The Greater Cape Town Water Fund

Monitoring and Evaluation Plan

August 2020

The Nature Conservancy, Cape Town, South Africa

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Acronyms and Abbreviations

ASPT	:	Average Score Per Taxon
ANOVA	:	Analysis of Variance
BACI	:	Before/After/Impact/Control
BGCMA	:	Breede-Gouritz Catchment Management Agency
CCS	:	Core Cape Subregion
CCT	:	City of Cape Town
CFE	:	Cape Fold Ecoregion
DCA	:	Detrended Correspondence Analysis
DEA&DP	:	Department of Environmental Affairs and Development Planning
DEFF	:	Department of Environment, Forestry and Fisheries
DoA	:	Department of Agriculture
DSS	:	Decision Support System
DWS	:	Department of Water and Sanitation
EC	:	Electrical Conductivity
EI	:	Ecological Infrastructure
EIIF	:	Ecological Infrastructure Investment Framework
EIS	:	Ecological Importance and Sensitivity
EPWP	:	Expanded Public Works Programs
FFG	:	Functional Feeding Group
GCTWF	:	Greater Cape Town Water Fund
GEF	:	Global Environment Facility
HMU	:	Hydrological Management Unit
IAP	:	Invasive Alien Plants
IUCN	:	International Union for Conservation of Nature
M&E	:	Monitoring and Evaluation
MOU	:	Memorandum of Understanding
MR	:	Mont Rochelle
NBAL	:	Natural Biological Alien Land-cover attribute
NBS	:	Nature Based Solutions
NGO	:	Non-Governmental Organisation
NDVI	:	Normalised Difference Vegetation Index
NDWI	:	Normalized Difference Water Index
NRM	:	Natural Resource Management
PD	:	Person Day
PES	:	Present Ecological State
SANBI	:	South African Biodiversity Institute
SASS	:	South African Scoring System
SER	:	Society for Ecological Restoration
SLA	:	Service Level Agreement
SMME	:	Small, Medium and Micro-Enterprises
TMG	:	Table Mountain Group
TNC	:	The Nature Conservancy
TWK	:	Theewaterskloof
WCWSS	:	Western Cape Water Supply System
WF	:	Water Fund
WfW	:	Working for Water

WoF-HAT	:	Working on Fire-High Altitude Teams
WWF	:	World Wide Fund for Nature

Document Control

Version	Date	Comments
1	5 May 2020	First full draft
2	21 August 2020	Review comments incorporated

Summary: Outcome Indicators

Thematic Area 1: Water

Intermediate outcome - By 2025, to reclaim the loss of 55 billion litres per year (55 Mm^3/yr) by clearing Invasive Alien Plants (IAP) across 54 300 ha of the 7 priority sub-catchments, and 5 000 ha on the Atlantis Aquifer.

Long-term outcome – To schedule and implement follow up clearing and maintenance treatments across 54 300 ha of the 7 priority sub-catchments in order to maintain the water reclamation in perpetuity. By 2045, to reclaim a total of 152 billion litres per year by expanding the IAP management interventions to the remaining 17 of the 24 priority sub-catchments of the Greater Cape Town Water Fund (GCTWF).

Thematic Area 2: Biodiversity

Terrestrial

Intermediate outcome - By 2025, to clear all mature invasive trees and to implement a follow up control program according to prescribed schedules across the 54 300 ha of the 7 priority sub-catchments, and 5 000 ha on the Atlantis Aquifer, thus enabling a net gain of native fynbos vegetation.

Long-term outcome - The restoration of the biophysical characteristics, growth form structure and functioning of native fynbos communities across 70% of the invaded areas in the 7 sub-catchments and 5 000 ha of the Atlantis aquifer by 2045, i.e. within 2 – 3 fire cycles. Where necessary, this will incorporate the active restoration of self-sustaining ecological communities towards reference conditions.

Freshwater

Planned restoration actions upstream will result in the freshwater ecosystem structure and function reverting towards a more natural state, and recovery of certain indicator species in the long-term, by 2045. Specific outcome targets include:

- For freshwater invertebrate monitoring, an increase in the South African Scoring System (SASS) score by one category from Good or Fair to Natural, and an increase in Present Ecological State (PES) for invertebrates – A/B to A.
- For freshwater vertebrate monitoring, an increase in taxon abundance and diversity, and increase in available habitat for flow and sediment-sensitive taxa.
- For wetland health monitoring, a shift in the PES of each wetland towards pristine condition, and a consequent improvement in ecosystem services, as measured by wetland Ecological Importance and Sensitivity (EIS).

Thematic Area 3: Management and Operational Effectiveness

Intermediate outcome – By 2023:

- Collaboration amongst different stakeholders, focusing on a common vision while delivering on respective institutional mandates.
- Alignment and synergy between different key strategies.
- Coordinated long term strategic prioritization towards achieving overarching objectives.
- Control methods are integrated to achieve results in the most cost-effective and efficient manner without negatively impacting on biodiversity outcome indicators.
- Operations focus on priority areas following a strategy to deliver a set of objectives and implemented according to set of best practices
- Results are monitored and adaptive management put to practice.

By 2025, the 54 300 ha of the 7 priority sub-catchments and 5 000 ha on the Atlantis Aquifer will have received one treatment operation, through the implementation of effective and efficient IAP control operations (a combination of established and new clearing methods) and follow up treatments implemented according to schedule.

Long-term outcome – By 2045, the 54 300 ha of the 7 priority sub-catchments and 5 000 ha on the Atlantis Aquifer will be in a maintenance stage of treatment (< 1% occurrence of IAPs, no adult IAPs present, approved maintenance schedule implemented and recorded) and a clearing program commenced on the remaining 17 priority sub-catchments of the GCTWF.

Thematic Area 4: Socio-Economic Impacts
By 2025, the GCTWF partnership aims to develop three additional Small, Medium and Micro-Enterprises (SMMEs), specializing in remote access work, to create 350 job opportunities and to train 50 High Angle Technicians.

Thematic Area 5: Partnership Satisfaction
A healthy, transparent and functioning GCTWF collaborative, partners feeling valued, recognized for their contributions, empowered by their achievements and sharing resources for achieving the common vision while maintaining corporate and institutional identities and mandates.

Summary: Theory of Change

Objective 1
IF a GCTWF M&E WG is established and actively engaged; IF TNC M&E experts are engaged; IF M&E objectives are based on SMART principles; and IF M&E is based on evolving best practice and scientific finds:

THEN a fully operational multi-disciplinary M&E program will be developed by August 2020.

Objective 2
IF key stakeholders buy-in to the GCTWF; IF key stakeholders actively collaborate; IF a suitable governance and financing mechanism is established; IF donor relationships are maintained; IF new donors are engaged; IF M&E is actively carried out; and IF annual targets are achieved:

THEN sufficient funding will be mobilized to achieve short term (1-6 year) goals and to sustain long-term maintenance (30 years).

IF key stakeholders actively collaborate; IF stakeholders feel valued; IF stakeholders are recognized for their contributions; and IF appropriate and diverse forums are engaged and communication tools are utilized:

THEN a healthy and functioning multi-stakeholder relationship will be maintained and the communities of practice regarding the potential use and success of NBS for improved water security in the region will be increased.

Objective 3
IF key stakeholders actively collaborate; IF sufficient funding is mobilized to achieve short term (1-6 year) objectives; and IF mechanisms are implemented to develop and support SMMEs:

THEN the GCTWF partnership will develop three additional SMMEs, create 350 job opportunities and train 50 High Angle Technicians by 2022.

Objective 4
IF key stakeholders buy-in to the GCTWF; IF key stakeholders actively collaborate; IF a suitable governance and financing mechanism is established; and IF transparent and accountable leadership for the GCTWF is maintained:

THEN the GCTWF will be launched as a sustainably funded public-private partnership by 2023.

Objective 5
IF funding is available; IF appropriately skilled service providers are available for data collection, ground-truthing and mapping the priority sub-catchments and the Atlantis aquifer; IF the GCTWF Decision Support System (DSS) database is populated, maintained and enhanced:

THEN a comprehensive updated IAP distribution map for the 7 priority sub-catchments and the Atlantis aquifer will be completed; good quality data will be available to inform decision-making, track progress and to inform adaptive management.

Objective 6
IF key stakeholders actively collaborate; IF funding is secured for the high-impact phase (year 1-6); IF a sustainable long-term funding strategy is adopted:

THEN the remaining 17 priority sub-catchments identified in the GCTWF business case will be incorporated into the GCTWF implementation strategy.

Objective 7
IF key stakeholders actively collaborate; IF IAP clearing activities are prioritized; IF control operations are optimized; IF new control methods are integrated; IF specialized skills are acquired; IF general and skilled workers are retained; and IF adaptive management is practiced:

THEN the GCTWF partnership will clear IAPs across 54 300 ha of the seven priority sub-catchments and 5 000 ha on the Atlantis Aquifer by March 2025.

1. Introduction

Water Funds (WF) are collective-action catchment conservation mechanisms where downstream water users (e.g. municipalities, utilities, companies, public agencies, etc.) invest in the protection and restoration of upstream areas critical for water supplies. WF are informed by science, have clear goals and timelines, practice ongoing monitoring and follow an adaptive management approach. They create a multi-institutional governing body of public and private partners and provide opportunities to avoid costs of water treatment by investing in nature instead of engineered infrastructure (Goldman et al., 2010) and aim to improve water security, thereby ensuring a continuous supply of clean water. Generally, WF are a strategy that takes a landscape-scale, catchment approach to conservation in order to (Goldman et al., 2010):

- Improve or maintain water quality and secure near-natural regular flows (quantity) for downstream users.
- Maintain regular near-natural flows of water throughout the year.
- Maintain or enhance freshwater and terrestrial ecosystem biodiversity.
- Improve or maintain the well-being of upstream communities.

The Greater Cape Town Water Fund (GCTWF), South Africa's first WF, is a public-private partnership made up of national, provincial and local government, the private sector and Non-Governmental Organisation (NGO) partners. The GCTWF promotes the use of ecological infrastructure (EI) restoration as a critical intervention to enhance water security for all users of the Western Cape Water Supply System (WCWSS) in the Western Cape of South Africa (Stafford et al., 2018; Figure 1). Catchment EI restoration (e.g., invasive alien plant (IAP) removal, wetland rehabilitation, etc.) is estimated to be significantly more cost effective than alternative engineered water augmentation options currently being considered in the region (e.g., increased groundwater abstraction, seawater desalination, wastewater re-use and increasing capacity of some dams), supplying water at up to one-tenth the unit cost of these alternatives (Stafford et al., 2018; Turpie et al., 2018). The EI (rivers, native vegetation, wetlands, etc.) in the source water areas of the Greater Cape Town region play a critical role in increasing water security in the region, through the regulation of source water quality and quantity. However, over two-thirds of these source water areas are invaded by IAPs. If unmanaged, these IAPs (e.g., pine, wattle and eucalypts) quickly replace the native vegetation and therefore threaten the diversity of indigenous plant life in the Core Cape Subregion (CCS) of the Greater Cape Floristic Region (Manning and Goldblatt, 2012) , a biodiversity hotspot where 70% of the plants are endemic. Additionally, it is well known that the water use of these IAPs is significantly higher than the indigenous vegetation of the region. Studies have shown that currently invasions across 17% of the WCWSS are reducing the amount of water that reaches the rivers and dams that supply the region by 55 billion litres per year (Stafford et al., 2018; Turpie et al., 2018). These losses are expected to double over the next 30 years unless actions are taken. Furthermore, IAPs alter soil ecology, increase the frequency and severity of wildfires and significantly impact aquifer recharge (Stafford et al., 2018). Despite ongoing efforts by initiatives such as the Working for Water program, the extent of the problem is increasing (Van Wilgen et al., 2012).

Through collective action, the GCTWF partnership aims to reduce annual water losses of 100 Mm^3 to near zero within 30 years. Within the first 6 years (2019 – 2025), the water available to the WCWSS is estimated to increase by 55 Mm^3/yr through the targeted removal of IAPs across 54 300 ha. Increasing water availability is the main aim, as opposed to improving water quality. In addition, biodiversity in one of the world's biodiversity hotspots, i.e. the CCS, will be protected against alien plant invasions.

To ensure that investments in WFs are having the predicted impacts and to allow for modifications to management strategies, WFs must include robust Monitoring and Evaluation (M&E) plans to track the environmental, economic, and social impacts of their interventions (Higgins and Zimmerling, 2013). These M&E plans provide critical data and information to decision-makers, investors, communities, etc., and evaluate the effectiveness of interventions, as well as providing an opportunity for adaptive management. Adaptive management is the process of using monitoring information to adjust or correct management actions in order to achieve desired outcomes (TNC, 2015). M&E plans detail the rationale, strategies, and costs for monitoring and evaluating the various projects being implemented by a WF. Monitoring and evaluations are connected but perform different functions (Leisher et al., 2019):

- Monitoring is continuous and describes the current state.
- Evaluation is periodic and uses the monitoring data to judge the success of interventions and what difference they made.

Monitoring answers the question 'is the project doing things right' while evaluation answers the question 'is the project doing the right things' (Leisher et al., 2017). Monitoring is the act of systematically collecting data and information about indicator variables over time and space, to characterize their state and to track any changes in their state. There also must be some understanding of the dynamics of each variable so that managers can determine whether the values or trends are within the bounds or limits of acceptable change. It requires expertise not only in the methods for designing scientifically robust monitoring programs, but also in the various instruments, techniques, and software needed to properly collect, manage, analyse and interpret data. It is a cooperative process aimed at including the technical and scientific expertise to achieve sufficient rigor. There are different types of monitoring, depending on the project life cycle stage:

- Reconnaissance Monitoring – commonly used to identify the sources of problems affecting water quality and quantity that are not easily identified using desktop surveys. It also aims to obtain initial data on patterns of water quality, flow, habitat, biodiversity, etc., to inform longer-term monitoring methods and designs. Also referred to as baseline monitoring.
- Implementation Monitoring – tracks the inputs and outputs of the WF, e.g. the number of individuals employed, the area cleared, etc., and the specific sites and spatial extent of different activities. Essentially, it tracks progress towards achieving planned targets for inputs and outputs.
- Impact Monitoring – tracks changes in environmental, social and economic variables resulting from WF activities, also known as outcomes This monitoring is done at appropriate spatial scales and time-frames to address the specific information needs. The statistical resolution, accuracy, precision, and designs of monitoring approaches determine their strengths and weaknesses for measuring and communicating results (Higgins and Zimmerling, 2013).

Information and data needs must be identified when WFs are designed (Higgins and Zimmerling, 2013). Due to limited funding opportunities and capacity constraints, monitoring resources must be targeted to ensure that the most relevant data and information are collected, to evaluate whether the WF is achieving its near-term milestones and long-term goals. Targeted monitoring requires:

- A clear understanding of the questions the data will address.
- Clearly defined goals, defined as the overarching expectations of a WF.
- Set objectives, which are specific, quantified and time-bound milestones.

Although most WFs have unique characteristics, there is a general list of data typically collected as part of a WF (Higgins and Zimmerling, 2013) which include the spatially explicit and geo-referenced location of each current and planned interventions, the spatially explicit length of stream habitat that is expected to benefit as a result of the intervention, the types of interventions, the dates at which implementation was started and completed, the costs of implementation, etc.

WF should have specific long-term goals, i.e., evaluation goals, that are developed in consultation with subject experts and stakeholders as part of the initial project planning stage, and relating to the ecosystem functions, services and benefits deemed most relevant to the WFs success. A primary focus of monitoring should be to track progress toward achieving those goals as well as near-term objectives. These evaluations are critical for building the evidence to show that WFs make a difference for people and nature, and for improving the design of new WFs (Leisher et al., 2019). Additionally, it is pertinent for the sustainability of a WF because a WF needs demonstrate the benefits of watershed management in a systematic and rigorous way, in order to maintain political, social, and financial support (Leisher et al., 2017). Evaluation techniques are designed to provide accountability to donors, investors, agencies, external stakeholders, partners, participating communities, land and water managers, etc. (TNC, 2015).

2. Objectives of the GCTWF

1. By 2020, a multi-disciplinary Monitoring and Evaluation (M&E) program is launched and adopted by key stakeholders.
2. By 2021, funding is mobilized to achieve short term (1-6 year) objectives and a sustainable funding strategy is adopted for long-term maintenance towards restoration of priority sub-catchments and the Atlantis aquifer area.
3. By 2022, three Small, Medium and Micro-Enterprises (SMMEs) specializing in clearing invasive plants in remote areas are established, 50 additional High Angle Technicians are trained to increase the existing pool of specialized teams and 350 green job opportunities are created.
4. By 2023, the GCTWF is launched as a public-private governance entity.
5. By 2023, a comprehensive updated IAP distribution map is completed for the 7 priority sub-catchments and the Atlantis aquifer.
6. By 2024, the remaining 17 priority sub-catchments identified in the GCTWF business case are incorporated in the GCTWF implementation strategy.

7. By 2025, the high impact phase is completed across the 54 300 ha of the 7 priority sub-catchments and 5 000 ha on the Atlantis Aquifer and a long-term follow up and maintenance program is underway.

These objectives informed the development of the Theory of Change, which is presented in the Summary and graphically presented in Figure 2.

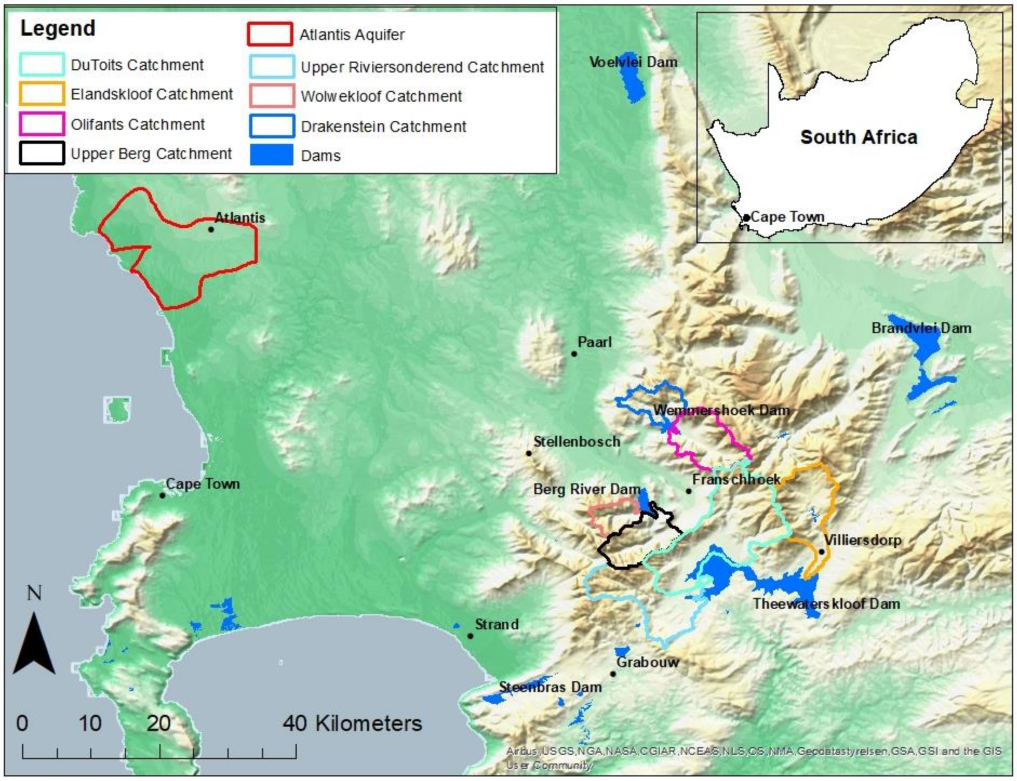


Figure 1. The location of the GCTWF 7 priority sub-catchments and the Atlantis Aquifer within the Western Cape province of South Africa. Major dams of the WCWSS are also shown.

3. Development of the GCTWF M&E Plan

This M&E Plan was developed under the auspices of the GCTWF M&E working group (see Acknowledgements), which is comprised of various key players, subject matter experts and stakeholders from the EI restoration sector in Cape Town (South Africa).

3.1. Objectives of this M&E Plan

- Describe the monitoring and evaluation protocols of the WF.
- Track the environmental, social and economic impacts of activities undertaken as part of the GCTWF.
- Ensure that investments are achieving their anticipated targets and if not, provide a reason why this is the case.
- Track the operational effectiveness and cost of EI restoration activities.
- Implement adaptive management.
- Report back to GCTWF steering committee and partners on progress and impact of activities

Role of the GCTWF M&E Working Group

- Develop SMART output and outcome indicators for the GCTWF M&E framework
- Inform and identify M&E activities.
- Oversight to ensure M&E is systematic, rigorous and scientifically based
- Evaluate the development of monitoring protocols
- Maintain accountability

This M&E Plan draws on information and lessons learned from Bremer et al. (2015), Goldman et al. (2010), Higgins and Zimmerling (2013), Leisher et al. (2019) and TNC (2015).

3.2. Thematic Areas

The M&E working group identified five thematic areas of output and outcome indicators, i.e. Water, Biodiversity, Management and Operational Effectiveness, Socio-economic Impacts and Partnership Satisfaction. These thematic areas are in line with those proposed by Higgins and Zimmerling (2013).

The plan presents the outcome indicators, output indicators, monitoring protocol, as well as the partner institution(s) leading each of the thematic areas. Each begins with a description of the current state, the desired state and long-term outcome indicators. The monitoring protocol describes the frequency of measurement, the methodology to be used, the spatial scales of monitoring and the source(s) of monitoring data.

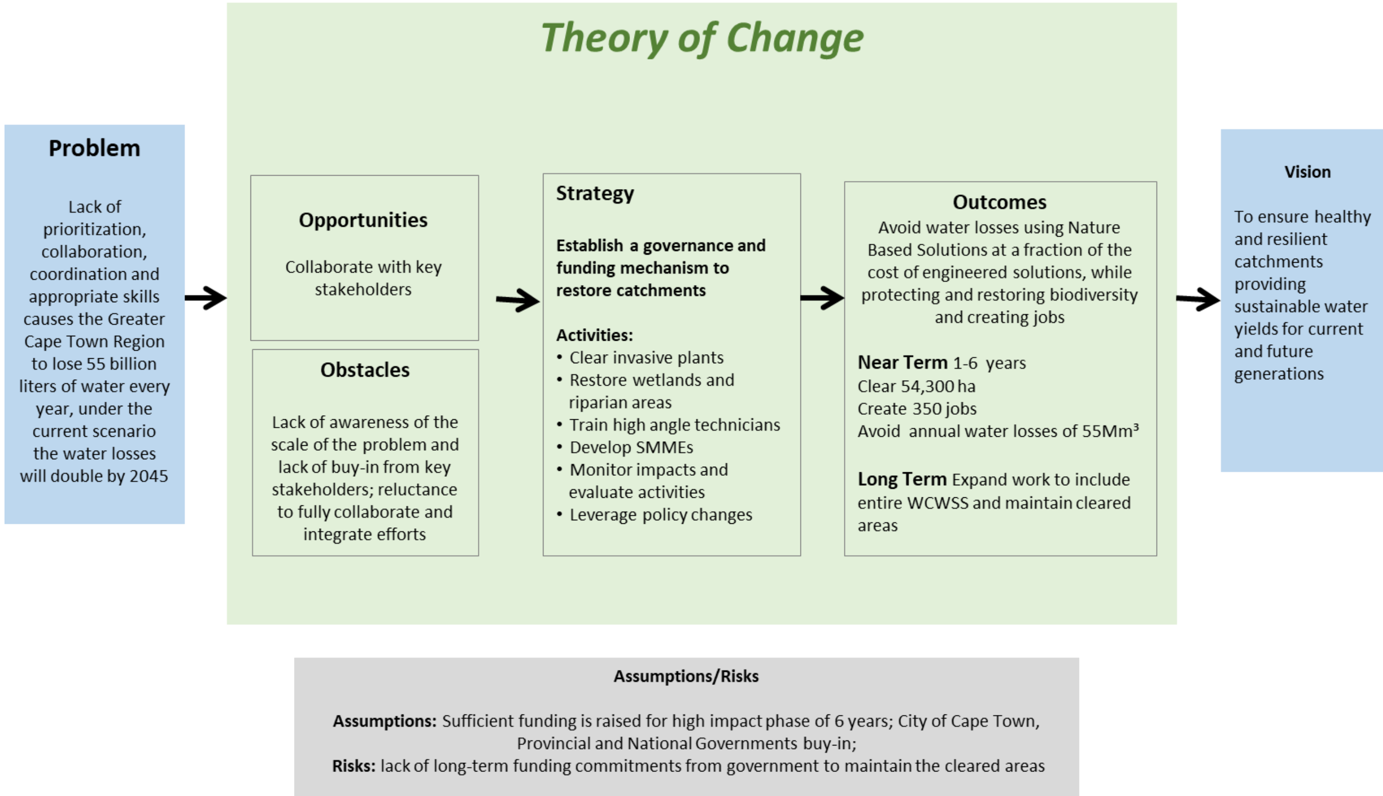


Figure 2. Theory of change graphic for the GCTWF.

4. Thematic Area 1: Water

An overview of the components of the water thematic area is presented in Figure 3.

4.1. Current State

According to the current best available estimate, 55 billion litres per year (55 Mm^3/yr, Stafford et al., 2018; Turpie et al., 2018) are lost due to IAP infestations across 54 300 ha of the WCWSS, i.e. the 7 priority sub-catchments of the GCTWF (Figure 1). Current estimates suggest that these losses will double by 2045 under a "no action" scenario.

4.2. Desired State

Intermediate outcomes - By 2025, to reclaim the loss of 55 billion litres per year (55 Mm^3/yr) by clearing IAPs across 54 300 ha of the 7 priority sub-catchments, and 5 000 ha on the Atlantis Aquifer.

Long-term outcomes – To schedule and implement follow up clearing and maintenance treatments across 54 300 ha of the 7 priority sub-catchments in order to maintain the water reclamation in perpetuity. By 2045, to reclaim a total of 152 billion litres per year by expanding the IAP management interventions to the remaining 17 of the 24 priority sub-catchments of the GCTWF.

The water reclaimed will be quantified using an empirical relationship between IAP clearing and WCWSS yield response developed by Turpie et al. (2018). This empirical relationship will be validated and improved by measuring the actual increases in streamflow through a before/after/control/impact (BACI) paired catchment experiment, a control-reference-impact multiple catchment experiment and reference-impact paired catchment experiment (Higgins and Zimmerling, 2013). It is anticipated that a 7 - 10% increase in streamflow at the catchment scale will be evident across the cleared catchments, compared to the control catchments (BACI design) by 2025. Similarly, a 7 - 10% increase in streamflow will be evident in the reference and impact catchments, compared to the control catchment (control-reference-impact and reference-impact designs) by 2025. These anticipated increases in streamflow are based on the results provided by Turpie et al. (2018), who quantified water gains resulting from IAP removal at the dam catchment scale.

The data generated through this M&E plan will be used as a basis for generating more accurate estimates of water gains using hydrological models. Providing updated data for models will allow for ongoing calibration (adjusting estimations based on measured data) and validation (confirming model accuracy by comparing expectations to observations). Ultimately, this will produce valuable regional and site-specific information for guiding activities and for defining further activities of the GCTWF.

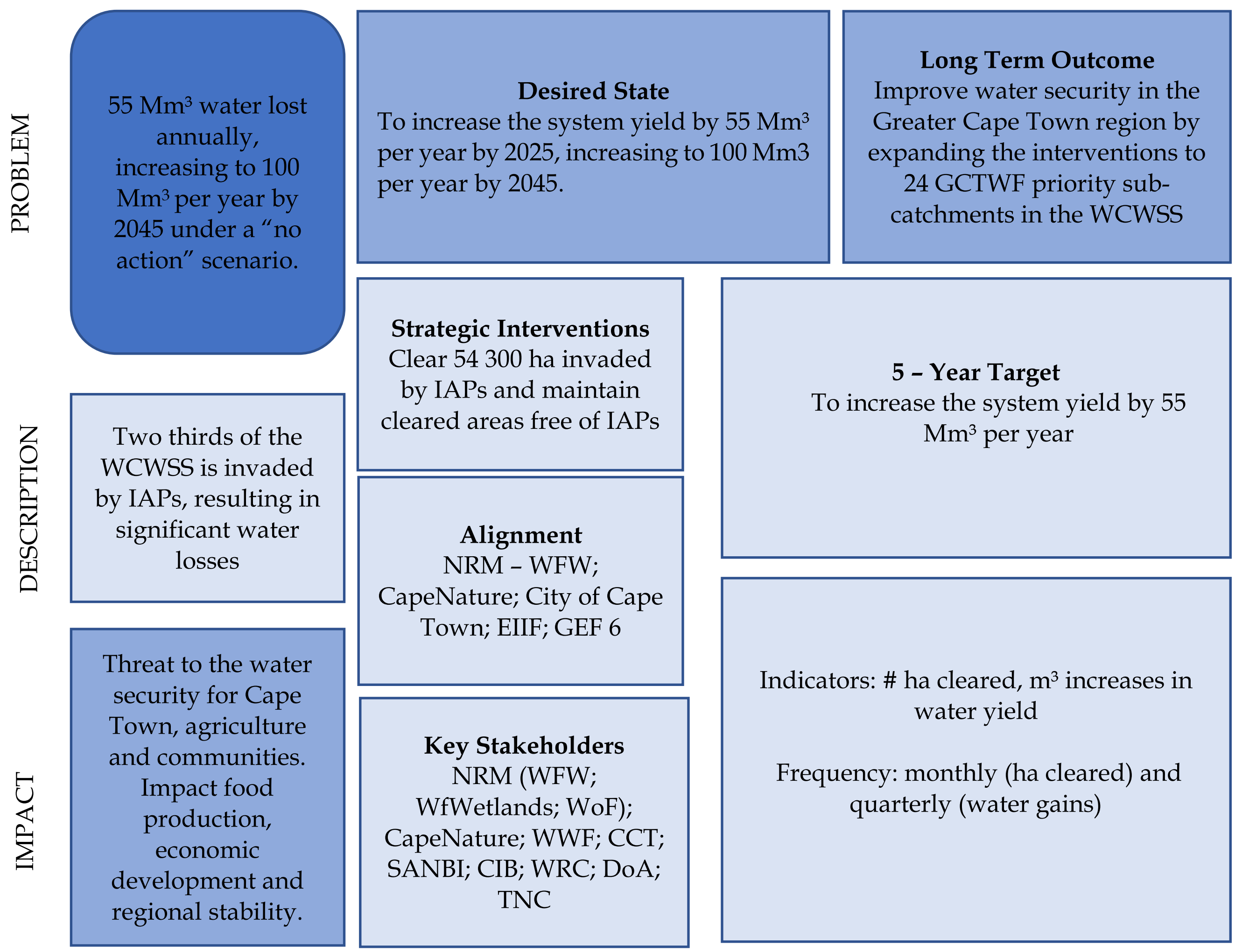


Figure 3. A schematic of the different components of the water thematic area.

4.3. Output Indicators

To achieve the desired state within the anticipated timeframe, the following indicators will be monitored:

IAP Clearing
Data are collated from all implementing partner institutions, i.e. CCT, WWF, CapeNature, TNC and Working on Fire-High Altitude Teams (WOF-HAT). The variables reported on will include:

- the area (# ha) cleared,
- IAP species cleared,
- size class of species cleared (seedling, young, mature),
- IAP density (% of area invaded) before each clearing intervention
- the landscape where the intervention is actioned, i.e. terrestrial, riparian or wetland.

Water Yield and Streamflow Volumes
Quantifying increases in water yield as a result of IAP clearing will be undertaken as follows

- The empirical relationship developed by Turpie et al. (2018) allows for the calculation of increased water yield as a function of the areas cleared.
- Based on the selected evaluation techniques for the water category (see below), streamflow monitoring stations were set-up in the monitoring catchments.

The specific flow metrics which will be analysed, include:

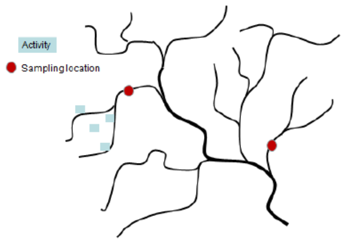
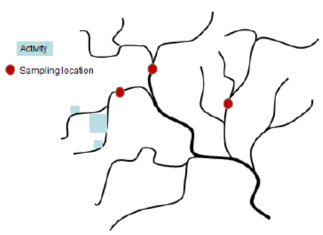
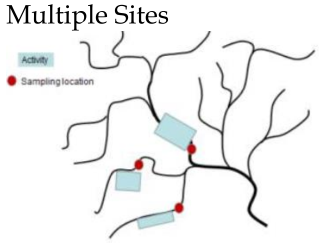
- Annual and monthly runoff coefficients (flow volume/rainfall volume)
- Base flow indices
- Flow duration curves
- Flow response relationships and recession curves, e.g. double mass curves of cumulative rainfall vs cumulative runoff
- Lag times of seasonal catchment flow responses
- Graphic visualization of selected rainfall events in high-resolution time series

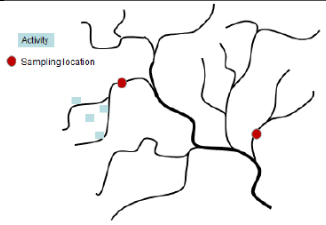
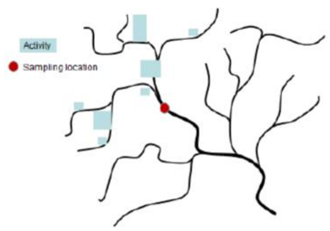
4.4. Evaluation

This category will utilise an evaluation strategy that primarily measures before and after intervention changes. This strategy aims to directly illustrate what would have happened without the intervention and is entirely quantitative.

Higgins and Zimmerling (2013) provide a detailed description of the various evaluation techniques commonly used, which is then well summarized by Leisher et al. (2019, Table 1).

Table 1. The evaluation techniques used in the GCTWF.

Technique	Advantages	Limitations
Paired Catchments 	• A catchment with water fund interventions is matched with a control watershed that is similar but has no activities. • This option allows for attribution. • Works well on headwaters of watersheds. • Well suited to micro-watersheds.	• Depends on accurate matching of paired catchments. • Need two or more years of baseline data to show pre-existing differences (if any) between paired catchments. • Fires, insect infestations, water abstraction, construction, road building, or any unintended large-scale land-use changes in either catchment can negate the comparison.
Multiple Catchments 	• This compares three matched catchments: control, impact and reference. • This option allows for attribution. • Shows if the water fund catchment is diverging from the control watershed and converging with the reference watershed that is in the desired condition.	• Requires an intact reference site for comparison. • The three catchments have to respond to inputs in similar ways. • Need two or more years of baseline data to show pre-existing differences among catchments. • Fires, insect infestations, water abstraction, construction, road building, or any large-scale land-use changes in a catchment can negate the comparison.
Monitoring Downstream of Multiple Sites 	• This measures changes over time at several locations downstream of water fund activities. • Provides multiple sample points for comparing before/after changes.	• Does not allow for attribution. • Assumes there are no changes upstream of the treatment area that could influence the results. • Catchments may respond differently to the same inputs.
Two Catchments Without Baseline Data	• This compares a catchment with water fund activities and an unmatched control catchment. • Does not require a baseline calibration period.	• Measured difference may be due to inherent differences in the watersheds. • Does not allow for attribution. • Not known if the two catchments started with the same conditions or respond

		differently to rainfall or water fund activities.
Monitoring Downstream at a Single Site 	• This measures changes over time at a single downstream location. • Often seen at existing monitoring site with a long record of data collection. • Useful in monitoring long-term trends in a large watershed. • Contributes data that can corroborate other data sources.	• Does not allow for attribution. • Shows long-term trends but not if water fund activities changed these trends.

Source: Higgins and Zimmerling (2013)

4.4.1. Before/After/Control/Impact (BACI) Paired Catchment Experiment

A BACI paired catchment experiment is a robust method of measuring the impact of an intervention. It is an impact analysis which compares parameter values before vs after interventions have been implemented. The "before data" provides baseline or temporal control conditions. BACI experiments incorporate a spatial component, i.e. a control catchment, that provides a measure of whether natural changes at the control site coincide with changes observed at the impact site. This design provides strong inference about causality because comparisons with spatial and temporal controls reduce the likelihood of confounding effects with natural spatial and temporal changes, i.e. the control and impact sites exhibit the same conditions prior to activity implementation.

The inclusion of control sites is essential for isolating the effects of WF interventions and evaluating the extent to which these activities contribute to any observed changes. A control site reflects what would have happened in the absence of an intervention. The impact site is expected to diverge from the control site due to WF activities. Monitoring at the control site is initiated with the same or very similar characteristics as the impact site (expected to be affected by WF activities), and control sites are subjected to the same conditions over time. As a result, causation may be isolated from correlation and happenstance (Higgins and Zimmerling, 2013).

A control and impact catchment should be evaluated prior to the implementation of any interventions for similarity in terms of characteristics such as catchment size, elevation, stream density and gradients, geology, climate, and patterns of land use/cover, water quality and flow (Higgins and Zimmerling, 2013). No control and impact catchment are a perfect match. The most rigorous test of matched sites is known as the 'parallel paths assumption', i.e. the comparison sites do not have to be identical, but they do need to have parallel trendlines before WF fund activities are initiated (Leisher et al., 2019).

The number of years required for pre-impact (calibration) and post-impact (treatment) monitoring is dependent on the system's natural variability and the extent of changes resulting from WF activities. For example, WF activities will generally affect flow in a gradual way, so abrupt significant differences are not expected to occur, and long-term trend data will be required. The types and scope of activities in the impact catchment should be expected to be sufficient to make significant changes, well beyond the natural variation that exists within and among these paired catchments. It is envisaged that this experiment will be structured as follows:

- 3 years (minimum) of identical monitoring in both the control and impact catchments, which are densely invaded by IAPs.
- Clearing of the IAPs in the impact catchment.
- 3 years (minimum) of identical monitoring in both the control and impact catchments after the IAP clearing.

4.4.2. Control-Reference-Impact Multiple Catchment Experiment

This experiment provides a statistical analyses test for divergence in temporal trends between the impact and the control, and for convergence in temporal trends between the impact and the reference site. A reference site represents the desired direction of change for the impact. This design provides a causal link and the ability to assess whether the trends are moving toward reference conditions. In this case, a reference catchment would represent a catchment covered by fynbos, which is the indigenous vegetation type for the region.

4.4.3. Reference-Impact Paired Catchment Experiment

This experiment does not utilize any before-activity implementation data, however, the same parameters are monitored through time at a reference and impact catchment. This design provides a causal link between temporal changes in response, because natural changes through time are measured at a reference site as well. Additionally, it is also possible to identify whether the trend of change at the impact location is towards the reference condition.

4.5. Experimental Sites

A detailed analysis was undertaken to identify suitable paired catchments for this experiment. For a detailed description of the process followed, as well as the monitoring equipment installation process, the reader is referred to Aurecon (2019). The location of the paired catchments within the areas occupied by the 7 priority catchments of the GCTWF is presented in Figure 4, and the general characteristics of each catchment are presented in Table 2.

The experimental design is as follows:

- Du Toits 1 and Du Toits 2 – BACI paired catchment experiment
- TWK1 and TWK2 - BACI paired catchment experiment
- Du Toits 1, Du Toits 2, MR1, MR2 – Control-Reference-Impact multiple catchment experiment
- Du Toits 1, Du Toits 2, MR1 and MR2 – Reference-Impact paired catchment experiment

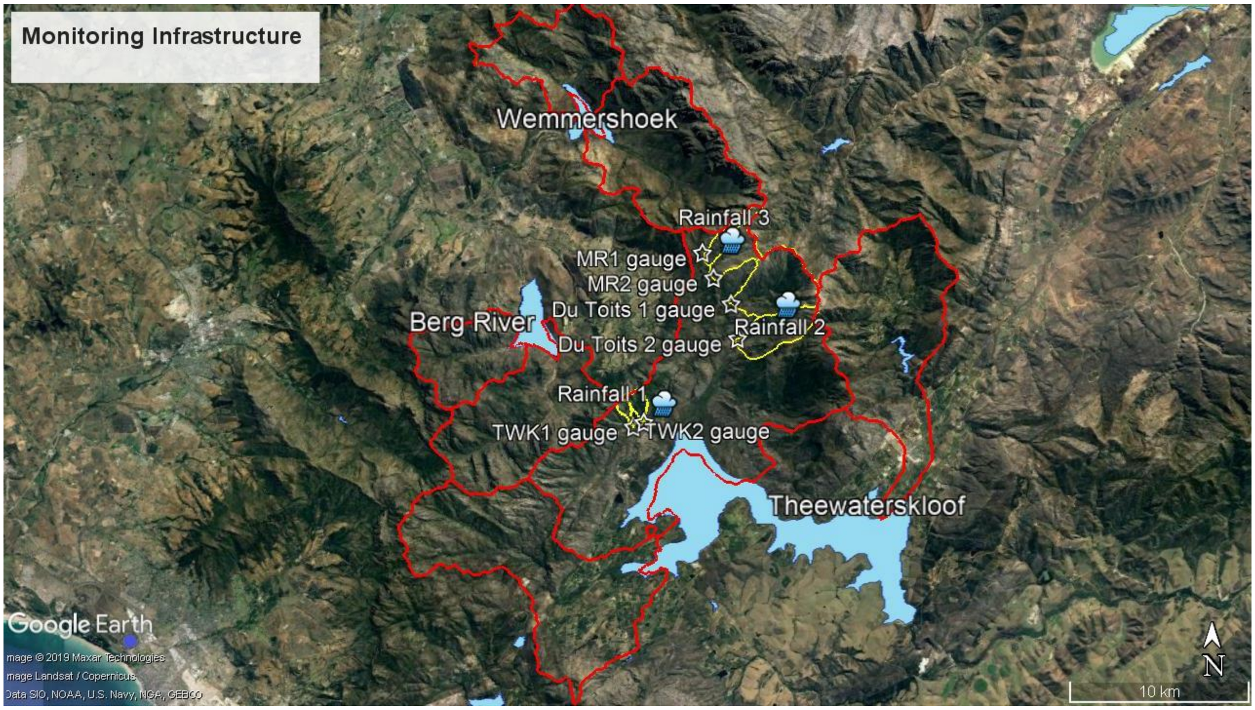


Figure 4. The location of various M&E monitoring infrastructure. The GCTWF 7 priority sub-catchments (red polygons) and the catchment experimental sites (yellow polygons) are also shown.

Photos of the various experimental catchments, as well as the experimental set-ups at each site are shown in Figures 5 – 10 (Aurecon, 2019).

Table 2. General characteristics of the experimental catchments used for the evaluation of the GCTWF interventions.

Experimental Catchment	Catchment Size (km^2)	Experimental Category *	Elevation Range (mamsl)	Dominant Land Cover	Geology	Soil
Du Toits 1	11.70	Control/Impact	514 - 1641	Pine	TMG, Peninsula FM	Shallow (30 – 45 cm) sandy soils
Du Toits 2	7.90	Control/Impact	579 - 1603	Pine	TMG, Peninsula FM	Shallow (30 – 45 cm) sandy soils
TWK1	0.14	Control/Impact	479 - 1340	Pine	TMG, Peninsula FM	Shallow (30 – 45 cm) sandy soils
TWK2	0.10	Control/Impact	429 - 1337	Pine	TMG, Peninsula FM	Shallow (30 – 45 cm) sandy soils
MR1	2.22	Reference	737 - 1555	Fynbos	TMG, Peninsula FM	Shallow (30 – 45 cm) sandy soils
MR2	4.12	Reference	759 - 1565	Fynbos	TMG, Peninsula FM	Shallow (30 – 45 cm) sandy soils

* It has not been established yet which of these catchments will be used as the control site or the impact site.
Abbreviations: TWK – Theewaterskloof, MR – Mont Rochelle, TMG – Table Mountain Group, FM - Formation

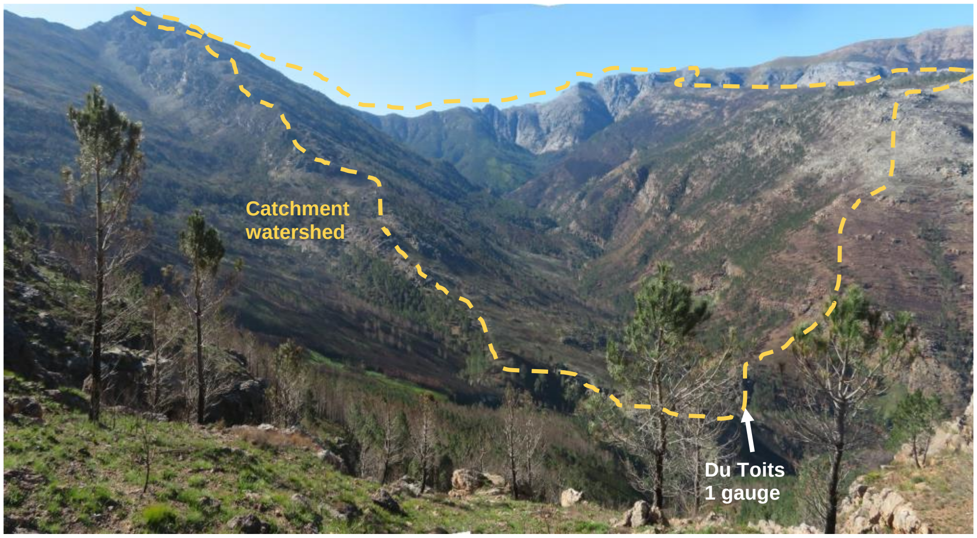


Figure 5. The catchment area of the Du Toits 1 experimental catchment.

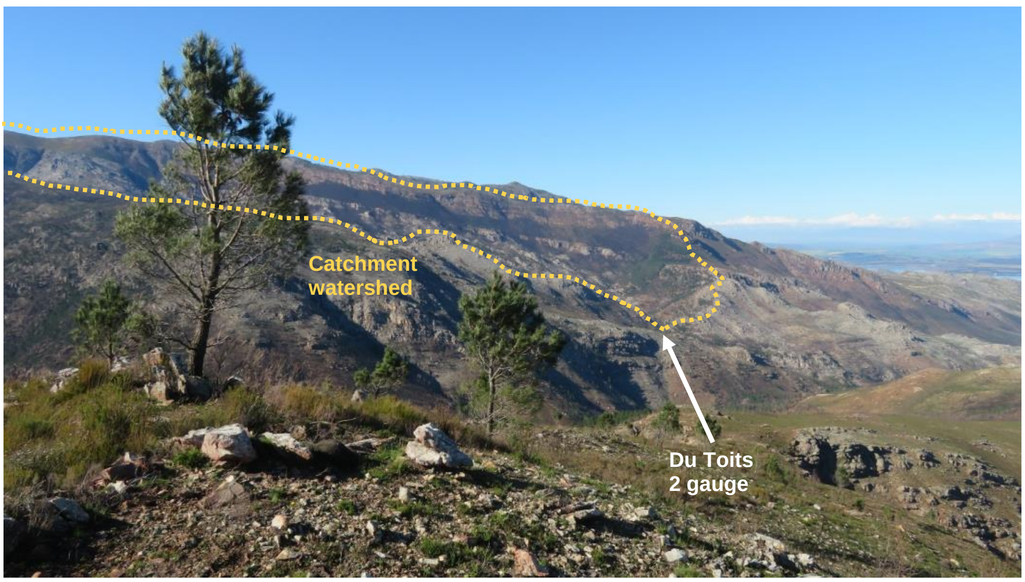


Figure 6. The catchment area of the Du Toits 2 experimental catchment.

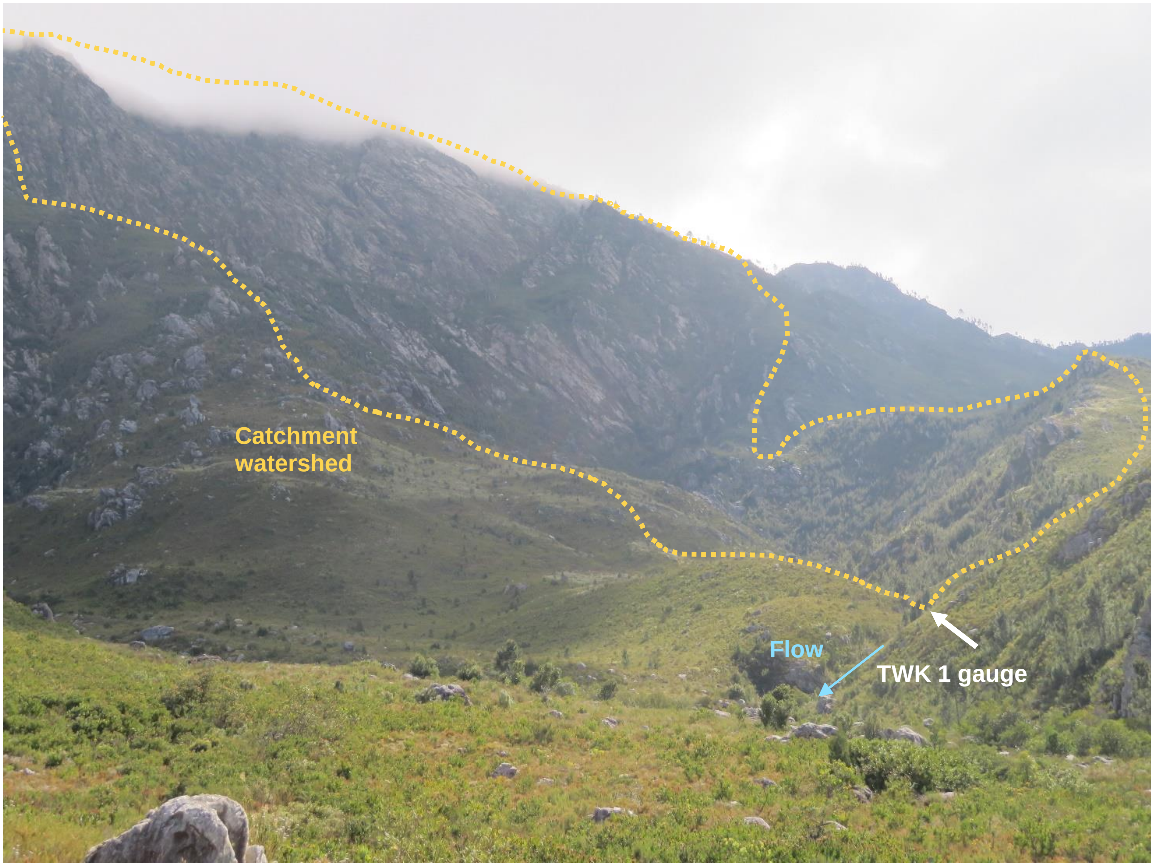


Figure 7. The catchment area of the TWK1 experimental catchment.

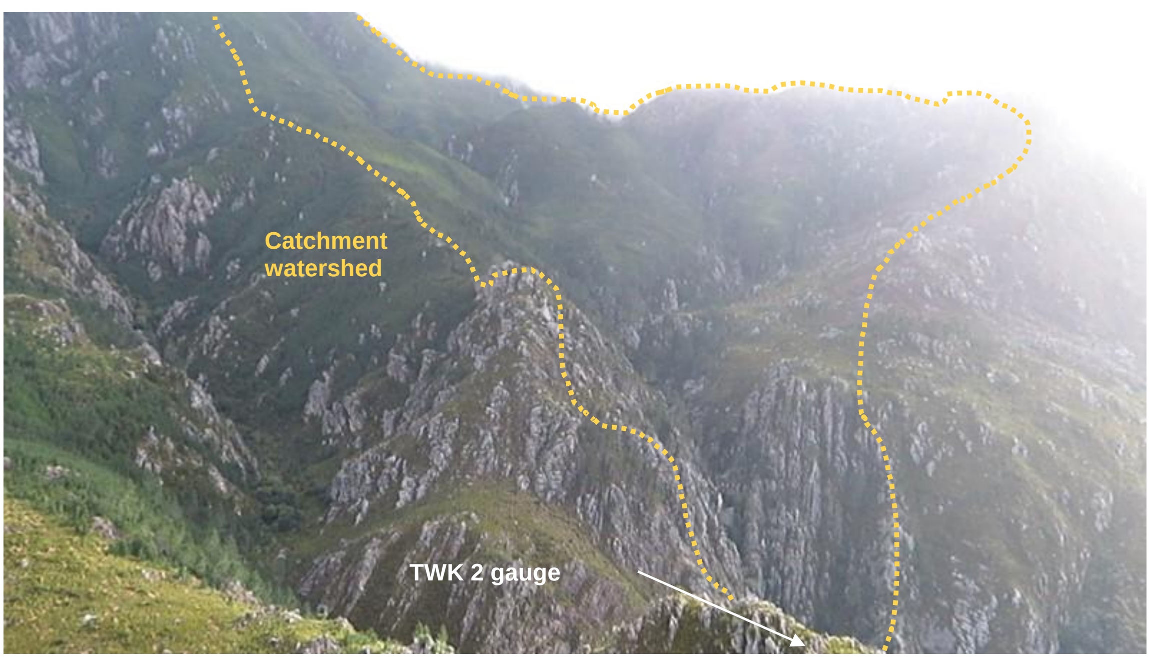


Figure 8. The catchment area of the TWK2 experimental catchment.

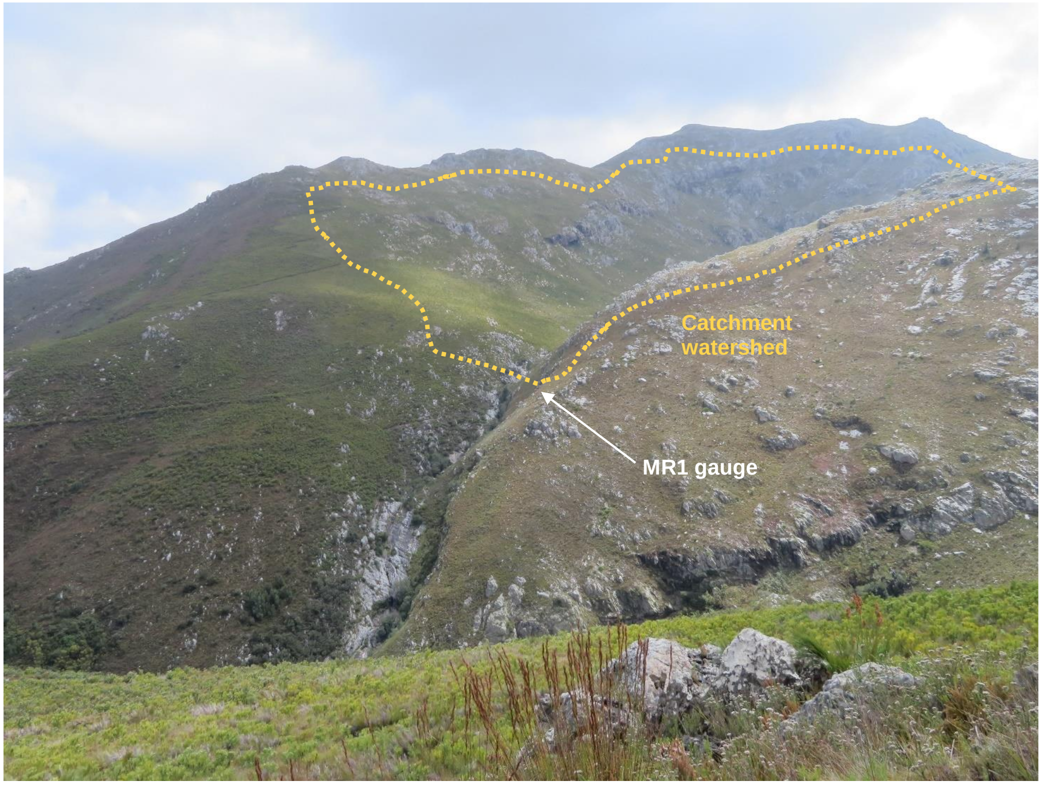


Figure 9. The catchment area of the MR1 experimental catchment.

Figure 10. The catchment area of the MR2 experimental catchment.

4.6. Data Collection and Analysis

IAP Clearing
Tracking the extent (# ha) of areas cleared is done on a monthly basis by collating data from all implementing partner institutions. Based on the IAP clearing target of 54 300 ha by 2025, an annual clearing rate of approximately 9,050 additional ha needs to be sustained, while follow ups on cleared hectares are maintained. IAP clearing data will be analysed on a quarterly basis and compared to annual targets. This frequency of analysis will allow for adaptive management.

Streamflow Volumes
At each experimental catchment (Table 2) the following data are collected:

- Water level (m), temperature (^{o}C) and electrical conductivity (EC, mS/m) at 5 minute intervals with Solinst LTC loggers (Model 3001, Solinst Canada Ltd, Figure 11).
- Event-based (hourly and daily) rainfall (mm) and hourly temperature with TR-525USW 8″ Texas Electronics rain gauges (Texas Electronics, Dallas, USA) and Onset Hobo Pendant loggers (Onset Computer Corporation, Massachusetts, USA). 3 monitoring stations were installed, i.e. one station per adjoining catchments.
- Stage measurements are observed on the gauge plate (Figure 11) during each field visit and these data are also used to confirm the automatically logged water levels.
- During each routine field visit the discharge is recorded (volumetric and/or with a OTT MF Pro streamflow meter (OTT Hydromet GmbH, Germany, Figure 12))

The primary statistical approach which will be used is regression analysis between the control and impact catchments during both the calibration and treatment periods. Regressions evaluate changes in water quantity over time. These regression relationships are then compared for identical slopes and intercepts using analysis of covariance. Further investigations of regressions among a dependent variable, such as a water quantity parameter, and an independent variable, such as the total area of activities, are used to understand dose/response relationships resulting from WF activities. In addition, several other hydrological variables will be analysed:

- Annual and monthly runoff coefficients (flow volume/rainfall volume)
- Base flow indices
- Flow duration curves
- Flow response relationships and recession curves, e.g. double mass curves of cumulative rainfall vs cumulative runoff
- Lag times of seasonal catchment flow responses
- Graphic visualization of selected rainfall events in high-resolution time series

Rainfall data are checked for gaps and aggregated to produce time series at required intervals, e.g. hourly, daily, monthly, yearly, etc. Analysis will include spatial variability, total rainfall in the catchment, seasonal variations, and the intensities of individual rainfall events.

Streamflow discharge will be calculated from water level data. Correct logger operation will be checked by comparisons with gauge plate readings or instantaneous discharge measurements, performed during each routine site visit. Discharge data will be normalized for catchment size so that values of specific discharges are comparable between catchments. Streamflow discharge will be calculated at hourly, daily, monthly and annual temporal scales. Indicators such as the mean flow, minimum flow in the dry season and maximum flow in the wet season will be calculated. Streamflow data will, at minimum, be processed at quarterly intervals (3 monthly) to be mindful of achieving annual targets, i.e. approximately 9 Mm^3/yr of additional streamflow, and to allow for adaptive management.

At this stage, due to the climatic variability in the GCTWF study area, it is interpreted that the time period required for the collection of pre-impact and post-impact data will be 3 years each. Additionally, it is expected that there will be a delay between the IAP clearing and the subsequent streamflow response, which will affect the post-impact monitoring period. Therefore, illustrating significant differences in attributes of streamflow may require several years of data collection and thus the anticipated data collection period will be reviewed annually.

4.7. Roles and Responsibilities

TNC will be responsible for the M&E of the water thematic area. This will include coordinating the data collection, tracking and reporting of areas cleared and quantifying water gains.

Figure 11. The stilling well and gauge plate set-up (left) used at each experimental catchment. The Solinst LTC loggers (right) are installed within the stilling well.

Figure 12. Streamflow discharge measurements are routinely collected at each experimental catchment during field visits.

5. Thematic Area 2: Biodiversity

The conservation and restoration of habitats and biodiversity is an essential mechanism to support ecosystem services, which are derived directly and indirectly from healthy ecosystems. Where possible, the GCTWF interventions aim to restore the natural fynbos land cover. Biodiversity monitoring provides data that directly link WF activities to quantified biological responses. These responses involve a lag-time, which is influenced by the types of activities and the linkages between terrestrial and freshwater habitats and biodiversity (Higgins and Zimmerling, 2013). Responses may occur downstream, as well as in areas proximal to the impacted site. Additionally, the responses of freshwater habitats and biodiversity may be affected by all areas upstream in the catchment, as all land uses affect terrestrial and freshwater ecosystem processes (Higgins and Zimmerling, 2013).

Terrestrial Biodiversity

In recent decades, ecological restoration has emerged as an essential action to mitigate the negative human induced impacts, e.g. the introduction of IAPs, exerted on natural environments (Gann et al., 2019). The Society of Ecological Restoration (SER) defines ecological restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (Gann et al., 2019). This recovery can either manifest through spontaneous succession after the removal of the degrading factor (passive restoration) or through manipulation of biotic and/or abiotic conditions (active restoration; Holmes et al., 2020). According to Mostert et al. (2018) it is critical to understand the criteria governing the success of passive restoration and to prioritize sites for intervention before they reach a point where active restoration is required.

These human induced environmental impacts are particularly evident in global biodiversity hotspots, such as the CCS (Holmes et al., 2020), where the spread of IAPs is a significant concern and threat to biodiversity and the provision of essential ecosystem services. These IAPs have developed into extensive dense stands across vast landscapes where they supress the indigenous vegetation and reduce streamflow (Richardson et al., 2000). This is a result of IAPs changing ecosystem characteristics such as vegetation structure, dynamics and functioning. In the mountain fynbos ecosystems of the CCS the dominant invaders are alien pines (especially *Pinus pinaster* and *P. radiata*) and hakeas (especially *Hakea sericea* and *H. gibbosa*, Wilson et al., 2014). Riverine ecosystems are also highly susceptible to invasion by alien plants as a result of the dynamic hydrological nature of rivers and the high transmission rate of propagules along rivers (Blanchard and Holmes, 2008). The riparian vegetation plays a critical role in maintaining ecosystem health and services. Riparian ecosystems in the winter rainfall region of the Fynbos Biome are mainly invaded by Australian Acacia (e.g. *Acacia mearnsii*, *A. longifolia*, *A. saligna*) and Eucalyptus (e.g. *E. camuldulensis*) species (Richardson and Van Wilgen, 2004).

IAP management programmes have been initiated over many parts of the CCS. These have had some successes over recent decades (Macdonald et al., 1989; Esler et al., 2010; Cheney et al., 2020), however the invasive species have continued to spread. IAP management produces long-term biodiversity conservation benefits through the restoration indigenous vegetation structure, species richness and species diversity (Holmes and Marais, 2000). Across the CCS, it is often assumed that passive restoration of the indigenous vegetation would occur subsequent to the control of the invasive aliens (van Wilgen and Wannenburgh, 2016). The commonly applied control methods for IAPs in fynbos ecosystems include (Holmes et al., 2020):

- Fell only - in threatened lowland ecosystems slash is often stacked, then left to rot or stacks burnt in winter)
- Fell and burn - usually with burning in autumn if fuel loads are low, or burning in winter/spring if fuel loads are high

Most fynbos species will recruit immediately after a fire (Le Maitre and Midgley, 1992). Therefore, it is required that the cleared area burns to stimulate germination of dormant soil-stored fynbos seeds. The fell and burn method is, however, seldom used in South Africa as a result of the legislation which places responsibility for any negative impact of a fire on the person igniting the fire (Holmes et al., 2020).

For passive restoration to succeed in fynbos ecosystems, either some indigenous vegetation must persist under the aliens, or soil-stored seed banks should have remained relatively intact. The passive restoration potential of invaded fynbos plant communities, is a function of (Holmes et al., 2020):

- The density of the invasion
- The duration of the invasion
- Species of invader
- Major ecosystem type, e.g. mountain vs lowland fynbos types.

Additionally, the control method utilized and the efficacy of the control method applied also significantly influences the potential for restoration. The control method should incorporate careful clearance of the aliens to avoid damage to indigenous species, while also ensuring a high kill rate for re-sprouting alien species. Additionally, it is important that alien follow-up control is maintained at a suitable frequency and that adaptive management is exercised to consider unplanned events, e.g. fire or a high rainfall year, that may stimulate renewed alien recruitment (Holmes et al., 2008).

According to Holmes et al. (2020), fynbos species can survive under the aliens until the projected alien canopy cover is >70%, after which all species die off owing to shading or other competitive effects. Galloway et al. (2017) also demonstrated that in mountain fynbos ecosystems following pine forestry, the limit to recovery through passive restoration falls between 30 – 50 yrs based on post-fire recruitment and persistent soil seed banks. At sites with a longer history of invasion, post-fire sowing may be required to accelerate restoration (Holmes and Marais, 2000). Holmes et al. (2020) suggest that low density invasions and sites with recent, dense invasion should be prioritized to optimize the benefits of passive restoration, to contain the spread and achieve the greatest long-term ecological gains from alien control.

An overview of the components of the terrestrial biodiversity thematic area is provided in Figure 13.

5.1. Current State

Extensive areas of the 7 priority sub-catchments of the GCTWF are invaded by IAPs.

5.2. Desired State

Intermediate outcome - By 2025, to clear all mature invasive trees and to implement a follow up control program according to prescribed schedules across the 54 300 ha of the 7 priority sub-catchments, and 5 000 ha on the Atlantis Aquifer, thus enabling a net gain of native fynbos vegetation.

Long-term outcome - The restoration of the biophysical characteristics, growth form structure and functioning of native fynbos communities across 70% of the invaded areas in the 7 sub-catchments and 5 000 ha of the Atlantis aquifer by 2045, i.e. within 2 – 3 fire cycles. Where necessary, this will incorporate the active restoration of self-sustaining ecological communities towards reference conditions.

According to Holmes and Richardson (1999), a fully functioning fynbos community is characterised by a balance between the major growth form, regeneration and nutrient acquisition guilds. Holmes et al. (2008) suggests that ecosystem functioning is restored when vegetation post-clearance resembles an uninvaded, reference site in terms of vegetation structure (e.g. growth form composition), species composition and aerial cover.

In cases where dense to closed IAP stands persist, it may be unrealistic to target the restoration of the vegetation cover to a reference condition (in terms of species composition and diversity) within short (5 – 10 yrs) time frames, particularly where slash is left *in situ* (Holmes et al., 2008). However, once indigenous structural components have re-established and the IAPs are controlled, diversity and composition are likely to continue to converge towards reference conditions over a longer time frame.

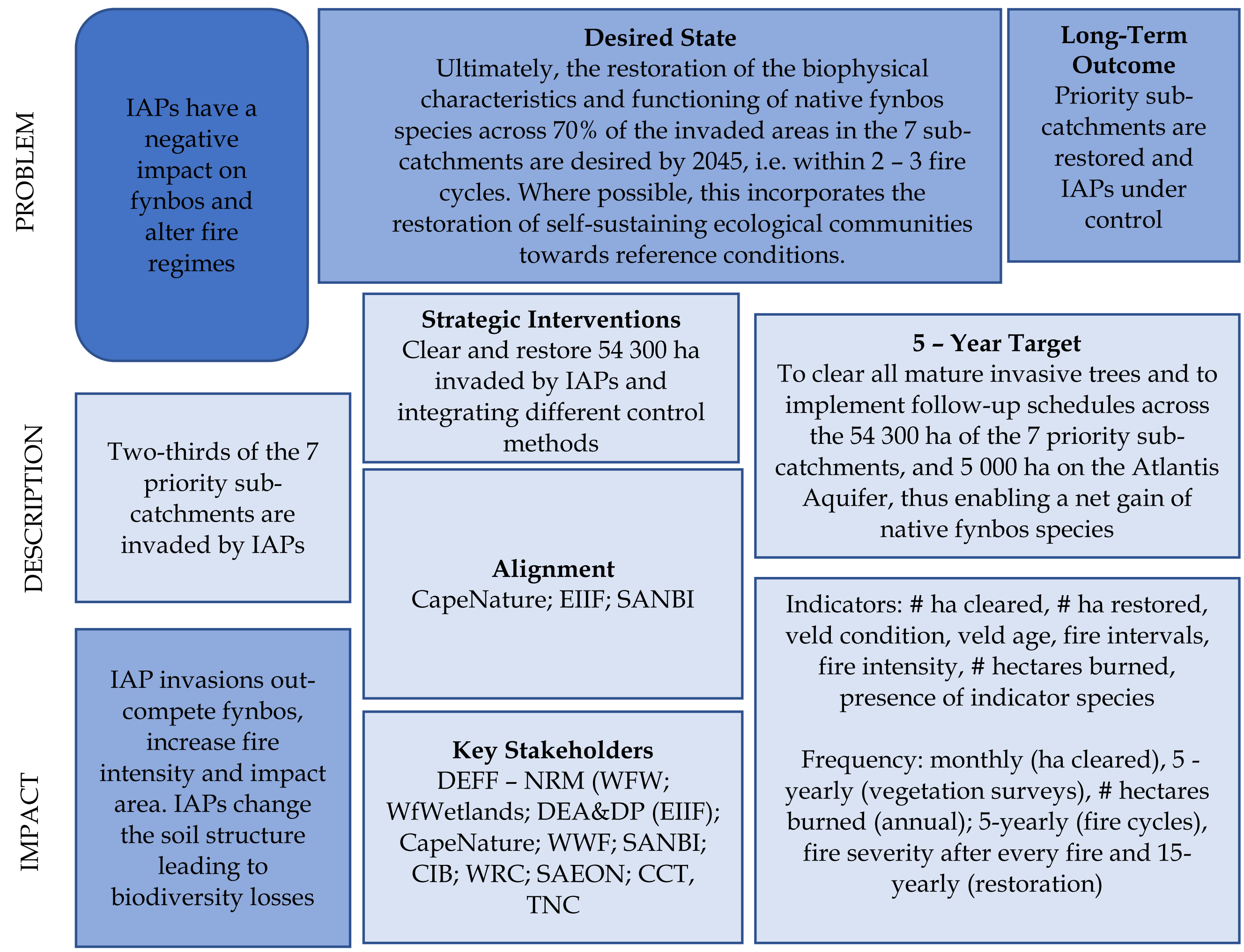


Figure 13. A schematic of the different components of the terrestrial biodiversity thematic area.

5.3. Output Indicators

To achieve the desired state within the anticipated timeframe, the following indicators will be monitored:

Reduction in Areas Invaded

Partner institutions routinely report on area cleared (ha), IAP species cleared, density of IAP invasions (before clearing), veld condition and veld age distribution.

Restoration of Cleared Areas

The passive restoration of cleared areas will be assessed according to evaluation techniques which:

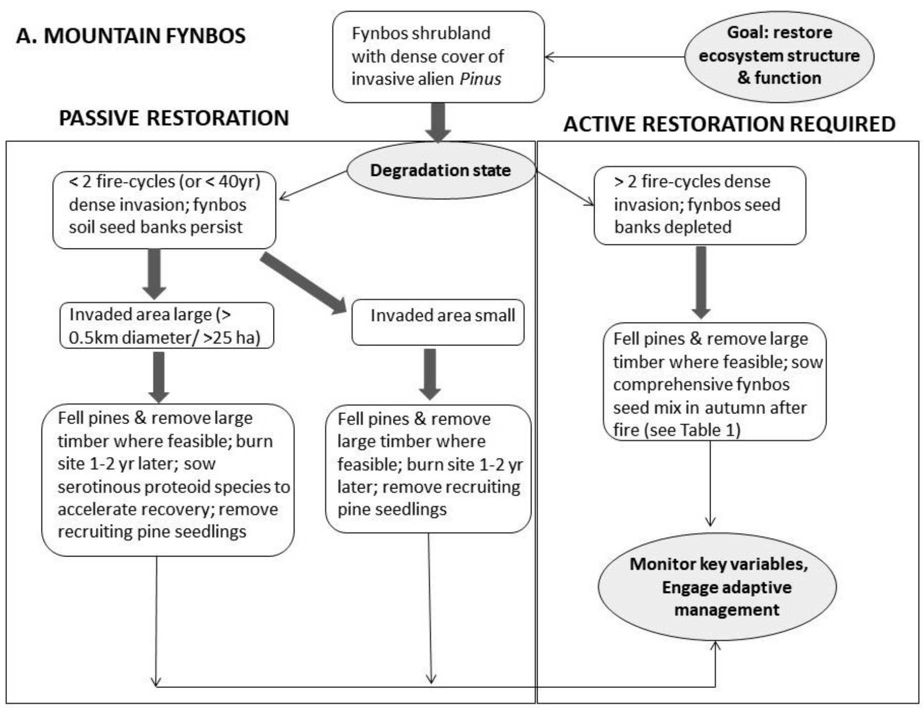
- Consider the restoration potential as a function of several environmental factors, i.e. species of invader, density of invader, duration of invasion, the ecosystem type and the method of IAP clearance.

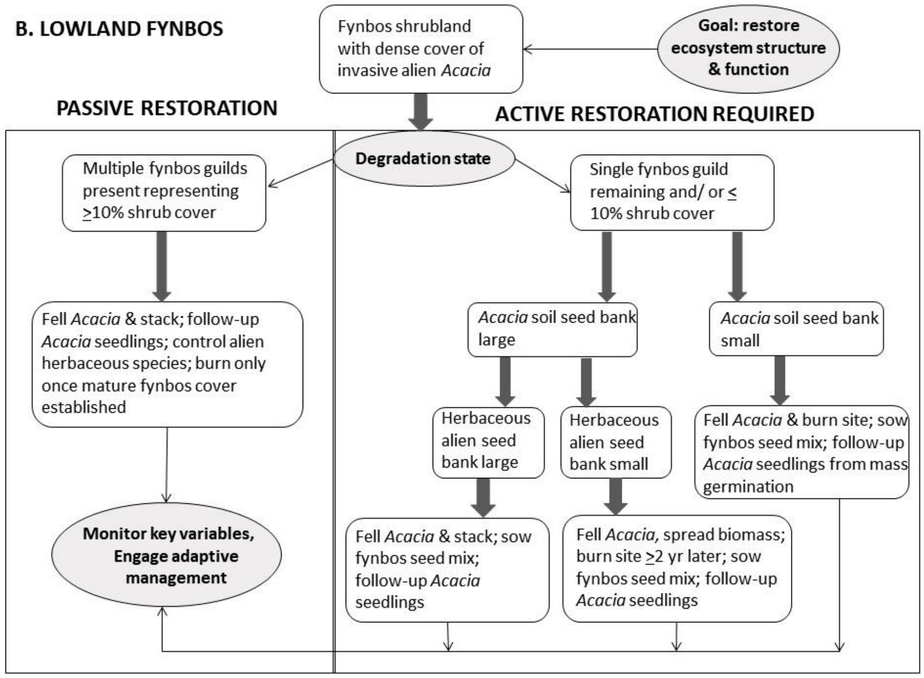
Restoration approaches:

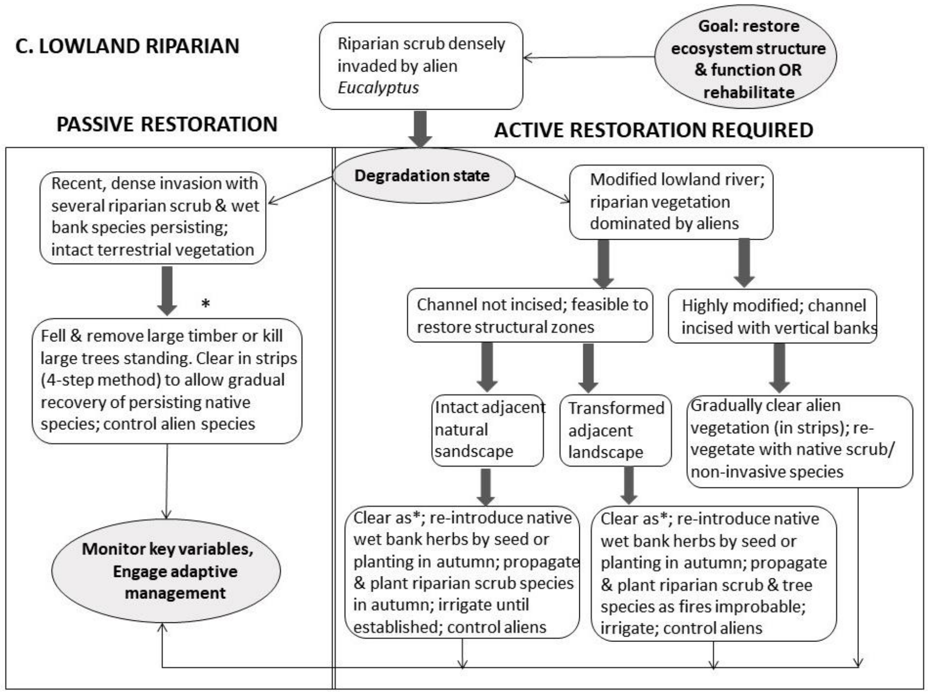
- Passive - continued removal of IAP allow for natural recovery of native vegetation
- Active - areas are actively seeded or replanted

- Incorporate the establishment of permanent survey plots, where routine vegetation surveys will be conducted.

Holmes et al. (2020) developed decision trees for restoring invaded ecosystems using case studies from the CCS, which indicate where passive restoration, which relies on spontaneous succession, is an appropriate strategy. The decision trees consider mountain fynbos, lowland fynbos and lowland riparian ecosystems. According to Blanchard and Holmes (2008), mountain riparian ecosystems are resilient and therefore are characterised by a very high likelihood of passive restoration, provided that appropriate clearing methods are utilised and that the fuel is removed from the riparian zone during clearing. The mountain fynbos, lowland fynbos and lowland riparian decision trees are presented in the information boxes below.







Holmes and Marais (2000) studied the impacts of dense, mixed pine and hakea stands and control operations on indigenous mountain fynbos vegetation structure and composition in vegetation survey plots. Two permanent monitoring sites were identified, and at each site four 50 m^2 monitoring plots were established before IAP control operations were initiated. The monitoring plots were a combination of invaded plots and uninvaded control plots. Indigenous and alien plant species cover and density were recorded from which the following variables could be monitored: species richness and diversity, indigenous vegetation canopy cover, plant density, growth form structure and functional guild richness, and community similarity. The IAPs were controlled by clearing the stands mechanically to facilitate seed release, and the sites subsequently burnt 12 – 18 months later in unplanned fires which killed any alien seeds and seedlings. The follow up vegetation surveys were done 1 – 2.5 yrs after the fires. The results of the study showed that the post-fire recovery of the indigenous vegetation was rapid. Additionally, the study concluded that clearing of serotinous IAP species by felling and burning is an effective method of controlling the IAPs and initiating fynbos recovery in dense stands that are relatively young (8 and 9 yrs in this case). The study also recommended that biological control be developed, where not readily available, to reduce the re-invasion risk from clearance escapees.

Holmes et al. (2000) investigated the recovery of mountain fynbos vegetation after invasions by dense stands of IAPs and subsequent clearing by 'burn standing', 'fell and burn', or 'fell, remove and burn' control methods. The indigenous plant density, cover, functional and biological guilds, and species richness where compared to uninvaded control sites, which were burnt in the same fires. Three 25 m² plots were established at each of the invaded and control sites. Within each plot, a 1 m² nested plot was established at the centre, within which species richness was recorded. The main results of the study were:

- Invaded sites exhibited lower species richness, indigenous plant densities and cover when compared to control sites
- The 'burn standing' control method resulted in the least change to vegetation variables. The 'fell, remove and burn' and the 'fell and burn' control methods caused greater, but otherwise similar changes. The 'fell and burn' treatment resulted in the greatest negative effect on guild survival and indicated the negative impact of a severe fire on soil and fynbos seed banks that burnt through dense alien biomass.

Evaluating the success of riparian restoration interventions, i.e. to acceptable structural or functional reference levels, is a challenge to conceptualize due to the inherent dynamic nature of these ecosystems (Richardson et al., 2007). Frequent disturbances in riparian ecosystems provide opportunities for change in the diversity and relative abundance of component species (Esler, et al., 2008). Blanchard and Holmes (2008), assessed indigenous vegetation composition and structure following IAP removal in closed-stand invasions (> 75% canopy cover) of riparian areas. A minimum of two years' passive recovery was allowed post removal. Three initial clearing treatments, i.e. 'fell only', 'fell and remove' and 'fell and burn', were utilized and the extent of passive restoration compared to uninvaded reference sites. 78 alien-cleared sites were sampled along 15 rivers and compared to 69 reference sites. More than one plot was sampled per river, but these were located at least 200 m apart. Vegetation plots with dimensions of 10 x 5 m were set up in the dry bank zone of the riparian zone, with the long edge parallel to the river. Indigenous species richness was recorded in three 1 m² quadrats within each plot. The results indicated that the vegetation recovery in areas where the 'fell and remove' treatment was applied, most closely approached the reference condition, while the 'fell only' and 'fell and burn' plots exhibited altered composition and structure. Blanchard and Holmes (2008) further concluded that passive recovery of fynbos riparian scrub is likely to occur in a relatively short time frame (< 10 yrs) following the clearance of dense aliens, provided a 'fell and remove' treatment is applied. Where it is impractical to remove slash, it should be stacked away from the riparian zone in areas where small (< 1.2 m high), wet season stack burns can be safely carried out. Where possible, stacks should be burned on sandbars in the riverbed, before the onset of the major rains, to avoid damage to surrounding vegetation. An alternative option is to kill large trees standing (Holmes et al., 2008). Invaded sites cleared by the other methods may take a longer time to resemble the reference condition in structure and composition.

Reinecke et al. (2008) monitored the spontaneous succession of riparian vegetation following wildfires and IAP removal over several years at two sites on the Cape Peninsula, i.e. a pine plantation in an upland plateau and an *Acacia* spp.-invaded valley floodplain. At each site, two belt transects, which consists of adjoining 1 m^2 plots, positioned approximately 15 m apart and perpendicular to the river, were used to survey the vegetation. The transects extended into the mountain fynbos ecosystem on each side of the valley. After clearing, the indigenous vegetation at the pine site was successfully recovering, which suggested that no active restoration is required. On the other hand, the areas cleared of *Acacia* spp. may be less resilient, with extensive regeneration of woody aliens and only a negligible recovery of indigenous trees. Reinecke et al. (2008) proposed that under such circumstances, active restoration would be required in order to re-instate the riparian community. It should however also be noted that a variation in soil type is evident between the sites, i.e. the areas cleared of *Acacia* spp. are characterised by shale derived soils, which may have influenced the restoration at this site.

The recovery of the indigenous vegetation after clearing operations, in the majority of invaded foothill and mountain stream reaches of the Fynbos Biome, is achievable and should therefore be the target (Holmes et al., 2008). However, this may not be achievable when:

- Closed alien acacia stands, of older age, are cleared in a degraded and transformed catchment and there is a lack of indigenous propagule sources;
- Closed alien acacia stands are cleared via 'fell and burn' operations.
- Closed pine stands which have been present for more than 30 years.

5.4. Evaluation

Intermediate Outcomes

Due to the characteristics and dynamics of passive fynbos restoration, it is highly likely that vegetation recovery will still be in its early stages by 2025. Therefore, progress towards achieving the intermediate outcomes will be evaluated through:

- Tracking the reduction of invaded areas, and the effectiveness of treatments, including follow-up treatments
- Tracking the use of herbicides which negatively impact on fynbos restoration
- Assessments of fynbos restoration potential. This will also identify sites that require active restoration interventions.

Considering the factors which influence the passive restoration potential of mountain fynbos, including riparian areas, it is assumed that passive restoration will occur in areas if:

- The density of the pine or hakea invasions cleared did not exceed 70% canopy cover and the veld age of any dense invasions was < 30 yrs.
- All mature invasive trees are cleared using an appropriate method that does not negatively impact on remaining fynbos vegetation and seed banks. For terrestrial areas this would entail avoiding fires through areas of dense alien biomass (e.g. where alien stands are > 10 yrs old; either through removal of biomass, allowing several years for

decomposition to first occur, or by burning biomass in early spring when the soil remains wet to avoid soil damage). For riparian areas the optimal method is to remove large biomass from the riparian zone. In some cases of large alien trees, it may be appropriate to kill standing.

Note that for lowland fynbos invaded by *Acacia* spp., the potential for passive restoration is lower than in mountain fynbos. All dense stands of acacias have low restoration potential unless 10% of diverse shrub cover persists under the aliens. If these conditions do not persist, active restoration will be required.

Long-term Outcomes

Changes to the vegetation composition and structure will be monitored within impact and reference plots, which will be located within experimental catchments. The following evaluation techniques will be utilized:

5.4.1.Multiple Plot Design

This evaluation technique uses multiple plots (an adaptation of "Monitoring Downstream of Multiple Sites" in Table 1) to evaluate changes in vegetation, soils and other habitat characteristics. "Before data" to assess baseline conditions and "after data" will be collected to assess differences due to treatment, i.e. IAP clearing. This design may include control and impact sites, or reference and impact sites (Higgins and Zimmerling, 2013). In this case, we will use reference and impact sites.

Statistically sufficient replicates of each type of plot will be used to strengthen the inference power of the results. It is assumed that all the reference and impact plots experience the same environments and that all impact plots receive the same treatments.

The advantages of plot monitoring approaches include:

- Plot designs generally allow for the control of several variables, e.g. soils, slope, direction to sunlight (e.g. facing north or south on the side of a mountain) and climate.
- The experimental design can facilitate the grouping of plots in a single site receiving the same experimental treatment, to account for antecedent differences and variations resulting from external factors affecting the experiment.

5.5. Experimental Sites

The restoration potential of invaded areas is a function of:

- The density of invasions, i.e. passive restoration is unlikely to occur if the alien density exceeds 70%canopy cover
- The position in the landscape, i.e. upland areas vs riparian areas
- Vegetation types, i.e. lowland vs mountain fynbos ecosystems
- Duration of invasion, i.e. passive restoration is unlikely to occur if the invasion > 30 yrs old

Impact monitoring plots will be set-up in areas:

- Which exhibit a < 70% invasion density and where the age of the invasion is < 30 years

- Which exhibit a > 70% invasion density and where the age of the invasion is > 30 years

Reference plots with similar environmental attributes as the invaded plots will also be set-up in areas which have been uninvaded for at least 30 years and where indicator species are present, i.e. species most likely to be impacted by the presence of IAPs, such as overstorey *Proteaceae*. Impact and reference plots will be installed in sites which exhibit similar soil conditions, slope, aspect, landscape setting and climate.

The following vegetation survey plot designs are proposed (Figure 14). For plots which may be in mountain fynbos or lowland fynbos ecosystems, the following is proposed (a selection will be made between the 2) (Figure 14 (a)):

- A nested plot design, which is characterized by a 20 x 20 m plot, within which 2 x 2 m plots are nested.
- A nested plot design, which is characterized by a 5 x 10 m plot orientated with its long side parallel to the slope, within which a 2 x 2 m plot is nested.

For plots which may be in mountain riparian or lowland riparian ecosystems, we propose transects with permanent plots which extend across the riparian zone, i.e. wet bank to dry bank (Figure 14 (b)):

- 10 x 5 m plots in both the wet bank and dry bank subzones, within each of which a 1 x 1 m plot is nested. The long edge is orientated parallel to the river.
- Braun–Blanquet vegetation belt transects, with relevés in the wet bank and dry bank subzones. The area of the relevé is a function of the lateral width of each zone up the river bank.

At this stage the exact location of the impact and reference plots and the sample size has not been established. Potentially, at both the impact and reference sites, 10 plots will be set-up. It is likely, that monitoring plots will be established in the vicinity of the experimental catchments (Figure 4, Table 2). This configuration would produce 30 plots.

5.6. Data Collection and Analysis

Reduction in Areas Invaded

Tracking the reduction in areas invaded will be done on a monthly basis by collating data from all partner institutions, i.e. CCT, WWF, CapeNature, TNC and Working on Fire-High Altitude Teams (WoF-HAT).

Restoration of Invaded Areas

At impact monitoring sites, baseline information will be recorded prior to clearing. Baseline information will also be recorded at reference sites. Impact plots will be monitored annually post clearing and post fire for the return of indicator species, guilds and/or guild composition which will provide an indication of the return to reference conditions. Reference plots will be monitored every 5 years. It may be required that monitoring activities continue for extended periods in order to assess whether populations and communities have not only re-established but can complete their life cycles and becoming self-sustaining (Holmes and Richardson, 1999).

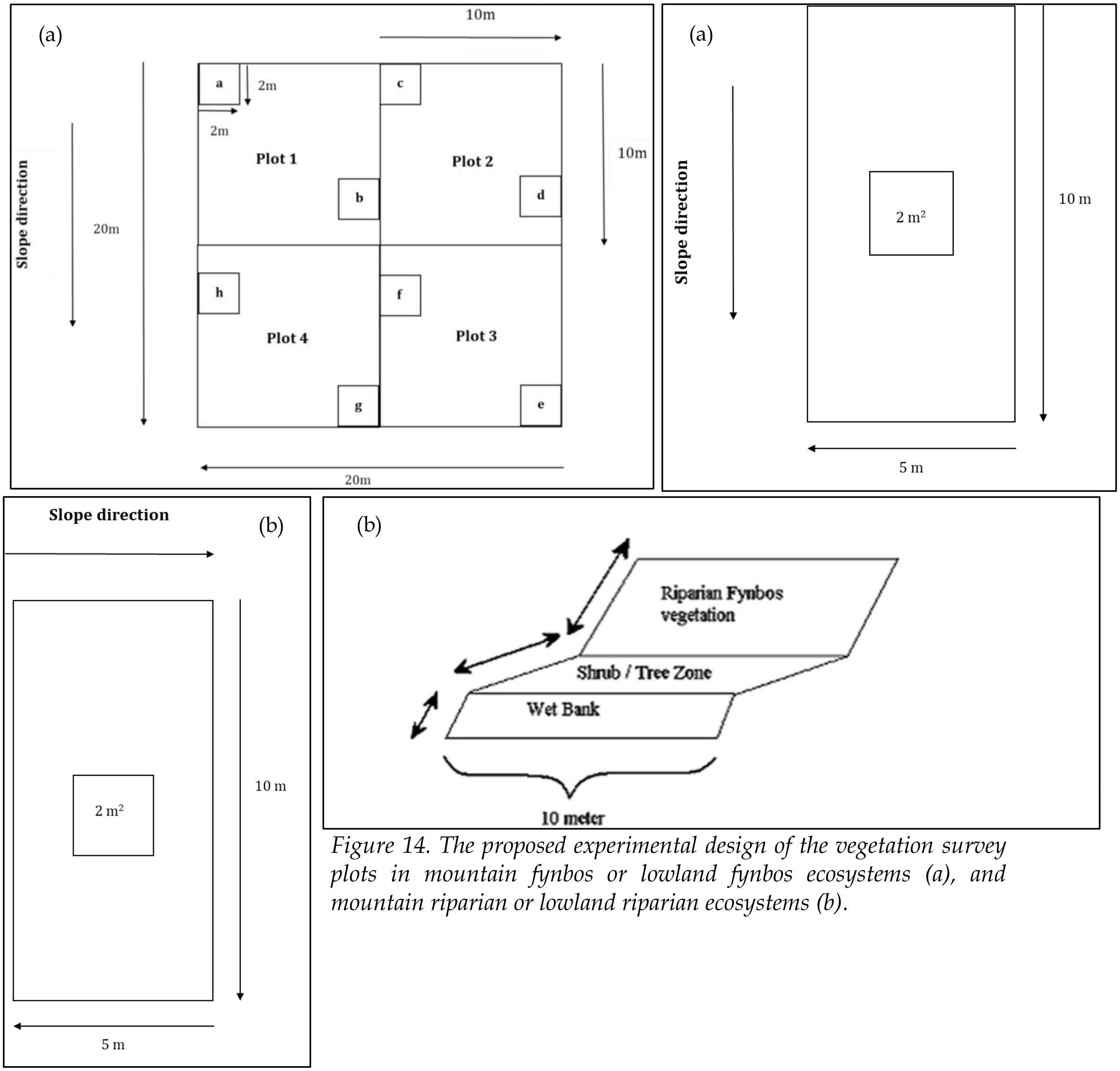


Figure 14. The proposed experimental design of the vegetation survey plots in mountain fynbos or lowland fynbos ecosystems (a), and mountain riparian or lowland riparian ecosystems (b).

The monitoring will be undertaken by an experienced field botanist. The variables to be monitored within the plot and within each nested plot differ. Within the plots broad species level monitoring will be done which include:

- Listing indicator species presence/absence
- Indigenous and alien plant species cover and density

Within the nested plots, monitoring will be done at the individual species level which include:

- The identification and counting of every individuals of every species (Gotelli and Colwell, 2001)
- Density of individuals
- Species richness

From the in-field measurements the following variables can be analysed:

- Diversity and composition (level of taxonomic resolution)
- Species richness
- Vegetation structure
- Growth form structure
- Net gain of native vegetation

The primary statistical approaches to assess differences among impact and reference) sites include the analysis of variance (ANOVA), t-tests and u-tests (Higgins and Zimmerling, 2013) and detrended correspondence analysis (DCA) as a measure of community similarity. However, other methods of statistical analysis will also be explored in order to obtain the best statistical representation (model) of processes. Data will be analysed on an annual basis.

The use of satellite remote sensing tools, e.g. Slingsby et al. (2020), will also be explored to monitor the recovery of vegetation structure and productivity towards reference conditions across the broader landscape

5.7. Roles and Responsibilities

CapeNature, the landowner, will be responsible for the M&E of the terrestrial biodiversity thematic area. This will include coordinating the data collection, tracking and reporting.

Freshwater Biodiversity

Lecerf et al. (2007) and Stockan et al. (2013) point out a global paucity of studies investigating IAP impacts on freshwater ecosystems. The same is true in South Africa where, despite the vast extent of IAP invasions throughout catchment areas and riparian zones, and known impacts on water quantity, the scientific literature documenting responses of freshwater ecosystems and their biota to IAP invasions is relatively scarce (Ractliffe et al., 2003; Richardson and Van Wilgen, 2004; Foxcroft et al., 2017). Studies that do exist suggest that riparian IAPs can impact both biotic and abiotic components of freshwater ecosystems (see Ractliffe et al., 2003; Samways et al., 2011; Rivers-Moore et al., 2015).

Abiotic factors such as temperature and flow often show strong response to IAP invasion or clearing, but there can also be effects on water chemistry, nutrient levels, and on habitat complexity (e.g. sediment and detritus dynamics) (see review by Castro-Diaz and Alonso, 2017). These abiotic effects can translate into biotic responses, typically including impacts on the presence and abundance of invertebrates (mostly insects and crustaceans) and vertebrates (fish and frogs), and ultimately freshwater community structure and function as a whole (e.g. Ractliffe et al., 2003; Samways et al., 2011; Rivers-Moore et al., 2015). The degree to which IAP infestation or removal impacts on the freshwater ecosystem may ultimately depend on the functional similarity (or difference) between the native and invasive vegetation (Pusey and Arthington, 2003). Castro-Diaz and Alonso (2017) outline the extent of potential impact of IAPs in freshwater systems, which include:

- Altered fire regimes
- Changing the depth of the water table
- Altered nutrient cycles and organic matter processing
- Changes to soil properties, communities of detritivore invertebrates and vertebrates dwelling in rivers and riparian zones.

In addition to these, IAPs also impact:

- Water temperature
- Water availability (particularly base flows)
- Riparian vegetation canopy cover, litter fall and single species dominance

Pusey and Arthington (2003) summarise some of these mechanisms in Figure 15.

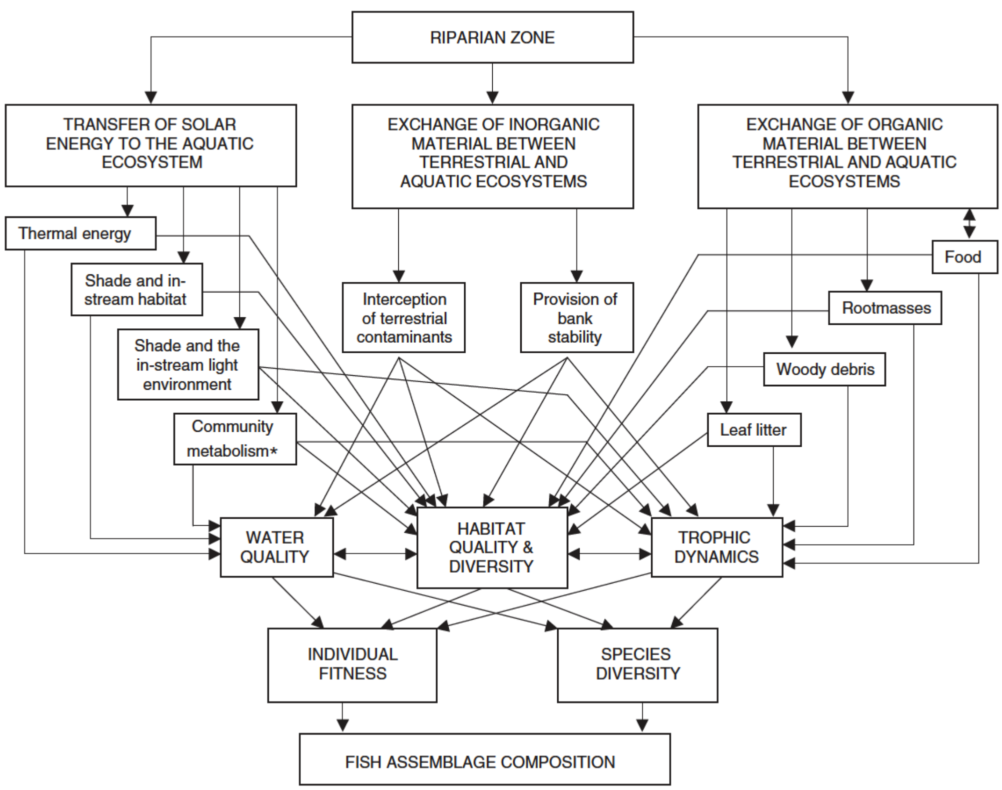


Figure 15. Conceptual model showing mechanisms of how riparian communities can regulate riverine ecosystems and biodiversity (from Pusey and Arthington, 2003).

The focus of this freshwater biodiversity monitoring framework is on (1) river health and biodiversity, and (2) wetland health and biodiversity. The planned interventions provide a unique and valuable opportunity to improve our understanding of IAP impacts on freshwater ecosystems in the CCS. The variables and associated sampling methodologies are outlined in the sections below. An overview of the components of the freshwater biodiversity thematic area is provided in Figure 16.

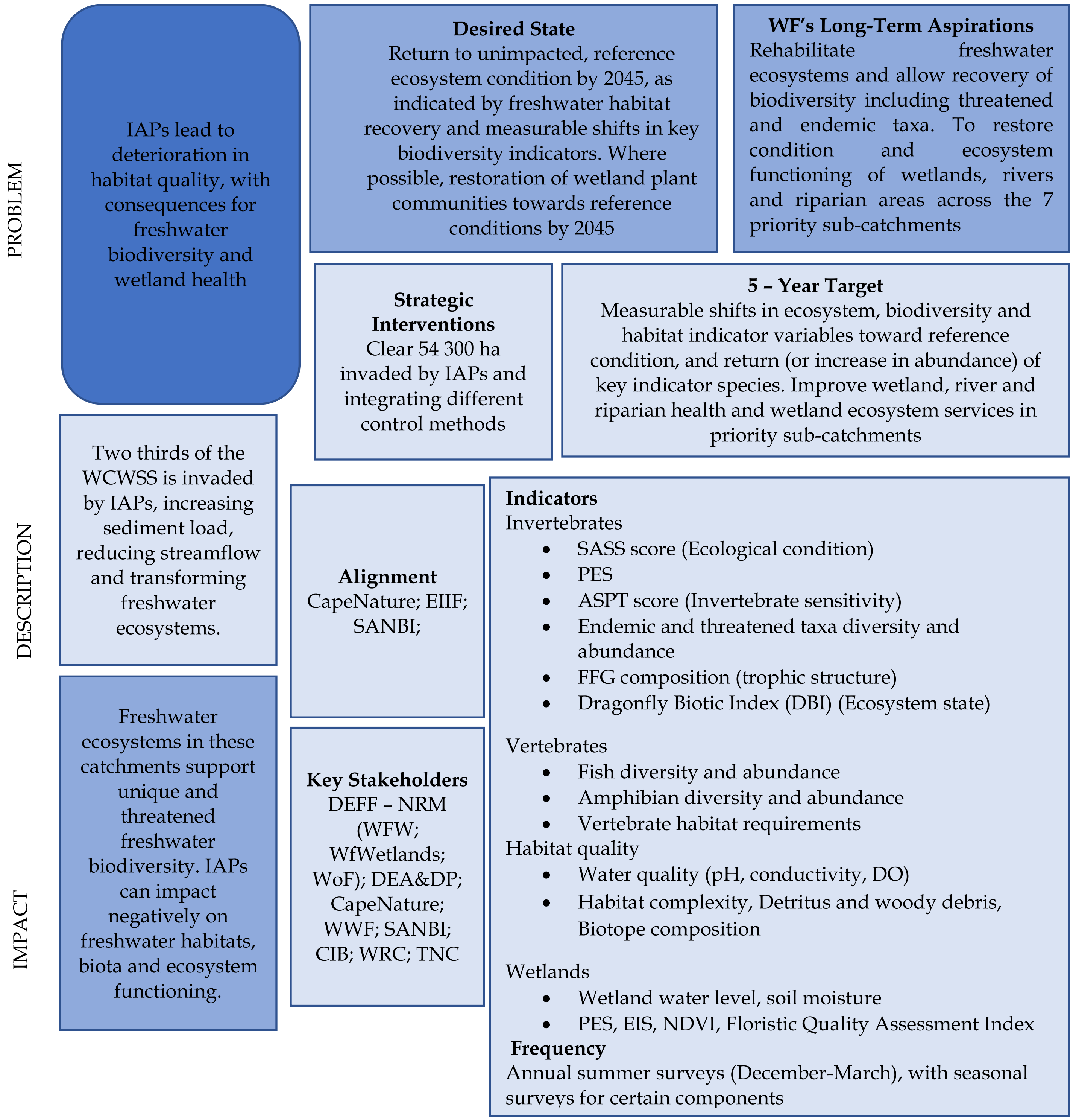


Figure 16. A schematic of the different components of the freshwater biodiversity thematic area.

5.8. Current State

Snaddon et al. (2019) indicate that the inland freshwater ecosystems within the Sonderend, Du Toits and Amandel River catchments (Figure 17) are generally in good-to-natural condition, and are home to a particularly high concentration of endemic freshwater species, several of which are considered threatened by the International Union for Conservation of Nature (IUCN) Red List. Degradation, resulting from invasive species (fauna and flora), pollution and wetland transformation is evident in certain low-lying areas where freshwater ecosystems are exposed to human activity (agriculture, settlements) and where habitats are accessible to upstream fish invasions from Theewaterskloof Dam. Initial site surveys of the paired catchment experimental sites (Figure 4) and desktop analyses indicate that IAP infestations are the primary impact on the freshwater ecosystems in these catchments. Freshwater ecosystems in IAP-free catchments are expected to be in a natural (or near-natural) condition, while freshwater ecosystems in catchments with IAP invasions are expected to be in an impacted state.

River Health and Biodiversity

- Freshwater invertebrates: The best indicators of ecosystem condition and invertebrate assemblages include, (1) South African Scoring System (SASS) score (an indication of ecological condition) and Present Ecological State (PES), (2) Average Score Per Taxon (ASPT) (an indication of mean taxon sensitivity), (3) general and endemic indicator taxon abundance and diversity, (4) functional feeding group (FFG) composition and (5) the Dragonfly Biotic Index (DBI). Pristine sites should have higher SASS and ASPT scores than impacted sites, and a higher diversity and abundance of endemic taxa than at altered sites (Ractliffe et al., 2003; Samways and Taylor, 2004; Magoba and Samways, 2010; Samways et al., 2011). Shelton et al. (2015) provide information of the FFG composition of pristine headwater streams in the study area, showing a community dominated by collector-gatherers. This may shift with removal of IAPs, due to shifts in leaf litter composition and decomposition rates and changes in algal communities (King, 1982; Lecerf et al., 2007; Lowe et al., 2008; Remor et al., 2013; Serra et al., 2013; Stockan et al., 2013). Certain Odonata species (including sensitive and endemic taxa) may be excluded from streams shaded by alien trees that are normally surrounded by fynbos (Magoba and Samways, 2010; Samways et al., 2011). Odonates are anticipated to respond to removal of IAPs with an increase in diversity and endemic taxa (Samways and Taylor, 2004; Samways and Samaika, 2016).
- Freshwater vertebrates: Freshwater vertebrate response variables include diversity, abundance and size structure of freshwater fish, frogs and tadpoles, as well as shifts in habitat availability for specialized, sensitive taxa. Healthy native fish populations occur in sections and tributaries of the upper Sonderend, Du Toits and Amandel Rivers (Shelton et al., 2015; Snaddon et al., 2019), and in some of the paired catchment tributaries (Shelton pers. obs., 2020). Fish abundance and diversity is generally reduced at impacted sites exposed to human-linked habitat degradation or invasive species impacts (Snaddon et al., 2019). Baselines for tadpole and frog diversity and abundance are yet to be determined. Observations at sampling sites indicate a river amphibian fauna with charismatic indicator species like Purcell's ghost frog present. The study area is home to some very 'ecologically-specialized' vertebrate and invertebrate taxa, with specific habitat

requirements in terms of flow and substrate and depth. Examples include the endemic *Galaxias* spp. 'Rectognathus' and *Heleophryne purcelli* tadpoles, which appear to need fast flows and good substrate complexity. Habitat availability for such taxa is expected to be influenced by IAPs, with a reduction in available habitat where IAPs increase sedimentation and reduce flow at IAP-infested sites.

- Riverine habitat quality: Important aspects of stream habitat likely to be influenced by IAP removal include habitat complexity (substrate composition and embeddedness), detritus and woody debris leaf litter, woody debris and mesohabitat (pool, riffle) depth and flow. Data from Snaddon et al. (2019) show good habitat complexity at unimpacted sites, with a mean particle size of 100-300 mm. Sedimentation (proportion fine substrates) and embeddedness (reduction in gaps between stones due to sedimentation) are expected to be relatively low at unimpacted sites (Pusey and Arthington, 2003; Ractcliffe et al., 2003; Chamier et al., 2012; Castro-Diaz and Alonso, 2017). Leaf litter accumulation and woody debris should also be relatively low and comprise native vegetation at unimpacted sites (King, 1982; cited in Rivers-Moore et al., 2015; Ractcliffe et al., 2003). In general, pools are expected to be deeper, and flows swifter, in pristine relative to altered habitats. In addition to water temperature and flow already covered in Thematic Area 1, monitoring should focus on three main water quality indicators that will be useful for interpreting responses in the biota: pH, conductivity (mS/m) and dissolved oxygen (DO, mg/L). Based on Snaddon et al. (2019), unimpacted sites are expected to have an acidic pH (4-5), low conductivity (<100 mS/m) and high DO (>100%).

Wetland Health and Biodiversity

- Wetland health: The key wetlands in the Du Toits and Upper Sonderend (Vyeboom wetland) are in moderate to good condition. The Vyeboom wetland has been impacted by runoff and irrigation return flows from agricultural areas. Additionally, IAP infestations currently impacting on these wetlands have led to changes in wetland hydrology, soil desiccation and subsequent erosion, due to soil instability. IAPs can lead to a build-up of sediment that alters the sediment and water flow dynamics of wetlands, and the formation of gullies and head-cuts. All of these impacts lead to deterioration in wetland condition and ecosystem functioning, leading to deterioration in the quality of ecosystem services offered by the wetlands. There has been, and continues to be, substantial clearing of IAPs from the main wetlands in these catchments, but it is expected that further clearing and restoration in the upper catchments will return more natural hydrological regimes, and a return to reference conditions.
    - Wetland plant diversity: The desiccation of soils and localized erosion have impacted on the plant communities in the wetlands, which show a loss of sensitive indigenous species and an increase in weedy pioneer species (such as reeds and bulrush), and facultative wetland and terrestrial species (such as bracken) replacing obligate wetland species (such as palmiet, i.e. *Prionium serratum*).

5.9. Desired State

Planned restoration actions upstream will result in the freshwater ecosystem structure and function reverting towards a more natural state, and recovery of certain indicator species in the long-term, by 2045. This time frame is based on estimates for terrestrial vegetation recovery, since this is considered a good proxy for freshwater biodiversity recovery.

However, in the intermediate term, we anticipate negative impacts of IAP clearing on some components of the freshwater ecosystems. Specifically, we predict shifts in both abiotic (water and habitat quality) and biotic components (riverine invertebrates and vertebrates, wetland plants) of the ecosystems toward reference states, as indicated by unimpacted 'control' sites.

River Health and Biodiversity

- Freshwater invertebrates: IAP clearing is predicted to cause an increase in SASS score, ASPT score and a general increase in taxon diversity and endemic species abundance (Samways et al., 2011). We predict an increase SASS score by one category from Good or Fair to Natural, and an increase in PES for invertebrates – A/B to A. We also predict a significant increase in ASPT score, taxon (and particularly endemic taxon) richness and diversity relative to current values, and a shift in these indicators towards that at control sites. Moreover, FFG composition and EPTO indicator taxa are predicted to return towards that at control (pristine sites), as resources at the base of the food web (e.g. detritus inputs), and habitat quality, return towards a natural state. Finally, we anticipate a significant increase in DBI score from current score towards control site score, as indicated by an increase in the number of sensitive and/or endemic Odonate taxa.
- Freshwater vertebrates: IAP removal is expected to translate into a measurable increase in freshwater fish, frog and tadpole richness, diversity and abundance. In particular, endemic and threatened indicator taxa sensitive to a reduction in habitat complexity through sedimentation (e.g. ghost frog tadpoles, redfin minnows, Cape galaxias), flow velocity (ghost grog tadpoles, Cape galaxias) and riparian habitat (Ghost frog adults) are expected to show the strongest response to IAP clearing (Pusey and Arthington, 2003; Nunes et al., 2019; Snaddon et al., 2019). Two predicated taxon-specific responses for vertebrates are (1) for the ghost frog *H. purcelli*, we expect a measurable increase in tadpole abundance in response to improved flow and substrate complexity, (2) for Galaxias spp., "*G. zebratus and G. rectognathus* species complex" we expect a measurable increase in abundance in response to increased habitat availability resulting from increased summer base flows.
- Riverine habitat quality: After an initial increase after alien clearing, the recovery of native vegetation should result in a decline in sedimentation and substrate embeddedness should result from IAP clearing, leading to an overall increase in habitat complexity (Pusey and Arthington, 2003; Chamier et al., 2012; Castro-Diaz and Alonso, 2017). In particular, we forecast an increase in habitat availability for flow-sensitive species during summer low-flows, as stream bed complexity increases and sedimentation decreases, in response to native vegetation recovery. As sedimentation decreases and habitat complexity (biotope diversity) increases, pools should become deeper, and flows swifter downstream of clearing. Declines in leaf litter and woody debris are expected following IAP removal (King, 1982; cited in Rivers-Moore et al., 2015; Ractliffe et al., 2003), and detritus derived from native plants should comprise an increasing proportion of detritus on the steam bed. IAP removal is also expected to result in a measurable decrease in pH

as the natural riparian vegetation recolonizes cleared catchments (Bird et al., 2012; Simaika et al., 2018). A decline is predicted for conductivity as sediments stabilize following IAP removal and native plant recolonization (King et al., 1987; cited in Rivers-Moore et al., 2015; Naude, 2012; Fourie, 2014). Dissolved oxygen is expected to increase following IAP removal as a function of increased water quantity and flow (Samways et al., 2011).

Wetland Health and Biodiversity

- Wetland health: IAP clearing in upstream catchments is likely to lead to an overall improvement in wetland health, and specifically, in terms of wetland hydrology, geomorphology and vegetation. This should be seen in a shift in the PES (a measure derived from the WET-Health protocol of MacFarlane et al., 2009) of each wetland towards pristine condition, and a consequent improvement in ecosystem services, as measured by wetland Ecological Importance and Sensitivity (EIS – a measure derived from the WET-Ecoservices protocol of Kotze et al., 2009). Local water levels in portions of the wetlands fed by overbank spill from the main channels entering the wetlands should increase, with subsequent increases in soil moisture/saturation levels. In response, the Normalized Difference Vegetation Index (NDVI) and/or the Normalized Difference Water Index (NDWI) should increase due to an improvement in wetland health, and an increase in soil moisture.
- Wetland plant diversity: Impacted wetland plant communities are likely to move from a predominance of weedy, pioneer species to more sensitive indigenous species, and a shift from terrestrial / facultative species to obligate wetland species (e.g. Cowden et al., 2013). There is likely to be an increase in plant diversity from impacted to non-impacted conditions (Kotze et al., 2009; MacFarlane et al., 2009).

5.10. Output Indicators

Based on available literature, and previous monitoring in the GCTWF priority sub-catchments (Snaddon et al., 2019), for the purposes of this framework the focus is on the following sets of indicator variables (1) river health and biodiversity, and (2) wetland health and biodiversity. The variables and associated sampling methodologies are unpacked in Table 3.

Table 3. Priority indicators for monitoring rivers and wetlands. Predicted impacts of IAPs on each indicator, current state and desired state are based on previous monitoring in the catchments (Snaddon et al., 2019) and on other scientific literature.

Variable category		**Variable/indicator**	**Method**	**Predicted impact of IAPs on variable (reference)**	**Current state (based on Snaddon et al. 2019, or literature)**	**Desired state (2045)**
(1) River health and biodiversity	Freshwater invertebrates	SASS Score and Present Ecological State	SASS, kick sampling	Showed an initial decrease after IAP removal (Magoba and Samways 2010; Samways et al., 2011). Shifts in invertebrate assemblages may follow changes in leaf litter composition and decomposition rates (Lecerf et al. 2007; Remor et al. 2013; Serra et al. 2013; Stockan et al. 2013).	SASS scores at paired catchment sites unknown. SASS scores at baseline sites: **Du Toits**: 136 – 193 (PES = A/B) **Upper Sonderend**: 51 – 194 (PES= A/B) **Amandels**: 131 – 190 (PES= A/B)	Increase SASS score by one category from Good or Fair to Natural. Increase in Present Ecological State (PES) for invertebrates – A/B to A.
		ASPT Score (overall invertebrate sensitivity score)	SASS, kick sampling	More sensitive taxa are replaced with widespread, tolerant taxa.	ASPT scores at paired catchment sites unknown. ASPT scores at baseline sites: **Du Toits**: 6.46 – 7.36 **Upper Sonderend**: 4.94 – 7.41 **Amandels**: 7.2 – 8.13	Significant increase in ASPT score relative to current. Shift in score towards that at control sites.
		General and endemic taxon diversity and abundance	SASS, kick sampling, and family level identification	Indigenous riparian, marginal and instream vegetation supports a greater number of taxa than IAPs (Ractliffe et al., 2003). Increased sediment input can lead to decreased taxon richness (Ractliffe et al., 2003).	Taxon diversity at paired catchment sites unknown. Number of taxa at baseline sites: **Du Toits**: 21 - 28 **Upper Sonderend**: 10 - 28 **Amandels**: 17 - 25	Significant increase in taxon diversity and/or the abundance of endemic taxa. Shift in diversity indices and abundance values towards that at control sites.

				Diversity of more sensitive taxa is replaced by fewer widespread, tolerant taxa, especially if water quality has deteriorated. However, may also see a loss of endemic taxa that had adapted to shaded, cooler water temperatures under woody IAPs (Samways et al., 2011); replaced by widespread, tolerant taxa.	Levels of endemism still to be assessed	
		Functional Feeding Group (FFG) composition	SASS, kick sampling	Shifts in invertebrate assemblages and/or key indicator taxa (EPTO taxa) may follow changes in leaf litter composition and decomposition rates (Lecerf et al. 2007; Remor et al. 2013; Serra et al. 2013; Stockan et al. 2013). Shredders and particle feeders in particular may increase in numbers due to higher input of leaf litter from IAPs (Ractliffe et al., 2003; Lowe et al. 2008).	Still to be assessed	Return to reference FFG composition, and EPTO indicator taxon abundance as indicated by control sites.
		Dragonfly Biotic Index (DBI)	Species level identification of adult Odonata	Certain Odonata species (including sensitive and endemic taxa) are excluded from streams shaded by alien trees that are normally surrounded by fynbos	Still to be assessed	Significant increase in DBI score from current score towards control site score, as indicated by an increase in the number of sensitive

				(Magoba and Samways 2010; Samways et al., 2011) Odonates respond to removal of IAPs with an increase in diversity (Samways and Taylor 2004; Samways and Samaika, 2016).		and/or endemic Odonate taxa
	Freshwater vertebrates	Fish diversity & abundance	Kick net, fyke net, electro-fishing, video	Increased sedimentation (from IAP-linked erosion) could decrease habitat availability for benthic taxa, while reduction in flow could reduce habitat for flow-sensitive taxa (Pusey and Arthington 2003). Fish could also respond to changes in invertebrate abundance – their main food source.	Healthy native fish populations occur in sections of the upper Sonderend, Du Toits and Amandel Rivers (Shelton et al. 2015, Snaddon et al. 2019). Fish abundance and diversity is negatively impacted at sites exposed to habitat degradation of invasive species impacts. Native freshwater fish are present in at least two of the paired catchment streams, and the remaining tributaries still need be surveyed.	Measurable increase in diversity and abundance of sensitive, threatened & endemic fish taxa in response to improved instream habitat from IAP clearing. Increase in Fish Index score by one category in response to IAP removal. For *Galaxias* sp. "zebratus rectognathus" we expect a measurable increase in abundance in response to increased habitat availability resulting from increased summer base flows.
		Frog diversity & abundance	Visual and/or acoustic encounter surveys, pitfall trapping	Adult frog assemblage expected to mirror changes in in stream tadpole abundance, but could also be directly impacted by changes in riparian plant community (Nunes et al. 2019).	Still to be assessed.	Increased amphibian diversity and increased abundance of sensitive, threatened and endemic taxa.

		Tadpole diversity & abundance	Kick net, fyke net, video	Increased sedimentation (from IAP-linked erosion) decreases habitat availability and predation refugia for benthic taxa. Reduction in flow decreases habitat for flow-sensitive taxa like *Heleophryne* spp. (Avidon et al. 2018).	Still to be assessed.	Increased amphibian diversity and increased abundance of sensitive, threatened and endemic taxa. For *H. purcelli* we expect an increase in tadpole abundance in response to improved flow and substrate complexity.
	Riverine habitat quality	Habitat complexity	Transect grid	IAPs lead to increased sediment input into rivers and wetlands, as they tend to be less effective at binding soils (Rowntree 1991, Ractliffe et al., 2003, Pusey and Arthington 2003, Chamier et al. 2012, Castro-Diaz and Alonso 2017).	Habitat availability for flow- and substrate-sensitive taxa reduced at IAP-impacted sites. Mean particle size at baseline sites: **Du Toits**: 134-304mm **Upper Sonderend**: 10-1318mm **Amandels:** 306-274mm Embeddedness still to be assessed	Reduction in sedimentation and embeddedness. Increase in substrate complexity. Increased habitat availability for flow- and substrate-sensitive taxa, and corresponding increases in populations of these taxa.
		Habitat availability for sensitive and specialized taxa	Flow/depth transects to link flow to habitat availability for flow-sensitive fish and amphibian species	Reduction in flow decreases habitat for flow-sensitive taxa. For example, *Galaxias* sp. "zebratus rectognathus" prefers habitats with flow >0.6m/s (Snaddon et al. 2019).	Suitable summer low flow available habitat still to be estimated from Snaddon et al. (2019) data set.	Increased habitat for flow-sensitive species during summer low-flows, and increase stream bed complexity as sedimentation resides in response to native vegetation recovery.
		Detritus and woody debris	Transect grid	Rate of leaf litter fall from woody IAPs found to be approximately double that from indigenous Afromontane riparian forest, and rate of leaf breakdown of alien vegetation	Still to be assessed	Long-term significant decrease in IAP-derived (and overall) woody debris and detritus.

				by invertebrate shredders was three times that of indigenous vegetation (King, 1982, cited in Rivers-Moore et al., 2015; Lecerf et al. 2007; Remor et al. 2013; Serra et al. 2013). Increased presence of woody debris from IAPs leads to increased retention of leaf litter and woody debris in the channel (debris dams) (Ractliffe et al., 2003).		
		Water quality	Point sampling	Replacement of fynbos by IAPs is predicted to cause an increase in pH, given the decrease in polyphenol and humic substance inputs (Bird et al 2012, Simaika et al. 2018). Increase in electrical conductivity (EC) due to erosion from destabilized ground cover. Dissolved Oxygen (DO) expected to increase with IAP invasion due to increased insolation and erosion (Samways et al., 2011).	pH at paired catchment sites unknown. pH range at baseline sites is acidic: **Du Toits**: mean of 4.4 **Upper Sonderend**: mean of 4.1 **Amandels**: mean of 4.6 Conductivity levels at paired catchment sites unknown. Conductivity at baseline sites is relatively low: **Du Toits**: mean of 69 mS/m **Upper Sonderend**: mean of 66 mS/m **Amandels**: mean of 61 mS/m DO generally high (>100%) at headwater sites (yet to be measured at paired catchment	Long term significant pH decreases due to return of native vegetation. Return to value range measured at control sites. Long-term decrease in EC as natural vegetation stabilizes bank sediments. Return to value range measured at control sites. Long-term significant increase in DO as flows increase. Return to value range measured at control sites.

					sites), and somewhat lower (80-130%) at lowland sites in Du Toits, Sonderend and Amandels.	
(2) Wetland health and biodiversity	Wetland health	Vegetation health	WET-Health vegetation PES (Level 2)	Replacement of indigenous plants with alien invasive plant species leads to a deterioration in overall vegetation health (see above).	**Du Toits** – vegetation PES = **Category C (Score = 2.0**); in moderate condition, but consistently improving, no significant IAP invasions in the wetland (already removed). **Vyeboom** – vegetation PES = **Category C (Score = 3.0)**; in moderate condition, but with patches heavily impacted throughout the wetland, especially along margins where IAPs have invaded	Improved condition and ecosystem services
		Geomorphology	WET-Health geomorphology PES (Level 2)	Desiccation and destabilization of soils, which leads to gully and head-cut erosion (MacFarlane et al., 2009; Kotze et al., 2009).	**Du Toits** – geomorphology PES = **Category B (Score = 1.6)**; in good overall condition, with some gully erosion at the head of the wetland, and head-cut erosion at the toe (close to the edge of Theewaterskloof) **Vyeboom** – geomorphology PES = **Category C (Score = 3.1);** in moderate condition, with head-cut erosion in	Improved condition and ecosystem services

					the middle and at the toe of the wetland.	
		Hydrology, Wetland water levels	WET-Health hydrology PES (Level 2), wetland water levels (piezometers)	Reduced inflow and evapotranspiration from IAP infestations leads to lowered water levels, desiccation of wetland soils, and an increased risk of erosion.	**Du Toits** – hydrology PES = **Category E**; low condition is largely due to the eroded gully at the head of the wetland and presence of bridge, concentrating flow through the wetland, instead of diffuse flow. **Vyeboom** – hydrology PES = **Category E**; poor condition due to agricultural drains, roads, bridges, erosion and some IAP invasion; changing the way water flows through the wetland and drying out soils.	Improved condition and ecosystem services. Raised water levels
		Overall Wetland health	WET-Health Index (Overall PES) (Level 2)	Deterioration in wetland health, leading to lower WET-Health score and PES.	**Du Toits** – **Category C**; moderately modified **Vyeboom – Category D;** largely modified	Improved condition
		Wetland Ecological Importance and Sensitivity	WET-Ecoservices	Deterioration in ecological functioning, leading to a lowering of ecosystem service value	Still to be assessed.	Improved ecosystem services
	Wetland plant diversity	Vegetation composition	Drone transects, and monitoring of specific plant communities identified from drone footage	Replacement of indigenous plants with alien invasive plant species leads to a deterioration in overall vegetation health, loss of diversity (Ractliffe et al., 2003), increased weediness of species, shift from obligate	Still to be assessed.	Community composition shifts: • Hydric status – from terrestrial / facultative to obligate • Disturbance status – from invasive /

			Remote sensing imagery and NDVI data	wetland species to more facultative or even terrestrial species (Cowden et al., 2013).		ruderal / weedy to sensitive indigenous • Increase in Floral Quality Assessment Index • NDVI may show an increase, as vegetation health improves.
	Wetland amphibians	Frog diversity and abundance	Visual and/or acoustic encounter surveys, pitfall trapping	Adult frog assemblage expected to mirror changes in tadpole abundance, but could also be directly impacted by changes in wetland plant community	Still to be assessed	Increased amphibian diversity and increased abundance of sensitive, threatened and endemic taxa.