international research on biogeochemistry in wetlands, and assessment of pollution in developed estuaries. Of note is *Z. capensis,* an endemic Southern African species, which has not been analysed for compartmentalisation of metals before. All three of the studied species have potential as metal accumulators, and therefore a sink of metals. They localise the metals, limiting bioaccumulation to the rest of the food chain, which reduces the ecotoxic effect of metals in the environment. Higher accumulation in vegetated (rhizosediment) over bare sediment, make these habitats valuable metal sinks. This increases their importance in estuaries receiving high pollution loads, and they should be prioritised in conservation efforts. Two sites within the Swartkops Estuary, Tippers'

Creek (Site 4) and the Launch Site (Site 3), are potential sites for long-term monitoring due their capacity to trap and accumulate metals. The results of this study will inform local management on the state of metals in the Swartkops Estuary, providing crucial information on the importance of preserving local wetlands for the purpose of regulating toxic levels of metals in the ecosystem.

Priscah Lakane

MSc submitted for examination. Quantifying nutrient storage capacity of invasive aquatic plants in the upper Swartkops Estuary (Supervisors: Prof Janine Adams & Dr Daniel Lemley)

The water quality in the Swartkops Estuary has been measurably changed by the long-term stress caused by anthropogenic inputs from upstream wastewater treatment works that introduce high levels of nutrients into the system. These nutrient loads promote the growth of invasive alien aquatic plants (IAAPs), including water hyacinth (*Pontederia crassipes*) in the upper reaches of the estuary. Priscah Lakane is investigating solutions to mitigate the effects of increased nutrient inputs into the estuary by measuring the nutrient storage capacity of water hyacinth and, subsequently, proposing solutions to improve the water quality inputs to the estuary. Water hyacinth was collected at the upper tidal limit of the estuary (Perseverance) at different temporal scales (i.e. weekly, and monthly). Aerial images were used to map the cover of IAAPs on each sampling trip, while the collected hyacinth samples were sorted into leaves, stems and roots to determine total phosphorus (TP) and total nitrogen (TN) concentrations.

The results show that *P. crassipes* accumulates at Perseverance with increasing flow. Average plant nutrient concentrations indicate relatively consistent TP levels during the high (0.31 ± 0.24 g m^{-2}) and low flow season (0.29 ± 0.16 g m^{-2}). Conversely, average TN concentrations were greater (0.75 ± 0.48 g m^{-2}) during low flow periods compared to the high flow season (0.58 ± 0.54 g m^{-2}). Additionally, tissue nutrient concentrations were highest in the stems compared to other plant parts. From a temporal perspective, water hyacinth displayed maximum cover (>30% of water surface) and nutrient storage (TN and TP > 650 kg) during the summer months at Perseverance. The study showed how water hyacinth can be used as a phytoremediator to take up nutrients before they enter the estuary.

Emily Whitfield 2022

Uptake and storage of nutrients by primary producers in the Swartkops Estuary. MSc dissertation, Department of Botany, Nelson Mandela University, South Africa. pp. 120. (Supervisors: Dr Daniel Lemley & Prof Janine Adams)

Estuaries occur at the interface between the terrestrial and marine environment and as such act as the last 'filtering' mechanism prior to nutrient pollution entering the adjacent ocean. This study focused on the Swartkops Estuary which is eutrophic and requires the removal of nutrients. The role of phytoplankton as nutrient filters and storage of nutrients by seagrass and salt marsh was investigated.

This study found that phytoplankton temporarily took up a large percentage of dissolved inorganic nitrogen (max. 99%) and dissolved silica (max. 76%) and limited amounts of dissolved inorganic phosphorus (max. 18%). The amount of carbon, nitrogen and phosphorus stored by the salt marsh species *Spartina maritima* and *Salicornia tegetaria* and the seagrass species *Zostera capensis* were determined. It was found that the salt marsh grass *Spartina maritima* stored the most nutrients (149.61 ± 16.59 N g m^{-2}; 105.44 ± 13.41 P g m^{-2}; 1690.52 ± 168.90 C g m^{-2}), while for the salt marsh succulent *Salicornia tegetaria* less nutrients were stored (27.01 ± 4.17 N g m^{-2}; 22.97 ± 3.21 P g m^{-2}; 458.66 ± 69.43 C g m^{-2}). *Zostera capensis* also acted as a nutrient store (22.17 ± 6.94 N g m^{-2}; 23.75 ± 4.70 P g m^{-2}; 221.10 ± 26.74 C g m^{-2}). The macrophytes were able to store nutrients for longer periods and thus prevent these nutrients from being exported into the adjacent ocean. On the contrary, phytoplankton uptake was temporary as the nutrients are released once the bloom decays. Without intervention there will be an increase of harmful algal blooms (HABs) and fish kills in the eutrophic Swartkops Estuary. Nutrient input from upstream wastewater treatment works, canals and stormwater run-off must be reduced. Conservation and management of the seagrass and salt marsh habitats is needed to ensure the long-term storage of nutrients.

Saudiqa Benjamin 2022
Changes in multi-decadal waterbird biodiversity and abundance on the Swartkops Estuary: a case-study of saltpan restoration. Zoology Department, Nelson Mandela University, South Africa. 45 pp (Supervisors: Dr Gavin Rishworth, Prof Janine Adams & Dr Paul Martin)

In the face of natural wetlands deteriorating, artificial wetlands can serve as alternative breeding, foraging, and roosting habitats to waterbirds. Saltpans as artificial wetlands have become valuable habitats to waterbirds. Saltpan sites (Redhouse and Bar None) of the Swartkops Estuary are historically known for being important sites for waterbird species. The Redhouse saltpan was rewetted while Bar None remains inactive. This study investigated the changes in waterbird biodiversity and abundance and associated changes in land cover using a multi-decadal dataset corresponding to three ecosystem states of saltpan operation, decommissioning and rewetting at the Swartkops saltpans, Eastern Cape. Results of the study showed a decline in waterbird abundance following saltpan decommissioning and an increase in abundance when the Redhouse saltpan was rewetted with freshwater. The study revealed a change in community and habitat composition as freshwater depth increases and salinity decreases, facilitating a shift in community from shallow water preferred groups (i.e. waders) to deep water preferred groups (i.e. diving birds). Management recommendations are provided as findings suggest a more controlled hydrological regime aimed at accommodating a more diverse waterbird community.

Vusumzi Tsipa 2022
Developing a socio-ecological framework for the restoration of estuaries using the Swartkops Estuary as a case study. MSc Dissertation. Department of Botany, Nelson Mandela University, South Africa. 172 pp. (Supervisor: Prof Janine Adams)

Marine ecosystems are experiencing intensive deterioration in ecosystem health globally due to anthropogenic factors. Development of residential areas and industries, agriculture, erosion, and sea level rise are all factors contributing to this deterioration. This is a concern as estuaries are ecologically important systems that support and maintain a diverse range of flora and fauna while also providing humans with a diverse range of services. In trying to solve this problem, a socio-ecological system (SES) approach for estuary restoration is proposed in this study as conventional methods have proven to be ineffective. Conventional methods of restoration include focusing mainly on ecological processes or engineering-driven designs. The concept of socio-ecological systems is an important approach for managing natural resources as it emphasises that human populations and marine ecosystems are interlinked, and that interdependent relations should not be taken for granted when managing these ecosystems.

The aim of this study was to develop and test a socio-ecological systems framework for the restoration of estuaries in South Africa using the Swartkops Estuary as a case study. This necessitated a review of existing SES frameworks that have been developed for use in other disciplines. As part of the newly developed framework, the Swartkops estuary condition was assessed using the Estuary Health Index to understand the present ecological state (PES) of the estuary following from the last assessment done in 2013/2014. The Estuary Health Index is a nationally accepted method of measuring the health of South African estuaries. The state of the societal system was assessed through field observations, engagements with estuary users on site, insights provided by the Zwartkops Conservancy and from recent literature. The potential for restoration of habitats for the purpose of carbon storage was also assessed as part of this study. Suitability of disturbed habitats for stimulating future salt marsh growth was investigated since an important incentive for restoration is blue carbon storage. This is important as blue carbon ecosystems offer a great potential as a climate change mitigation measure through their ability to sequester carbon. This was done through evaluating plant cover and sediment characteristics at sites along the length of the estuary representing disturbed and undisturbed areas.

The estuarine health score for the Swartkops Estuary was found to be 47 out of 100 translating to a PES Category D (largely modified estuary). The main problem in the estuary is water quality along with habitat loss and resource exploitation. The three Wastewater Treatment Works (WWTWs) located upstream of the estuary are the main drivers behind the decline in estuary health in addition to other threats to the water quality which are stormwater run-off inputs from the Motherwell canal and Markman canal. This study showed that the health of the estuary is on a negative trajectory towards a largely degraded estuary. Fishing, bait collection and the use of spiritual sites are the dominant ecosystem services used at the estuary. Through the assessment of the state of the societal system, the estuary was highlighted to be a major food source for many people living close to the estuary through subsistence fishing and bait collection for selling to recreational fishers. The estuary is also a health hazard to the very same people that depend on it for survival because of the poor water quality particularly high metal inputs from past and present nearby industrial activities. Restoration plans need to be developed in consideration of the estuary status quo that includes the societal system and the ecosystem services provided by the estuary.

Removing wastewater input to the estuary from the river, adding water to the Redhouse salt pan, restoring riparian habitat by removing alien vegetation, reducing fishing pressure and reducing bait collection pressures were identified as priority restoration activities needed at the Swartkops Estuary. From the assessment of restoration of salt marsh for carbon storage, disturbed areas in the supratidal salt marsh habitat were not significantly different from the undisturbed in terms of carbon storage. The

disturbed plots were found to be unsuitable for salt marsh growth due to hypersalinity and remedial actions will need to be taken for future salt marsh growth to occur. Lastly, the restoration framework for the Swartkops Estuary was constructed.

The SES framework developed as part of this study suggests that feasible restoration actions need to be identified for the Swartkops Estuary. This can be done based on an SES conceptualisation of the estuary, ease of implementation and available budget. These plans then need to be communicated with all the relevant stakeholders including community and estuary users. Implementation of restoration plans in conjunction with the implementation of the Estuary Management Plan will lead to improved ecosystem service delivery and simultaneously improving societal health. Monitoring and engagement with stakeholders need to continuously occur throughout the restoration process. This research is timely considering that we are in Decade of Ecosystem Restoration (2021-2031) according to the United Nations. Research of this nature will also help achieve various objectives of the sustainable development goals.

Lastly, implementation of the restoration framework in estuaries can form a precursor to a ‘Working for Estuaries’ programme where resources can be directed towards improving the health of estuaries in a realistic and sustainable manner where all relevant stakeholders work together. Employing a SES framework for the restoration of estuaries helps managers and policymakers to keep in mind that environmental management decisions have the potential to alter not just the ecological components of the system, but also the supply of ecosystem services, and hence the human benefits associated with them.

Johan Wasserman 2021

Recreating a wetland at an abandoned saltworks: towards a rehabilitation plan. MSc Dissertation. Department of Botany, Nelson Mandela University, South Africa. pp. 141. (Supervisor: Prof Janine Adams)

A saltworks at Swartkops Estuary was abandoned in 2018. While operational, the saltworks hosted some of the largest breeding colonies of several shorebird species in southern Africa and hosted thousands of Palearctic migrant waterbirds annually. The abandonment of the saltworks has resulted in the loss of the artificially managed hydrological regime and therefore the wetland function and habitat value of the site, and the rich and diverse avifauna that once occurred at the site have not returned. The rehabilitation of the saltworks as a wetland that functions as a waterbird sanctuary is currently being organised, and this research aimed to create a plan for implementing and monitoring the rehabilitation. In order to do so, the baseline environmental condition of the abandoned saltworks was established, the possible rehabilitation interventions necessary for rehabilitating the site were assessed, and the potential ecological implications of any interventions were investigated.

The assessment of the saltworks' baseline condition revealed that the site is now characterised by vast expanses of dry hypersaline sediment with sparse patches of monospecific vegetation and depauperate avifauna. The once rich and diverse birdlife will not return if the site remains dry, and the reinstatement of a managed hydrological regime is necessary to rehabilitate the area as a sanctuary for waterbirds. Furthermore, it is unlikely that vegetation will cover the area due to the high concentration of salts in the sediment, thus the area will remain barren if no rehabilitation action is taken.

Two potential rehabilitation options for reinstating a hydrological regime at the saltworks were identified: (1) pumping estuary water into all of the saltpans; or (2) pumping estuary water into some of the saltpans, while allowing the largest one to be filled with stormwater. Both options were deemed to be feasible; however, the second option will likely have lower running costs. The use of stormwater to fill the one saltpan is expected to result in brackish conditions initially, while the saltpans filled with estuary water would have salinity levels ranging from euhaline to slightly hypersaline. Both the stormwater and estuary water are rich in inorganic nutrients – the estuary water is rich in both dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP), while the stormwater has an exceptionally high DIN content. This raised concerns of creating eutrophic wetlands with detrimental conditions such as algal blooms and a hypoxic water column.

A microcosm experiment investigating the response of the dry hypersaline sediment to inundation with either stormwater or estuary water revealed that initially eutrophic conditions with phytoplankton blooms (accounted for by the proliferation of diatoms) and a turbid water column can be expected if the saltpans are inundated with either water source. The bloom was most notable in a stormwater treatment with the highest total oxidised nitrogen (NO_x) concentration. However, in both the stormwater and estuary treatments, these blooms collapsed within a week of being recorded after depleting the nutrients from the water column. Within two more weeks, the water column became clear and primary production was mostly accounted for by microphytobenthos (MPB) and submerged macrophytes (*Ruppia cirrhosa*). This oligotrophic, benthically-driven regime with a clear water column persisted until the end of the experiment.

However, one of the replicate tanks with estuary water persisted in a turbid state due to a *Tetraselmis* sp. bloom throughout the study, suggesting that phytoplankton blooms are more likely to occur if estuary water is used to fill the saltpans. However, as it will be required to repeatedly fill the saltpans with nutrient-rich water to maintain water levels, recurrent phytoplankton blooms may occur. It is therefore expected that the rehabilitated saltpans might cycle between a regime characterised by a turbid water column with phytoplankton as the dominant primary producers while the saltpans are being filled with water, and a clear water-benthically driven regime once the blooms collapse.

Lastly, there was no evidence suggesting that potentially harmful algal bloom (HAB) forming species would proliferate at the saltpans using either water source.

As the use of stormwater to fill the Redhouse saltpan would have lower maintenance costs, and are not expected to cause any ecological damage, the second rehabilitation option was recommended. These research findings were used to develop a plan for rehabilitating the saltworks. The plan established a vision and relevant ecological targets, as well as recommendations for implementing the rehabilitation and managing the site. Finally, a monitoring plan was developed, and the Society for Ecological Restoration's Five-Star system was adapted for evaluating the success of this project over time.

APPENDIX 5: WORKSHOP OVERVIEW - INNOVATIVE METHODS FOR ESTUARY WATER QUALITY IMPROVEMENT

11 November 2020 from 09:00-11:45

WORKSHOP RECORDING AVAILABLE https://youtu.be/-

The workshop was held virtually via *Zoom* on Wednesday the 11th of November 2020. The workshop was attended by 59 participants from various academic (NMU, RU, Wits, and UFS) and non-academic organisations (e.g. CSIR, DEA, DEDEA, DEFF, DWS, Isidima, Ministry of Fisheries of Namibia, SAIAB, SANBI, SAEON, and the Zwartkops Conservancy). The presentations and discussion focussed on methods to improve the water quality of South African estuaries, using the Swartkops Estuary as a case-study. A summary of the workshop participants is provided in Table 15.

Prof. Janine Adams presented the introduction of the workshop, elaborating on the context of the workshop and its relevance to the Swartkops Estuary. She described the Swartkops Estuary, the current studies being conducted in the area, and the various pressures on the estuary. Dr Farai Tererai (Department of Environment, Forestry and Fisheries) followed with an overview of the Working for Wetlands programme. He elaborated on the restoration methods used in various inland wetland systems and the work conducted in the catchment areas of several estuaries nationally. Mr Jonny Harris (Isidima) introduced various biomimicry approaches with the potential to alleviate the pressures on aquatic systems and that could be applied to the Swartkops Estuary.

Subsequently, Prof. Neil Armitage (University of Cape Town) discussed Sustainable Drainage Systems (SuDS) and the specific ways that urban drainage could be enhanced to ultimately improve the water quality and quantity of urban runoff. Ms Thandi Mmachaka (Department of Water and Sanitation) discussed the importance of smart catchment management and the implementation of a SuDS treatment train for the runoff flowing into the Swartkops Estuary from the Markman Canal. This was followed by a presentation by Prof. Paul Oberholster (University of Free State) on algal pond wastewater treatment and its application at treatment plants in South Africa. Finally, Dr Nelson Odume (Institute for Water Research, Rhodes University) highlighted the need for urgent action in urban catchments and the main governance issues and solutions to effectively manage urban estuaries. The session was concluded by Prof. Susan Taljaard (CSIR) who summarised the presentations and discussions.

NRF National Research Foundation | SAEON South African Environmental Observation Network | NELSON MANDELA UNIVERSITY SARChI Chair Shallow Water Ecosystems | science & innovation Department: Science and Innovation REPUBLIC OF SOUTH AFRICA

CMR Coastal and Marine Research | CSIR our future through science | ZWARTKOPS CONSERVANCY Protecting Our Estuary

WATER RESEARCH COMMISSION

WATER RESEARCH COMMISSION WORKSHOP
INNOVATIVE APPROACHES FOR ESTUARY WATER QUALITY IMPROVEMENT

WRC PROJECT C2020/2021-00076

Date: 11 November 2020
Time: 9:00 – 11:45

Zoom link

https://mandela.zoom.us/j/92313607523?pwd=MnhVRm1yNm5BTnhEVFJCT0dqUm45dz09

RSVP : Carla.dodd@mandela.ac.za

Please join us in a workshop/discussion on innovative methods for water quality improvement in estuaries. The National Biodiversity Assessment showed that South Africa's estuaries are under severe pressure and that improvement of water quality as a key intervention would lead to significant improvement in estuary health and associated benefits that society derive from them. Experts will present on different approaches for water quality improvement. The specific study site will be the Swartkops Estuary and background documents can be found at https://www.dropbox.com/sh/oi1jthlqghvt26s/AAAEE25hwf38bKfz6TLZXhVEa?dl=0. This workshop will provide input to the development of a socio-ecological systems approach for estuary restoration – aligned with the UN decade of ecosystem restoration (2021-2030).

PROGRAMME

TIME	TOPIC	PRESENTER
9:00	Welcome Overview, Objectives, Study Site	Janine Adams (Nelson Mandela University)
9:20	Department of Environment, Forestry & Fisheries: Short and Medium Term Restoration Approaches for Estuaries	Tererai, Beetge, Bahadur (DEFF)
9:40	Department of Water and Sanitation: Innovative Approaches for Water Quality Improvement	Thandi Mmachaka (DWS)
10:00	Biomimicry Approaches	Jonny Harris (Isidima)
10:20	Sustainable Urban Drainage Systems	Neil Armitage (UCT)
10:40	Algal Ponds	Paul Oberholster (UFS)
11:00	Governance, Monitoring and Improvement of Catchment Inputs	Nelson Odume (Rhodes and IWR)
11:20	Conclusion	Susan Taljaard (CSIR)
15 min presentations + 5 min questions		

Table 13: List of workshop participants, contact details and affiliations.

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Short presenter biographies

Prof. Janine Adams is a researcher at the Nelson Mandela University where she holds the national SARChI in Shallow Water Ecosystems, she is also the deputy director of the Institute for Coastal and Marine Science (CMR). Her research interests are in estuary conservation and management. Prof. Adams has published over 165 journal articles, as well as a number of book chapters and she actively collaborates with partners from Australia, the UK, France, Mozambique, Tanzania and Portugal.

Dr Farai Tererai is the Deputy Director at the DEA, specialising in planning, monitoring and evaluation of wetland conservation projects. He obtained his honours and MSc degrees at the University of Zimbabwe and completed his PhD (Plant Ecology) at Stellenbosch University. He worked as a research hydrologist and monitoring and evaluation officer in Zimbabwe, and after his PhD he worked at the Agricultural Research Council and African Climate and Development Initiative.

Mr. Jonny Harris is a civil engineer and environmental manager with over 15 years of experience in SA and UK water sectors. He is the founder and director of Isidima Design and Development. Isidima's focus is on efficient sanitation and wastewater treatment systems, currently working on various projects that collaborate with the urban poor to alter the landscapes of informal settlements through the delivery of sanitation and greywater management systems.

Prof. Neil Armitage is a researcher and lecturer in the Department of Civil Engineering at the University of Cape Town. He is also the Deputy Director of the "Future Water" research institute at UCT. His research interests include urban drainage, specifically sustainable drainage systems (SuDS) and stormwater harvesting as an additional supply of water, as well as Permeable Interlocking Concrete Pavements (PICP), stormwater quality improvement, water sensitive design and informal settlement drainage.

Ms. Thandi Mmachaka works at the South African Department of Water and Sanitation, specifically in water quality management. She is a PhD candidate at the Nelson Mandela University and her research focusses on smart catchment management and application in the Swartkops River catchment.

Prof. Oberholster is the director of the Centre for Environmental Management at the University of the Free State. His research expertise is on limnology, ecotoxicology, integrated water resource management, and water ecosystem services. He has over 20 years' experience in wetland restoration, wastewater sludge management, reuse and treatment.

Dr Oghenekaro Nelson Odume is a senior researcher at the Rhodes University and director of the Unilever Centre for Environmental Water Quality, Institute for Water Research. His research expertise is in sustainable freshwater resource management, specifically by developing integrative and multi-criteria tools for water quality monitoring and management to assess anthropogenic influences on water resources.

Prof. Susan Taljaard is a principal researcher at the CSIR and an adjunct professor at the Nelson Mandela University. Her research speciality is on aquatic biogeochemistry (water quality) and coastal systems processes and their response to global change pressures. Her research develops and applies to coastal water quality and integrated coastal management plans and best practice guidelines, as well as the development and application of management policies and methods for estuaries.

Presentations overview

1. Introduction - WRC Workshop 11 November: Innovative Approaches for Estuary Water Quality Improvement

Name of Speaker: Prof. Janine Adams

Take Home Message: Increasing pressures on estuaries are deteriorating water quality and restoration interventions are needed to improve estuary health and the delivery of multiple ecosystem systems. By restoring, conserving, and practicing wise use of wetland and estuarine systems it is possible to achieve Sustainable Development Goals (SDGs). The Swartkops Estuary is used as a case study as it is an ecologically important system under the influence of various urban pressures (e.g. industrial waste, WWTWs, polluted stormwater, and invasive aquatic plants). Best practice from this study can be applied to other urban estuaries under similar pressures. Current studies on the Swartkops Estuary and catchment area includes nutrient studies for both the estuary itself, as well as at the Motherwell Artificial Wetland. Furthermore, research is being conducted on harmful algal blooms and restoration studies are underway regarding rehabilitation of the abandoned saltworks using stormwater inflow.

2. Short- and Medium-Term Restoration Approaches for Estuaries

Name of Speaker: Dr Farai Tererai

Take Home Message: The Working for Wetlands (WfWs) programme is currently operating mainly on inland wetland systems. However, there is a shift taking place to implement a source to mouth approach. The overarching aim of the programme is to improve water security and often by solving water quality issues, other objectives such as biodiversity improvement also fall into place without further interventions. The interventions of the programme are mostly "soft" and require less maintenance and are often much less expensive than the construction of hard structures previously applied. The WfWs programme has operated in eleven estuaries (mainly in the catchment areas), including but not limited to the Ramsar site, Du Mond, as well as other well-known systems such as St Lucia. However, estuary work requires specific knowledge and skill-sets not always available to the programme and therefore the short-term focus of the programme will be to focus on the catchment areas of the estuaries, while the medium-term focus will be to develop a strategic plan as informed by the National Biodiversity Assessment of 2018. The plan is to assess two estuaries every year based on a prioritisation model. In South Africa we have strength in monitoring but not evaluation of Restoration.

3. Biomimicry Approaches for Estuary Water Quality Improvement

Name of Speaker: Mr. Jonny Harris

Take Home Message: Biomimicry seeks to answer the question: "How do we design systems that not only do not hinder natural performance but also enhances systems to perform at their maximum potential?" This has been achieved both nationally and globally using wetland treatment systems. The benefits of using wetland treatment systems include reclaiming of water, which is especially important in the current climate of South Africa and water restrictions, as well as being passive systems that require little to no mechanical or energy inputs. Furthermore, it is cost-effective and can reduce the flows to WWTWs and stormwater canals while simultaneously providing opportunities to create urban gardens and/or farms.

4. Sustainable Drainage Systems (SuDS)

Name of Speaker: Prof. Neil Armitage

Take Home Message: A big issue of urban development is the hardening of runoff structures, in other words going from vegetated areas to residential/urban environments. As water flows from these hard structures it is not only being polluted by point sources but also diffuse sources. Sustainable Drainage Systems (SuDS) uses natural processes to maintain/control/improve the flow, quality, and amenity of rain and stormwater runoff, while promoting biodiversity. This can be achieved by four basic concepts namely 1) Good Housekeeping; 2) Source Controls (e.g. green/blue roofs); 3) Local Controls (e.g. swales and filter strips); 4) Regional Controls (e.g. wetland systems, detention and retention ponds). It is important to account for large floods when designing these systems and often bad practice is the result of a lack of resources and maintenance. Ultimately, it is not about one system in one place, but rather multiple systems in many places accompanied by the mind shifts of people.

5. Smart Catchment Management

Name of Speaker: Ms. Thandi Mmachaka

Take Home Message: Stormwater is a major contributor to the degradation of estuaries. Current interventions mainly focus on the quantity of stormwater flow, rather than the quality. Furthermore, the lack of early warning systems and tedious analyses for grab samples often result in delayed response times, by which time the system has already been degraded. Sustainable drainage systems have been applied as intervention methods, where on a municipal level the focus is on local and regional controls. A sustainable drainage treatment train was developed for the Swartkops Estuary making use of sedimentation, filtration, biodegradation, as well as phyto- and phycoremediation methods to remove pollutants. This treatment train aims to produce water that can be reused for gardening purposes. Alternatively, in the case of hard-structured canals, where water cannot be diverted for reuse, the treatment train aims to improve the water quality to comply with discharge limits. Furthermore, to address the lack of early warning systems *in situ* monitoring is taking place for parameters such as pH, conductivity and turbidity, while a mobile lab that measures heavy metals has been implemented in collaboration with Department of Environmental Affairs.

6. Low Cost Green Technology for Domestic Wastewater Treatment for Reuse and Beneficiation

Name of Speaker: Prof. Paul Oberholster

Take Home Message: Algal treatment ponds in South Africa are predominantly applied to micro, small and medium-sized WWTWs, which account for more than 60% of the national treatment plants and can treat flows of up to 10 ML/d. Algal technology also has the added benefits of not requiring electricity, harmful chemicals, or skilled labour to operate. In addition, it utilises existing infrastructure and specific algae consortiums. This is especially significant in countries like South Africa where operators and energy sources are often unreliable. After treatment, the algal biomass can be reused for example in gardening, or if the algae are removed from the systems via aquaculture the fish can be resold. This is being applied both in other African countries (e.g. Malawi), as well as nationally, for example at the Brandwacht plant, threshold limitations of microbial content was reached within six months. Furthermore, preliminary results indicate that the algal treatment also improves the groundwater underlying treatment plants with only soil underlayers and no hard structures.

7. Governance and Institutional Drivers of Water Quality in the Swartkops River Catchment

Name of Speaker: Dr Nelson Odume

Take Home Message: The Swartkops system has an urban catchment that requires urgent action. The main governance obstacles for effectively managing the system are: 1) lack of a systems view of the water train (i.e. drinking water infrastructure is prioritised over WWTWs) with little understanding of the interconnection; 2) lack of clear roles, responsibility and accountability during emergencies; 3) short term economic agendas are prioritised over long term environmental agendas; 4) silo operation, systems and mindsets; 5) over-centralised top-down governance; 5) inadequate human capacity. Solutions to these issues includes: 1) strengthening the science-policy-society linkage; 2) mainstream planning across administrative scales; 3) establish participatory/cooperative platforms monitoring and regulatory instruments. For effective management and governance there is a need to think beyond the environment and create inclusive, multidisciplinary pathways to achieve restoration goals.

8. Conclusion - WRC Workshop 11 November: Innovative Approaches for Estuary Water Quality Improvement

Name of Speaker: Prof. Susan Taljaard

Take Home Message: Presented within this workshop are various innovative solutions to major water quality issues. It is important to note that successful national programmes, such as Working for Wetlands can be extended to include estuaries. On the other hand, solutions can also originate at a household scale as seen through the various options of SuDS. An alternative point-source treatment option is presented by biomimicry, which also has tremendous restoration potential. In the face of coastal development, source treatments including algal pond and sustainable technologies will become increasingly important. However, effective management can only be achieved by breaking down silo systems-thinking and forming multidisciplinary work groups.

YouTube site for workshop recording

The workshop was recorded and uploaded to the Mandela Estuarine Ecology YouTube Channel. The presentation recordings can be viewed at the following link:
https://youtu.be/-qpThArk218

APPENDIX 6: DRAFT DISCUSSION DOCUMENT

Restoration case studies towards the development of a National Estuarine Restoration Programme (submitted to Umesh Bahadur, Director Working for Wetlands, DFFE – August 2021)

CSIR
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UNIVERSITY

DRAFT DISCUSSION DOCUMENT

Restoration case studies towards the development of a National Estuarine Restoration Programme

AUGUST 2021

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1. Introduction to South African estuaries

Estuaries are "super" ecosystems. Although they comprise less than 2% of South Africa's territory, these highly productive ecosystems contribute R4.2 billion per annum to the South African economy. They are focal points for development, tourism and recreation, as well as important for supporting biodiversity, livelihoods and marine fisheries. However, the development in estuaries and their catchments has come at a cost of about R700 million per annum in terms of lost fishery benefits as well as unknown costs to society from the overexploitation of resources and loss of biodiversity. This has reduced the diversity of benefits delivered by estuaries as well as the diversity of beneficiaries enjoying their services. Moving forward, development and resource use needs to be balanced to ensure the equitable sharing of benefits derived from these highly productive systems.

South Africa has 290 estuaries and 42 micro-estuaries which have been classified into 22 estuarine ecosystems and 3 micro-estuary types. This represent a high diversity of estuary types stemming from the country's diverse climatic, oceanographic and geological drivers. Four biogeographical regions characterise the South African coast; namely the Cool Temperate (Orange to Ratel), the Warm Temperate (Heuningnes to Mendwana), the Subtropical (Mbashe to St Lucia) and the Tropical (uMgobezeleni to Kosi) (Emanuel *et al*. 1992; Harrison 2002; Turpie *et al*. 2000). South Africa's National Biodiversity Assessment of 2018 defines an estuary as 'a partially enclosed permanent water body, either continuously or periodically open to the sea on decadal time scales, extending as far as the upper limit of tidal action, salinity penetration or back-flooding under closed mouth conditions. During floods an estuary can become a river mouth with no seawater entering the formerly estuarine area or, when there is little or no fluvial input, an estuary can be isolated from the sea by a sandbar and become fresh or even hypersaline' (modified after Van Niekerk & Turpie 2012). A defining feature of this definition is that complex estuarine abiotic processes dominate, i.e. restricted tidal action, mixing of fresh and salt water, increased retention and/or increased water levels under closed mouth conditions.

In South Africa there are 176 estuarine-associated plant species, the majority (56 species) of which are associated with salt marsh habitat. Key estuary habitats in South Africa cover a total area of 103 500 ha, with reeds and sedges (17 500 ha) overall the dominant habitat type. On a bioregional scale, supratidal salt marsh dominates in the cool temperate region (6 300 ha) and warm temperate region (2 400 ha, reeds and sedges in the subtropical region (10 800 ha), and swamp forest in the tropical region (2 000 ha). Estuaries with the largest extent are St Lucia (44 800 ha), Groot Berg (8 000 ha) and Knysna (2 400 ha). The number of macrophyte species per estuary varied from 1 to 54 (recorded at Kosi).

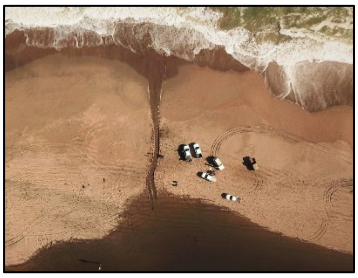
Approximately 50 of the 150 estuarine-associated fish species that regularly occur in estuaries are Southern African endemics of which 20 are exclusively found in South African waters with some species confined to only a few systems. For example, the iconic Knysna seahorse only occurs in three estuaries (Knysna, Swartvlei, Keurbooms), the Bot River Klipvis in two estuaries (Bot/Kleinmond and Klein) and the Estuarine Pipefish in five estuaries (Bushmans, Kariega, Kasouga, East and West Kleinemonde but only confirmed extant in two of these systems).

More than 60% of SA estuaries are relatively healthy, but this amounts to only 22% of total estuarine extent, comprised mostly of small estuaries. However overall, more than 63% of estuarine area is significantly modified with important ecological processes under severe pressure and with resultant reductions in productivity, food security, fisheries livelihood, property values and recreational enjoyment.

The estuarine realm is the most threatened of all realms in South Africa, in terms of both number of ecosystem types and by area. About 86% of the 22 estuary types are threatened with 9% Critically Endangered, 45% Endangered and 32% Vulnerable. Of total estuarine area, 99% is threatened with 3% Critically Endangered, 74% Endangered and 22% Vulnerable. Multiple interventions are required to avoid further decline in health. These include protection of freshwater inflow, restoration of water quality, reduction in fishing effort and avoidance of mining, infrastructure development and crops in the EFZ.

The decline in conditions stems from multiple escalating pressures managed across a number of key sectors. **A third of South Africa's freshwater flow no longer reaches the coast, with present inflows down from 36 900 to 24 800 million cubic metres per annum.** Twenty percent of estuaries are severely impacted (very high to high pressure) by freshwater flow reduction. **There has been a substantial increase in pollution pressure in estuaries, e.g. 840 million litres of wastewater flows daily into estuaries, with deteriorating water quality driving change on regional scales.**

Consequently, about 33% of estuaries are under severe pollution pressure. This reduces ecosystem resilience and nursery function, kills invertebrates and fish; and makes estuaries vulnerable to invasive species, parasites, pathogens and disease, threatening human health, wellbeing and food security. **Over 3 730 t of fish is caught annually in contrast with 3 030 t in 2011, with 21% of estuaries subjected to high or very high fishing pressure.** There's been a substantial increase in fishing effort in estuaries in the Subtropical and Tropical bioregions, exacerbated by the effective open access to resources that arose with the collapse of fisheries compliance in KwaZulu-Natal. Less than 1% of estuaries are not under some fishing pressure as few have "no-take" status. In addition, the integrity of estuarine protected areas is being eroded by both sanctioned and unlawful fishing in these areas. In many instances, fishing effort is now five times higher inside than outside restricted areas, e.g. estuaries in the Dwesa-Cwebe Marine Protected Area (MPA) and Nature Reserve. **Overall, 29% of South African estuaries are subject to severe habitat modification pressure from land-use and development.** Less than 10% of all estuaries in South Africa are under no pressure from development, most of these being confined to national, provincial or municipal protected areas. Agriculture was responsible for about 10% of land-use change, while urban areas comprise about 4% of change in land-use. Plantations contributed <1% to land-use changes. **Small-scale mining of sand, diamonds and heavy minerals is causing permanent habitat destruction in about 12% of estuaries,** with especially low-value sand mining impacting on critical habitats, estuary hydrodynamics, sediment structure (grain size) and depleting sediment reservoirs needed to replenish physical habitat after scouring by floods. **The mouths of only 15% of South African estuary are artificially manipulated, but these estuaries represent more than 60% of the total estuarine habitat in the country.** Artificial breaching at low water levels is causing premature closure, reduced marine connectivity and the accumulation of marine sediments in the lower reaches. Artificial breaching is a listed activity that should only be allowed under exceptional circumstances that are guided by a national breaching policy. **Alien, extralimital or translocated fish occur in 25 % of**



South Africa's estuaries. There are 22 species recorded to date with one to nine per system. **A third of estuaries have invasive terrestrial plants occurring within the estuarine functional zone whilst aquatic invasive species heavily infest 8% of estuaries.**

Salt marsh, seagrass and mangrove habitats are under severe pressure, e.g. mangroves no longer occur in 10 estuaries that they previously occurred in, and nearly 30% of salt marsh habitat has been lost. Estuarine-dependent fish species are threatened by overfishing (especially gill-netting), declining water quality, and reduced flows with their concomitant influence on recruitment and marine connectivity. **All exploited estuarine fish are overfished with stocks of the five most important species collapsed.** Historically, the latter contributed more than 80% of landed catch biomass. Global and local pressures have seen more than 265 000 waterbirds having been lost from our estuaries, most of which are waders from larger estuaries.

2. Urgent need for an Estuarine Restoration Plan

The ongoing decline in estuary condition, high number of threated estuarine ecosystem types, and low protection levels emphasise the need for strategic interventions across multiple sectors to restore estuarine health and protect benefits to people. **To avoid further compromising of the benefits derived from estuaries there is a need to invest in solutions to restore estuarine ecological infrastructure to strengthen climate resilience and sustain ecosystem services.** There is a pressing need for a '**National Estuary Restoration Programme'** that focuses on degraded and novel systems, with an emphasis on the larger systems of high biodiversity importance and the socially important urban systems. Here an opportunity exists for flagship programmes that could be developed in a collaborative manner between government agencies and civil society.

The United Nations Decade of Ecosystems Restoration 2021-2030 makes restoration and protection of critical ecosystems an imperative at a global scale. This call to arms, aims to scale up the restoration of degraded ecosystems to combat the climate crisis and enhance food security and biodiversity. It also presents a host of funding opportunities through climate finances instruments (e.g. Blue Carbon trading), Ecosystems-based Adaptation (EbA) global funds, and national debt restructuring mechanisms which will be highly supportive of a **South African Restoration programme**. However, restoration and/or rehabilitation of degraded or novel ecosystems (highly transformed estuaries) have not been systematically dealt with in South Africa. This assessment set out to consolidate the various outputs from a range of studies into one integrated summary to guide restoration efforts moving forward by highlighting systems under severe pressure in need of key sectorial interventions.

An analysis of present state (PES) versus desired state (REC) indicates that about a quarter of estuaries do not meet biodiversity targets. Overall about 43% of estuaries need some restoration or protection of base flows, while about 5% require some increase in flood allocation (Figure 17). From a pollution perspective, 42% of estuaries need an improvement in catchment river water quality, while an additional 28% require a reduction in the input of stormwater and agricultural drainage from the flood plain, and 14% require wastewater reduction measures. **Nearly 39% of estuaries require restoration or rehabilitation of the estuarine floodplain or adjacent wetlands.** Overall 39% of systems require removal of invasive alien vegetation, while 20% of estuaries need investigation into the possible eradication of alien or extra-limital fish. Overall, 32% of estuaries should be targeted for the reduction of fishing pressure. Mouth Management practises (artificial breaching) need to be re-evaluated, and improved on where possible, for 15% of estuaries. A minimum of 14% of estuaries need management of recreational activities to reduce impacts on birds. Nearly 13% of estuaries need restoration or rehabilitation of mining impacts. About 4% of systems need mangrove harvesting to be controlled, while 3% need the implementation of cattle exclusion zones and an additional 2% need measures to control grazing.

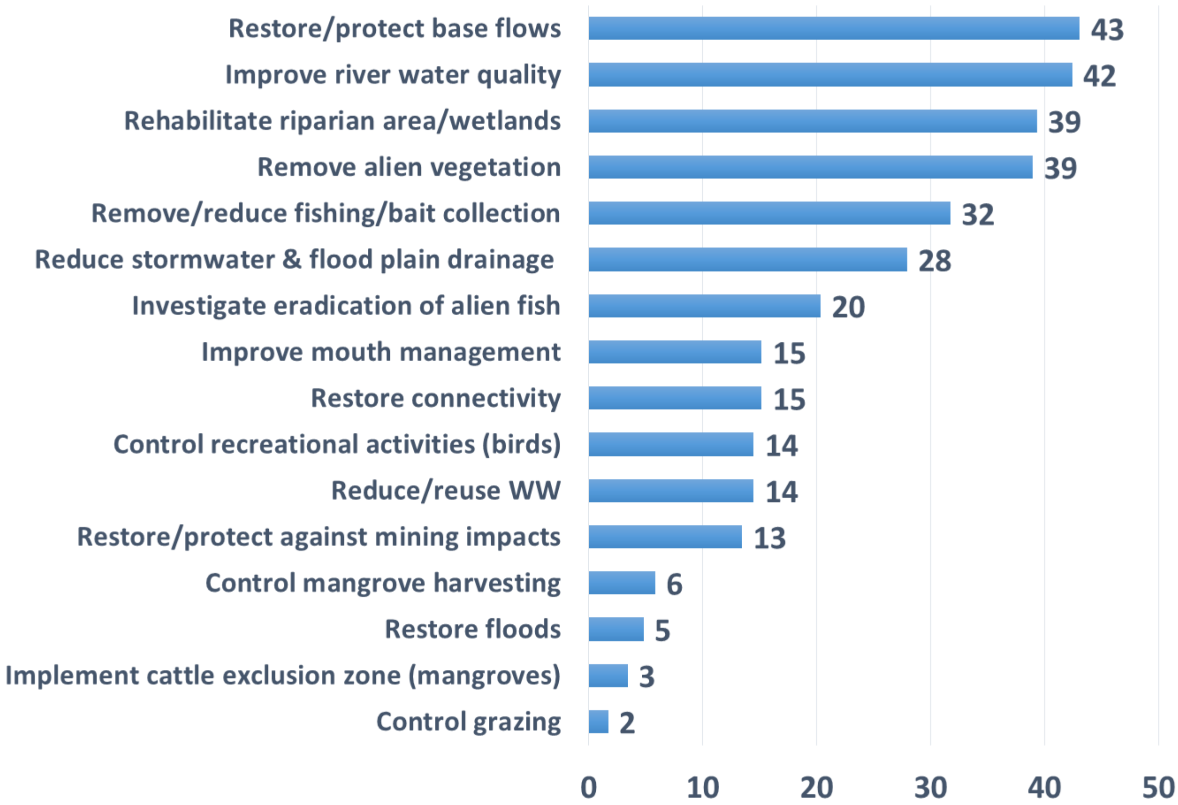


Figure 15: A summary of restoration interventions required in estuaries to address decline in condition.

Transdisciplinary approaches to aquatic ecosystem restoration are important, i.e. a socio-ecological systems approach to restoration through action research should be adopted. There are opportunities to implement a circular, regenerative economic approach to restoring estuary health with a focus on water quality management. Globally, there is a call to action as the UN has announced a 'Decade of Restoration (2021-2030)' that includes wetlands. Reducing nutrient inputs whilst culturing a harvestable resource as a restoration activity would significantly improve estuary health in South Africa. This provides for the opportunity to develop a 'National Estuarine Restoration Programme'.

3. Restoration case studies towards the development of an "National Estuarine Restoration Programme"

At present South Africa's most important estuarine system, the Greater St Lucia Lake System is undergoing a tremendous restoration effort to restore estuarine functionality. Lessons learned from this and other restoration processes will inform future management and restoration efforts of estuaries across the country. The Berg River Improvement Plan aims to address water quality concerns in the Berg River (including the estuary) and has a vision of improving water quality of water of the Berg River to an acceptable quality and quantity for sustainable farming, industrial development, human consumption and recreation, as well as ecological health. However, the Berg Estuary with its expansive floodplain marshes is unique nationally and must also be prioritised for rehabilitation in collaboration with the Western Cape Government. Agricultural impacts pose a serious threat to the state of the estuary

Priority systems for pilot testing restoration approached in estuaries include:

- **Swartkops:** Restoration of fragmented saltmarsh mash, old salt pans no longer in use, bank restoration where inappropriate bank protection has been applied.
- **Klein Brak:** Restoration of severely fragmented saltmarsh mash, bank restoration where inappropriate bank protection has been applied, increase tidal flows in upper reaches, and removal of alien vegetation.
- **Groot Brak:** Restoration of saltmarsh mash, the building of artificial wetlands to restore water quality and prevent build-up of algae near the bridge "The Island," increase tidal flows at the small Searle town bridge, and removal of alien vegetation.
- **Keurbooms:** Restoration of severely fragmented saltmarsh and floodplain vegetation (especially in Bitou arm), infilling of old drainage channels to raise the water table in the Bitou floodplain, bank restoration where inappropriate bank protection has been applied, and removal of alien vegetation.

In addition, the rampant spread of alien invasive terrestrial and aquatic plants in most small KZN estuaries also lends itself to a provincial level invasive alien removal programme. In future redesigning severely degraded systems to maximise estuarine fish nursery function should also be explored as it can be a useful tool for the recovery of overexploited resources, e.g. Eerste Estuary, Durban Bay.

Restoration of the extensive salt marsh at Orange Estuary is also needed to halt the ongoing decline of this system. However, given the distance and technical challenges, this should be prioritised as part of a second phase.

4. Potential partners

Potential collaborators in the estuary restoration space include:

- DFFE (Branches: Oceans and Coast, Fisheries, Biodiversity, Climate change);
- SANBI;
- Expanded Public Works Programme (e.g. Working for Wetlands);
- Provincial governments (DEA&DP);
- District and Local municipalities;
- National (SANParks) and Provincial conservation agencies (E.g. CapeNature);
- Council for Scientific and Industrial Research;
- Nelson Mandela University; and
- Water Research Commission.

5. Funding Sources

The United Nations Decade of Ecosystems Restoration 2021-2030 makes restoration and protection of critical ecosystems imperative at a global scale. This call to arms, aims to scale up the restoration of degraded ecosystems to combat the climate crisis and enhance food security and biodiversity. It also presents a host of funding opportunities through climate finances instruments (e.g. Blue Carbon trading), Ecosystems-based Adaptation (EbA) global funds, and national debt restructuring mechanisms which will be highly supportive of a South African Strategic Estuarine Management Framework.

International funding bodies include:

- Green Climate Fund;
- UNDP; and
- Payments for Ecosystem Services schemes through for example REDD+.

APPENDIX 7: RESTORATION MEASURES NEEDED TO IMPROVE ESTUARY CONDITION AND PRODUCTIVITY

Estuary	PES	REC	Biodiversity Importance Rating (>80 =High Importance, 60 - 80=Important >60 = Average Importance) (Turpie et al. 2002, Turpie and Clark 2009)	DAFF Important Fish Nurseries (5 =Very High priority, 3= Priority)	Restore/protect base flows	Restore floods	Manage/reduce stormwater & drainage from flood plain	Improve river water quality	Monitor & reduce/reuse WW	Restore connectivity/ hydrodynamic	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Reduce grazing (sheep, cattle, goats)	Implement cattle exclusion zone	Control mangrove harvesting	Control recreational activities impacting on	Remove/reduce fishing pressure/ bait collection	Investigate eradication of alien fish	Restore/protect against impact from mining
Orange	D	D	High Importance	High	●	●	Agric	Agric		●	●	●	●	●				●		●
Buffels	D	D	Low to Average Importance	Low	●		Agric	Agric		●	●	●	●							●
Swartlintjies	B	B	Low to Average Importance	Low																●
Spoeg	A/B	A/B	Low to Average Importance	Medium-Low	●															●
Groen	B	B	Low to Average Importance	Low	●								●							
Sout (Noord)	E	E	Low to Average Importance	Low	●					●		●								●
Olifants	C	C	High Importance	High	●	●	Agric	Agric	●			●	●	●				●*	●	
Jakkals	D	D	Low to Average Importance	Low	●		Agric	Agric			●	●								
Wadrift	E	E	Low to Average Importance	Low	●		Agric	Agric		●		●		●						
Verlorenvlei	D	D	Important	Medium	●			Agric		●	●	●		●				●*	●	
Groot Berg	C	C	High Importance	High	●	●		Agric	●			●	●				●	●*	●	
Langebaan	B	B	High Importance	High													●	●*		●
Diep/Rietvlei	D	D	Important	High	●		Urban	Urban	●	●	●	●	●				●	●	●	
Sout (Wes)	F	F	Low to Average Importance	Low	●		Urban	Urban												
Disa	E	E	Low to Average Importance	Low	●		Urban						●				●		●	
Wildevoëlvlei	D/E	D	High Importance	Low	●				●	●		●	●							
Schuster	B	B	Low to Average Importance	Low	●		Urban													
Krom	A/B	A	Low to Average Importance	Low																
Silwermyn	E	E	Low to Average Importance	Low	●		Urban	Urban		●	●						●		●	
Zand	D	D	Important	High	●		Urban	Urban		●	●	●	●				●	●	●	
Zeekoei	E	E	Low to Average Importance	Low	●		Urban	Urban	●	●	●		●				●		●	

Estuary	PES	REC	Biodiversity Importance Rating (>80 =High Importance, 60 - 80=Important >60 = Average Importance) (Turpie et al. 2002, Turpie and Clark 2009)	DAFF Important Fish Nurseries (5 =Very High priority, 3= Priority)	Restore/protect base flows	Restore floods	Manage/reduce stormwater & drainage from flood plain	Improve river water quality	Monitor & reduce/reuse WW	Restore connectivity/ hydrodynamic	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Reduce grazing (sheep, cattle, goats)	Implement cattle exclusion zone	Control mangrove harvesting	Control recreational activities impacting on	Remove/reduce fishing pressure/ bait collection	Investigate eradication of alien fish	Restore/protect against impact from mining
Eerste	E	E	Low to Average Importance	Medium-Low	●			Urban	●	●	●	●	●						●	
Lourens	D	D	Low to Average Importance	Low	●		Urban	Urban			●	●	●				●		●	
Sir Lowry's Pass	E	E	Low to Average Importance	Low	●		Urban	Urban					●							
Steenbras	B	B	Low to Average Importance	Low	●								●							
Rooiels	A	A	Low to Average Importance	Low									●				●			
Buffels (Oos)	B	B	Low to Average Importance	Low	●								●							
Palmiet	C	C	Important	Low	●	●		Agric		●		●	●						●	
Bot/Kleinmond	C	C	High Importance	High	●			Agric	●		●		●				●	●*	●	
Onrus	D	D	Low to Average Importance	Low	●	●	Urban	Urban			●		●						●	
Klein	C	C	High Importance	High	●		Urban	Agric	●		●		●				●	●*	●	
Uilkraals	D	D	Important	Medium	●			Agric	●	●	●	●	●				●	●		
Ratel	B	B	Low to Average Importance	Low				Agric												
Heuningnes	C/D	B	High Importance	High	●		Agric	Agric		●	●	●	●	●			●	●	●	
Klipdrifsfontein	A	A	Low to Average Importance	Low																
Breede	B/C	B	High Importance	High	●			Agric				●	●				●	●	●	
Duiwenhoks	C	C	High Importance	High-Medium	●		Agric	Agric				●	●				●	●	●	
Goukou	C	C	High Importance	High-Medium	●		Agric	Agric	●			●	●				●	●	●	
Gouritz	C/D	C	Important	High	●	●						●	●				●	●	●	
Blinde	B/C	C	Low to Average Importance	Low	●			Urban					●							
Tweekuilen	D/E	E	Low to Average Importance	Low	●		Agric			●										
Gericke	D/E	E	Low to Average Importance	Low	●		Agric			●										
Hartenbos	D	D	Important	Medium	●	●			●	●	●	●	●				●		●	
Klein Brak	C	C	Low to Average Importance	High-Medium	●		Urban	Agric	●	●		●	●				●	●	●	

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Groot Brak	D	D	Important	Medium	●	●	Urban	Agric		●	●	●	●				●	●	●	
Maalgate	B	B	Low to Average Importance	Low	●								●							
Gwaing	B/C	B	Low to Average Importance	Low			Urban		●				●						●	
Kaaimans	B	B	Low to Average Importance	Low	●								●				●			
Touw/Wilderness	B/C	C	High Importance	High	●					●	●		●				●	●	●	
Swartvlei	B/C	B	High Importance	High	●			Agric		●	●		●				●			
Goukamma	A/B	B	Important	Medium	●			Agric		●			●				●	●	●	
Knysna	B/C	B	High Importance	High	●		Urban		●								●	●	●	
Noetsie	B	B	Low to Average Importance	Low									●							
Piesang	D	D	Important	Medium	●		Urban	Urban		●	●	●	●				●			
Keurbooms	A/B	A/B	High Importance	High									●				●		●	
Matjies	A/B	A/B	Low to Average Importance	Low																
Sout (Oos)	A	A	Low to Average Importance	Low																
Groot (Wes)	B	B	Important	Low	●								●					●		
Bloukrans	A	A	Low to Average Importance	Low																
Lottering	A	A	Low to Average Importance	Low																
Elandsbos	A	A	Low to Average Importance	Low																
Storms	A	A	Low to Average Importance	Low																
Elands	A	A	Low to Average Importance	Low																
Groot (Oos)	A/B	A/B	Low to Average Importance	Low				Agric												
Tsitsikamma	B	B	Low to Average Importance	Low	●			Agric												
Klipdrif (Oos)	B/C	B	Low to Average Importance	Low				Agric												
Slang	C/D	C	Low to Average Importance	Low				Agric												
Kromme	D	D	High Importance	High	●	●		Agric				●					●	●	●	

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Seekoei	D/E	D	Important	Medium	●			Agric		●	●	●	●							
Kabeljous	C	C	Important	Medium	●			Agric					●						●	
Gamtoos	B/C	B	High Importance	High	●		Agric	Agric				●	●				●	●	●	
Van Stadens	B	B	Low to Average Importance	Low	●								●							
Maitland	B/C	B	Low to Average Importance	Low	●								●							
Baakens	E	E	Low to Average Importance	Low	●		Urban	Urban												
Papkuils	F	F	Low to Average Importance	Low	●		Urban	Urban	●											
Swartkops	D	D	High Importance	High	●	●		Urban				●	●				●	●*	●	
Coega (Ngqurha)	E	E	Low to Average Importance	Low	●							●							●	
Sundays	C	C	Important	High	●			Agric				●	●				●	●	●	
Boknes	C	C	Low to Average Importance	Low	●															
Bushmans	B/C	B	Important	High	●				●								●	●	●	
Kariega	C	C	High Importance	High	●				●								●	●		
Grant's	C	C	Low to Average Importance	Low	●															
Kasouga	B	B	Important	Medium																
Kowie	C	C	High Importance	High	●				●			●	●				●	●	●	
Rufane	C	C	Low to Average Importance	Low	●															
Riet	B	B	Important	Low																
West Kleinemonde	B	B	Important	Medium																
East Kleinemonde	B	B	Important	Medium				Agric												
Great Fish	C	C	High Importance	High	●			Agric					●				●	●	●	
Old Woman's	C	C	Low to Average Importance	Low	●		Agric	Agric												
Mpekweni	B	B	High Importance	Medium	●			Agric									●	●		

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Mtati (Mthathi)	B	B	High Importance	Medium	●															
Mgwalana	B	B	High Importance	Medium	●															
Bira (Bhirha)	B	B	Important	Medium	●															
Gqutywa	B	B	Important	Medium	●															
Ngculura (Ngculurha)	B	B	Low to Average Importance	Low	●															
Mtana	B	B	Low to Average Importance	Low																
Keiskamma	B/C	B	High Importance	High	●			Urban				●			●		●	●	●	
Nqinisa	A/B	A	Low to Average Importance	Low																
Kiwane (Khiwane)	A/B	A	Low to Average Importance	Medium																
Tyolomnqa	B	B	Important	Medium														●		
Shelbertsstroom	B/C	B	Low to Average Importance	Low				Agric					●							
Lilyvale	B	B	Low to Average Importance	Low																
Ross' Creek	A/B	A/B	Low to Average Importance	Low																
Ncera (Ncerha)	B	B	Low to Average Importance	Low	●															
Mlele	B	B	Low to Average Importance	Low				Agric												
Mcantsi	B	B	Low to Average Importance	Low																
Gxulu	B/C	B	Low to Average Importance	Medium																
Goda	B	B	Low to Average Importance	Low	●		Agric	Agric												
Hlozi	B	B	Low to Average Importance	Low				Agric												
Hickman's	B	B	Low to Average Importance	Low				Urban												
Buffalo	D	D	Low to Average Importance	Medium	●		Urban	Urban										●	●	
Blind	D	D	Low to Average Importance	Low	●		Urban	Urban												
Hlaze (iHlanze)	C/D	C	Low to Average Importance	Low	●		Urban	Urban		●										
Nahoon	C	C	Important	Medium	●	●	Urban	Urban					●				●	●	●	

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Qinira (Quinirha)	B/C	B	Important	Low			Urban	Urban			●							●		
Gqunube	B	B	Important	Medium								●						●	●	
Kwelera (Kwelerha)	B	B	Important	Medium														●		
Bulura (Bulurha)	B	B	Low to Average Importance	Low														●		●
Cunge	A/B	A/B	Low to Average Importance	Low									●							
Cintsa	B	B	Low to Average Importance	Low														●		
Cefane	B	B	Important	Medium														●		
Kwenxura (Kwenxurha)	A/B	A/B	Low to Average Importance	Medium								●	●					●		
Nyara (Nyarha)	A/B	A/B	Low to Average Importance	Low																
Imtwendwe (Mtwendwe)	A/B	A/B	Low to Average Importance	Low																
Haga-haga	A/B	A/B	Low to Average Importance	Low																
Mtendwe	A/B	A/B	Low to Average Importance	Low																
Quko	A	A	Low to Average Importance	Medium																
Morgan	B	B	Low to Average Importance	Medium						●								●	●	
Cwili	B	B	Low to Average Importance	Low															●	
Great Kei	C	C	High Importance	High	●	●			●			●						●	●	
Gxara (Gxarha)	A/B	A/B	Low to Average Importance	Low				Agric				●								
Ngogwane	B	B	Low to Average Importance	Low	●			Agric												
Qolora (Qolorha)	B	B	Important	Low																
Ncizele	A/B	A/B	Low to Average Importance	Low																
Timba	B	B	Low to Average Importance	Low	●															
Kobonqaba (Khobonqaba)	B	B	Low to Average Importance	Medium	●							●								
Nxaxo/Ngqusi	B	B	Important	Medium								●	●		●			●		

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Cebe	A/B	A/B	Low to Average Importance	Low																
Gqunqe	A/B	A/B	Low to Average Importance	Low																
Zalu	A/B	A/B	Low to Average Importance	Low																
Ngqwara (Ngqwarha)	A/B	A/B	Low to Average Importance	Low	●							●								
Sihlontlweni	A/B	A/B	Low to Average Importance	Low																
Nebelele	A/B	A	Low to Average Importance	Low																
Qora (Qhorha)	A/B	A/B	Important	Medium								●						●		●
Jujura (Jujurha)	A/B	A/B	Low to Average Importance	Low	●															
Ngadla	A/B	A/B	Low to Average Importance	Low																
Shixini	A/B	A/B	Low to Average Importance	Low														●		
Beechamwood	A/B	A/B	Low to Average Importance	Low																
Kwazlelitsha (Kwazwedala)	A/B	A/B	Low to Average Importance	Low																
Kwa-Goqo	A/B	A/B	Low to Average Importance	Low																
Ku-Nocekedwa	A/B	A/B	Low to Average Importance	Low																
Nqabara/Nqabarana	A/B	A/B	Important	Medium								●	●		●			●		
Ngomane (East)	B	B	Low to Average Importance	Low																
Ngoma/Kobule	A/B	A/B	Low to Average Importance	Low																
Mendu	A/B	A/B	Low to Average Importance	Low														●		
Mendwana	A	A	Low to Average Importance	Low														●		
Mbashe	B	B	High Importance	High	●							●			●			●*	●	
Ku-Mpenzu	A/B	A/B	Low to Average Importance	Low													●	●		
Ku-Bhula (Mbhanyana)	A/B	A	Low to Average Importance	Low	●							●	●		●			●		
Kwa-Suku	A/B	A/B	Low to Average Importance	Low														●		

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Ntlonyane	B	B	Low to Average Importance	Low								●			●			●		●
Nkanya	B	B	Low to Average Importance	Low																
Sundwana	A	A	Low to Average Importance	Low																
Xora	A/B	A/B	Important	Medium									●			●		●		
Bulungula	A/B	A/B	Low to Average Importance	Low									●							
Ku-Amanzimuzama	A	A	Low to Average Importance	Low																
Nqakanqa	A/B	A/B	Low to Average Importance	Low												●				
Mdikana	A	A	Low to Average Importance	Low																
Mncwasa	B	B	Low to Average Importance	Low				Agric												
Mpako	A/B	A/B	Low to Average Importance	Low				Agric										●		●
Nenga	C	C	Low to Average Importance	Low				Agric		●		●				●		●		
Mapuzi	A/B	A/B	Low to Average Importance	Low				Agric												
Mtata	C	C	Important	Medium	●	●		Urban				●	●		●	●		●	●	●
Thsani	B	B	Low to Average Importance	Low				Agric												
Mdumbi	B	B	Important	Medium								●	●		●	●		●		●
Lwandilana	A/B	A/B	Low to Average Importance	Low																
Lwandile	A/B	A/B	Low to Average Importance	Low																
Mtakatye	A/B	A/B	Important	Medium								●	●		●	●		●		
Hluleka	A/B	A/B	Low to Average Importance	Low								●	●					●		
Mnenu	A/B	A/B	Low to Average Importance	Medium														●		

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Mtonga	A/B	A/B	Low to Average Importance	Low																
Mpande	A/B	A/B	Low to Average Importance	Low																
Sinangwana	B	B	Low to Average Importance	Low																
Mngazana	B	B	High Importance	High	●							●			●	●		●*		
Mngazi	B	B	Low to Average Importance	Medium												●		●		
Gxwaleni	A	A	Low to Average Importance	Low																
Bulolo	B	B	Low to Average Importance	Low														●		
Mtumbane	B	B	Low to Average Importance	Low	●							●								
Mzimvubu	B	B	Important	High	●			Agric					●					●	●	
Ntlupeni	A/B	A/B	Low to Average Importance	Low																
Nkodusweni	A/B	A/B	Low to Average Importance	Low								●								
Mntafufu	B	B	Important	Medium								●	●			●	●	●		
Ingo	A	A	Low to Average Importance	Low																
Mzintlava	A/B	A	Low to Average Importance	Medium								●				●		●		
Mzimpunzi	A/B	A/B	Low to Average Importance	Low								●								
Kwanyambalala	B	B	Low to Average Importance	Low								●						●		
Mbotyi	B	B	Important	Low								●						●		
Mkozi	A	A	Low to Average Importance	Low												●				
Sikatsha	A	A	Low to Average Importance	Low																
Lupatana	A/B	A/B	Low to Average Importance	Low																

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Mkweni	A	A	Low to Average Importance	Low																
Msikaba	A/B	A	Low to Average Importance	Low									●					●		
Mgwegwe	A	A	Low to Average Importance	Low																
Mgwetyana	A	A	Low to Average Importance	Low																
Mtentu	A/B	A/B	Important	Medium	●							●	●			●		●	●	
Sikombe	A/B	A/B	Low to Average Importance	Low								●								
Kwanyana	A/B	A	Low to Average Importance	Low																
Mtolane	A	A	Low to Average Importance	Low																
Mnyameni	A/B	A/B	Low to Average Importance	Low								●						●		
Mpahlanyana	A/B	A/B	Low to Average Importance	Low														●		
Mpahlane	A/B	A/B	Low to Average Importance	Low														●		
Mzamba	B	B	Important	Medium									●					●		
Mtentwana	C	C	Low to Average Importance	Low	●		Urban			●		●				●				
uMthavuna	B	B	Important	High									●					●		
iSolwane	B	B	Low to Average Importance	Low				Agric					●							●
iSandlu	C	C	Low to Average Importance	Low				Agric					●							
uMbhoyibhoyi	B	B	Low to Average Importance	Low			Urban						●							
uMuntongazi	B/C	B	Low to Average Importance	Low			Urban		●											
iKhandalendlovu	B	B	Low to Average Importance	Low			Urban	Agric					●							●
iMpenjani	B/C	C	Low to Average Importance	Low					●			●	●					●		●

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uMhlangomkhulu (South) (Umhlangankulu)	C	C	Low to Average Importance	Low			Urban	Agric												
iKhaba	C	C	Low to Average Importance	Low			Urban	Agric				●	●							●
iMbizana	B	B	Low to Average Importance	Low			Urban	Agric					●					●	●	
iMvutshini	B/C	B	Low to Average Importance	Low			Urban	Agric					●							
iBilanhlonhlo	C	C	Low to Average Importance	Low			Urban	Agric			●	●	●							
uVuzana	C	C	Low to Average Importance	Low			Urban	Agric					●							
iKongeni	D/E	D	Low to Average Importance	Low	●		Urban	Agric	●	●	●	●						●	●	
uVunguza	B	B	Low to Average Importance	Low			Urban		●				●							
oHlangeni	C	C	Low to Average Importance	Low			Urban		●		●	●						●		●
iZotsha	B/C	B	Low to Average Importance	Low				Agric			●	●	●					●		
iBhobhoyi	B/C	B	Low to Average Importance	Low				Agric	●			●								
uMbango	E	E	Low to Average Importance	Low	●		Urban	Agric	●	●		●								●
uMzimkhulu	B	B	Important	High							●		●					●*		
uMthente	C	C	Low to Average Importance	Low	●		Urban	Agric				●								
uMhlangomkhulu (North) (Mhlangamkulu)	C	C	Low to Average Importance	Low	●		Urban	Agric					●							
iDombe	D	D	Low to Average Importance	Low	●		Urban	Agric		●		●	●							
iKhoshwana	C/D	C	Low to Average Importance	Low			Urban	Agric	●			●								
iNjambili	C	C	Low to Average Importance	Low	●			Agric		●		●	●						●	●
uMzumbe	C/D	C	Low to Average Importance	Low				Agric				●	●							
uMhlabashana	B/C	B	Low to Average Importance	Medium			Urban	Agric	●			●	●							
uMhlungwa	C	C	Low to Average Importance	Low			Urban	Agric				●	●							
uMfazezala	C	C	Low to Average Importance	Low	●			Agric				●						●		

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uMakhosi	B/C	B/C	Low to Average Importance	Low				Agric				●								
uMnamfu	C	C	Low to Average Importance	Low				Agric										●		●
uMthwalume	C	C	Low to Average Importance	Low			Urban	Agric					●					●		
uMvuzi	C	C	Low to Average Importance	Low				Agric										●		●
iFafa	C/D	C	Important	Low	●						●	●	●					●		
uMdesingane	D	D	Low to Average Importance	Low			Urban	Agric		●		●						●		
iSezela	C	C	Low to Average Importance	Low			Urban	Agric	●			●						●		
uMkhumbane	C	C	Low to Average Importance	Low			Urban	Agric				●						●		
iNkomba	C	C	Low to Average Importance	Low			Urban	Agric				●								
uMuziwezinto	C/D	C	Low to Average Importance	Low	●			Agric			●	●						●		
uMzimayi	C/D	C	Low to Average Importance	Low	●			Agric		●								●		
Rocky Bay	C/D	C/D	Low to Average Importance	Low	●								●					●		●
uMphambanyoni	C	C	Low to Average Importance	Low			Urban		●			●						●		●
aMahlongwa	C	C	Low to Average Importance	Low								●	●					●		
uMahlongwane	C	C	Low to Average Importance	Low			Urban	Agric	●			●	●					●		●
uMkhomazi	C	C	Important	High	●			Agric	●			●	●				●	●*	●	●
iNgane	C	C	Low to Average Importance	Low								●	●							
uMgababa	C	C	Low to Average Importance	Medium	●			Urban				●	●					●*		
uMsimbazi	B/C	B	Low to Average Importance	Medium				Urban				●	●					●*		●
iLovu	C/D	C	Low to Average Importance	Medium	●		Urban				●	●	●					●*		
aManzanamtoti	E	E	Low to Average Importance	Low	●		Urban	Urban	●	●	●	●	●							●
aManzimtoti	D/E	D	Low to Average Importance	Low	●		Urban				●	●	●							●
iZimbokodo	E	E	Low to Average Importance	Low	●		Urban		●	●		●	●							
iSiphingo	F	F	Low to Average Importance	Low	●		Urban	Urban		●	●	●	●							

Estuary	PES	REC	Biodiversity Importance Rating (>80 =High Importance, 60 - 80=Important >60 = Average Importance) (Turpie et al. 2002, Turpie and Clark 2009)	DAFF Important Fish Nurseries (5 =Very High priority, 3= Priority)	Restore/protect base flows	Restore floods	Manage/reduce stormwater & drainage from flood plain	Improve river water quality	Monitor & reduce/reuse WW	Restore connectivity/ hydrodynamic	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Reduce grazing (sheep, cattle, goats)	Implement cattle exclusion zone	Control mangrove harvesting	Control recreational activities impacting on	Remove/reduce fishing pressure/ bait collection	Investigate eradication of alien fish	Restore/protect against impact from mining
Durban Bay	E	E	High Importance	High	●		Urban	Urban	●			●						●*		●
uMngeni	E	E	Important	Medium	●	●	Urban	Urban	●		●	●	●					●*	●	
uMhlanga	D	D	Important	Low	●			Urban	●	●	●	●	●					●	●	●
uMdloti	D	D	Important	Low	●		Urban	Urban	●	●	●	●	●					●	●	●
uThongathi	D	D	Important	Low	●		Urban	Urban	●		●	●	●						●	●
uMhlali	D	D	Important	Low	●		Urban	Urban	●			●	●					●		
Bob's Stream	B/C	B	Low to Average Importance	Low			Urban	Urban												
uSetheni	B/C	B	Low to Average Importance	Low			Urban	Urban				●								●
uMvoti	D	D	Low to Average Importance	Low	●		Urban	Urban	●		●	●	●						●	
uMdlotane	B	B	Important	Low			Urban	Urban			●	●						●		●
iNonoti	C	C	Low to Average Importance	Low			Urban	Urban	●			●						●		●
iZinkwazi	B/C	B	Important	High			Urban	Agric			●	●						●*		●
uThukela	D	D	Important	Medium	●			Agric			●	●	●					●*	●	
aMatigulu/iNyoni	B	B	Important	High							●							●*		
iSiyaya	E	E	Low to Average Importance	Low	●			Agric		●		●	●					●*		
uMlalazi	B	B	High Importance	High	●		Agric	Agric			●	●	●				●	●*	●	●
uMhlathuze	D	D	High Importance	High			Agric	Agric		●		●						●*	●	
Richards Bay	D	D	Important	High	●					●		●						●*		●
iNhlabane	E	E	Important	Medium	●			Urban		●		●						●*		●
iMfolozi/uMsunduze	D	D	High Importance	High				Agric				●	●			●		●*		
St Lucia	D	D	High Importance	High						●			●			●		●*		
uMgobezeleni	B	B	Low to Average Importance	Low							●					●		●*		
Kosi	A/B	A	/	High	●								●			●		●*		

*Indicate illegal gill netting (except Olifants Estuary which is legal)