BIOPHYSICAL MONITORING OF THE UPPER TSITSA RIVER CATCHMENT (T35 A-E)

TSITSA PROJECT

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PREFACE

This report provides a framework for the proposed Biophysical Monitoring and Evaluation plan (BM) for the Tsitsa Project. It provides an indication of the proposed biophysical monitoring objectives, data inventory, data that will need to be collected to fulfil the monitoring objectives and how this data might be collected, analysed and managed to:

- Meet the needs for ongoing technical biophysical monitoring; and
- Determine the baseline biophysical data of the catchment.

This report was written as a practical guide. It provides the conceptual framework for the monitoring and evaluation activities and the practical outline (but not in depth methodology) for data collection, analysis and interpretation. This report is also conceived to provide practical guidance of monitoring and evaluation for projects that are implementing an ecosystem approach to management of rural landscapes.

Finally, this report is regarded as a living document that will be updated and modified based on experience gained in the Tsitsa Project Biophysical Monitoring (TPBM) as well as the other parts of the Participatory, Monitoring, Evaluation, and Reflection and Learning (PMERL) plan for the Tsitsa Project. Ultimately, we aspire to establishing rigorous monitoring and evaluation procedures that can be replicated and that facilitate learning around improvements in ecological infrastructure and ecosystem services.

The Tsitsa Project is currently doing restoration work in T35A-E and is referred to as phase 1 that targets the upper Tsitsa River catchment. This area is the current focus of the BM, but will be expanded to the larger Tsitsa River catchment once funding for expansion is secured.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Context

The Tsitsa Project (TP) aims to improve ecological infrastructure and by doing so strengthen institutional Natural Resource Management (NRM) and increase livelihood sustainability for the local beneficiaries who directly and indirectly benefit from restored, healthy ecosystems. This is accomplished by carrying out erosion prevention, avoided habitat degradation, improved NRM and general rehabilitation efforts in the Tsitsa catchment (T35), starting in catchments T35 A-E. Reducing likely sediment inputs into proposed dams and associated infrastructure of the Mzimvubu Water Project (MWP) is core to the project. In the long-term the TP will strive towards ***sustainable land management*** across the catchments. TP is a collaborative venture into polycentric governance with the main proponents and sponsors being the Department of Environmental Affairs (DEA), The Department of Science and Technology (DST), the Water Research Commission (WRC) and the Department of Water and Sanitation (DWS). The project framing is social-ecological and systemic (holistic) in nature, and centres around local livelihoods especially in the ex-homeland areas of the catchment.

The purpose of this monitoring framework is to aid in improving the efficiency, effectiveness and overall quality of our work and to better understand the environmental impacts of our interventions. To this end, we have sought to develop a framework of monitoring activities that will facilitate the collection and organisation of key biological and natural landscape data. Through monitoring and periodic evaluation of these datasets, we aim to improve our knowledge of the current ecosystem goods and services and the ecosystem infrastructure within the catchment, improve the rehabilitation interventions, resulting in better outcomes for the ecosystems in which we work and for the marginalised communities, which we serve. Such a system will provide TP with improved standardisation of operations that are relevant to the context of the Tsitsa River catchment. This in turn will enable more uniform, comprehensive data collection, comparison among project areas, increased scientific rigor in our work, and enhanced organisational learning. In short, a single monitoring framework for biophysical changes will guide us as we create plans to monitor the impacts of our actions. The overall goal of this framework is to evolve a conceptually clear, comprehensive and robust tool for monitoring biophysical and ecological changes at the landscape level.

Goals of the biophysical monitoring framework

This report will attempt to:

I. Provide a conceptual framework that will guide the implementation and mainstreaming of biophysical and ecological monitoring in the upper Tsitsa River catchment;

II. Identify and describe indicators that can be measured to discern current ecosystem goods and services and ecosystem infrastructure of the catchment and larger changes in the landscape, as well as the impacts of rehabilitation and management efforts in the catchment;

III. Present easily understandable, scientifically rigorous methods for data collection and analysis; and

IV. Contribute to organisational learning by presenting the framework in an easily understandable, educational manner.

CONCEPTUAL FRAMEWORK

This section is based on work done by FES (2008) unless stated otherwise.

Principal concepts

If we seek to understand the biophysical and ecological changes occurring in a landscape, we must share common definitions for these terms as well as a few others:

I. **Biophysical** – 'Biophysical' refers to the biological and physical components of the environment put more simply, biophysical refers to the living (the biological) and the non-living (the physical) components of the environment. Biophysical descriptions tend to quantify the ecosphere in physical units such as meters, kilograms, or joules.

II. **Ecological** – 'Ecological' relates to the interrelationships of organisms and with their environment. The term comes from Ecology. The science of ecology is the study of how organisms interact with each other and with their physical environment.

III. **Ecosystem** – An 'Ecosystem' refers to communities of organisms and their physical environment that interact as a unit. The scale of an ecosystem is not fixed. A single stream, a watershed or an entire forest could be considered an ecosystem.

IV. **Landscape** – A portion of land or territory which the eye can comprehend in a single view, including all the objects it contains. A landscape level approach takes into account biological, geophysical and a range of social and cultural factors that affect how the land is used (Frost et al, 2006). The approach was born out of the science of landscape ecology which, according to Troll (1969) is concerned with the "entire complex cause-effect network between living communities and their environmental conditions which prevails in a specific section of the landscape (Odum and Barrett, 2005).

V. The **Monitoring System** is defined as the process of systematic collection and analysis of data in order to improve the management and implementation of the project through provision of information that is useful for assessing the state of achievement against objective indicators in a timely manner to project managers.

VI. The **Evaluation System** is defined as the process of systematic collection and analysis of data in order to attribute project impact through provision of information that is useful for assessing the state of achievement against long-term performance indicators to project managers and evaluators. The Evaluation System is comprised of a baseline assessment and periodic assessments of impact. These periodic assessments are similar in form to the baseline assessment and are carried out in such a way as to assess departure from the baseline that is attributable to project activities.

VII. An **indicator** can be defined as a 'measure based on verifiable data that conveys information about more than just itself'. This means that indicators are purpose dependent - the interpretation or meaning given to the data depends on the purpose or issue of concern.

Linking the main concepts together

The core of this Framework is comprised of four interconnected concepts: Ecosystem health, Ecosystem services, Eco-restoration (rehabilitation) and Succession. Understanding how these terms are related on a Landscape scale provides the context within which the practical framework of indicators and methods are rooted.

- **Ecosystem health** has both a human and natural component. Measure of human health can be used to judge the sustainability and status of the human systems component. The current model simply recognises this but does not explore the impact on human health any further at this time. Instead the focus is on natural systems, which can be assessed by looking at the structure, function, and resilience of an ecosystem. Resilience is an ecosystem function that involves understanding the capacity of that system to buffer or rebound from disturbances (both natural and anthropogenic). Resilience is important and can be determined once one has data on how the structure and function or the ecosystem is changing. To determine both structural and functional changes over time, ecosystem services can be estimated based on measured data.

- **Ecosystem services** represent the goods and services that an ecosystem provides to society. It embraces both the ecosystems which deliver the services and the people who benefit from them. These services range widely from products like food through to stabilising and regulatory services such as flood control, and life-enhancing functions such as environments for recreation and spiritual inspiration (de Groot et al., 2002; Westma, 1977; Daily et al., 2000). Measurements of changes in the components of the system such as soil, water, phytomass and biodiversity of an ecosystem can be used to assess changes in the level and type of ecosystem services that ecosystem provides. Note how the concept of ecosystem services serves to connect the conceptual and practical components of the framework.
- **Succession** is a concept that describes directional (not cyclical) changes in structure and function over time. It is a phenomenon or process by which an ecological community undergoes more or less orderly and predictable changes following a disturbance or the initial colonisation of a new habitat. The types of communities of plants and animals that inhabit an ecosystem fundamentally change it, resulting in changes in the communities themselves.
- **Eco-restoration (rehabilitation/ management):** Succession occurs naturally but outside stressors (disturbances) such as overgrazing, deforestation or invasive species can change or derail this process. To put the natural system back on track, eco-restoration (rehabilitation or management) techniques can be used to accelerate or aid system recovery.

A biophysical monitoring program needs to incorporate methods for measuring certain ecosystem parameters (indicators) that will provide data on the changing structure and function of an ecosystem over time. Ecosystems can be analysed at many different levels. For TP, we chose to use the sub-catchment (100 – 500 km^2) as a convenient, landscape-level unit of analysis; however some indicators will be measured at different scales from site-specific (5 m^2) to regional remote sensing data (5000 km^2).

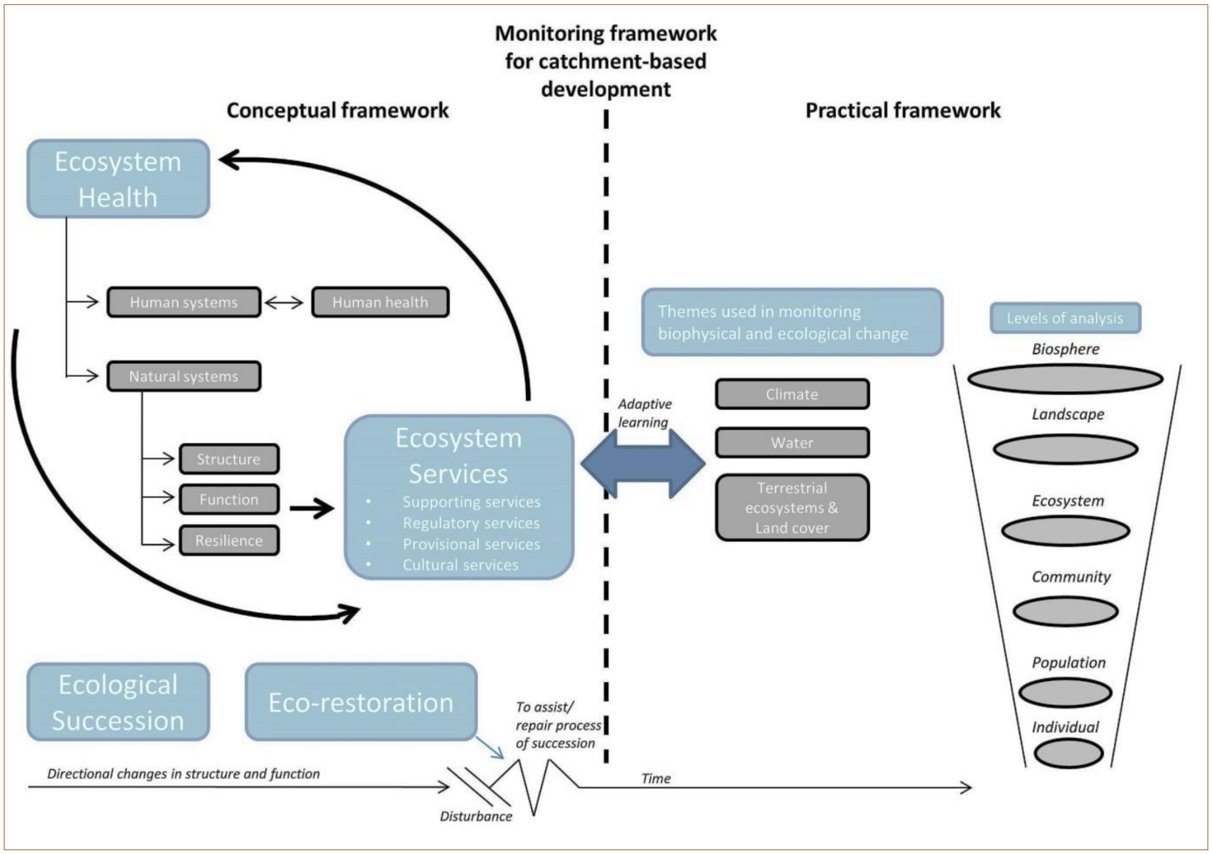


FIGURE 1: A CONCEPTUAL MODEL CAPTURING ALL THE CONCEPTS (TAKEN FROM FES (2008))

For a concise description of these concepts, please see the concept summary below. The key terms (in bold above) are explained in detail in the sections that follow.

Ecosystem Health

In broad-brush terms, ecosystem health may be described as a "socio-ecological unit, that is 'stable' and sustainable, maintaining its organization and autonomy over time and its resilience to stress, while capable of remaining economically viable and able to sustain human communities" (Rapport et al., 1998). A healthy ecosystem, as defined by Rapport et al. (1998) is "free from distress and degradation, maintains its autonomy over time, and is resilient to stress."

The field of ecosystem health encourages the fundamental links between a healthy functioning environment and healthy human communities. This is done with the recognition that healthy ecological systems will support healthy communities of humans and vice versa. By focusing on the connections between humans and their surrounding environments, ecosystem health is seen as a new, holistic method for ecosystem management and assessment.

Ecosystem health cannot be directly observed and thus requires looking at surrogate measures. Ecosystems vary greatly in terms of soil type, biodiversity, water availability and stress levels. Looking at the health of each of these aspects requires the development of indicators that can proxy for the organisation, function and resilience of such a complex system.

The advantage of this monitoring framework is that it incorporates the concepts of ecosystem services and the ecological succession (succession) as guiding principles. By developing indicators based on connections to relevant ecosystem services, and collecting long-term monitoring data, the changing structure and function (and thus ecosystem health) of an area can be observed. If collected over a long enough period of time (a minimum of 5-10 years), such data can also provide insight into the successional changes occurring in an ecosystem.

The linkages between human and ecological health are well recognised. The biophysical monitoring group, while recognising the links, will be focusing on the natural science view of ecosystem health. In other words, instead of identifying indicators of human health and ecological drivers for changes in human health, the biophysical monitoring team has chosen to focus on assessing ecosystem health in terms of ecosystem function, structure and resilience. The social monitoring will be covered in a separate report.

Ecosystem services

The Millennium Ecosystem Assessment defines ecosystem services simply as “the benefits people obtain from ecosystems” (MEA, 2005). According to the MEA, there are four types of ecosystem services:

I. Provisioning services such as food, water, timber, and fibre;

II. Regulating services that affect climate, floods, disease, wastes, and water quality;

III. Cultural services that provide recreational, aesthetic, and spiritual benefits; and

IV. Supporting services such as soil formation, photosynthesis, and nutrient cycling”.

de Groot et al., (2002), views ecosystem services in terms of functions, goods and services, offering a typology based on these aspects.

Ecosystem service monitoring can be carried out to provide data of ecosystem health (MEA, 2005), to provide data for economic valuation of such services (de Groot et al, 2002), or both. Because ecosystem services are well defined and organised into products and processes that are either directly or indirectly measurable, they provide an excellent conceptual and practical basis for a monitoring program.

Succession

Succession refers to the phenomenon or process by which an ecological community undergoes more or less orderly and predictable changes following a disturbance or the initial colonisation of a new habitat. Generally, when we talk about succession, we are referring to plant succession. However the concept applies to animals as well. Succession describes both structural and functional changes in an ecosystem over time. Structural changes refer to the change in species composition (which species are present) and variety (the number of species present). Functional changes describe an increase in biomass (both living and dead organic matter), and a change in the overall function of the area from primarily autotrophic (organisms that make their own food, like plants) to heterotrophic (organisms that depend on others for food, like animals, decomposers and parasites).

Monitoring of ecosystems involves measuring certain symptomatic parameters that will likely change over time and provide information about what is changing and why. Understanding succession is necessary to conceive of the changes that are occurring in an ecosystem, and thus to be able to design a monitoring program.

Regardless of whether or not succession is used as a guiding concept for monitoring, understanding the concept is important for those working to restore degraded ecosystems. When succession fails, ecological restoration activities are how humans can help to restore ecosystems to their natural trajectories. By incorporating eco-restoration into the framework, the creation of goals and thus monitoring is simplified.

Eco-restoration/ Rehabilitation

SER International (2005) defines ecological restoration as: "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed." Eco-restoration comprises a range of activities that increases ecosystem recovery in terms of its health (functional processes), integrity (species composition and community structure), and sustainability (resistance to disturbance and resilience). Restoration activities are carried out in degraded lands with a focus on placing the ecosystem firmly back onto historical trajectory, taking into account factors such as social-ecological interactions that may dramatically affect the future direction of the area. When an ecosystem no longer requires external assistance, it is said to be "restored" (SER International, 2004). In order to make this decision, a reference ecosystem is required. The reference ecosystem serves as an important source of knowledge about roughly what the degraded ecosystem should look like.

Indicators

The ultimate aim of ecological indicators is to integrate the monitoring and assessment of ecological and environmental indicators with management practices.

Environmental indicators are simple measures that monitor and gather information on what is happening in the environment. Since the environment is very complex, indicators provide a more practical and economical way to track the state of the environment.

It is useful to identify the uses and desirable properties of indicators. Following Tunstall (1992, 1994), Gallopín (1997) identifies major functions of indicators as:

- to assess conditions and changes;
- to compare across place and situations;
- to assess conditions and trends in relation to goals and targets;
- to provide early warning information; and,
- to anticipate future conditions and trends

THREE PHASE IMPLEMENTATION STRATEGY

This section is based on work done by FES (2008); Riginos and Herrick (2010); Herrick et al., (2005) unless stated otherwise.

Introduction- from theoretical, to practical, to implementation

An implementation strategy allows the monitoring framework to be actionable. This strategy provides a three phase plan that can be used to create and implement the monitoring plan. The three phases are:

- **Phase I**: Creation of an area profile
- **Phase II**: Detailed survey and creation of a monitoring plan

- **Phase III**: Implementation of the monitoring plan

Phase I: Creation of an area profile

This phase is concerned with secondary research and primary surveys of the project area. Secondary data collection includes conducting a literature review, reviewing available data, conferring with other organisations that work or have worked in the area, and searching for studies that may contain information on the site. This research can inform a reconnaissance survey that will collect primary data regarding the ecosystem health of the area. The primary survey would be conducted through rapid scientific reconnaissance studies and creating a database of all data pertaining to the catchment.

Out of these initial studies would come a general understanding of the landscape and of the relevant ecological issues that might require further attention. Identification of the existing ecological stressors would help to clarify draft eco-restoration goals. Baseline information, for example collected on the status of water, soil, ecosystems, biodiversity and phytomass would allow for an initial report and recommendations. All of this information would be used to select sites and methodologies for the scientific studies conducted in phase II.

Phase II: Detailed survey and creation of monitoring plan

A variety of detailed scientific studies would be carried out in this phase. The detailed studies of Phase II would provide baseline data for the project. Stressors such as overgrazing, excessive lopping and felling of trees, over extraction of ground water and human-induced erosion and habitat destruction of particular species would be clearly identified and quantified. This information would aid in the creation of eco-restoration goals, which would then guide a monitoring plan.

The monitoring plan would select indicators and appropriate methodologies (including methods for site selection) to monitor progress against the chosen eco-restoration goals, using the practical framework as a resource. Finally, a timetable, data management plan, budget would be created, and responsibilities would be defined for the various activities in the monitoring plan.

According to Herrick et al. (2005), a monitoring program can be developed following six easy steps as shown by the box below.

Develop Monitoring Program: The six steps	STEP 1: Define/ refine management and monitoring objectives STEP 2: Stratify land into monitoring units STEP 3: Assess current status , identify stressors and drivers STEP 4: Select monitoring indicators, number of monitoring plots, measurements and measurement frequency STEP 5: Select monitoring locations STEP 6: Establish monitoring plots and record long-term monitoring data (baseline)

Guidelines for selecting indicators

While designing the monitoring plan in Phase II, it is very important to consider carefully the selection of indicators. First, one should be clear of the goals of the program. It is also crucial to take into account who the end user of the information will be. Even if the initial focus of this manual is on strengthening the methods and monitoring plans of the Tsitsa Project as an organisation, integrating participatory monitoring practices at an early stage will ensure that the right information is collected and that is useful to those who need it most.

Selecting the right indicators for your needs can be confusing. To guide the indicator selection process, there are several commonly used mnemonic devices. The first is SMART. A SMART indicator is one that is:

I. **Specific** – it reflects the things the project intends to change and avoid things that can be influenced by other outside factors;

II. **Measurable** – it is precisely defined so that measurement is unambiguous;

III. **Attainable** – it should be within the realm of project;

IV. **Reliable** – it must consider budget and feasibility of data collection;

V. **Time bound (or timely)** – it describes when a certain change is expected and measure changes that will occur during the life of the project.

Good indicators may also be SPICED. SPICED indicators are: **Subjective, Participatory, Interpreted and Communicated, Cross-checked and Compared, Empowering, and Diverse and Disaggregated**. Finally, The CREAM methodology can be used to select indicators. CREAM indicators should be also cites useful criteria under the acronym “CREAM”: Indicators should be:

I. **Clear** – precise and unambiguous;

II. **Relevant** – appropriate to the subject at hand;

III. **Economic** – available at a reasonable cost;

IV. **Adequate** – providing a sufficient basis to assess performance; and

V. **Monitorable** – amenable to independent validation.

The purpose of these mnemonic devices (SMART, SPICED, and CREAM) is to help ensure that the indicators chosen in a monitoring plan will effectively represent the changes we desire to monitor. In some cases, an indicator might seem perfect, but if it requires expensive remote sensing data or costly equipment, it might not be economical. Other indicators, such as changes in levels of wells may be commonly used, but taken alone they are not “specific.” That is, there are other factors that influence well levels that also must be considered. In this case, the indicator “changes in well levels” is still useable, if rainfall, evaporation, water use, and aquifer characteristics are taken into account.

Guidelines for selecting methods

In the process of selecting indicators, some thought will no doubt be given to methods of monitoring the indicators. As is apparent from the section above, it would not make sense to choose indicators that cannot be effectively monitored. The below list provides a very brief guide of key points that should be considered when choosing methods. For each method, what are the:

I. Advantages – compared with other possible indicators and with respect to the goals of the program;

II. Disadvantages;

III. Human resource requirements (technical know-how, number of people with required skills and their availability);

IV. Financial resource requirements;

V. Scientific rigor – acceptability of the method (international standards); and

VI. Type of method – is this a simple field method (perhaps ocular); is it a rigorous field method that gives solid scientific data; or is it a laboratory method?

VII. Are data sheets available for organising the information collected or will we have to create new forms?

Phase III: Implementation of the monitoring plan

Implementation of the biophysical and ecological monitoring plan, from start to finish, is carried out in this phase. Laying of permanent transects and/or establishing plots where studies will be conducted; routine collection of data to monitor the indicators selected in phase II; and analysis of data to inform, adjust or redirect project activities would form the bulk of this phase.

Evaluations will occur throughout the implementation of the monitoring plan. Ongoing data collection in combination with periodic studies would enable mid-course corrections that are deemed necessary. The methodologies used to collect data would be evaluated and improved in this stage. The list of monitoring parameters themselves could be amended as necessary. Thus a key output would be improvement of the monitoring framework. Reports generated may contain findings that could be used to inform policy recommendations.

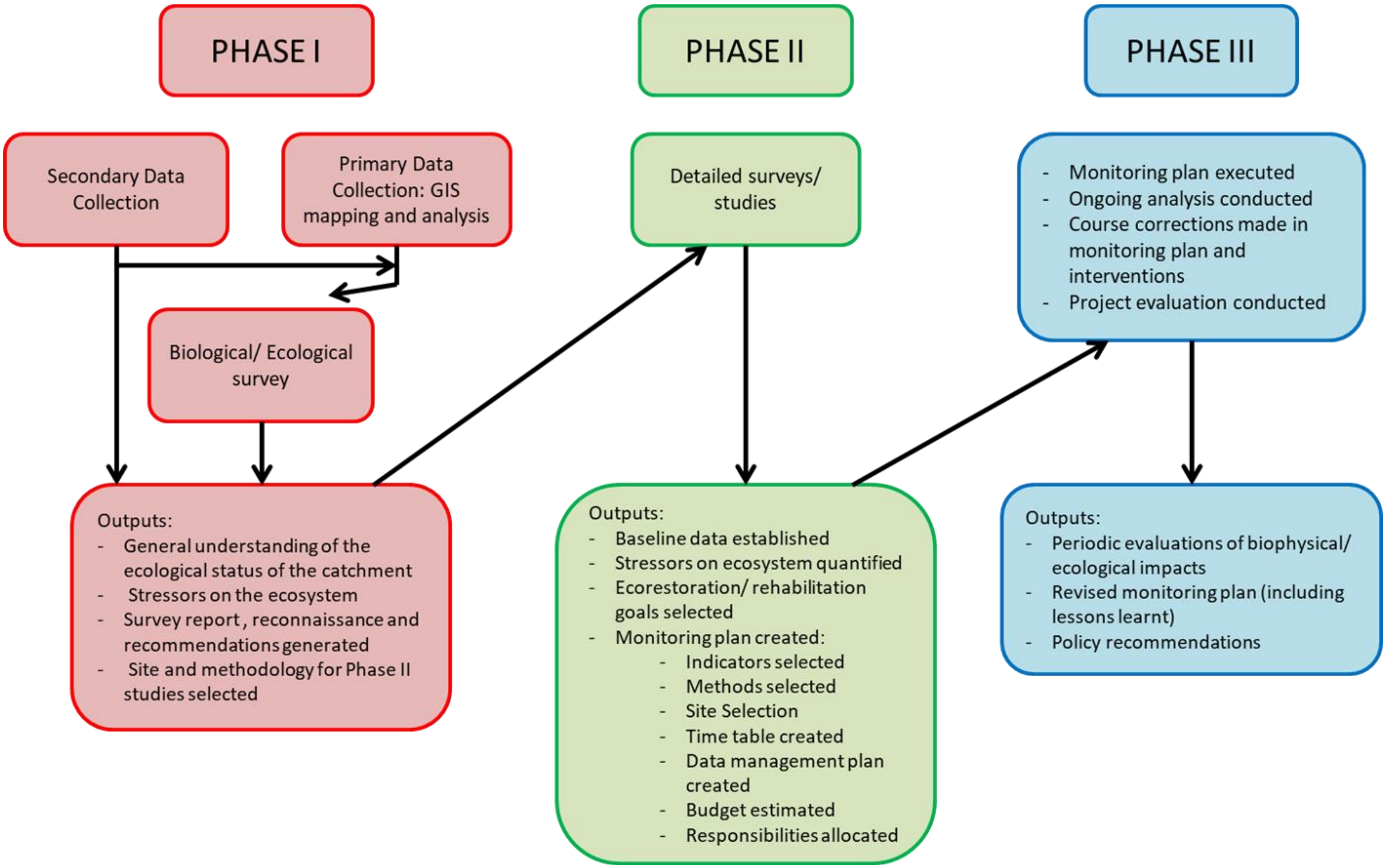
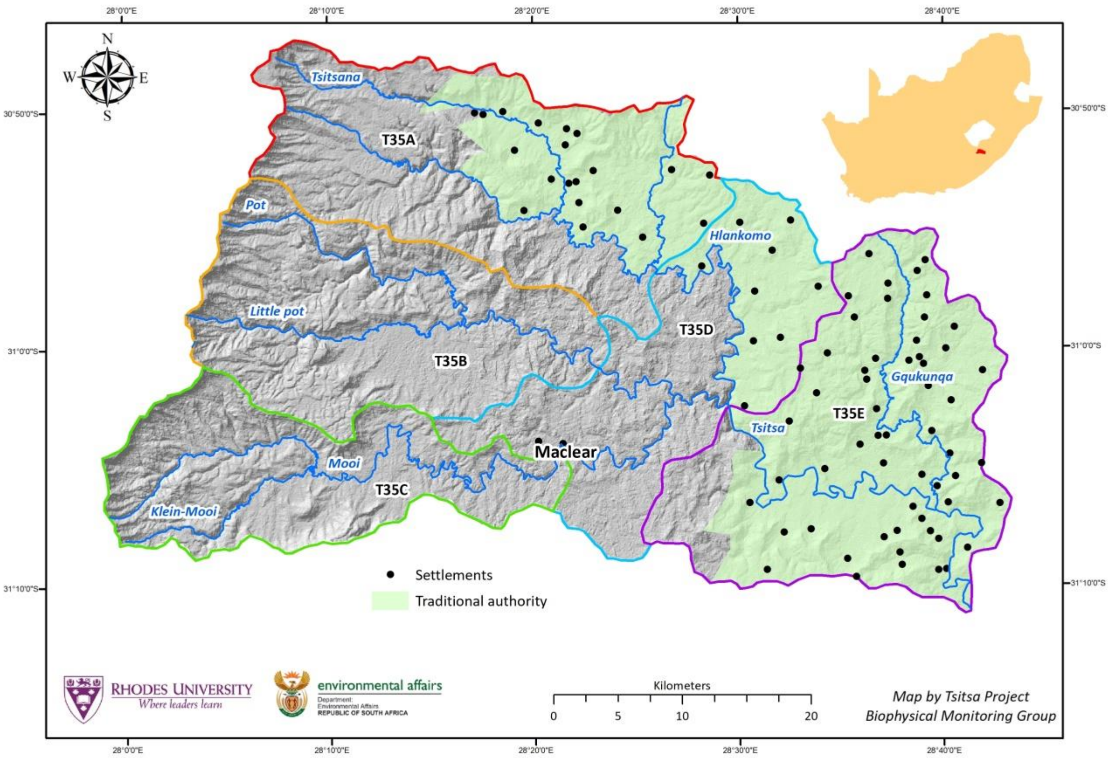


FIGURE 2: THREE PHASE IMPLEMENTATION STRATEGY (TAKEN FROM FES, 2008)

UPPER TSITSA RIVER CATCHMENT



The upper Tsitsa River Catchment (T35 A-E) is in the Eastern Cape province of South Africa. The catchment receives summer rainfall and is characterised by steep topography, with the prominent Drakensburg Escarpment forming the headwaters, followed by a second smaller escarpment in the lower catchment. Soils become increasingly more erodible as you move down the catchment, evidenced by the formation of huge gullies.

AREA

~200 000 ha (Catchments T35A-E)

INTERVENTION AREA

~76 000 ha Traditional area

~124 000 ha Private

POPULATION

~45 000 Residents

MAIN LAND COVER/ USE

71.8% Grasslands

7% Cultivation

6.9% Plantations

4% Thicket/ shrubland

3.2% Urban areas

2.2% Wetlands

2% Woodland

PHASE I: AREA PROFILE

Setting: Upper Tsitsa River Catchment (T35 A-E)

Location

The Tsitsa River is a tributary of the Umzimvubu River that has its headwaters in the Drakensberg Mountains in the Eastern Cape, South Africa. The upper Tsitsa River catchment (T35 A-E; the focus of this monitoring plan) drains an area of approximately 2 000 km². Roughly 38% (76 000 ha) of the Upper Tsitsa River catchment lies in the communal areas (found mostly in the middle and lower parts of the catchment) of the former Transkei homeland where the majority of the population resides in low-density rural villages, often situated on the mid-slopes of hillsides. Land use in the communal areas is dominated by rural subsistence farming. The larger portion (62 % or 124 000 ha) of the middle and upper catchment is privately owned land, with larger commercial farms, and plantations; with urban and semi-urban centres scattered around the catchment. The largest town found in the catchment is Maclear. Although there are some urban centres, commercial farms and plantations, the Tsitsa catchment is one of the poorest and least developed regions of South Africa. During the Apartheid era, the communal land was part the Transkei Homeland where population density was high and livelihoods were dependent on migrant labour, grants and subsistence farming. Even though the homeland policy was abolished in 1994 the area remains poor with a shortage of infrastructure and employment opportunities. Thus the rural communities in the area rely heavily on natural resources and practice subsistence agriculture which includes both livestock and crop farming (Kakembo & Rowntree, 2003; Blignaut et al., 2010; van der Waal, 2015).

Topography

The Tsitsa River originates in the Drakensberg Mountains, in the Great Escarpment geomorphic province, and flows through the South-eastern Coastal Hinterland geomorphic province (Partridge et al., 2010) to its confluence with the Mzimvubu River. Elevations in the area range from ~2 700 m in the Drakensberg in the north-east, to ~600 m towards the confluence with the Mzimvubu (Le Roux et al., 2015). The topography of the study area is steep around the escarpment in the headwaters and middle catchment. The remainder of the landscape is hilly to rolling with v-shaped valleys and limited sediment accommodation space.

The Tsitsa River transitions between a bedrock and mixed bedrock alluvial river. The river long profile is strongly influenced by rock type, where steeper sections form on more resistant bedrock (such as basalt, dolerite) and gentler sections form on sandstones, mudstones and mudrocks (Figure BB). Along the steeper escarpment zones the river beds are dominated by bedrock with rapids and waterfalls. The gentler sections of the river profile is dominated by a mixed alluvial/bedrock river, typically with a sandy bed except where dolerite dykes or sills are evident. Instream vegetation is generally absent, with riparian vegetation dominated by alien invader tree species. In many places, channels are deeply to very deeply incised in the alluvial plains, and may be locally characterised by flood benches, meanders and ox-bow lakes. Below the Tsitsa waterfall, the Tsitsa River passes through a deep and largely inaccessible gorge as it crosses the middle escarpment. The Mooi River, having been joined by the Pot River, converges with the Tsitsa River within this gorge.

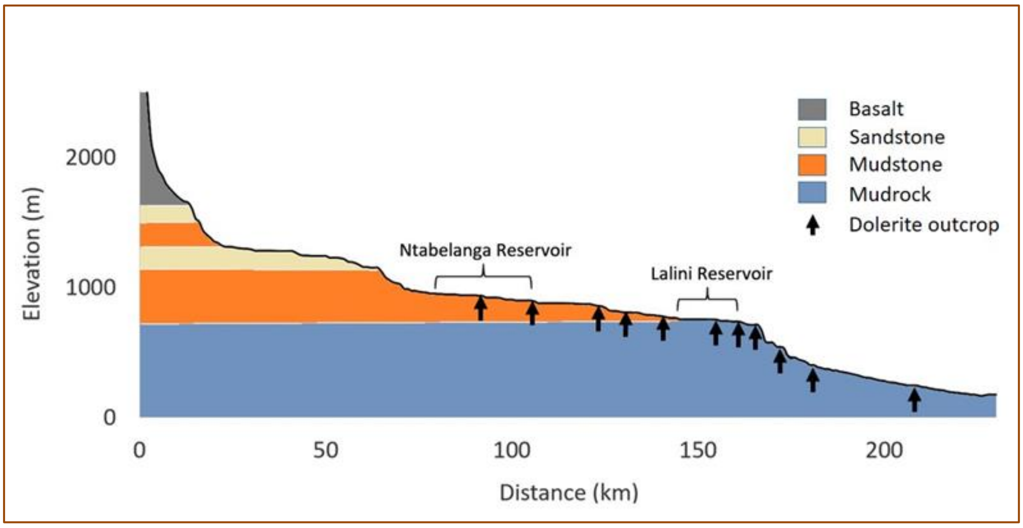


FIGURE 3: LONGITUDINAL PROFILE OF THE TSITSA RIVER SHOWING GENERALISED ROCK TYPES

Climate

The climate of the Tsitsa River Catchment has been described variously as sub-tropical (Iliso Consulting, 2015), sub-humid (Le Roux et al., 2015), and warm-temperate (Mucina & Rutherford, 2006). Given its altitudinal range the catchment traverses a range of climate types (Mucina & Rutherford, 2006). Iliso Consulting (2015) report 749 mm in the lower catchment area as measured at Tsolo whilst Le Roux et al., (2015) put mean annual rainfall in the upper parts of the catchment at 1 327 mm. The study area experiences summer rainfall between October and March, often in the form of afternoon thundershowers (Mucina & Rutherford, 2006). The average maximum hourly rainfall rate is 13 mm/hr with the maximum occurring in September (Agrometeorology Staff. 1984-2008). These are described as high intensity rainfall events and result in high erosion rates in the catchment (Fraser et al., 1999). Spatio-temporal variability in the rainfall is due to the varied topography across the catchment (Base et al., 2006).

Both rainfall and temperature peak in January with a monthly average of ~130 mm and ~20 °C respectively (Ref?). The driest and coldest month is July, with a monthly average rainfall and temperature of ~13 mm and ~0 °C respectively (Mucina & Rutherford, 2006). Snowfalls can be expected during the winter months in the upper part of the catchment, and may occur less frequently in other parts.

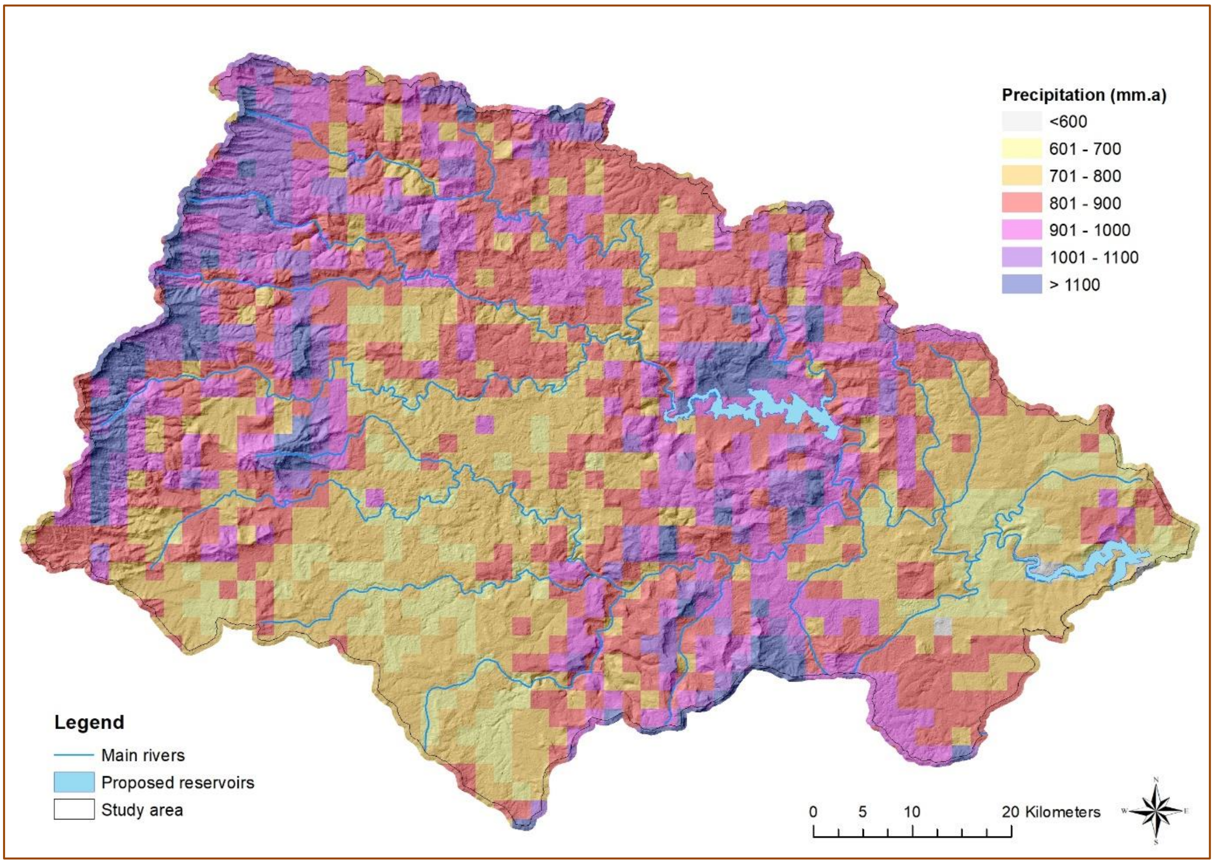


FIGURE 4: MEAN ANNUAL PRECIPITATION (MAP) FOR THE TSITSA RIVER CATCHMENT (T35 A-K)

Geology and Soils

Figure 2 shows the geology of the Tsitsa River catchment (T35 A-E). The upper Tsitsa River catchment is underlain by the Tarkastad Subgroup (mudstones) and the Molteno (sandstones) and Elliot (mudstones) Formations of the Karoo Supergroup, which are succeeded towards the headwaters of the catchment by the Clarens Formation (sandstone). Drakensberg Group basalt caps the sequence, whilst intrusive dolerite sills and dykes occur throughout the catchment (Le Roux et al., 2015).

Soils in the catchment vary significantly throughout the catchment, but the most prominent soil forms include poorly drained and shallow to moderately deep loams usually with minimal soil development on hard or weathering rock (Land Type Survey Staff, 2012). Less common in the catchment are soils of moderately-deep to deep sandy loams. Soils that develop on the Tarkastad, Molteno and Elliot Formations found in the central part of the catchment are associated with duplex and dispersive soils and are particularly vulnerable to the formation of soil pipes and subsequent gullying (Le Roux et al., 2015).

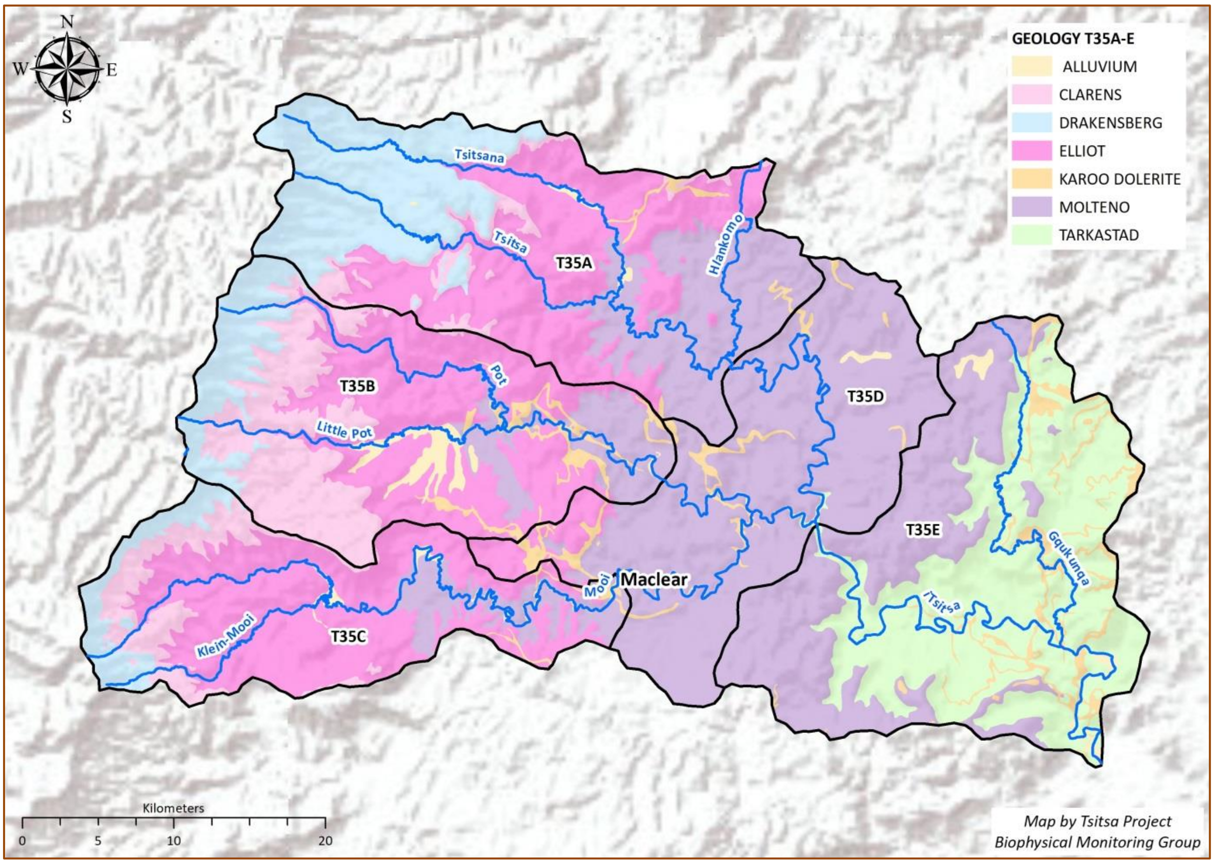


FIGURE 5: GEOLOGY OF THE UPPER TSITSA CATCHMENT T35 A-E

Vegetation

Figure 6 depicts the vegetation types that occur in Catchment T35 A-E. The upper Tsitsa River Catchment is dominated by grassland which varies from Lesotho Highland Basalt Grassland, Southern Drakensberg Highland Grassland, East Griqualand Grassland, Drakensberg Foothill Moist Grassland, Eastern valley bushveld, Mthatha Moist Grassland, Eastern Temperate Freshwater Wetlands and small pockets of Southern Mistbelt Forests in ravines (Mucina & Rutherford, 2006). Natural vegetation is fundamentally influenced by aspect, catena, slope, geology, soil type, altitude, as well as fire occurrences.

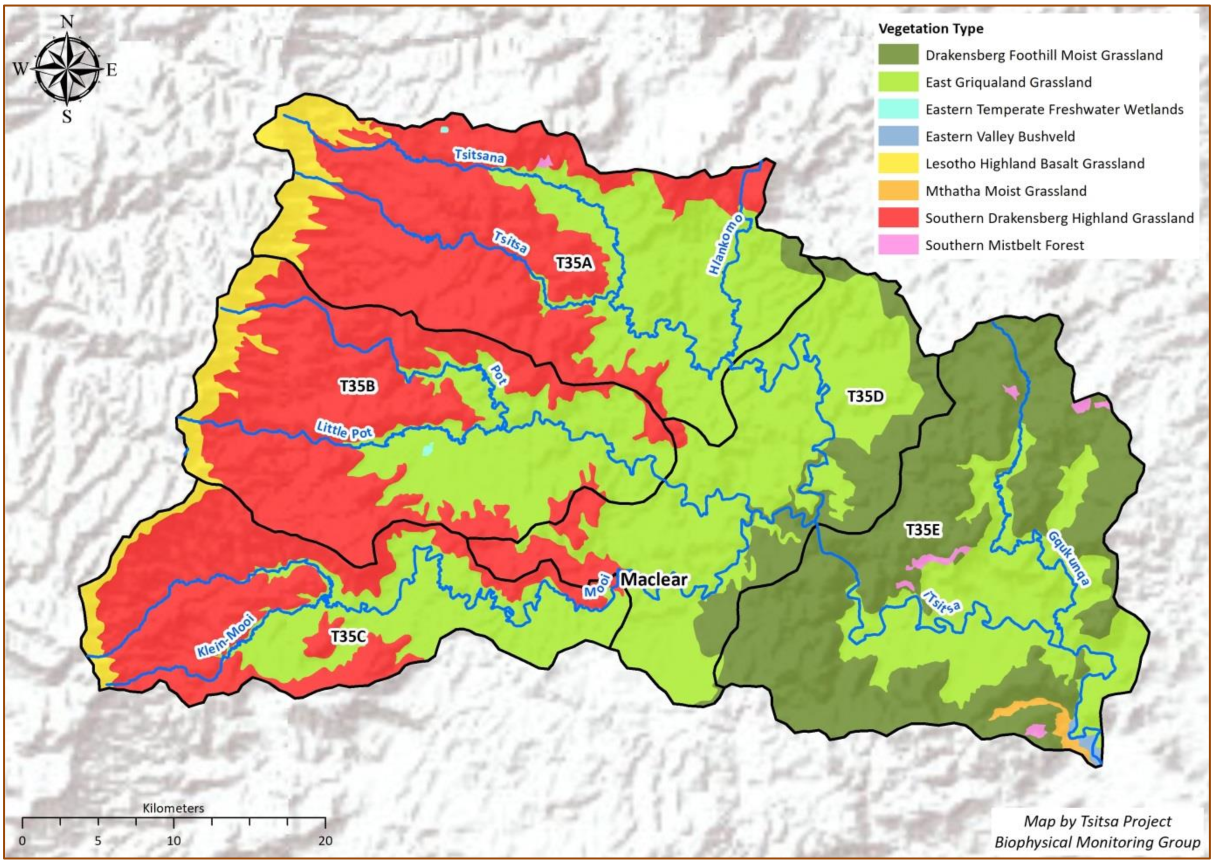


FIGURE 6: VEGETATION OF THE UPPER TSITSA CATCHMENT T35 A-E (MUCINA & RUTHERFORD, 2011)

Land cover and land use

Land cover distribution and percentage per land cover type for the Tsitsa River Catchment are given in Table 1, Figure 7 and Figure 8. Grassland constitutes the dominant land cover (71%) found in the catchment, followed by plantations, cultivated fields, indigenous bush/forests, and villages/urban centres.

TABLE 1: LAND COVER DISTRIBUTION AND PERCENTAGE PER LAND COVER TYPE FOR THE UPPER TSITSA RIVER CATCHMENT

Land cover	Percentage of catchment (%)
Grassland	71.79
Plantations/ woodlots	6.96
Cultivated subsistence fields	5.33
Thicket/ dense bush	3.84
Cultivated commercial fields	3.47
Urban area	3.26
Wetlands	2.22
Woodland/ open bush	2.05
Low shrubland	0.32
Indigenous forests	0.20
Bare soil	0.19

Cultivated commercial pivot fields	0.07
Erosion (donga)	0.07
Water permanent	0.04
Mines	0.01
Water seasonal	0.01

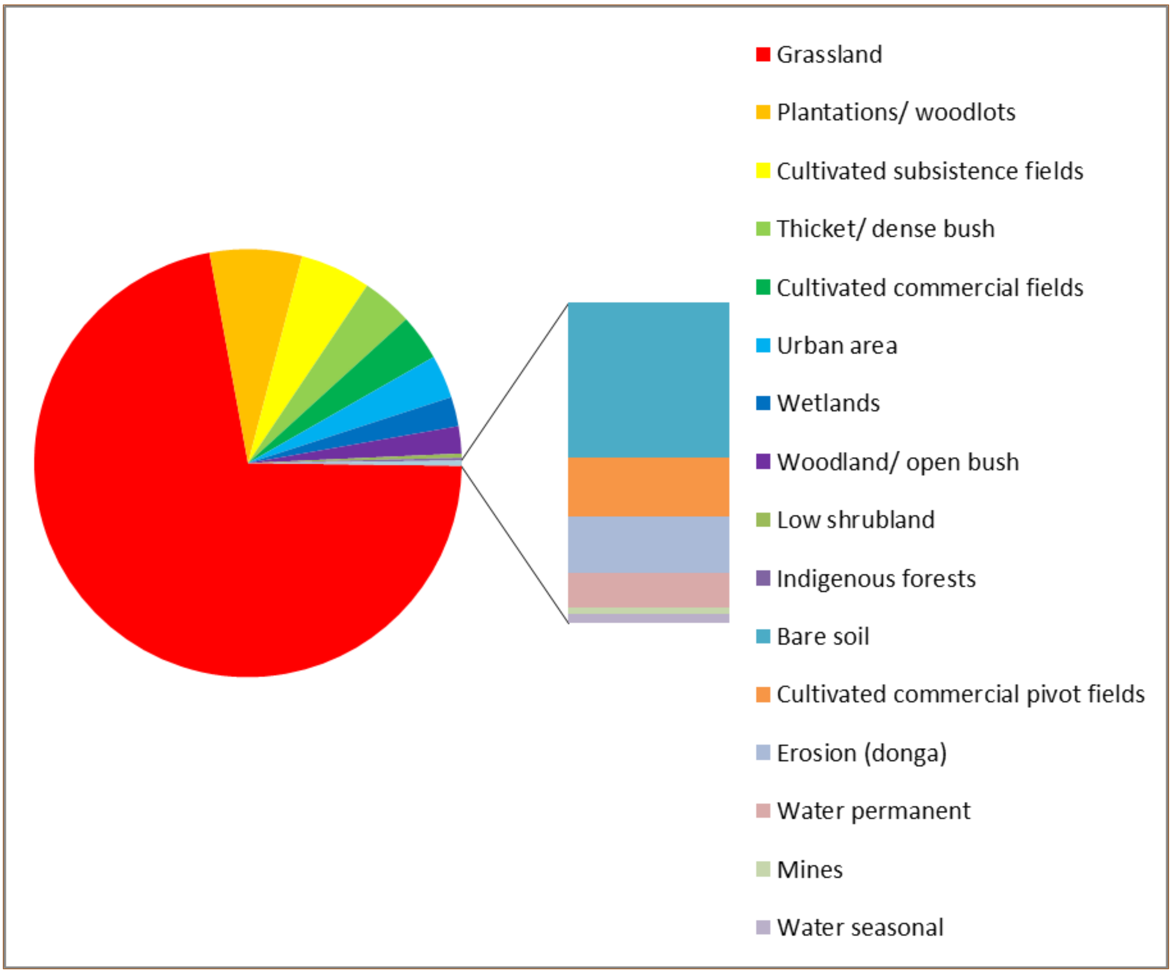


FIGURE 7: LAND COVER IN THE UPPER TSITSA RIVER CATCHMENT

In the lower communal part of the catchment agricultural practices are mostly small scale (household scale) subsistence farming located on household properties or within fenced areas close to villages. Commercial farmers found in the upper part of the catchment predominantly plant maize, potatoes and beans.

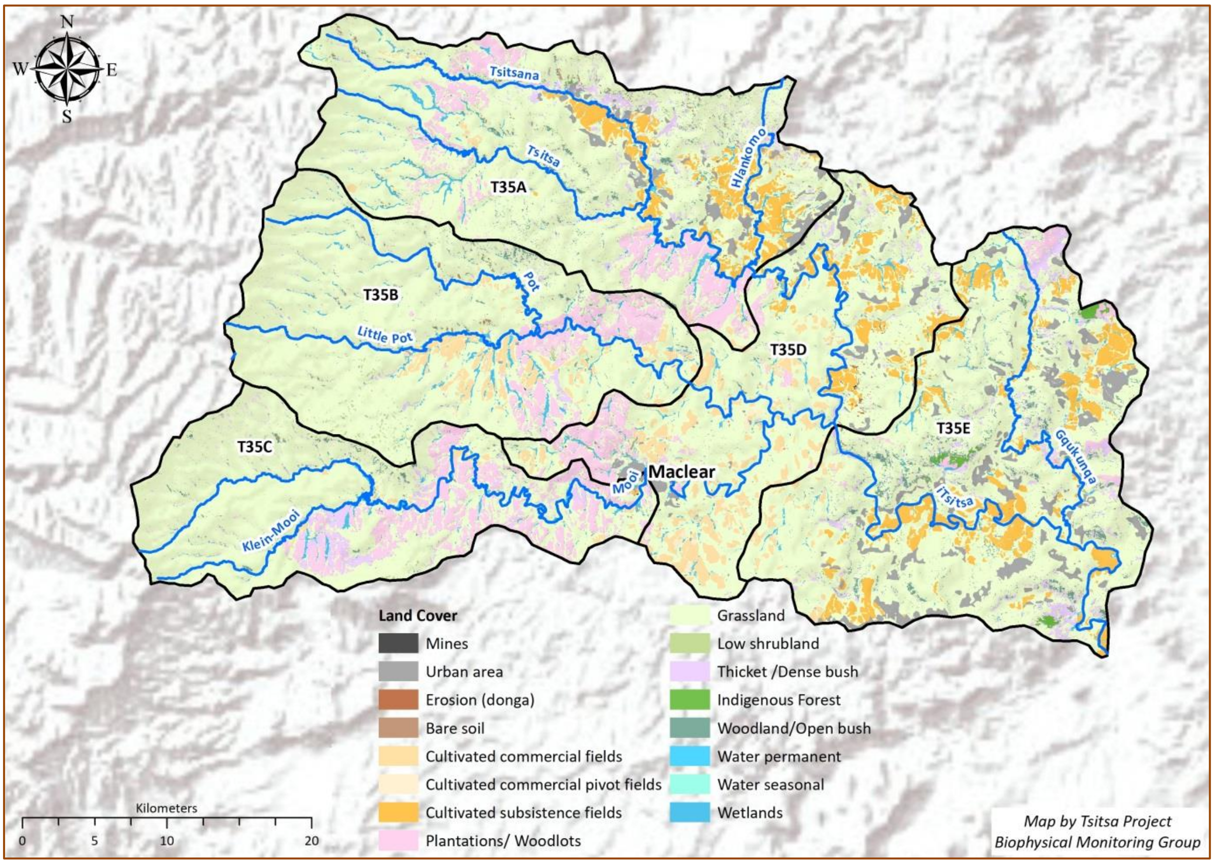


Figure 8: Land cover classes in Catchment T35 A-E (Geoterraimage, 2015)

Data Inventory

The data inventory shown in Table 2 is the datasets that are currently accessible and pertinent to the Biophysical Monitoring Plan for the Tsitsa Project. Maps of GIS data that has been collected are displayed in Appendix 1.

Table 2: Table showing data that is currently accessible for the Tsitsa Project

Data Source	Data Type	Scale	Frequency
Department of Water and Sanitation (DWS)	Gauging Stations T3H006- Current T3H009- Current T3H003- Historical T3H014- Historical T3H016- Historical	Catchment	6 min continuous
	Boreholes Multiple locations, not monitored Groundwater recharge model	Catchment	
	Water Quality Stations	Catchment	Yearly
Department of Environmental Affairs (DEA- EGIS)	Maps and data of Land cover (1990, 2001 & 2013/2014) Protected areas	National	10 yearly

South African Weather Station (SAWS)	Weather/ Climate stations Mthatha Elliot Matatiele	Regional	
	Rainfall (daily) Maclear Tsolo	Regional	Daily
SANBI	Maps and data of Vegetation Ecosystems (NBA 2011) Wetland inventory/ vegetation Eastern Cape Biodiversity Conservation Plan (ECBCP)- aquatic/ terrestrial National Protected Areas Expansion Strategy (NPAES)- focus areas National Freshwater Ecosystem Priority Areas (NFEPA)	National	Once off
Agriculture Research Council (ARC)	Maps and data of Grazing Capacity Degraded lands Weather station at Sommerville	Catchment	
Accelerated and Shared Growth Initiative for South Africa (AsgiSA)	Maps and data of Agriculture Forestry potential	Catchment	
Council of Geoscience	Maps and data of Geology Dolerite dykes	National	Once off
Tsitsa Project Automated loggers for rainfall, discharge and suspended sediment concentration	Rainfall tipping buckets (0.2 mm, event based) Level loggers (Flow) Acoustic Backscatter Sediment probe (Sediment) Barologgers (air pressure)	Catchment/ Reach/ Plot	Event based 20 min 6 min 20 min
Citizen Technicians	Suspended sediment	Sub-catchment/ plot	Sub daily
Existing eco-restoration, rehabilitation and management efforts	Existing wetland structures (pre 2018) Planned wetland structures locations (2018/2019) Existing AIPs clearing locations Existing landscape rehabilitation locations	Catchment	
GIS maps and data created	Wetlands Erosion associated with wetlands Alien vegetation Cultivated lands Gullies Discontinuous gullies Continuous gullies Roads- Main, arterial, dirt roads, jeeps tracks Livestock tracks Settlements	Catchment	3 years 3 years 3 years 5 years 5 years 5 years

	Geology Slope		

PHASE II

Management Objectives

Knowing what you want from the land in the long term and defining your specific management objectives will ensure that your monitoring informs your future management decisions.

The Tsitsa Project vision is:

"To support sustainable livelihoods for local people through integrated landscape management that strives for resilient social-ecological systems and which fosters equity in access to ecosystem services."

As such the broad management objectives for the Tsitsa Project are:

- Minimise land degradation and erosion risk
- Maintain or/and increase land productivity
- Maximise forage production for livestock
- Improve water quality and quantity
- Maintain or improve ecosystem services and ecological infrastructure

Monitoring Objectives

Monitoring is what you use to evaluate the direction in which your management is going. For monitoring and management systems to work, you need to know what direction you want to go (management objectives) and what you need to know to stay on course (monitoring objectives). Defining your monitoring objectives is thus essential to designing an effective monitoring programme. It is important to recognize, however, that your monitoring objectives can change over time and that you may periodically need to revisit, refine, and/or update your monitoring objectives.

- Comparing areas where you are trying different management approaches – such as bush clearing, fire, various grazing regimes, or reseeding – with each other or with areas where no new management approach is being tried out.
- Comparing how well a management system works on different types of land to learn where that management system will be most effective.
- Monitoring changes in specific, target areas that you think might change more quickly than the rest of the landscape or are particularly important areas in the landscape.
- Monitoring changes in the landscape as a whole (or in the most common or most important areas in the landscape) to determine when a change in management system is necessary.

Indicators and Measured Variables

The Tsitsa Project Biophysical Monitoring Group's selection of the catchment indicators began with a review of existing monitoring plans and programs from around the world (e.g. Northern Colorado Plateau Inventory and Monitoring Network; Vital Signs Monitoring Plan; U.S National Park Service; Action Against Desertification; FAO United Nations etc.). This review provided a list of catchment biophysical indicators (**Error! Reference source not found.**) that are used in similar situations elsewhere. The review resulted in indicators that could be summarised along the following themes:

- Climate;
- Terrestrial ecosystems, land cover and land use, which included indicators of changing land use/land cover, fire dynamics, and important ecosystems such as grasslands, forests, riparian vegetation and wetlands, as well as alien vegetation; and
- Water systems, which included indicators of hydrology, water quality, aquatic ecology and ground water condition.

The integrated monitoring framework for the Tsitsa Project is based upon drivers, pressures, stressors, condition and responses that affect ecosystems (**Error! Reference source not found.**) (Texas Coast Eco-health Metrics Framework and Prototype Report Card, 2017). 'Drivers' are the fundamental forces driving the coupled human-environment system (e.g. industry, climate change), leading to 'pressures', i.e., human activities and natural processes (e.g. natural resource use), which generate the chemical, physical, or biological 'stressors' (e.g. toxic chemicals, habitat alteration, invasive species) that affect ecosystems. 'Stressors' cause effects on 'condition' via changes to ecological structure, processes, and/or diversity and associated effects on ecosystem services that link ecological systems, societal systems and human well-being. Ecological condition is assessed on selected indicators and measurable variables, those ecologically and/or societally important attributes that specifically represent each type of ecosystem of concern. Management actions feed back to the ecological systems through four types of 'responses' namely:

I. Reduction of stressors through regulation or other constraints on the drivers and pressures (e.g. land use policies);
II. Remediation, the removal of existing stressors (e.g. removal of Alien Invasive Plant species (AIPs);
III. Restoration of damaged ecosystems (e.g. wetland rehabilitation); and
IV. Recovery of ecosystems through natural processes once stressors are reduced or eliminated.

Each component of the framework has specific sets of indicators that characterise ecological health, ecosystem services, human well-being, and associated pressures and stressors. The status and trends of these indicators informs the decision-making process on appropriate actions to improve ecological health and achieve ecosystem sustainability.

TABLE 3: TABLE SHOWING PROPOSED INDICATORS AND MEASURED VARIABLES UNDER DIFFERENT DOMAINS AND THEMES

Theme	Domain	Indicators	Measured Variables
Climate	Regional Weather and climate	Hydro-meteorological trend over time	Rainfall (mm) Temperature (°C) Evaporation (mm/per unit time/ unit area) Atmospheric pressure (millibar)

			Solar radiation Wind speed (m/s) Relative humidity (%)
Ecosystems/ Land cover/ Land use	Geomorphology	Hillslope features and process	Slope (% or gradient) Connectivity (m) Erosion (m³) Gully expansion (% or ha or m²)
		River channel characteristics	Channel classification Index of channel stability Index of channel condition
	Soils	Soil quality, function and dynamics	Soil classification map Soil Carbon trend (%) Microbial Activity Soil infiltration (mm/hr) Soil erosivity
	Land cover/ Land use	Land cover/ use	Land cover/ use (% or ha) Productivity (?)
		Fire dynamics	Fire frequency, location, extent, severity (% or ha)
	Ecosystems	Grassland	Cover, composition, functional species (% or ha)
		Forests	Extent, composition, threatened (% or ha)
		Riparian vegetation	Extent, composition, condition (% or ha)
		Wetlands	Size, type, location, health, ecosystem services (% or ha)
		Alien vegetation	Extent, composition, density, age (% or ha)
Water	Hydrology	Groundwater dynamics	Borehole water levels (m) Seep dynamics (wet-dry periods) (ha and time)
		Surface water flow	Base flow modeling (m³) Flood peaks (m³) Runoff (m³)
	Water quality	Water quality-chemical and physical	Nitrates Phosphates Suspended sediment (t/ha/yr) pH Dissolved oxygen Electric conductivity Turbidity Temperature

		Aquatic macroinvertebrates and diatoms	SASSv5 & MIRAI IHI VEGRAI

Monitoring Methods

Climate

Climate will continue to be monitored at existing weather stations in the region of the catchment. Programs external to the Tsitsa River Project Biophysical Monitoring Plan are currently monitoring this. The TP biophysical monitoring efforts consist of acquiring and archiving data from the chosen existing stations, and analysing data specific to the program. Station locations have been determined by the external programs according to program-specific objectives and sampling frames. Target populations of these programs are regional in scope. Within the TP scope (catchments T35 A-K) there are 10 tipping buckets collecting rainfall data at the plot scale and two barologgers measuring air pressure in strategic positions in the catchment. These data will be used to correlate and disaggregate the regional datasets; and also be used as an input to a catchment/ sub-catchment scale sediment yield monitoring/model. Many of the climate stations have a long period of record, with some dating back to the 1950-60's. This temporal sample provides a useful context for delineating trends and future, broad-scale climatic extremes and change.

Ecosystems/ Land cover/ Land use

Geomorphology

Catchment scale geomorphology

Sediment pathways and landscape connectivity

Landscape connectivity over the past 100 years has been enhanced by the formation of gullies, livestock tracks and roads (Van der Waal & Rowntree, 2017). An increase in both downslope connectivity and across slope connectivity leads to highly increased hillslope to river channel coupling, making water and sediment routing very efficient (Van der Waal & Rowntree, 2017). A high increase in sediment routing and export results as areas that were formerly functioning as water and sediment buffers and sinks are turned into conduits of both water and sediment (Van der Waal, 2015). Van der Waal (2015) summarised the landscape setting, anthropogenic influences, and changes to landscape connectivity and the possible effects of increased vegetation cover and rehabilitation and its effects on sediment dynamics in the Thina River Catchment (Quaternary Catchment T34 A-C, Figure 9).

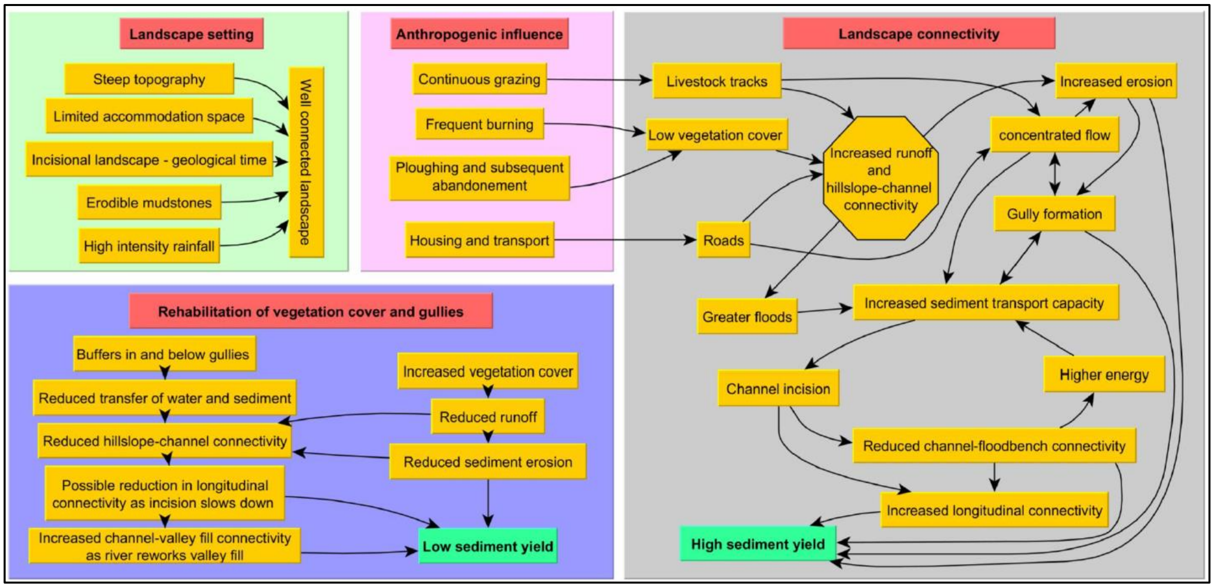


FIGURE 9: CONCEPTUAL DIAGRAM OF HOW LANDSCAPE CONNECTIVITY HAS ALTERED SEDIMENT DYNAMICS IN THE THINA RIVER CATCHMENT (VAN DER WAAL, 2015)

The downslope and across slope connectivity can be monitored by mapping connectivity features such as gullies, livestock paths, and roads and calculating a percentage increase or decrease in connectivity. This will indicate the level of hillslope to river channel coupling.

Sediment source tracing

Suspended sediment and recently deposited sediment on sand banks and behind river infrastructure can be to trace their source to igneous (Drakensberg Group) or sedimentary (Clarens, Elliot or Molteno Formations) parent materials. The magnetic susceptibility of the sediment can be used to discriminate between the two dominant sources (van der Waal et al., 2015). The igneous material is located in the upper reaches of the Catchment T35 A-E, with sedimentary rocks underlying the middle and lower catchment (see Figure 5).

Suspended sediment is collected using time-integrated samplers (Phillips et al., 2000; Figure 10) that are bolted onto bridges in the river at varying heights. Recently deposited sediment can be collected from sand banks and behind water infrastructure such as weirs using a 30 cm plastic corer.

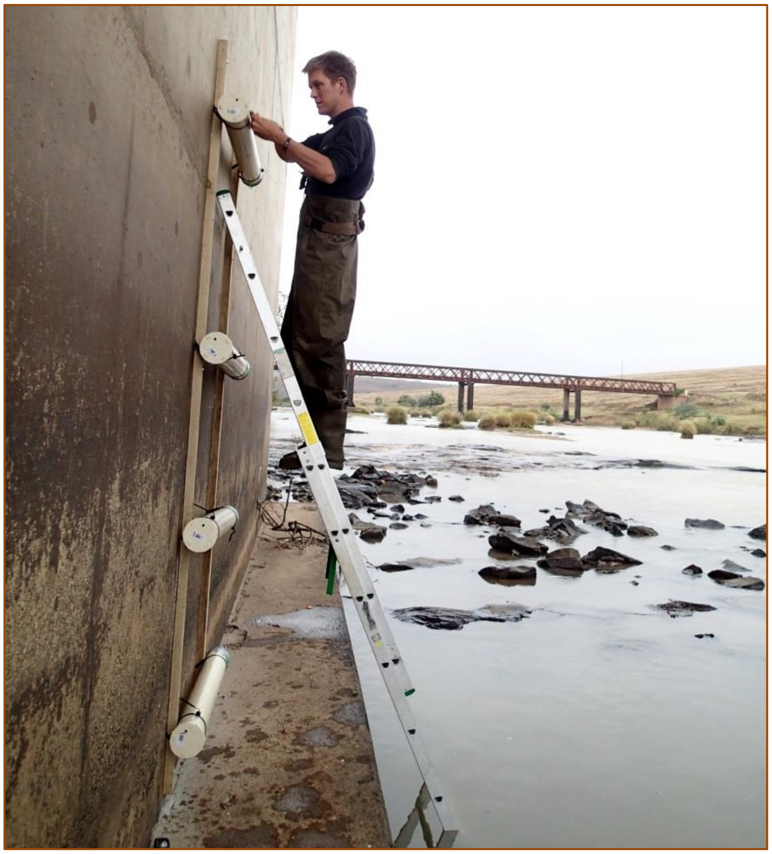


FIGURE 10: INSTALLING TIME INTEGRATED SAMPLERS IN THE TSITSA RIVER

Trollope (2016) identified sources of sediments using sediment tracing techniques in Catchment T35 A-K. Colour and magnetic tracing of sediment captured in time-integrated suspended sediment samplers installed in six tributaries of the Tsitsa River as well as on the Tsitsa River itself showed that the Mooi River, Hlankomo River and the Tsitsana River contributed a significant amount of sediment to the Tsitsa River. Trollope (2016) found that the highest proportion of sediment types captured in the time-integrated samplers was sourced from sedimentary geology that are characterised by erosion in the form of gullies. Further monitoring of sediment sources can indicate areas that are continuously contributing to the sediment load in the Tsitsa River.

Fluvial geomorphology/ Geo-habitats

Rowntree (2013) defines habitat components that respond to geomorphic processes and which are dependent on the interaction between flow and sediment as **geo-habitats**. The geomorphic condition of a river channel contributes to the quality and extent of the habitat that supports instream and riparian organisms (Rowntree, 2015). Geomorphic condition of the river channel is therefore an important indicator of the health of the river ecosystem. River habitats respond to a number of variables including water quality, substrate conditions and flow hydraulics.

The following methods are adapted from Rowntree (2015):

Desktop study

- Compile flood history for the catchment (see Hydrology)

- Construct long profile of the river(s) in the study area to classify the river reaches. Long profiles are constructed using 5 meter contour lines
- At each study site the following will be captured:
  - Site identifiers and characteristics (latitude, longitude, altitude etc.).
  - Describe reach geomorphology in terms of visible channel patterns and morphological units (can be verified in the field)
  - Construct a site map of geomorphic characteristics

Data collection

Determining the Present Ecological State (PES) using the Geomorphic Assessment Index (Rowntree, 2013):

I. Map/sketch of channel planform and channel transects with channel dimensions
II. Channel classification including:
   - reach type,
   - dominant sediment class
   - morphological units
   - geo-habitats.
   - description of reference condition
   - rating of driver metrics including geomorphic connectivity, sediment supply, channel stability and habitat change related to channel morphology
I. Identification and demarcation of key geomorphic features (e.g. bankfull level), morphological units and linked habitats along survey transects
II. Size distribution of bed material across survey transects (medium gravel and larger to be measured in the field; fine gravel and smaller to be sampled and bagged for laboratory analysis)
III. Size distribution of bank material (laboratory analysis)

The following procedure for each identified morphological unit is recommended by Rowntree (2015) for monitoring purposes:

I. Place 1 meter quadrat in the centre of the morphological unit and record the distance along the transect
II. Assess imbrication (degree of tilting of the bed material) using a scale of 1 to 3 where 1 indicates loose particles and 3 indicates strong packing giving high stability
III. Packing is a measure of bed stability and cab be assessed using the table below

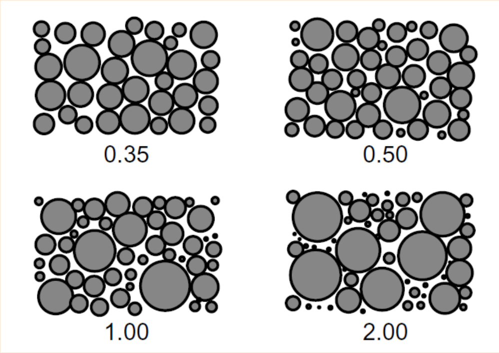
TABLE 4: PACKING CATEGORIES OF BED STABILITY (FROM: GORDON ET AL., 2004).

Packing Category	Description
Loosely packed	'Quick' sands and gravels with large voids filled with water
Normal	Uniform materials or a 'settled' bed with fairly random grain arrangements
Closely packed	Smaller materials fill the voids between particles

Highly imbricated	Tilling of particles to create a strong structure

I. Sorting accesses the range of particle sizes or particle size variability at a point in the channel. Sorting provides an indication of bedload transport processes and is assessed visually using the table below:

TABLE 5: SORTING CLASSES FOR SUBSTRATE (FROM: GORDON ET AL., 2004).

Sorting Category	Sorting Index	
Very well sorted	< 0.35	
Well sorted	0.35 - 0.50	
Moderately sorted	0.50 - 1.00	
Poorly sorted	1.00 - 2.00	
Very poorly sorted	> 2.00	

II. The Brusven Index can be used to describe both sediment size and the percent embeddedness (Gordon et al., 2004). The index is a three digit number devised by following the substrate description categories in Table 3. The size class of the largest and second largest clast type is recorded to make up the first two digits of the number, and following a full stop the percentage cover of fine sediment is estimated, making up the third digit. For example, a cobble bed with a substrate mixture of small cobble (code 6) and medium gravel (code 3) embedded by 40% fines (0.4) will result in an embeddedness index of 63.4. Bedrock or large boulders with no fines will result in an embeddedness index of 99.0 or when completely embedded by fines an embeddedness index of 91.9. Packing, sorting and embeddedness were quantified at a quadrat scale to set up a table of substrate properties along each transect in each site. The percentage fines (code 3) of the embeddedness index can be monitored seasonally under different flow conditions to monitor patches of fines collecting on the substrate.

TABLE 6: SUBSTRATE DESCRIPTION CATEGORIES FOR EMBEDDEDNESS VALUES (FROM: GORDON ET AL., 2004).

Code	Substrate Description
1	Fines (sand and smaller)
2	Small gravel (4-25 mm)
3	Medium gravel (25-50 mm)
4	Large gravel (50-75 mm)
5	Small cobble (75-150 mm)
6	Medium cobble (150-225 mm)
7	Large cobble (225- 300 mm)
8	Small boulder (300- 600 mm)

9	Large boulder/ bedrock (>600 mm)

- Conduct surveys across each site to characterise the particle size distribution of **coarse substrates (>4 mm and excluding bedrock outcrops).** A random pebble count, ranging across each site, will be conducted by measuring the particle diameters of a minimum of 100 clasts. In addition, the dominant particle size can be determined.

Soils

Soil properties influence natural landscapes and ecosystems, as well as areas in the catchment that are used by humans (agriculture, grazing etc.). Therefore, knowing the status and trends of soil conditions within the catchment is critical for maintaining the integrity of the catchment. Monitoring the soil structure and chemistry indicator will help managers make informed decisions on preventing erosion, blocking the invasion of native and alien plant species, averting the degradation of the soil biota, and avoiding the inhibition of important ecological services that soils provide (e.g., nutrient cycling).

There are potentially three monitoring objectives for this indicator. The first is determining trends in annual soil respiration measurements. The second is, detecting changes in ecosystem carbon balance. The third is determining status and annual trends in soil cover, aggregate stability, compaction, and erosion. Potential measures include soil nutrient (C, N, P) levels, soil microbial activity, soil classification, rates of erosion, percent cover of bare soil. The Tsitsa river catchment soil structure and chemistry monitoring protocol will largely be based on soil sampling and assessment methods previously developed by other agencies, such as the University of Fort Hare.

Land cover/ Land use

Land condition pertains to vegetative productivity of the landscape. The Normalized Difference Vegetation Index (NDVI) from the Moderate Resolution Imaging Spectroradiometer (MODIS) platform is used as a surrogate for productivity. Seasonal NDVI curves illustrate green-up times, production levels, and senescence periods. Among-year comparisons of NDVI curves for each 250 m pixel on the landscape will identify changes in vegetative conditions. Understanding reasons for changes requires consideration of abiotic factors (e.g., climatic trends) as well as on-site inspection of vegetative conditions. This analyse will be done every year as well as a historical analyse in order to understand the land condition trend for the catchment.

Land cover/use, landscape connectivity and fragmentation; and fire dynamics are monitored with medium-resolution satellite imagery and validated with higher-resolution aerial imagery. A base-line classified map of the catchment is generated using a combination of Landsat (or a similar platform) and field measures from the vegetation mapping effort. In subsequent monitoring events, the magnitude of spectral change at the pixel level indicates the degree of change. A vector-change assessment method assigns spectral change to a land cover designation. Classified maps from the most recent and previous monitoring occasions; and historical land cover maps (from Department of Environmental Affairs) are used to determine status and trends in land cover, and connectivity and fragmentation. Fire dynamics is monitored indirectly. Where relatively rapid and large-scale changes in spectral properties of sequential imagery are detected, field investigation is initiated to identify the occurrence and type of disturbance. Fire extent and locations can be mapped using Landsat (or a similar platform) by conducting a Normalized Burn Index (a ratio designed to highlight burned areas) from the imagery.

Ecosystems

Grassland: The Tsitsa river catchment vegetation is dominated by grassland (Mucina and Rutherford, 2011). Grasslands are an important resource for the people living within the catchment. The natural grassland has been heavily affected by poor grazing and fire management. **Methods of assessing veld condition (Van Oudtshoorn, 2015)**

Various methods of data collection can be used to access and monitor the condition of the veld.

The following methods can be carried out at known locations. Transects should be 50 meters long and for long-term monitoring marked by a start and end point (e.g. a peg or cairn).

- **Photographic monitoring:** Photographs taken from the same point in the same direction (fixed point) at the same time of year (preferably once in summer and once in winter). This can be used to monitor available fodder and change in vegetation structure over time.
- **Species composition**: At every meter along the transect the closest grass species should be identified and noted. The plants can then be grouped according to their ecological index (decreasers and increasers). These can then be used as indicators for veld condition and to monitor change in species structure over time. It is important to note the presence, abundance and type of forb species and woody vegetation.
- **Biomass method**: Using a pasture disk meter the biomass is calculated along the known transect. 50 readings should be taken along the transect. The average reading from the disk pasture meter is used to calculate the standing crop ($kg.ha^{-1}$). In turn the grazing capacity can be used using the methods set out by Van Oudtshoorn (2015).
- **Multi-Criteria visual assessment:** This method evaluates multiple criteria over a broader spectrum to give an indication of overall veld condition and health. This method uses observations and estimations and is therefore subject to the views of the person conducting the assessment. Criteria include soil health, productivity and general ecology.

The best time to access the condition of the veld is at the end of the growing season (approximately May).

Various other methods are described by Van Oudtshoorn (2015) that if found more suitable can be applied.

Forests: Indigenous forests exist in the Tsitsa river catchment as pockets in ravines. These are important as biodiversity hotspots as well as providing the local people with cultural and medicinal benefits. The forest pockets are threatened by poor management and protection as well as the encroachment of invasive alien species and fires. In order to protect and manage the remaining indigenous forest pockets the TRBMP will use remote sensing and aerial images to map the extent of the forests, extent of encroachment of AIPs as well as using historical images to conduct a trend analysis.

Riparian vegetation: Riparian systems perform numerous ecosystem functions important to human populations, yet are one of the most endangered ecosystem types. For the Tsitsa River Biophysical Monitoring Plan the protocol set out by the River Eco-classification: Riparian Vegetation Response Assessment Index (VEGRAI) will be followed. VEGRAI is designed for qualitative assessment of the response of riparian vegetation to impacts in such a way that qualitative ratings translate into quantitative and defensible results.

Wetlands: Wetlands are complex and dynamic ecosystems that provide indispensable services to the people and the environment of the Tsitsa river catchment. In order to protect and manage the remaining wetlands, assessment, monitoring and reporting on the state (health) of wetlands is crucial, as well as assessing the ecosystem services provision of the wetlands.

Firstly a catchment scale assessment of the wetlands using existing datasets and desktop assessments will be conducted. This will allow the TRBMP to report on the extent, type, and land cover surrounding the wetlands; and the current use and protection of these wetlands. Secondly a prioritisation process will be conducted at the catchment scale using aerial images, mapped data on use, and current degradation of the wetlands and vulnerability of the wetlands to erosion. Thirdly a selection of wetlands will be chosen in order to complete a rapid assessment of health (using WET-Health protocols, McFarlane et al., 2009) and ecosystem services (using WET-Ecosystem Services, Kotze et al., 2009) in the field across the catchment. Results from this will allow TRBMP to report on eight indicators, namely the extent of the wetland; the present state of hydrology, geomorphology, vegetation and water quality; present ecological state based on land use; scores for ecosystem services provided by the wetland; and a measure of the threats posed to the wetlands, such as, by listed invasive plants encroachment. Fourthly monitoring will be conducted on those wetlands chosen for the field assessment every 2 to 5 year interval, as well as, a catchment scale mapping of the wetlands using aerial images every 5 years to monitor the trends of the wetlands found in the catchment.

Alien Invasive Plants (AIPs): There are two components to this indicator: early detection and status and trends. The early detection portion involves monitoring and mapping of:

- key vectors and pathways for invasive species and their propagules,
- areas most vulnerable to exotic invasion,
- areas exposed to major disturbances, and
- likely habitat for targeted groups of invasive species.

Literature review of life-history traits of invasive species, inventory results, expert opinion, and predictive modelling/ mapping will determine targeted areas for early detection monitoring. All identified sites will be monitored for the occurrence of invasive species.

Status and trends monitoring will focus on target populations of management interest, including some treated for eradication. Areas selected to receive chemical or mechanical treatments will be monitored before and after treatment. Post-treatment monitoring will occur annually for the first one to three years depending on the species and treatment, followed by periodic monitoring.

Hydrology

Hydrographs can be separated into two main components (Gordon et al., 2004). The first component is *baseflow* which can be defined as the volume of water representing the groundwater contribution. The second component is *direct runoff* and is defined as the volume of water produced from rainfall and snowmelt events.

Groundwater dynamics

DWS (2016) identified groundwater as a key resource for poverty reduction and economic development of rural and semi-urban areas. Baseflow dynamics indicate groundwater dynamics. See methods below. When analysing flood duration curves the recession curve represents groundwater flow patterns (Gordon et al., 2004). If groundwater contributions are significant then the curve at the lower end tends to be flattened whereas a steep curve indicates minor baseflows.

The soluble load (see Water Quality section) in water can also indicate levels of groundwater (Gordon et al., 2004). Water originating as groundwater tends to have a higher soluble load than surface-derived runoff.

Borehole water levels

The Department of Water and Sanitation has a dataset of boreholes in the catchment. However, none of the boreholes in Catchment T35 A-E are currently being monitored by the Department of Water and Sanitation and no data is available in the National Groundwater Archive for this catchment. If funding permits groundwater level sensors can be installed in various boreholes across the catchment.

Hillslope seep dynamics (wet-dry periods) (ha and time)

Hillslope seep wetlands occur where topographic and stratigraphic conditions allow groundwater to intersect the surface (Stein et al., 2004). The condition and resilience of hillslope seep wetlands are therefore controlled by their hydrodynamic characteristics and recharge mechanisms. Underlying geology (sedimentary and/or basaltic), underlying deposits (alluvial/colluvial) and presence of faults and dykes will affect the volume and recharge rate of groundwater. Factors such as vegetation cover, which can also be linked to the geology (soils) also play a role. By understanding the mechanisms controlling functional wetland seeps, indirect impacts can be monitored and management actions can more accurately be applied (Stein et al., 2004). Van der Kamp and Hayashi (1998) state that small wetlands are a vital point for groundwater recharge. This can occur on wetlands that occur on shallow slopes where water accumulates such as depression wetlands and floodplain wetlands.

Surface water flow/ Discharge

Flood/peak discharge modelling

Discharge is an important variable that determines channel response over time with high discharges having the ability to entrain sediment and transport it downstream (Rowntree and Wadeson, 1999).

Current flow data will be sourced from gauging stations T3H006 (Tsitsa River at Xonkonxa; catchment area 4 285 km2) and T3H009 (Mooi River at Maclear, catchment area 307 km2). In addition historic flood data will be sourced from gauging stations T3H003 (Tsitsa River at Halcyon Drift; catchment area 482 km2; data logged from 1949-1959) and T3H014 (Inxu River at St Augustine Mission; catchment area of 1 134 km^2; data logged from 1999-2000).

Flood frequency curves will be drawn to show the relationships between flood magnitude (peak discharge) and recurrence intervals of floods. Annual peak discharges from gauging station T3H006 and T3H009 for the last 20 years will be plotted against the two year and ten year floods to get a trend of flood frequency and severity in the study area.

Base flow modelling

Measurements of discharge in relation to current water levels have been monitored in the catchment (Huchzermeyer, 2017; Bannatyne, 2017) and are currently still being monitored. Discharge data is used to monitor the current stream condition. Discharge measurements at each site are taken along a known cross-section, with a uniform and stable bed, using a Marsh McBirney Flo-Mate 2000 portable flow meter. The total width of the channel along each transect is measured and the width of the channel is divided into 20 equal units. At the mid-point in each unit the depth and velocity is measured. Discharge is calculated using the Velocity-Area Method (Gordon et al., 2004).

Discharge for each unit is calculated using the following formula:

$D = (d \times l) \times v$

Where:

D = discharge ($m^3.s^{-1}$)

d = depth (m)

l = length of unit (m)

v = velocity ($m.s^{-1}$)

The total discharge ($m^3.s^{-}1$) for each site is measured by calculating the sum of all the unit discharges along the transect.

During high discharges, when flow was too high to safely access the river, an adaption of the Velocity-Area Method (Gordon et al., 2004) was used to calculate discharge. This was done across a known cross-sectional transect with uniform flow and a stable bed. By using the known area of the river cross-section and the average velocity, measured by observing the rate of travel of a float across a known distance, discharge was calculated using the following formula:

$$Q = VA$$

Where:
Q = discharge ($m^3.s^{-1}$)

V = average velocity ($m.s^{-1}$)

A = cross-sectional area of the water (m^2)

The average surface velocity can be calculated using the following formula (Gordon et al., 2004):

$$V_{surf} = \frac{L}{t}$$

Where:

V_{surf} = surface velocity ($m.s^{-1}$)

L = known distance (m)

t = travel time (s)

Because the surface velocity is expected to be higher than the average velocity a correction coefficient of 0.8 was applied using the following formula (Gordon et al., 2004):

$$V = V_{surf}(0.8)$$

Where:

V = average velocity ($m.s^{-1}$)

V_{surf} = surface velocity (m.s^{-1})

Solinst level loggers installed at each site are used to collect continuous data on variations in depth (water pressure above the logger) and temperature. A barometric compensation is carried out on the level logger data using a Solinst Barologger which is installed proximal to the level loggers.

The continuous data collected from the loggers is used to calculate hydrodynamic properties of the river channel including floods and baseflows. To achieve this readings of discharge versus water level (depth to logger) are used to create rating curves. Measured discharges are plotted against the measured depth to the logger to create an equation to calculate discharge at any given level.

Water Quality

Physical and chemical water quality

Monitoring water quality variables gives an indication of the health of aquatic habitats. Five variables (Pennack, 1971; Díaz et al., 2008) were identified for a short term habitat assessment, namely dissolved nitrogen and phosphate concentrations, pH, electrical conductivity, dissolved oxygen content and water temperature. In rivers where the water is well mixed rapid assessments of water quality can be undertaken by taking a single representative sample at each site (Gordon et al., 2004). In addition turbidity and suspended sediment concentrations are continuously measured (Bannatyne, 2017). A comparison of trends over time and under different flow conditions can point to either an improved or degraded aquatic ecosystem.

Nitrate and phosphate concentrations

High concentrations of dissolved phosphates and nitrates can be toxic to aquatic organisms. A rapid test kit can be used to measure concentrations in mg/l.

Electrical conductivity (EC) and pH

Conductivity is the measure of the ability of a sample of water to conduct a current. Reduced growth rates and fecundity in aquatic organisms is commonly linked to small or sudden changes in EC and pH due to increased energy requirements. pH should fall between 6 and 8 to indicate a balanced system.

EC and pH were measured using a handheld Hanna Combo pH and EC meter which can be sourced from Hanna instruments.

Dissolved oxygen

The maintenance of sufficient DO concentrations (> 80%) is critical for the survival of aquatic organisms. DO can be measured using a DO probe.

Temperature

The thermal characteristics of a river system vary due to natural and anthropogenic hydrological, climatic and structural changes within a river channel and catchment area (Dallas and Day, 2004). In turn this directly affects the life cycle patterns (reproductive periods, rates of development and emergence times) and metabolic processes in aquatic organisms. Water should not be allowed to vary from the background daily average water temperature, considered to be normal for a site, at the specific time of day or season, by >2 ˚C (DWAF, 1996). The Solinst level loggers at each site record continuous data on water temperature (˚C)

Turbidity

Abiotic matter is commonly sourced from eroded materials or sediments that have been previously deposited on the river bed but have become entrained due to high flows. Increased turbidity and suspended sediment results in a change in water clarity. A river's water clarity changes seasonally and varies according to land use practices within the catchment, rainfall, hydrology and the physical structure of the river. Both the increase in turbidity and increase in total suspended solids affect light penetration into the water, directly affecting aquatic biota.

Data will be used from Bannatyne (2017).

Suspended sediment

A citizen technician based flood focused approach to direct suspended sediment sampling was developed (Bannatyne, 2017) and data collected from this will be used in the Biophysical Monitoring Plan.

Biological response indices: aquatic macroinvertebrates and diatoms

River health, in terms of water quality, can be rapidly assessed by looking at the taxa richness of macroinvertebrate species sensitive to water quality (Dickens and Graham, 2002).

South African Scoring System (SASSv5) and Macroinvertebrate Response Assessment Index (MIRAI)

A score derived using the South African Scoring System (SASS) (Dickens and Graham, 2002), a widely used technique in South African Rivers, was calculated for each site by sampling period to look at a rapid assessment of water quality. This gave a measure of river health at the site scale. The average score per taxa (ASPT) is the total sensitivity score for all the classes/families found, divided by the number of classes/families found. A specified net with fine mesh, held downstream of the sample point catching macroinvertebrates dislodged from the substrate or marginal vegetation, was used for sample collection. In addition, fine sediments were sieved through the net and visual observations of substrate and vegetation were conducted to record further habitat niches.

Index of Habitat Integrity (IHI)

The habitat integrity of a river refers to the maintenance of a balanced composition of physico-chemical and habitat characteristics on a temporal and spatial scale that are comparable to the characteristics of natural habitats of the region (Kleynhans 1996). Habitat integrity assessment is approached from an instream and riparian zone perspective. Both of these are formulated according to metric groups, each with a number of metrics that enable the assessment of habitat integrity. The model functions in an integrated way, using the results from the assessment of metric groups, or metrics within a metric group, for the assessment of other metric groups where appropriate.

Assessment of habitat integrity is based on an interpretation of the deviation from the reference condition. Specification of the reference condition follows an impact based approach where the intensity and extent of anthropogenic changes are used to interpret the impact on the habitat integrity of the system. To accomplish this, information on abiotic changes that can potentially influence river habitat integrity are obtained from surveys or available data sources. These changes are all related and interpreted in terms of modification of the drivers of the system, namely hydrology, geomorphology and physico-chemical conditions and how these changes would impact on the natural riverine habitats.

Table 7: Metrics rating table (Kleynhans et al., 2008)

IMPACT/ SEVERITY CLASS	DESCRIPTION	RATING
None: Reference	No discernible impact or the modification is located in such a way that it has no impact on habitat quality, diversity, size and variability.	0
Small	The modification is limited to very few localities and the impact on	0.5-1.0

	habitat quality, diversity, size and variability are very small.	
Moderate	The modifications are present at a small number of localities and the impact on habitat quality, diversity, size and variability are limited.	1.5-2.0
Large	The modification is generally present with a clearly detrimental impact on habitat quality, diversity, size and variability. Large areas are not influenced.	2.5-3.0
Serious	The modification is frequently present and the habitat quality, diversity, size and variability in almost the whole of the defined area are affected. Only small areas are not influenced.	3.5-4.0
Critical	The modification is present overall with a high intensity. The habitat quality, diversity, size and variability in almost the whole of the defined section are influenced detrimentally.	4.5-5.0

Riparian Vegetation

Important indicators in most riparian systems are plant community composition and structure. These can be monitored using a combination of one or more of the following methods: Riparian Vegetation Response Assessment Index (VEGRAI), Line-point intercept, Riparian channel vegetation survey, Belt transect and Tree density. Additional long-term monitoring methods can provide more complete information on relationships between changes in vegetation and channel morphology.

The South African Diatom Index (SADI)

Diatom field methods are the simplest of any biomonitoring protocol currently in use. Once the sample has been collected there are two options: Submit it to a commercial laboratory for analysis (several laboratories exist) or perform the analysis yourself.

Diatom indices allow for the quantification of a water quality impact in terms of producing an index score, as well as allowing the user to draw specific conclusions regarding the pH, electrical conductivity, nutrient status, organic content and oxygen levels of a stream and is thus a very powerful tool. For a small amount of added effort, a relatively large amount of information regarding the system under question can be gained.

TABLE 8: SUMMARY TABLE OF POTENTIAL VARIABLES FOR MONITORING. CURRENTLY MONITORED VARIABLES ARE IN BOLD

Theme	**Indicators**	**Measured variables**	**Methods**	**Frequency**	**Scale/ no. points**
Climate	Hydro-meteorological trend over time	Rainfall (mm)	Geostationary satellite (TARCAT; CPC/ FEWS RFE2.Ob; TRMM<2010); Radar- Mthatha airport; Tipping bucket; Voluntary network	1-10 days; Hourly; Instantaneous; Daily	5-10 km; 1 km; 10 for T35A-K
		Temperature (°C)	Radar	Hourly	
		Evaporation (mm/per unit time/ unit area)	SEBAL; EARS; CPC/ FEWS; Volunteer network; Evaporation network; t, rh, v, Rnet	Daily	
		Atmospheric pressure (millibar)	Pressure sensor	20 mn	2
		Solar radiation			
		Wind speed (m/s)			
		Relative humidity (%)			
Ecosystems/ Land cover/ Land use	Hillslope features and process	Slope (% or gradient)			
		Connectivity (m)	Mapped at 1:4000 scale based on 2013 aerial imagery	2013	T35 A-E
		Erosion (m³)			
		Gully expansion (% or ha or m²)			
	River channel characteristics	Channel classification			
		Index of channel stability			
		Index of channel condition			

	Soil quality, function and dynamics	Soil classification map			
		Soil Carbon trend (%)		Biannual (baseline)	
		Microbial Activity			
		Soil infiltration (mm/hr)			
		Soil erosivity	Plot measurements gully expansions; erosion pins	Annual	
	Land cover/ use	Land cover/ use (% or ha)	Remote sensing	2001, 2015	Catchment wide
		Productivity (?)			
	Fire dynamics	Fire frequency, location, extent, severity (% or ha)	Sentinel; Modis	1986 - 2017	Catchment wide
	Grassland	Cover, composition, functional species (% or ha)	Sentinel; Modis	2 to 5 years	Catchment wide
	Forests	Extent, composition, threatened (% or ha)	Sentinel; Modis	2 to 5 years	Catchment wide
	Riparian vegetation	Extent, composition, condition (% or ha)	Sentinel; Modis	2 to 5 years	Catchment wide
	Wetlands	Size, type, location, health, ecosystem services (% or ha)	Scientific measurements; volunteer observations	2 to 5 years 2015	Catchment wide
	Alien vegetation	Extent, composition, density, age (% or ha)	Sentinel; Modis	2 to 5 years 2017	Catchment wide
Water	Groundwater dynamics	Borehole water levels (m)	Borehole network; Citizen observation; baseflow modelling	Daily/ monthly; Weekly; Daily	
		Seep dynamics (wet-dry periods) (ha and time)	Citizen observation		
	Surface water flow	Base flow modeling (m^3)	Instrumental profiles;	20 mins;	

			Model; Volunteer observation	30 mins; Daily	
		Flood peaks (m³)	DWS gauging stations (Mthatha, Maclear); Instrumental profiles		
		Runoff (m³)	Instrumental profiles; Volunteer observations; Model	20 mins; daily; 30 mins	10 sites?
	Water quality-chemical and physical	Nitrates	Volunteer measurements	Biannual	
		Phosphates	Volunteer measurements	Biannual	
		Suspended sediment (t/ha/yr)	Instrument profile; Volunteer measurements; Sediment yield model (RUSLE/MUSLE/SWAT)	6 mins; daily/ event focused; daily	1 instrument 7 Volunteer
		pH	Volunteer measurements	Biannual	
		Dissolved oxygen	Volunteer measurements	Biannual	
		Electric conductivity	Volunteer measurements	Biannual	
		Turbidity	Volunteer measurements	Biannual	
		Temperature	Volunteer measurements	Biannual	
	Aquatic macroinvertebrates and diatoms	SASSv5 & MIRAI	Scientific measurements; volunteer measurements	Biannual 2016	10 sites 3 sites
		Diatoms	Scientific measurements	Biannual	10 sites
		IHI	Scientific measurements; volunteer measurements	2 to 5 years	10 sites
		VEGRAI	Scientific measurements; volunteer measurements	2 to 5 years	10 sites
Eco-restoration/ Rehabilitation	Alien vegetation removal	Mapping extent			

	Abandoned cultivated fields				
	Wetlands rehabilitation				
	Gully rehabilitation				
	Landscape rehabilitation				
	Small reservoir rehabilitation				

Monitoring Locations

Current monitoring sites are indicated in Figure CC and include previous locations for monitoring.

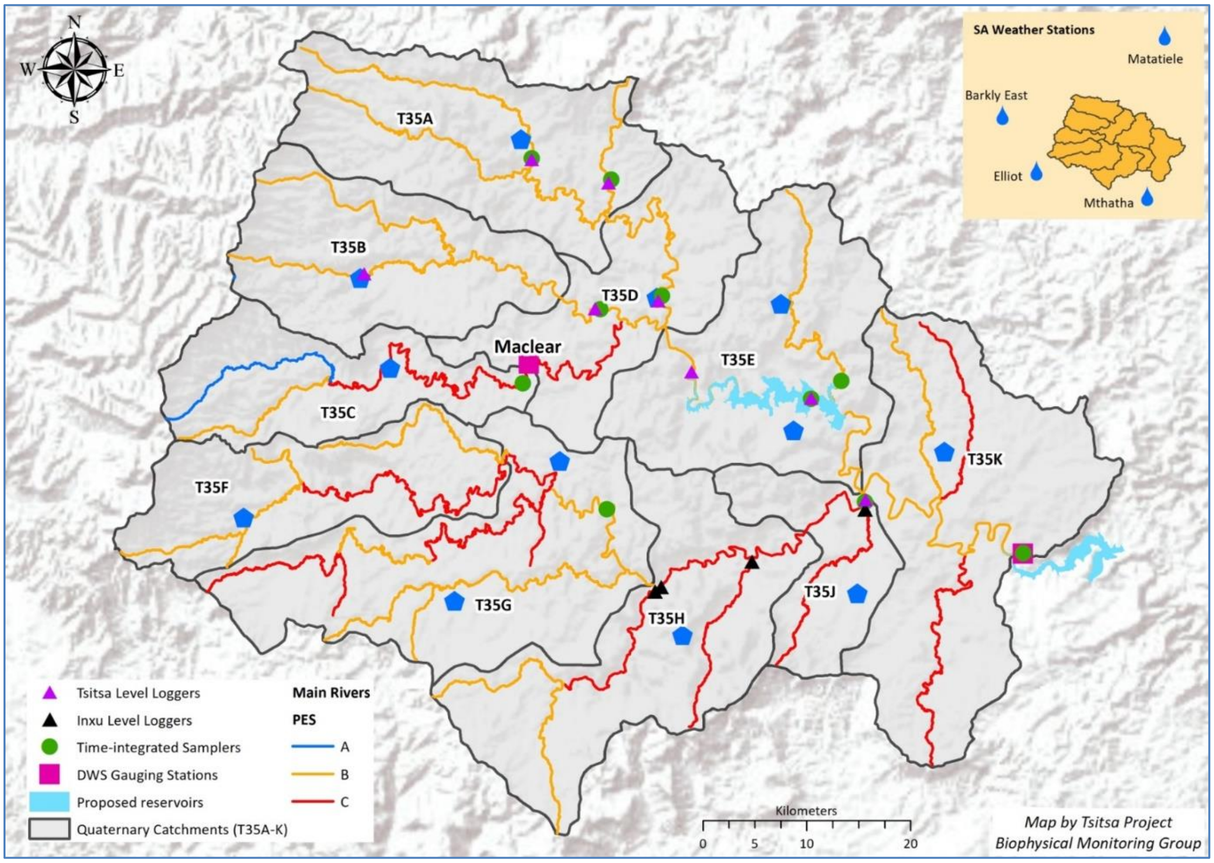


FIGURE 11: MONITORING LOCATIONS FOR THE TSITSA RIVER CATCHMENT.

Data Management

The Tsitsa Project Biophysical Monitoring Group (TPBMG) is a steward of the data that is a product from our inventory and monitoring work in the Tsitsa River Catchment. While this information is useful and crucial today, it will become even more valuable in the years and decades to come. As such data management is a cornerstone of the TPBMG. From planning, to field work, and through to analysis, priorities will be placed on:

- Data Accuracy

  The quality of the biophysical data we collect is paramount. Analyses to detect trends or patterns require data with minimal error and bias. To ensure data of the highest possible quality, we will use procedures to minimize, identify, and correct errors at every stage of the data life cycle.

- Data Security

  Data must be protected against loss. The TPBMG will set up storage, backup, and disaster recovery plans, and establish processes for long-term data archiving.

- Data Longevity

Data sets need to be cared for. The TPBMG will ensure that data sets are migrated to current software and formats, and methodology and processing documentation will accompany all data sets.

- Data Accessibility

  Data will be made available in a variety of formats to any interested and affected stakeholders through the TP knowledge hub.

Data Analysis and Reporting

Disseminating results in a useable format for managers and a wide audience is central to the success of the Tsitsa Project Biophysical Monitoring Program (TPBMP). Monitoring results, methods, and topical issues will be communicated to resource managers from various agencies and to external scientists through presentations at annual management-oriented meetings, professional meetings, and in scientific publications.

REFERENCES

Agrometeorology Staff. (1984-2008). ARC-ISCW *Agrometerorology weather station network data for South Africa*. Unpublished. ARC- Institute for Soil, Climate and Weather: Pretoria.

Bannatyne, L.J. 2017. *Developing a Citizen Technician Based Approach to Suspended Sediment Monitoring in the Tsitsa River Catchment, Eastern Cape, South Africa.* Rhodes University (Unpublished MSc).

Base, F., Helmschrot, J., Muller Schmied, H. & Flugel, W.A. 2006. The impact of land use change on the hydrological dynamic of the semi-arid Tsitsa Catchment in South Africa. *Proceedings of the 2nd Gottingen GIS and Reote sensing*, Gottingen. 257-268.

Blignaut, J., Mander, M., Schulze, R., Horan, M., Dickens, C., Pringle, C., Mavundla, K., Mahlangu, I., Wilson, A., McKenzie, M. & McKean, S. 2010. Restoring and managing natural capital towards fostering economic development: Evidence from the Drakensberg, South Africa. *Ecological Economics,* 69: 1313–1323. https://doi.org/10.1016/j.ecolecon.2010.01.007

Dallas, H.F. & Day, J.A. 2004. *The Effect of Water Quality Variables on Aquatic Ecosystems : A Review*. WRC Report No. TT 224/04.

Díaz, A.M., Alonso, M.L.S. & Gutiérrez, M.R.V.A. 2008. Biological traits of stream macroinvertebrates from a semi-arid catchment: patterns along complex environmental gradients. *Freshwater Biology,* 53: 1–21.

Dickens, C. W. S. & Graham, P. M. 2002. The South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. *African Journal of Aquatic Sciences,* 27: 1–10.

Department of Water Affairs and Forestry (DWAF). 1996. *South African Water Quality Guidelines, Volume 7; Aquatic Ecosystems.* Produced by the CSIR Environmental Services, Pretoria for the Department of Water Affaris and Forestry, Pretoria, South Africa.

Department of Water and Sanitation (DWS), 2016. *Department of Water and Sanitation Strategy: National Groundwater Strategy,* December 2016.

Fraser, A.I., Harrod, T.R. & Haygarth, P.M. 1999. The effect of rainfall intensity on soil erosion and particulate phosphorus transfer from arable soils. *Water and Science Technology*, 39, 41-45

Geoterraimage, 2015. 2013 - 2014 South African National Land-Cover Dataset, version 5b.

Gordon, N. D., McMahon, T. A., Finlayson, B. L., Gippel, C. J. & Nathan, R. J. 2004. *Stream Hydrology: An Introduction for Ecologists,* Second Edition. Wiley: Chichester, 440 pp. ISBN: 978-0-470-84357-4.

Huchzermeyer, N.H. 2017. *A baseline survey of channel geomorphology with particular reference to the effects of sediment characteristics on ecosystem health in the Tsitsa River, Eastern Cape, South Africa.* Rhodes University (Unpublished MSc).

Iliso Consulting (Pty) LTD. 2015. *Environmental Impact Assessment for the Mzimvubu Water Project: Environmental Impact Assessment Report.* Department of Water and Sanitation, Pretoria.

Kakembo, V. & Rowntree, K. M. 2003. The relationship between land use and soil erosion in the communal lands near Peddie town, Eastern Cape, South Africa. *Land Degradation and Development,* 14: 39–49.

Kleynhans CJ 1996. A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu river (Limpopo system, South Africa). Journal of Aquatic Ecosystem Health 5: 41-54

Kleynhans CJ, Louw MD, Graham M, 2008. Module G: EcoClassification and EcoStatus determination in River EcoClassification: Index of Habitat Integrity (Section 1, Technical manual) Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 377-08

Kotze, D.C, Marneweck, G.C., Batchelor, A.L., Lindley, D. and Collins, N., 2009. WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands. WRC Report TT339/09, Pretoria, South Africa

Land type survey staff. (1972-2006), Land types of South Africa: Digital map (1:250000 scale) and soil inventory databases. ARC-Institute for Soil, Climate and Water: Pretoria.

Le Roux, J.J., Barker, C.H., Weepener, H.L., van den Berg, E.C., & Pretorius, S.N. 2015. Sediment yield modelling in the Mzimvubu River Catchment. WRC Report 2243/1/15. Water Research Commission: Pretoria.

Macfarlane DM, Kotze DC, Ellery WN, Walters D, Koopman V, Goodman P & Goge C. 2007. WET-Health: A technique for rapidly assessing wetland health. WRC Report No TT 340/08, Water Research Commission, Pretoria.

Mucina, L., Hoare, D.B., Lotter, M.C., Du Preez, P.J., Rutherford, M.C., Scott-Shaw, C.R., Bredenkamp, G.J., Powrie, L.W., Scott, L., Camp, G.T., Cilliers, S.S., Bezuidenhout, H., Mostert, T.H., Siebert, S.J., Winter, P.J., Burrows, J.E., Dobson, L., Ward, L., Stalmans, M., Oliver, E.G., Siebert, G., Schmidt, E., Kobisi, K. & Kose, L. 2006. Grassland Biome. In: Mucina, L., Rutherford, M.C. (Eds.), *The Vegetation of South Africa, Lesotho and Swaziland*. South African National Biodiversity Institute: Pretoria, pp 349-431.

South African National Biodiversity Institute. 2012. Vegetation Map of South Africa, Lesotho and Swaziland [vector geospatial dataset] 2012. Available from the Biodiversity GIS website [http://bgis.sanbi.org/SpatialDataset/Detail/18].

Musa, R. & Greenfield, R. 2018. Use of diatom indices to categorise impacts on and recovery of a floodplain system in South Africa. *African Journal of Aquatic Science* 43(1): 59-69.

O'Dell, T., S. Garman, A. Evenden, M. Beer, E. Nance, D. Perry, R. DenBleyker, et al. *2005. Northern Colorado Plateau Inventory and Monitoring Network, Vital Signs Monitoring Plan, National Park Service,* Inventory and Monitoring Network, Moab, UT.

Ohmann, J.L., & Gregory, M.J. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest- neighbor imputation in coastal Oregon, U.S.A. Canadian Journal of Forest Research, 32:725-741, https://doi.org/10.1139/x02-011

Partridge, T., Dollar, E., Moolman, J. & Dollar, L. 2010. The geomorphic provinces of South Africa, Lesotho and Swaziland: A physiographic subdivision of earth and environmental scientists. *Transactions of the Royal Society of South Africa,* 65: 1–47.

Pennack, R. 1971. Toward a Classification of Lotic Habitats. *Hydrobiologia,* 38: 321–334.

Purevdorj, T., Tateishi, R., Ishiyama, T. & Honda, Y. 1998. Relationships between percent vegetation cover and vegetation indices. *International Journal of Remote Sensing*. 19: 3519–3535. https://doi.org/10.1080/014311698213795

Rowntree, K. M. & Wadeson, R. A. 1999. A *hierarchical geomorphic model for the classification of selected South African river systems.* WRC Report No. 497/1/99.

Rowntree, K. M. 2013. Module B: *Geomorphology Driver Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2).* Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No TT 551/13.

Rowntree, K. M. 2015. *Geomorphology and Environmental Flow Assessment: A guide to data collection and application*. Catchment Research Group, Rhodes University, November 2015.

Stein, E.D., Mattson, W., Fetscher, A.F. & Halama, K.J. 2004. Influence of geologic setting on slope wetland hydrodynamics. *Wetlands* 24: 244-260.

Taylor, J.C., Janse van Vuuren, M.S. & Pieterse, A.J.H. 2006. The application and testing of diatom-based indices in the Vaal and Wilge rivers, South Africa. *Water SA* 33:51-59.

Texas Coast EcoHealth Metrics Framework and Prototype Report Card, 2017. Accessed via https://www.harteresearchinstitute.org/sites/default/files/inline-files/Texas%20Coast-%20%20EcoHealth%20Metrics%20Framework%20and%20Prototype%20Report%20Card.pdf

Van der Kamp, G. & Hayashi, M. 1998. The groundwater recharge function of small wetlands in the semi-arid northern prairies*. Great Plains Research* 8:39-56)

Van der Waal, B. 2015. *Sediment Connectivity in the Upper Thina Catchment, Eastern Cape, South Africa*. Rhodes University (Unpublished PhD).

Van der Waal, B. & Rowntree, K.M., 2017. Landscape Connectivity in the Upper Mzimvubu River Catchment: An Assessment of Anthropogenic Influences on Sediment Connectivity. *Land Degradation and Development,* 29: 713–723. https://doi.org/10.1002/ldr.2766

Van Oudtshoorn, F. 2015. Veld Management: Principles and Practices. First Edition. ISBN: 978-1-920217-23-7

Wiens, J. A. 1999. The science and practice of landscape ecology. In J. M. Klopatek and R. H. Gardner, eds. Landscape Ecological Analysis: Issues and Applications, pp. 372–383. Springer-Verlag, New York.