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

TSITSA PROJECT

Huchzermeyer, N; Schlegel, P; van der Waal, B

June 2019

Department: Environmental Affairs
REPUBLIC OF SOUTH AFRICA

RHODES UNIVERSITY
Where leaders learn

DISCLAIMER

This document has been reviewed and approved by the Department of Environmental Affairs: Environmental Programmes – Natural Resource Management Programmes. Directorate – Operational Support and Planning.

Approval does not signify that the contents necessarily reflect the views and the policies of DEA, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

The research has been funded by the Department of Environmental Affairs: Environmental Programmes – Natural Resource Management Programmes. Directorate – Operational Support and Planning.

PREFACE

The Tsitsa Project strives to restore functional landscapes to the benefits of local and downstream users. It prioritises its limited resources for the maintenance of functioning, but threatened, ecological infrastructure overly severely degraded systems.

The Tsitsa Project is currently doing restoration work in Quaternary Catchment T35 A-E. This targets the upper Tsitsa River catchment and is the current focus area for the biophysical monitoring. In order to gain an understanding of the physical processes at play in the Catchment and the success of different rehabilitation processes it is imperative to conduct biophysical monitoring surveys. This report follows on the Biophysical Monitoring Plan set out by the Tsitsa Project (Schlegel *et al.*, 2019).

This report sets out the methods for the Biophysical Monitoring done to date for the Tsitsa Project and includes details on monitoring sites and the methodology for data collection.

The results and interpretations will be reported on in a separate monitoring report and will be accompanied by a biophysical database.

TABLE OF CONTENTS

DISCLAIMER ii
Preface iii
List of Figures vi
List of Tables vi
1. Upper Tsitsa River Catchment at a Glance 1
2. Background to the Upper Tsitsa River Catchment (T35 A-E) Monitoring Area 2
2.1. Location 2
2.2. Topography 2
2.3. Climate 3
2.4. Geology and soils 4
2.5. Vegetation 5
2.6. Land cover and land use as per the National Dataset 6
3. Biophysical Monitoring in the Upper Tsitsa Catchment (Schlegel *et al.,* 2019) 9
3.1. Management objectives 9
3.2. Monitoring objectives 9
3.3. Indicators and measured variables 10
4. Overall Monitoring Locations 13
5. Current Rainfall Monitoring 16
5.1. Rainfall 16
6. Current Terrestrial Biophysical Monitoring 17
6.1. Ecosystems 17
6.1.1. Hillslope features and process 19
Sediment pathways and landscape connectivity 19
Sediment source tracing (discontinued) 19
6.1.2. Fire dynamics (student project: Snyman, 2019) 20
6.1.3. Grassland condition (Veld assessment) 20
Desktop site selection 20
In-field site confirmation and marking 21
Fixed point photography 22
Species composition and biomass 23
Multi-Criteria visual assessment/LFA: 23
6.1.4. Forests 23

6.1.5. Riparian vegetation 23
6.1.6. Wetlands 24
6.1.7. Alien Invasive Plants (AIPs)....25
7. Current River Monitoring Sites and Methods....27
7.1. Hydrology....27
7.2. Water quality....31
7.2.1. Nitrate and phosphate concentrations 31
7.2.2. Electrical conductivity (EC) and pH....31
7.2.3. Dissolved oxygen 31
7.2.4. Temperature....31
7.2.5. Turbidity 31
7.2.6. Suspended sediment....32
7.2.7. South African Scoring System (SASSv5)....32
7.3. Channel classifications: Fluvial geomorphology/Geo-habitats....33
8. Student Projects....34
9. Data Management 34
10. Data Analysis and Reporting 35
References 36
Appendix 1: Check List for Biophysical Monitoring Sites 39
Appendix 2: Water Quality Capture Sheet....40
Appendix 3: SASSv5 Capture Sheet....41
Appendix 4: Veld monitoring Capture Sheets (Van OUdtshoorn, 2015)....42

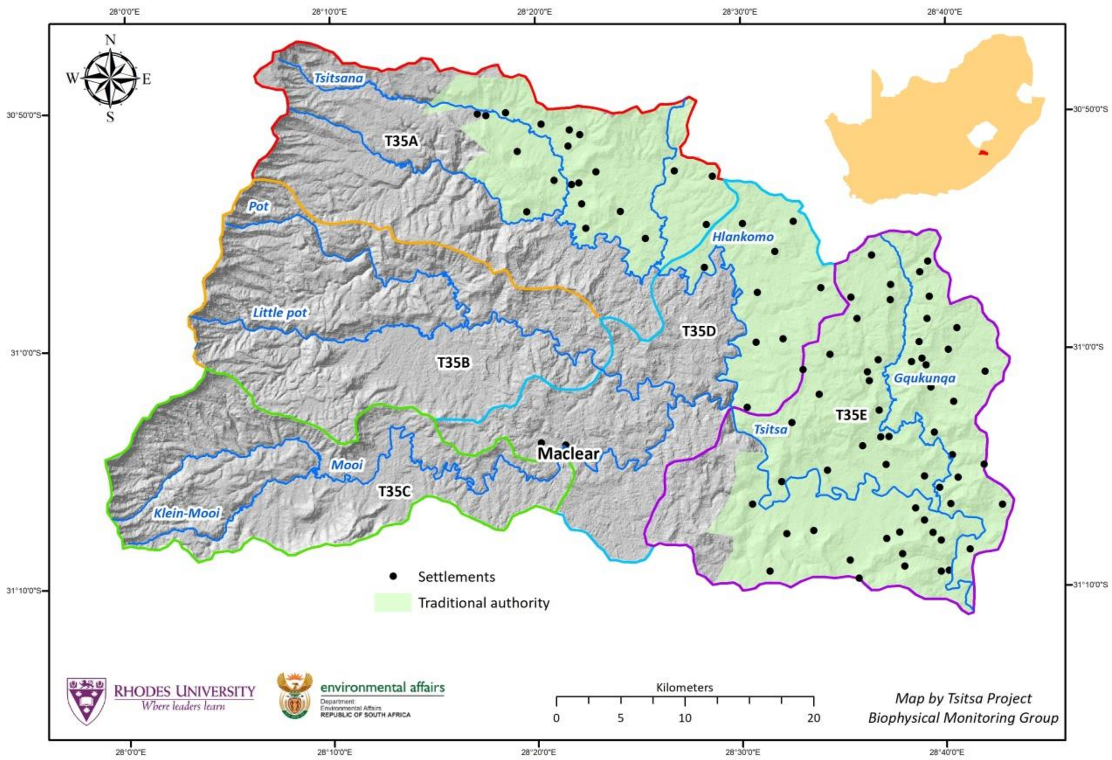
LIST OF FIGURES

Figure 1: Longitudinal profile of the Tsitsa River showing generalised rock types 3
Figure 2: Mean annual precipitation (MAP) for the Tsitsa River Catchment (T35 A-K) 4
Figure 3: Geology of the Upper Tsitsa Catchment T35 A-E..5
Figure 4: Vegetation of the Upper Tsitsa Catchment T35 A-E (Mucina & Rutherford, 2006)........6
Figure 5: Land cover in the Upper Tsitsa River Catchment 7
Figure 6: Land cover classes in Catchment T35 A-E (Geoterraimage, 2015) 8
Figure 7: Monitoring framework showing the links between Catchment processes 10
Figure 8: Current monitoring locations in the Tsitsa River catchment. 13
Figure 9: Location of tipping buckets collecting rainfall data in Catchment T35 A-E and F-K.....17
Figure 10: In-depth mapping of catchment characteristics in Catchment T35 A-E....................18
Figure 11: Location of Time Integrated Samplers in the greater Tsitsa Catchment. These need to be refurbished for continued research 20
Figure 12: Veld monitoring sites in the Tsitsa Catchment 21
Figure 13: Example of a Cairn marking the starting point of a veld monitoring transect 22
Figure 14: Mapped wetlands in Catchment T35 A-E (Schlegel et al., 2018a) 24
Figure 15: Wetland monitoring sites 25
Figure 16: Mapped woody vegetation in Catchment T35 A-E showing alien vegetation extent (Huchzermeyer et al., 2018a)..26
Figure 17: River monitoring sites in Catchment T35 A-E 27
Figure 18: Location of depth loggers and national gauging weirs on the main rivers in Catchment T35 A-K...29
Figure 19: Location of barometric loggers in Catchment T35 A-E..30

LIST OF TABLES

Table 1: Land cover distribution and percentage per land cover type for the Upper Tsitsa River Catchment 6
Table 2: Table showing indicators and measured variables under different domains and themes 11
Table 3: Breakdown of monitoring strategy 12
Table 4: Tables showing site coordinates for biophysical monitoring.......................................14

1. UPPER TSITSA RIVER CATCHMENT AT A GLANCE



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 large gullies.

AREA

~200 000 ha
(Catchments T35 A-E)

POPULATION

~45 000 Residents

MAIN LAND COVER/ USE for 2011

72% Grasslands
7% Cultivation
7% Plantations
4% Thicket/shrubland
3% Urban areas
2% Wetlands
2% Woodland
3% Other

INTERVENTION AREA

~76 000 ha Traditional councils

~124 000 ha Private land

2. BACKGROUND TO THE UPPER TSITSA RIVER CATCHMENT (T35 A-E) MONITORING AREA

2.1. 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 most 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. Therefore, 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).

2.2. 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 Umzimvubu 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 Umzimvubu (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 1). Along the steeper escarpment zones the river beds are dominated by bedrock with rapids, riffles 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.

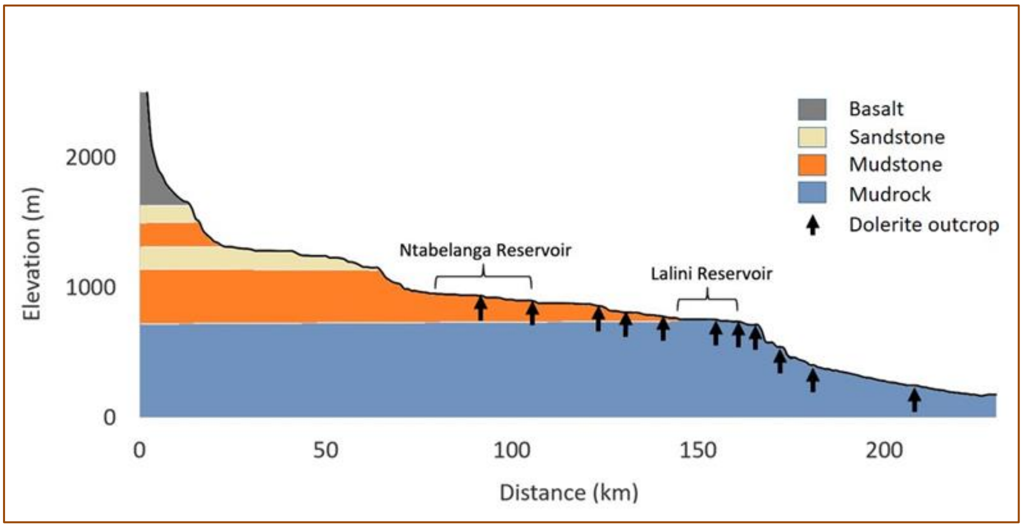


FIGURE 1: LONGITUDINAL PROFILE OF THE TSITSA RIVER SHOWING GENERALISED ROCK TYPES

2.3. 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 (Figure 2). 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 (Mucina & Rutherford, 2006). 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.

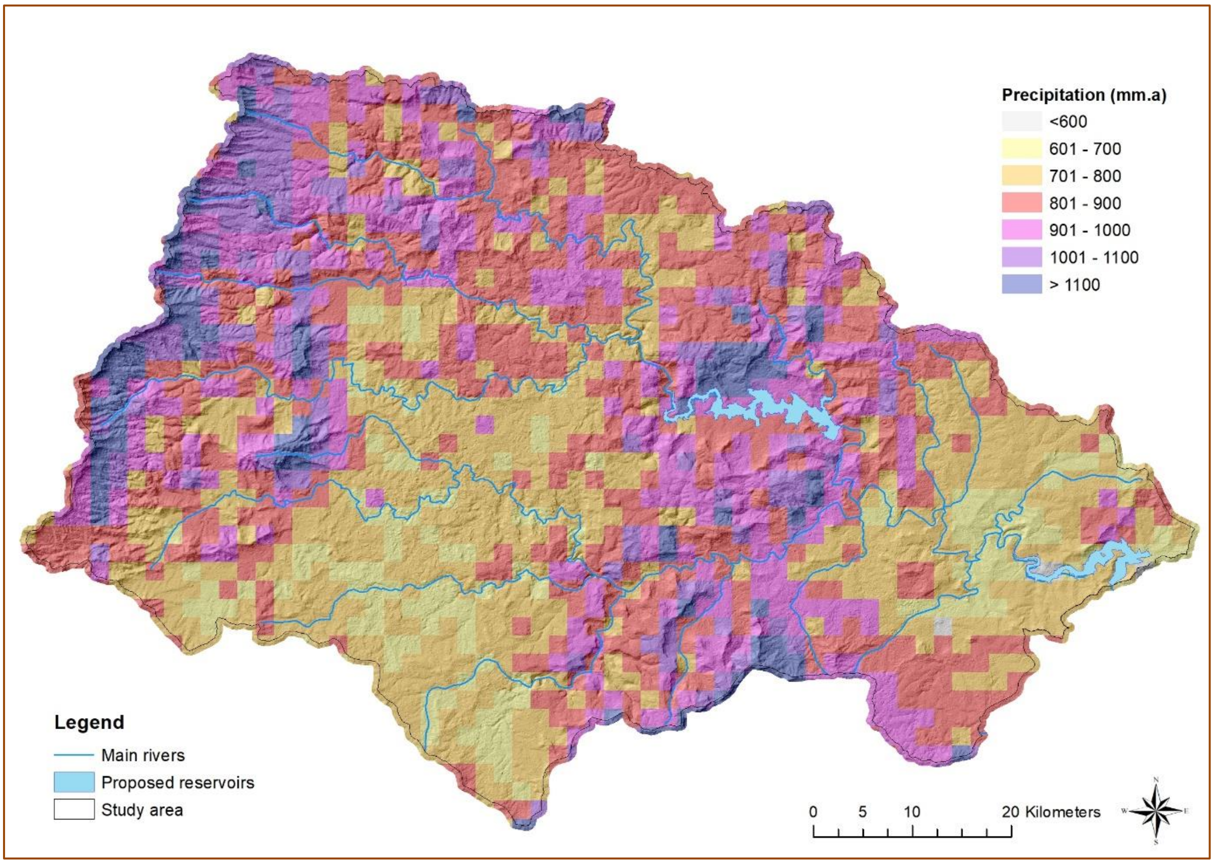


FIGURE 2: MEAN ANNUAL PRECIPITATION (MAP) FOR THE TSITSA RIVER CATCHMENT (T35 A-K)

2.4. Geology and soils

Figure 3 shows the geology of the upper 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).

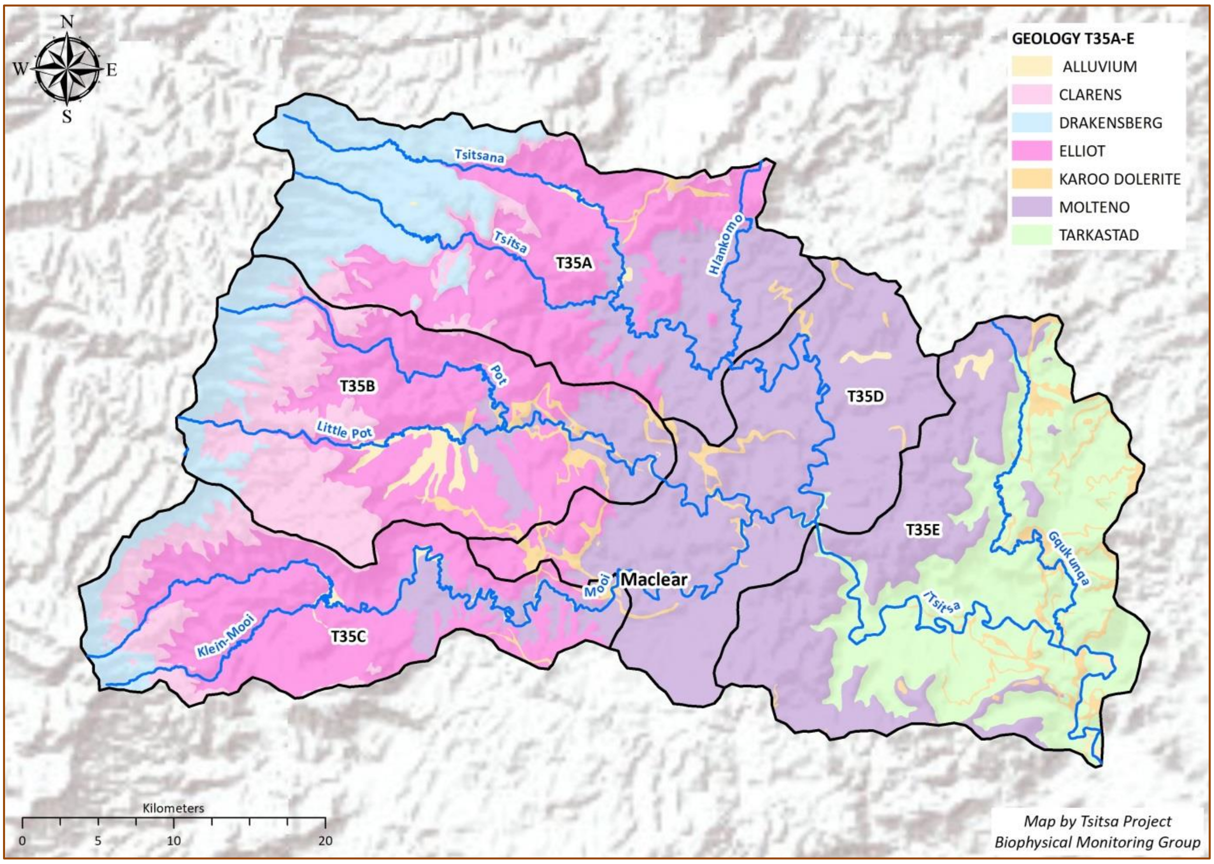


FIGURE 3: GEOLOGY OF THE UPPER TSITSA CATCHMENT T35 A-E

2.5. Vegetation

Figure 4 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.

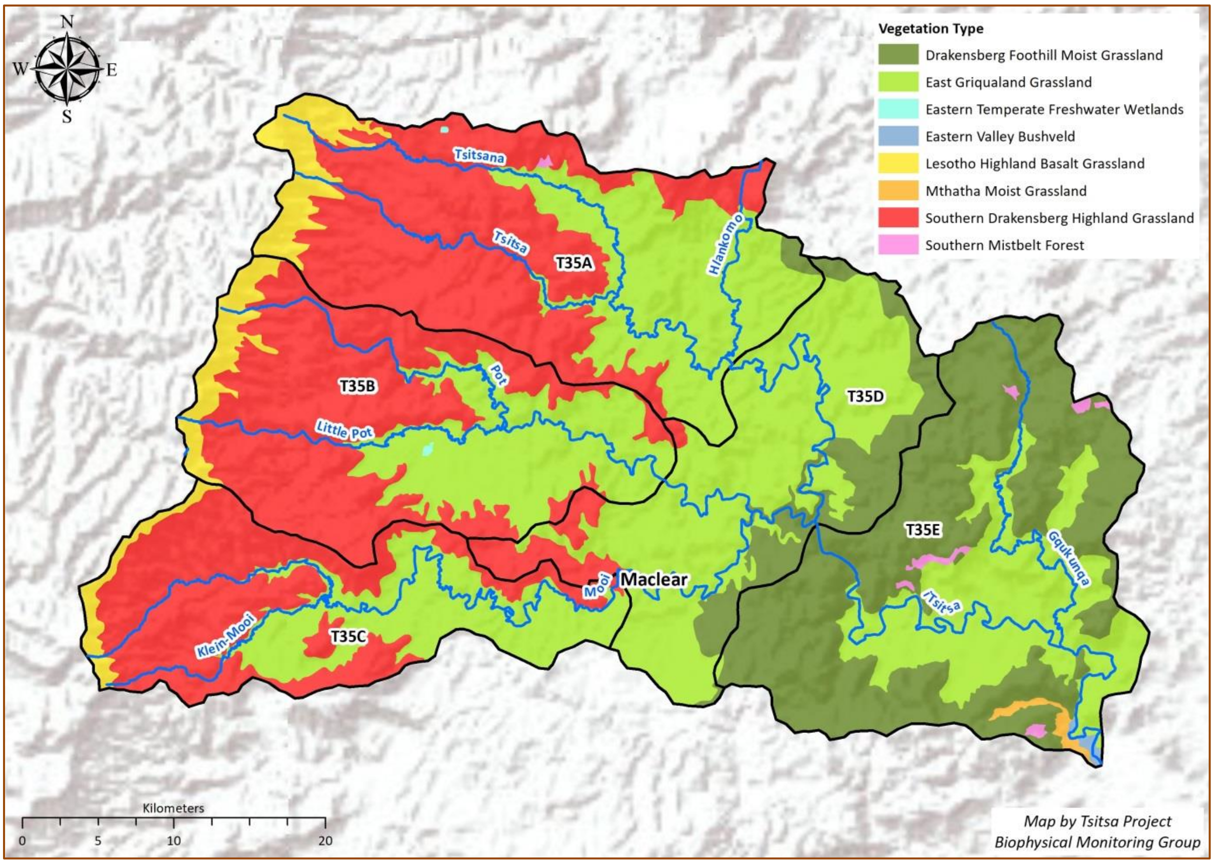


FIGURE 4: VEGETATION OF THE UPPER TSITSA CATCHMENT T35 A-E (MUCINA & RUTHERFORD, 2006)

2.6. Land cover and land use as per the National Dataset

Land cover distribution and percentage per land cover type for the Tsitsa River Catchment are given in Table 1, Figure 5 and Figure 6. 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

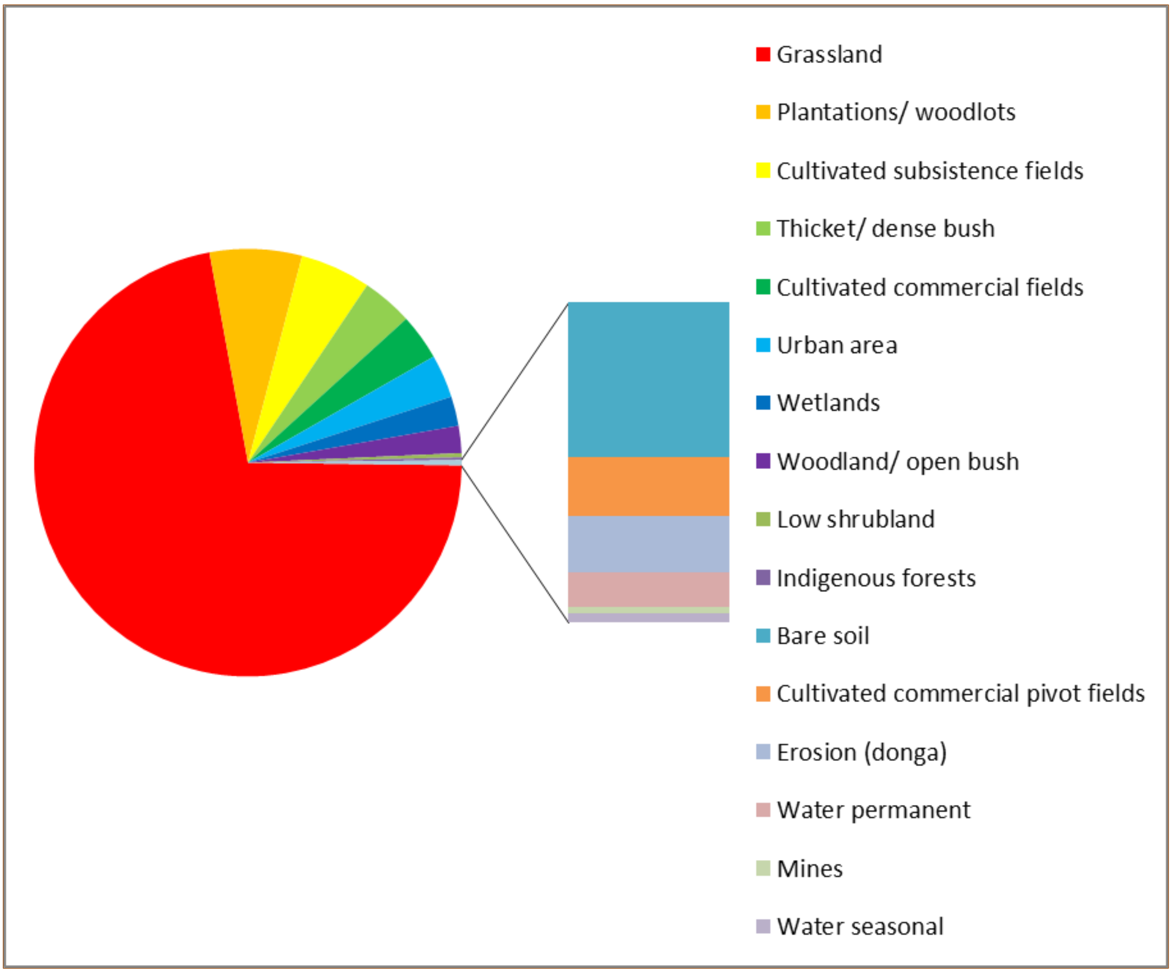


FIGURE 5: LAND COVER IN THE UPPER TSITSA RIVER CATCHMENT

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.

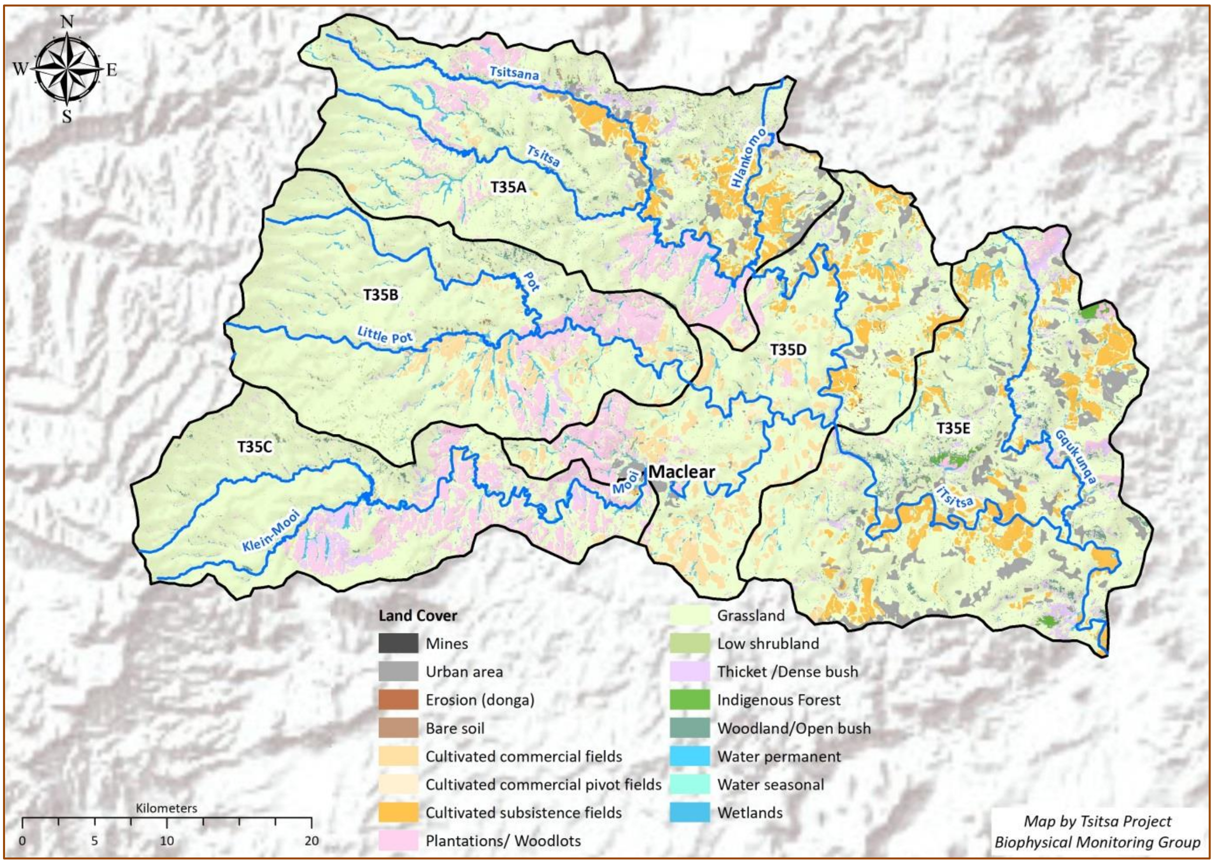


FIGURE 6: LAND COVER CLASSES IN CATCHMENT T35 A-E (GEOTERRAIMAGE, 2015)

3. BIOPHYSICAL MONITORING IN THE UPPER TSITSA CATCHMENT (SCHLEGEL *ET AL.*, 2019)

The Tsitsa Project strives to restore functional landscapes to the benefits of local and downstream users. It prioritises its limited resources for the maintenance of functioning, but threatened, ecological infrastructure overly severely degraded systems. The Tsitsa Project is currently doing restoration work in Quaternary Catchment T35 A-E. This targets the upper Tsitsa River catchment and is the current focus area for the biophysical monitoring. The aim is to better understand the physical processes at play under different land use scenarios currently existing in the landscape and those introduced by restoration and management efforts.

3.1. Management objectives

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.

3.2. Monitoring objectives

Monitoring is used to evaluate the current state of ecological infrastructure as well as the effects of management on the condition of ecological infrastructure. The following monitoring objectives have been preliminary chosen for the Tsitsa Project (Schlegel *et al.*, 2019):

- Compare baseline conditions of areas that are using different management approaches e.g. grazing and fire.
- Monitoring how different management systems affect the condition of ecological infrastructure over time.
- Monitoring changes in the landscape as a whole because of natural biophysical conditions (e.g. climate, pests, disasters etc.)

3.3. Indicators and measured variables

The Tsitsa Project Biophysical Monitoring Group's selection of the catchment indicators began with a review (Schlegel *et al.,* 2019) 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 that are used in similar situations elsewhere. The review resulted in relevant indicators that could be summarized along the following themes (Figure 7):

- Climate (Rainfall);
- Land/Terrestrial systems: 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 and aquatic ecology.

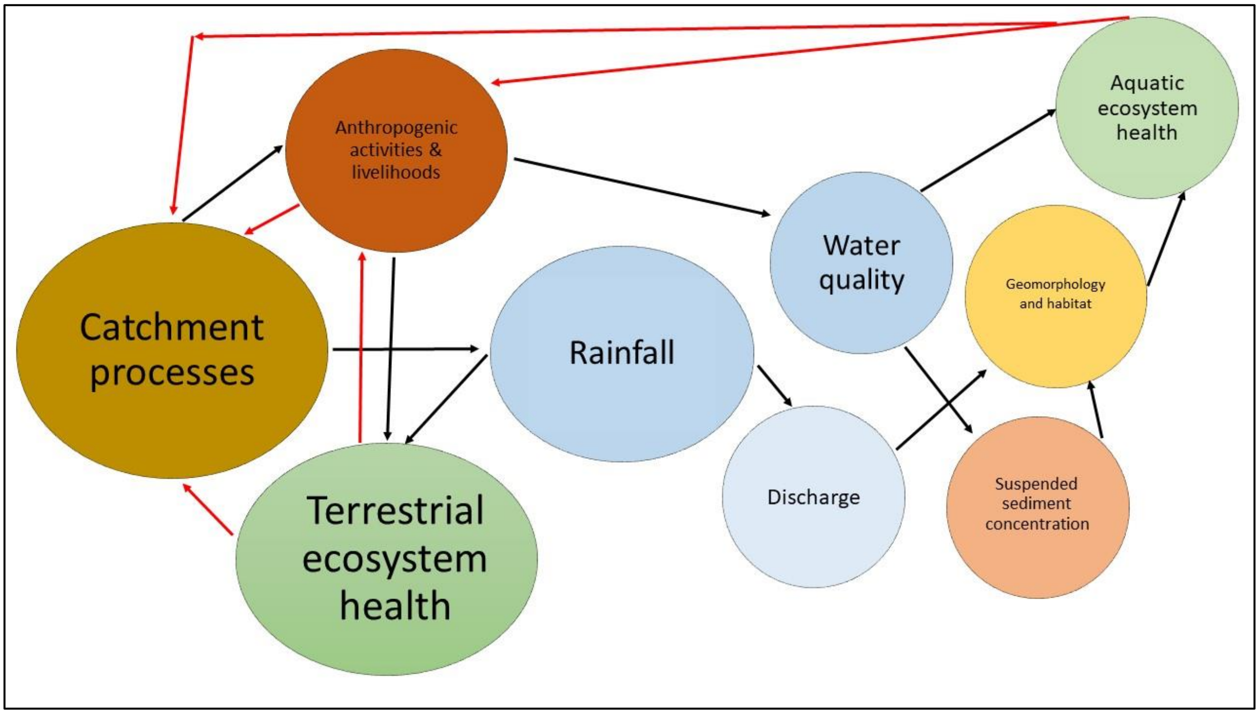


FIGURE 7: MONITORING FRAMEWORK SHOWING THE LINKS BETWEEN CATCHMENT PROCESSES

Table 2 shows indicators and measured variables under different domains and themes that have been adopted for the current biophysical monitoring in the Tsitsa Catchment.

Variables are measured at different time scales (Table 3). Monitoring of in-depth variables occur on a seasonal basis whereas catchment wide mapping of ecosystems occurs at longer time scales.

This is discussed in more detail in the chapters below.

TABLE 2: TABLE SHOWING INDICATORS AND MEASURED VARIABLES UNDER DIFFERENT DOMAINS AND THEMES

Theme	Domain	Indicators	Measured variables
Climate	Regional rainfall	Rainfall trend over time	Rainfall (mm)
Land	Geomorphology	Hillslope features and processes	Connectivity (m) Erosion (m^3) Gully expansion (%)
	Terrestrial ecosystems	Fire dynamics	Fire frequency, location, extent, severity (% or ha)
		Grasslands	Condition, species composition, grazing value
		Forests	Extent (% or ha)
		Riparian zones	Extent, composition, condition (% or ha) VEGRAI assessment
		Wetlands	Size, type, location, condition, dominant species (% or ha)
		Alien vegetation	Extent, composition, density, age (% or ha)
Water	River ecosystems	Hydrology	Base flow modelling (m^3) Flood peaks (m^3)
		Water quality	pH; Electrical conductivity; Temperature; Dissolved Oxygen; Nitrates; Phosphates; Turbidity; Clarity; Suspended Sediment Concentration (t/m^3)
		Aquatic macroinvertebrates	SASSv5 assessment
		River channel characteristics	Classification of river channel

TABLE 3: BREAKDOWN OF MONITORING STRATEGY

	Rainfall	**Terrestrial Ecosystems**							**River Ecosystems**		
	Tip-bucket rain gauges	Hillslope features and processes	Fire Dynamics	Grassland condition	Forests	Riparian zones	Wetlands	Alien vegetation	Hydrology	Water Quality	Channel classification
Dry season monitoring											
Wet season monitoring											
Continuous data collection											
≥ 5 Yearly mapping											

4. OVERALL MONITORING LOCATIONS

Current monitoring sites are indicated in (Figure 8) and coordinates are given in Table 4 . GIS shapefiles and Google Earth .kml layers can be made available on request.

Sites were adapted from previous studies (e.g. Huchzermeyer, 2017; Bannatyne, 2018; Nyamela, 2018) where the data already collected is invaluable for the biophysical monitoring. In addition new sites were chosen (veld monitoring and wetlands monitoring). Site locality is discussed in more detail in the sections below.

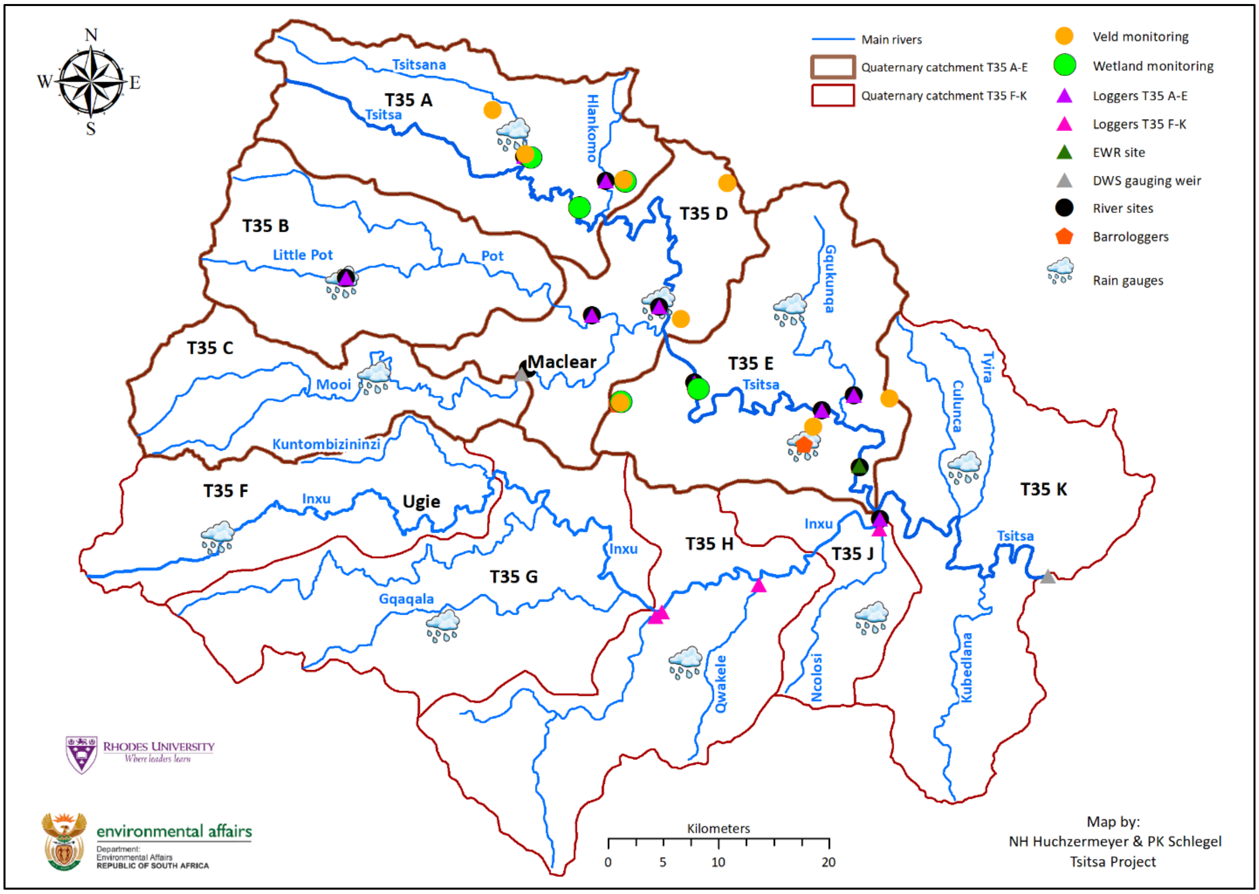


FIGURE 8: CURRENT MONITORING LOCATIONS IN THE TSITSA RIVER CATCHMENT.

TABLE 4: TABLES SHOWING SITE COORDINATES FOR BIOPHYSICAL MONITORING

	Raingauges	
Catchment	**Site name**	**Coordinates**
Catchment T35 A-E	Tsitsanana	30°52'35,637"S 28°20'49,83"E
	Tsitsa Falls	30°52'35,637"S 28°20'49,83"E
	Sinxaku	31°7'49,957"S 28°37'14,8"E
	Mooi	31°4'28,345"S 28°12'49,763"E
	Woodcliffe	30°59'46,764"S 28°11'2,851"E
	Gqunqunka	31°1'14,822"S 28°36'29,546"E
Catchment T35 F-K	Mposa	31°18'29,535"S 28°30'27,211"E
	Ntsiqo	31°16'21,1"S 28°41'4,781"E
	Tyirha	31°8'58,61"S 28°46'23,176"E
	Morvan	31°8'58,61"S 28°46'23,176"E
	Montgomery	31°8'58,61"S 28°46'23,176"E

	River Sites			
Catchment	**Site name**	**Coordinates**	**Current biomonitoring site**	**Depth logger present**
Catchment A-E	Tsitsa 2 (T2)	31°6'9,711"S 28°38'17,933"E	Yes	Yes
	Gqunqunka (G)	31°5'25,075"S 28°40'7,227"E	Yes	Yes
	Tsitsa (T3)	31°4'46,461"S 28°31'3,371"E	Yes	Yes
	Mooi (M)	31°4'56,623"S 28°22'31,692"E	Yes	No
	Mooi Gauging Weir (T3H009)	31°4'17,951"S 28°21'12,944"E	No	Yes
	Pot (P)	31°1'27,413"S 28°25'14,975"E	Yes	Yes
	Tsitsa 4 (T4)	31°1'3,516"S 28°29'3,691"E	Yes	Yes
	Hlankomo (H)	30°54'53,554"S 28°26'5,285"E	Yes	Yes

	Tsitsana (Ta)	30°53'39,079"S 28°21'27,655"E	Yes	Yes
	Little Pot (LP)	30°59'33,426"S 28°11'16,404"E	Yes	Yes
	Tsitsa EWR (N3)	31°8'51,776"S 28°40'24,946"E	Yes	Yes
Catchment T35 F-K	Inxu	31°11'28,447"S 28°41'35,739"E	Yes	Yes
	Tsitsa Gauging Weir (TN2/T3H006)	31°14'17,033"S 28°51'7,962"E	No	Yes
	T35 F-K_1	31°11'59,542"S 28°41'32,688"E	No	Yes
	T35 F-K_2	31°14'40,635"S 28°34'40,968"E	No	Yes
	T35 F-K_3	31°15'59,122"S 28°29'9,101"E	No	Yes
	T35 F-K_4	31°16'12,964"S 28°28'46,475"E	No	Yes

Veld monitoring site	
Site name	**Coordinates**
Veld 1	31°6'57,087"S 28°37'48,203"E
Veld 2	31°5'35,652"S 28°42'8,88"E
Veld 3	31°5'45,254"S 28°26'50,222"E
Veld 4	30°51'23,031"S 28°19'39,928"E
Veld 5	30°53'33,566"S 28°21'31,205"E
Veld 6	30°54'49,959"S 28°27'4,896"E
Veld 7	30°54'49,959"S 28°27'4,896"E
Veld 8	30°54'49,959"S 28°27'4,896"E

Wetland monitoring site	
Site name	**Coordinates**
Wetland 1	31°5'4,617"S 28°31'15,303"E
Wetland 2	31°5'41,451"S 28°26'52,211"E
Wetland 3	30°53'40,309"S 28°21'47,439"E
Wetland 4	30°56'18,04"S 28°24'23,765"E
Wetland 5	30°54'55,998"S 28°27'20,598"E

Barologgers	
Site name	**Coordinates**
Green village	31°7'49,742"S 28°37'17,42"E
Bob's Place	31°5'47,628"S 28°26'38,861"E

5. CURRENT RAINFALL MONITORING

5.1. Rainfall

Rainfall is an important driver of catchment processes. A total of 11 tipping rain gauges are currently managed by the biophysical monitoring team (Figure 9). Of these 6 tipping rain gauges are in Catchment T35 A-E. These were set up in 2015 by Bannatyne (2018). A further 5 rain gauges are in Catchment T35 F-K which were set up in 2016 by Nyamela (2018). The later rain gauges fall out of the current target area for the biophysical monitoring however these are easy to maintain and the data is seen as important to have for when the biomonitoring is expanded to Catchment T35 F-K.

The rainfall data is downloaded bi-annually (once before and once after the rainy season). Maintenance of the rain gauges is important. During the bi-annual visit the rain gauges are downloaded, batteries are replaced and the data consistency is checked.

The raw data is analysed and set out into a time-series database showing the following rainfall data:

- 5 minute,
- 30 minute,
- Hourly,
- Daily,
- Monthly and
- Yearly.

The location, magnitude, duration and extent of rainfall plays an important role in the effects of different catchment processes. Therefore, the rainfall data can be used to help aid the interpretation of catchment processes and can be linked to spikes in hydrology, increased sediment yields etc.

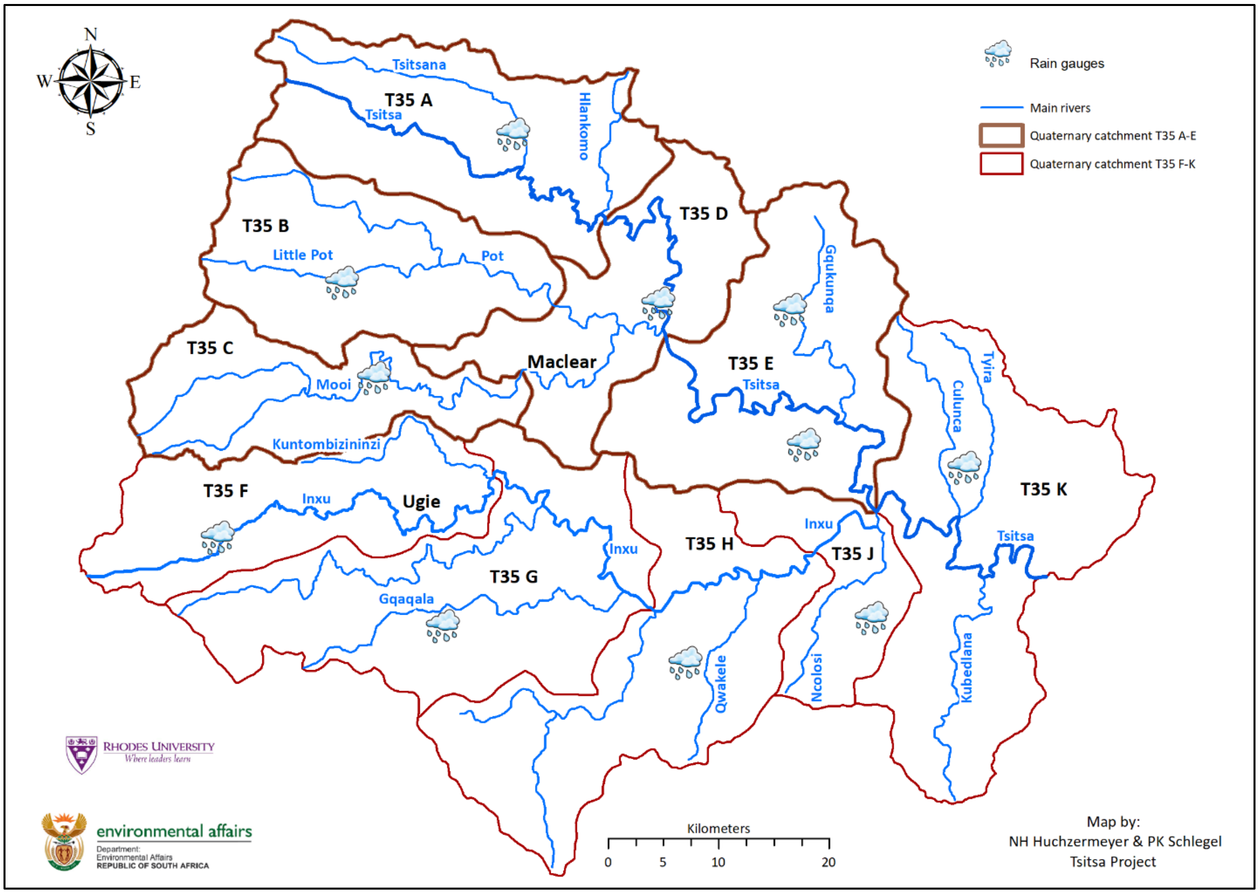


FIGURE 9: LOCATION OF TIPPING BUCKETS COLLECTING RAINFALL DATA IN CATCHMENT T35 A-E AND F-K

6. CURRENT TERRESTRIAL BIOPHYSICAL MONITORING

6.1. Ecosystems

Land cover/use, landscape connectivity and ecosystems have been mapped using a combination of medium-resolution satellite imagery, higher-resolution aerial imagery and field verification (Huchzermeyer *et al.*, 2018a; Huchzermeyer, *et al.*, 2018b & Schlegel *et al.*, 2018a). A base-line classified map of the catchment was generated (Figure 10). Mapping of these ecosystem components will be mapped on a ≥ 5 yearly interval.

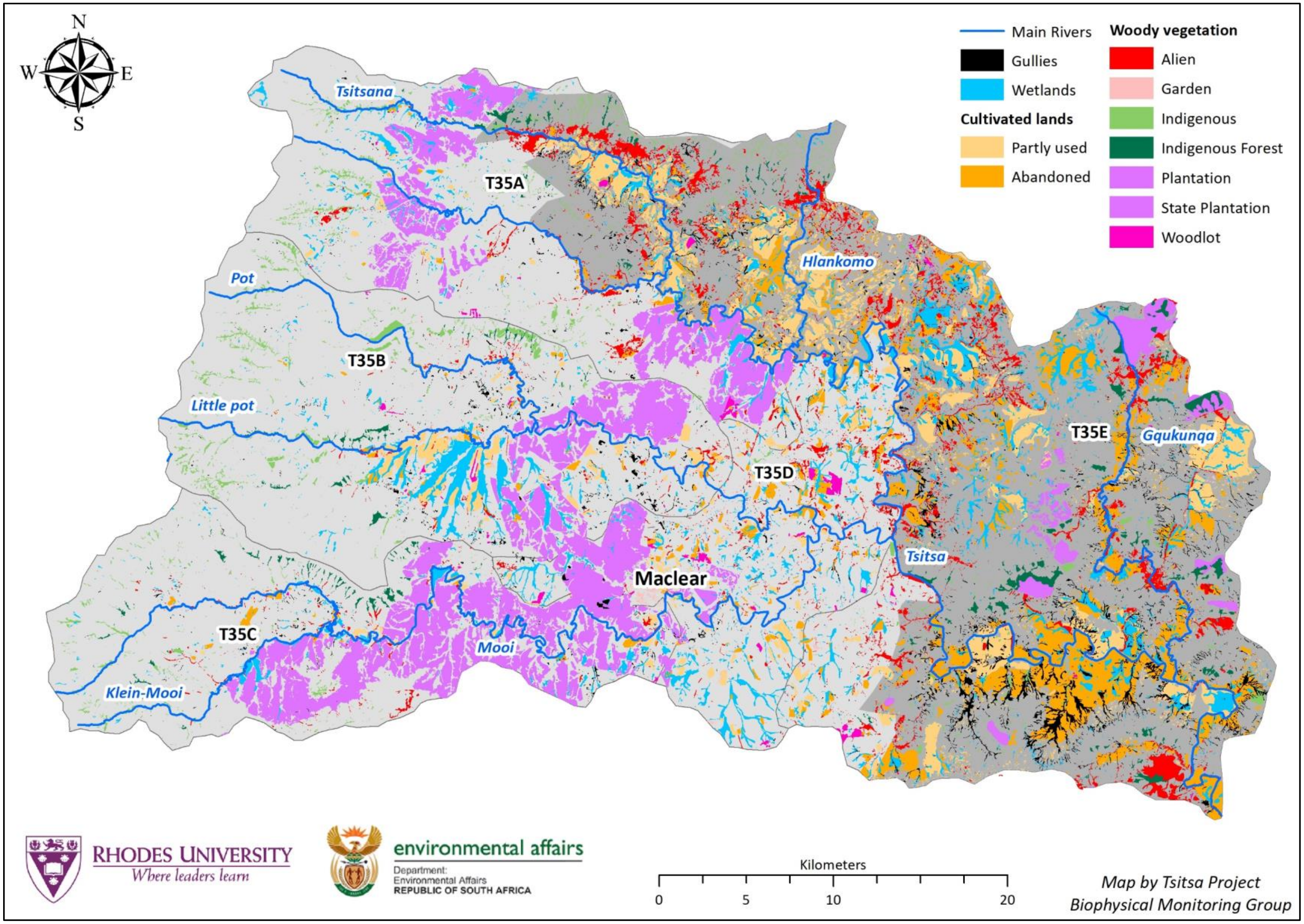


FIGURE 10: IN-DEPTH MAPPING OF CATCHMENT CHARACTERISTICS IN CATCHMENT T35 A-E

6.1.1. Hillslope features and process

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).

The downslope and across slope connectivity is 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 (discontinued)

Suspended sediment and recently deposited sediment on sand banks and behind river infrastructure can be used 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, 2015). The igneous material is found in the upper reaches of the Catchment T35 A-E, with sedimentary rocks underlying the middle and lower catchment (see Figure 3).

Trollope (2016) identified sources of sediments using sediment tracing techniques in Catchment T35 A-K. Suspended sediment was collected using time-integrated samplers (Figure 11) that were bolted onto bridges in the river at varying heights. Recently deposited sediment was collected from sand banks and behind water infrastructure such as weirs using a 30 cm plastic corer.

Colour and magnetic tracing of sediment 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. In order to continue with this study, the time integrated samplers need to be re-installed as they have been damaged during the high summer flows.

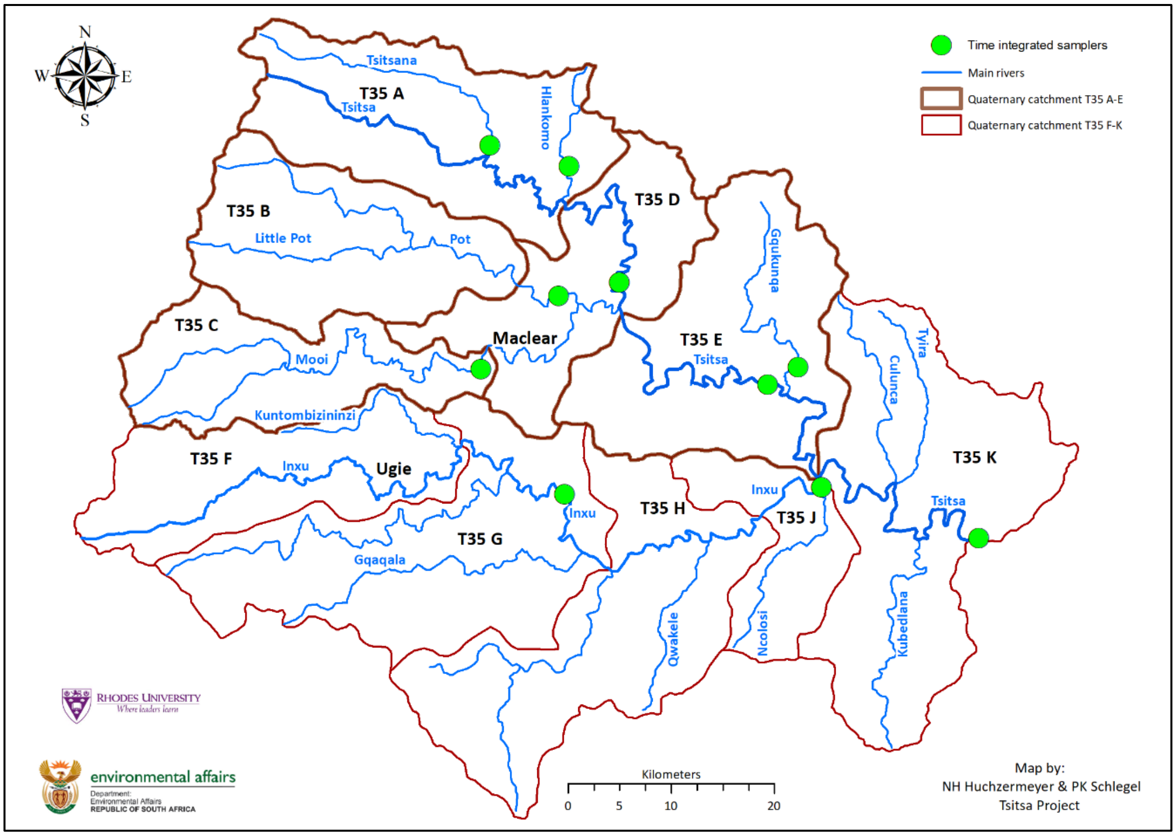


FIGURE 11: LOCATION OF TIME INTEGRATED SAMPLERS IN THE GREATER TSITSA CATCHMENT. THESE NEED TO BE REFURBISHED FOR CONTINUED RESEARCH

6.1.2. Fire dynamics (student project: Snyman, 2019)

Snyman (2019) is using LANDSAT imagery to extract burn scars in Catchment T35 A-E. A time-series analysis is being used to calculate fire frequency and MODIS/VIIRS point data is used to monitor the timing and intensity of fires. This data can then be used to help interpret catchment processes and aid management interventions.

6.1.3. Grassland condition (Veld assessment)

The Tsitsa river catchment vegetation is dominated by grassland (Mucina & Rutherford, 2006). Grasslands are an important resource for the people living within the catchment. However, grasslands in the Tsitsa Catchment are characterised by many symptoms of veld degradation with the most prominent being large-scale erosion and the encroachment of alien vegetation.

One of the driving forces behind this degradation is the lack of grazing and fire management systems. To assess the current veld condition veld monitoring sites were chosen that represent different land-use areas, geology, elevations and vegetation types. Phase 1 of the veld condition assessment is focused in the traditional council areas.

Desktop site selection

The following criteria were considered when selecting sites on a desktop scale to try ensure representative sites were chosen:

- Vegetation type (coarse–scale; national dataset),
- Geology type (coarse–scale; national dataset),
- Average Normalized Difference Vegetation Index value for 2018/03/13 (growing & rainy season),
- Location (traditional council, commercial farm etc.),
- Elevation,
- Topography (location on slope i.e. valley bottom, mid-slope),
- Slope (degrees) and
- Aspect.

In-field site confirmation and marking

Sites locations were confirmed in the field and if necessary locations were moved to ensure easier access for repeat monitoring. A total of 8 sites were chosen for monitoring (Figure 12)

Each site was marked with a cairn at the start point of the veld monitoring transect. Cairns consist of 50 centimeters of black irrigation pipe filled with cement that is buried in the ground with only the top 10 centimeters exposed. Additionally, rocks were packed around the cairn. Each cairn was marked with a GPS point for future reference.

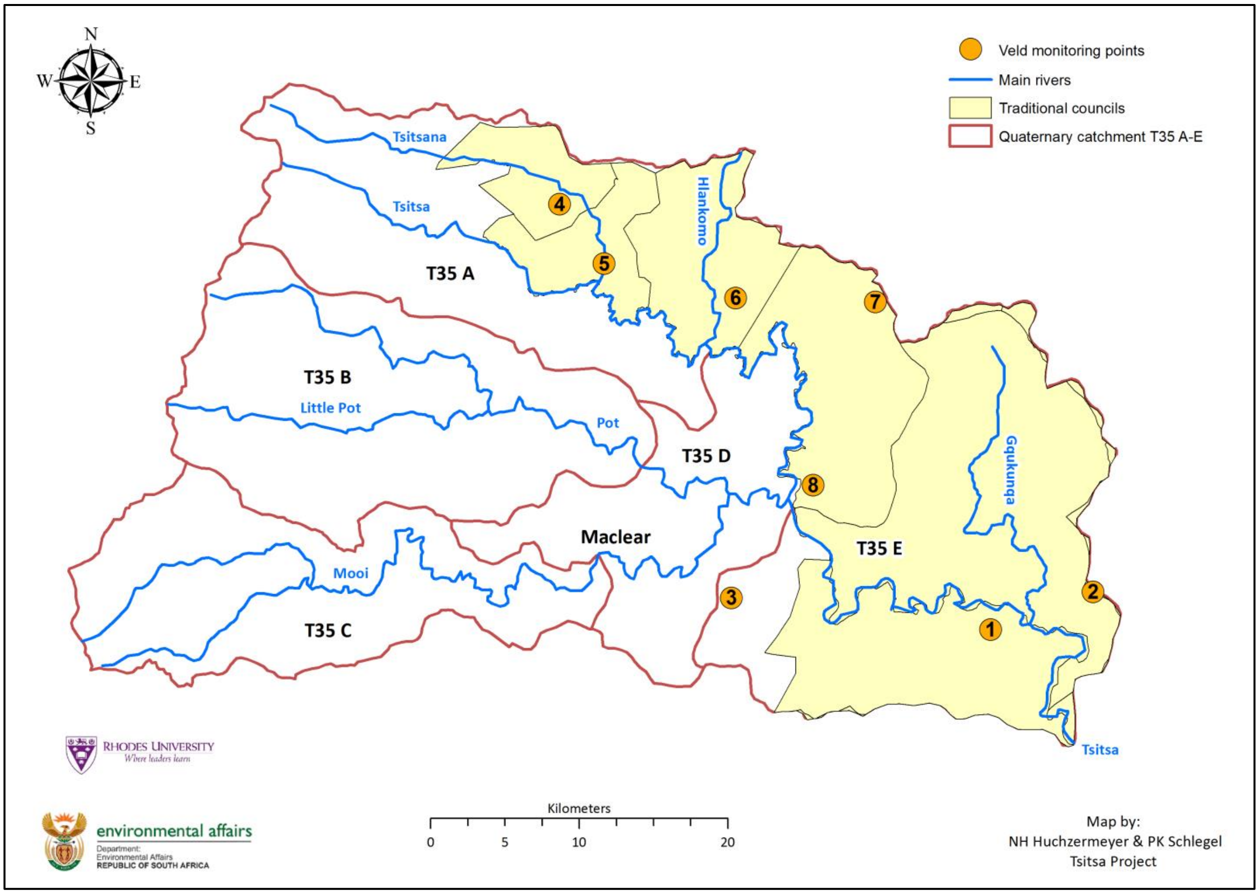


FIGURE 12: VELD MONITORING SITES IN THE TSITSA CATCHMENT

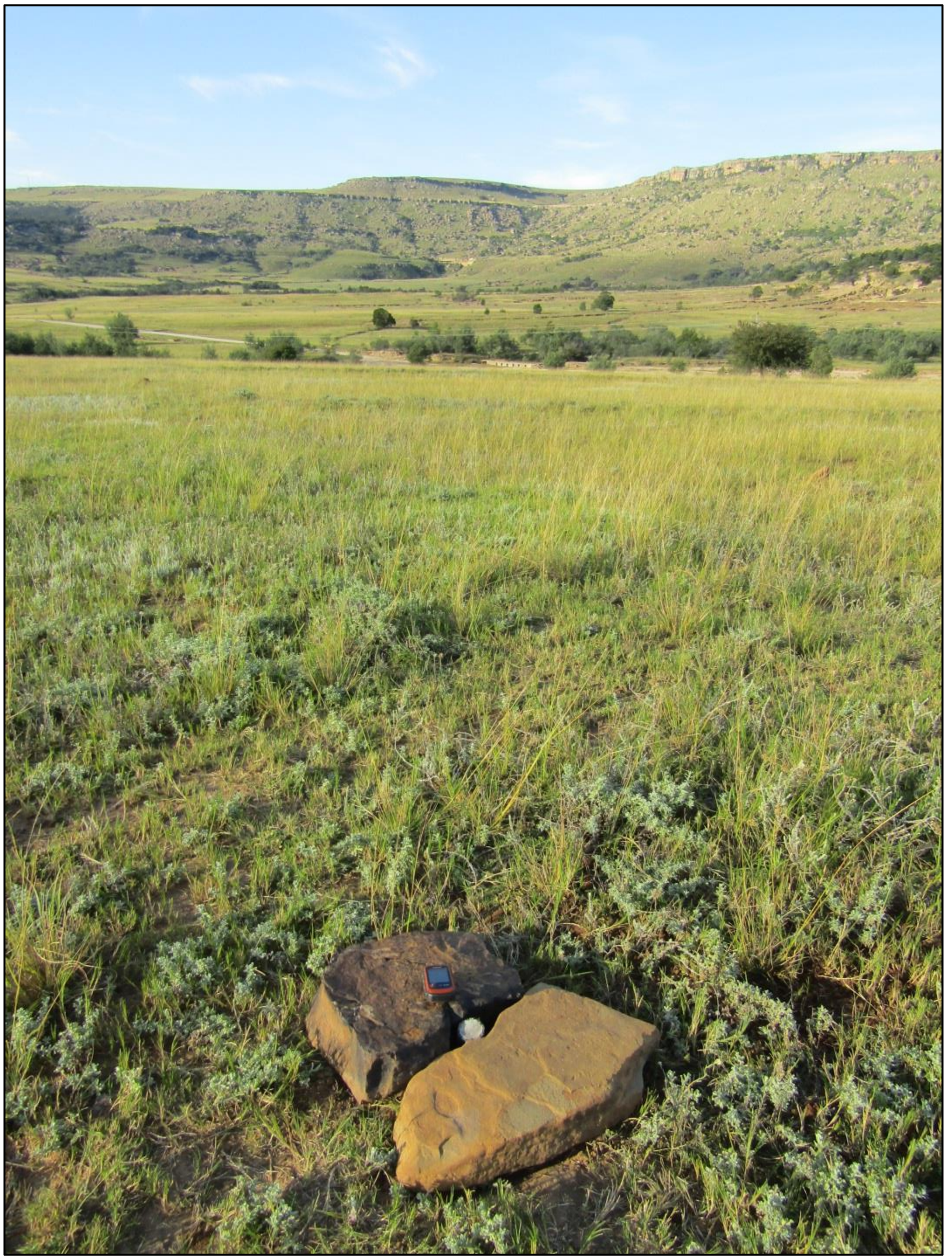


FIGURE 13: EXAMPLE OF A CAIRN MARKING THE STARTING POINT OF A VELD MONITORING TRANSECT

Fixed point photography

Photographs were taken at each veld monitoring point. The photographer stood over the cairn and faced the direction of the veld monitoring transect. If the transect branched in an 'L' shape, then a second set of photographs was taken were the transect changes direction (this distance is noted) and the position can be relocated by measuring the required distance from the cairn with a tape measure. Photographs were taken in both a landscape and portrait layout using a digital camera. The time and date were noted.

Repeat photographs can be 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 and biomass

The following methods are carried out at the selected sites on April/May at the end of the growing season in the Tsitsa Catchment. Transects are 50 meters long marked by a start point (cairn).

- **Species composition**: Whilst laying out the tape measure all plant species within visible distance are identified and noted (including the presence, abundance and type of forb species and woody vegetation).

  At every meter along the transect, the closest grass species is identified and noted. These can then be used as indicators for veld condition and to monitor change in species structure over time.

- **Biomass method**: A disk pasture meter is used to get readings of disc pasture meter height along the known transect. 50 readings are taken along the transect.

  The mean disc pasture meter height is used to calculate the standing crop (kg.ha^{-1}). A calibration table of mean disc pasture meter height vs. equivalent standing crop is used. In turn the grazing capacity can be calculated using methods set out by Van Oudtshoorn (2015).

Multi-Criteria visual assessment/LFA:

This method evaluates multiple criteria over a broader spectrum to give an indication of overall veld condition and health. Observations and estimations on soil health, productivity and general ecology are used to get an overall veld condition score for each site. It is important to note that this score is subject to the views of the person conducting the assessment.

6.1.4. 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 (Geldenhuys *et al.,* 2016; Ngwenya, 2016). The forest pockets are threatened by poor management and protection as well as the encroachment of invasive alien species and fires (Geldenhuys *et al.* 2016). In order to protect and manage the remaining indigenous forest pockets remote sensing, aerial images and field verification were used to map the current extent of the forests (Geldenhuys *et al*., 2016; Huchzermeyer *et al*., 2018a). This will be repeated every 5 years to monitor trends on the condition and extent of the Forests.

6.1.5. Riparian vegetation

Riparian systems perform numerous ecosystem functions important to human populations yet they are one of the most endangered ecosystem types. The River Eco-classification: Riparian Vegetation Response Assessment Index (VEGRAI) will be followed for monitoring purposes. 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. Monitoring surveys will occur every WET-season for VEGRAI assessments at the selected river sites (see Figure 17).

6.1.6. Wetlands

Wetlands are complex and dynamic ecosystems that provide indispensable ecosystem 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 was conducted. This gave insight on the extent, type, and condition of the land cover surrounding the wetlands; and the current use and protection of these wetlands (Schlegel *et al*., 2018a) (Figure 14). Secondly a prioritisation process was 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 (Schlegel *et al.,* 2018b). Thirdly, 5 wetlands were chosen to complete a rapid assessment in the field (Figure 15). Wet season monitoring will be conducted on the wetlands chosen for the field assessment. The following will be monitored:

- Photographic monitoring to monitor vegetation cover and wetland extent.
- Species composition to look at dominant wetland plant species and diversity under different conditions.
- Description of wetland condition.

A catchment scale mapping of the wetlands using aerial images will occur every 5 years to monitor the trends of the wetlands found in the catchment.

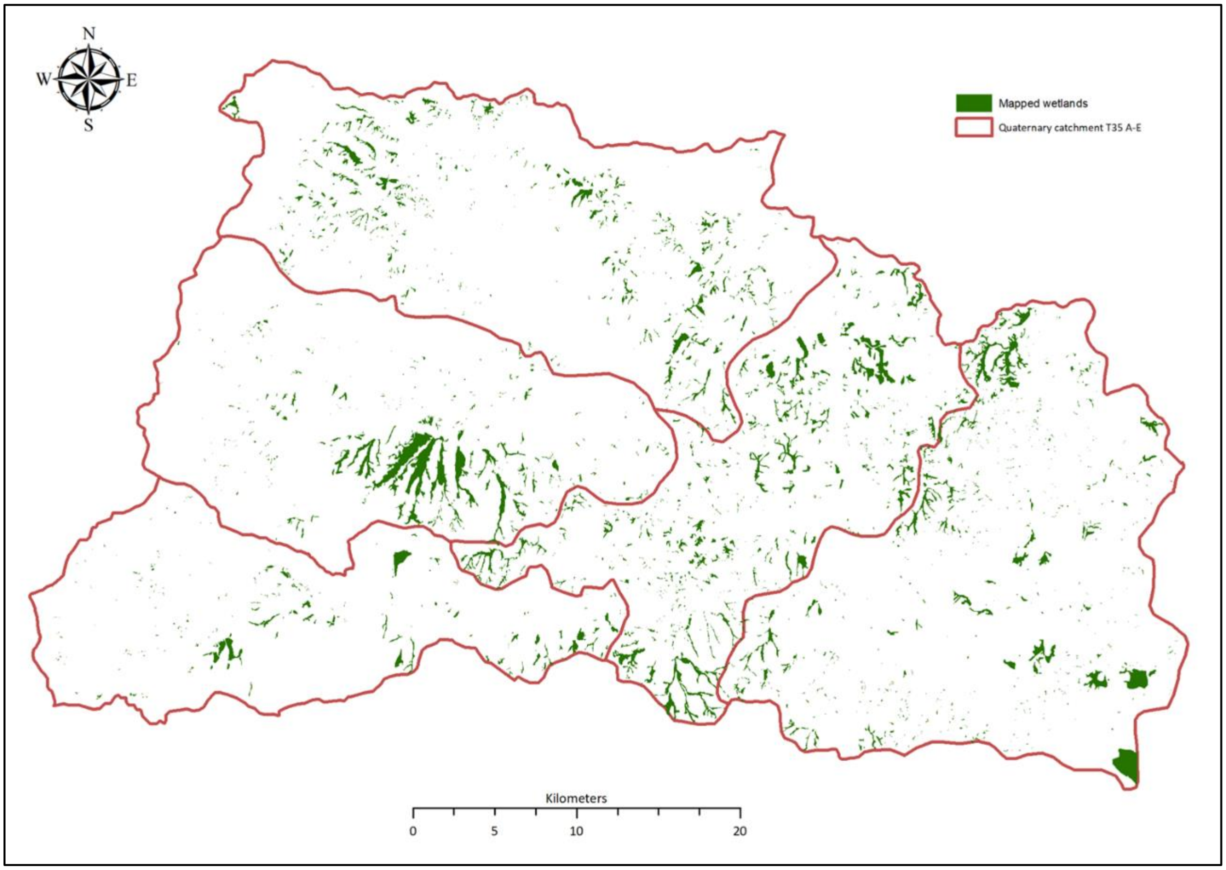


FIGURE 14: MAPPED WETLANDS IN CATCHMENT T35 A-E (SCHLEGEL ET AL., 2018A)

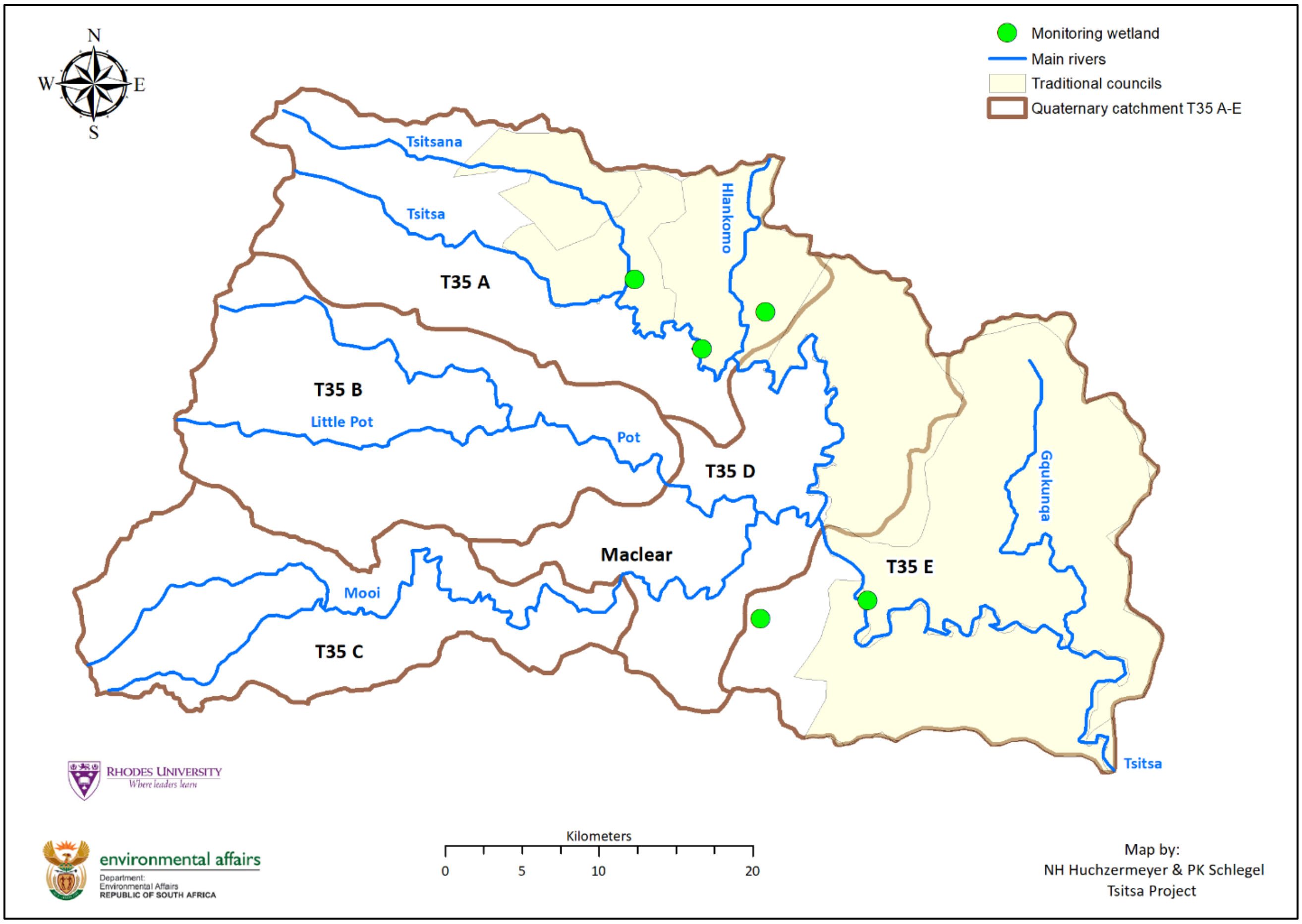


FIGURE 15: WETLAND MONITORING SITES

6.1.7. Alien Invasive Plants (AIPs)

Detailed national data sets on the location of alien tree species and their coverage extent at a catchment scale are scarce. Therefore, in order to separate indigenous vegetation from alien vegetation and to prioritise alien vegetation for clearing it is imperative to have a good overview of woody vegetation in the catchment (Huchzermeyer *et al.,* 2018a)(Figure 16).

A Normalised Difference Vegetation Index (NDVI) analysis was conducted using RapidEye satellite imagery with 5 meter resolution dated 31.10.2017. Woody vegetation exhibited an NDVI value between 0.4-0.8. The range of values were extracted and converted to polygons. The converted layer was overlain over 2015/2016 digital aerial photographs and the polygons were checked and reworked. This mapping process can be repeated every 5 years to pick up trends in changes in AIP extent.

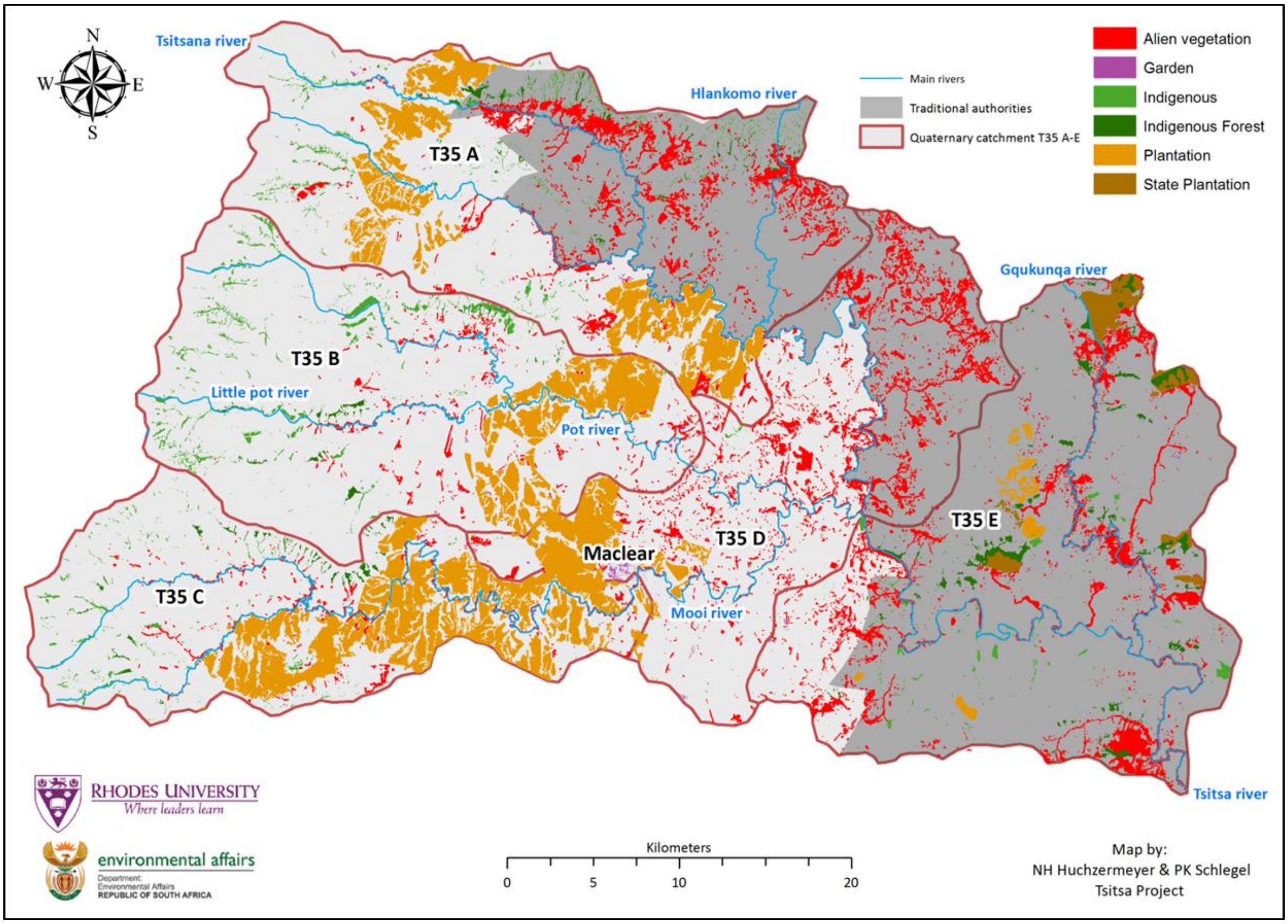


FIGURE 16: MAPPED WOODY VEGETATION IN CATCHMENT T35 A-E SHOWING ALIEN VEGETATION EXTENT (HUCHZERMEYER ET AL., 2018A)

7. CURRENT RIVER MONITORING SITES AND METHODS

The health of rivers is an important indicator of catchment processes. There are currently 11 river monitoring sites in Catchment T35 A-E (Figure 17). Hydrology, water quality and the geomorphic condition of the channel are being monitored at these points.

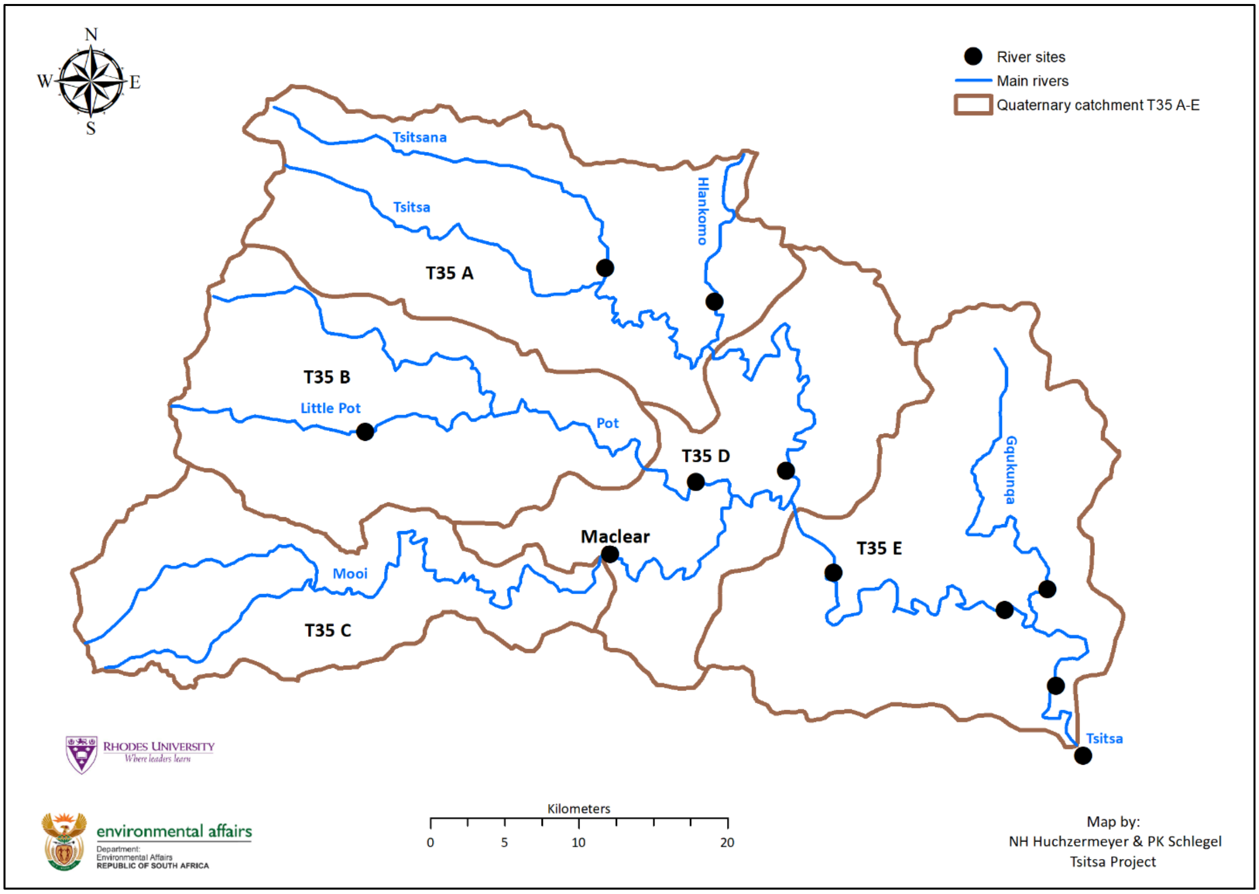


FIGURE 17: RIVER MONITORING SITES IN CATCHMENT T35 A-E

7.1. 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 (discharge).

Baseflow modelling

Measurements of discharge in relation to current water levels have been monitored in the catchment (Huchzermeyer, 2017; Bannatyne, 2018) 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 are 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 is too high to safely access the river, an adaption of the Velocity-Area Method (Gordon *et al.,* 2004) is used to calculate discharge. This is 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 is 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 (Figure 18). Currently 9 depth loggers are situated in Catchment T35 A-E. A further 4 depth loggers are maintained in Catchment T35 F-K.

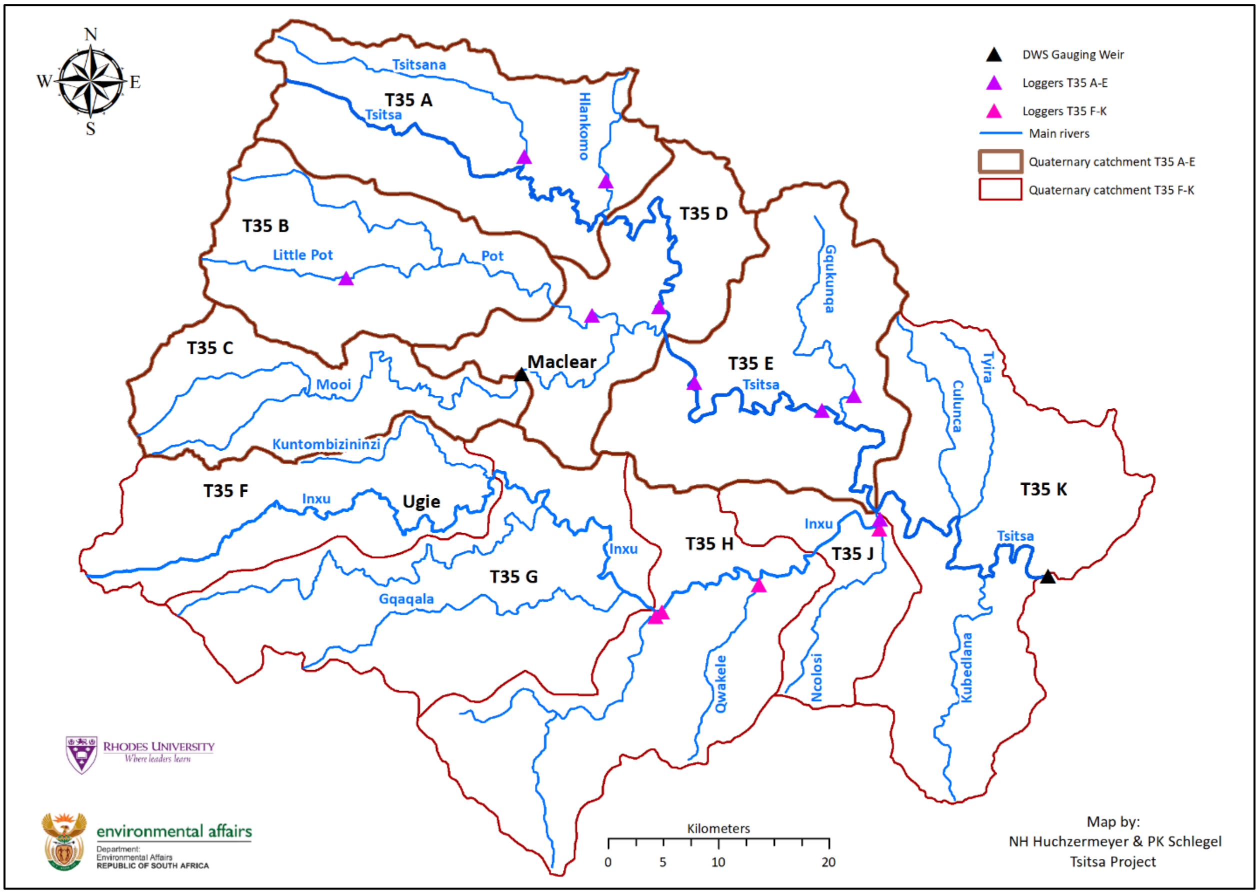


FIGURE 18: LOCATION OF DEPTH LOGGERS AND NATIONAL GAUGING WEIRS ON THE MAIN RIVERS IN CATCHMENT T35 A-K

Within Catchment T35 A-E two barologgers are measuring air pressure at different elevation ranges (Figure 19). These are used to compensate for atmospheric pressure fluctuations when measuring water level with the depth loggers. Two barologgers are installed in the catchment each within a 30 km radius and 300 meter change in elevation from a levellogger.

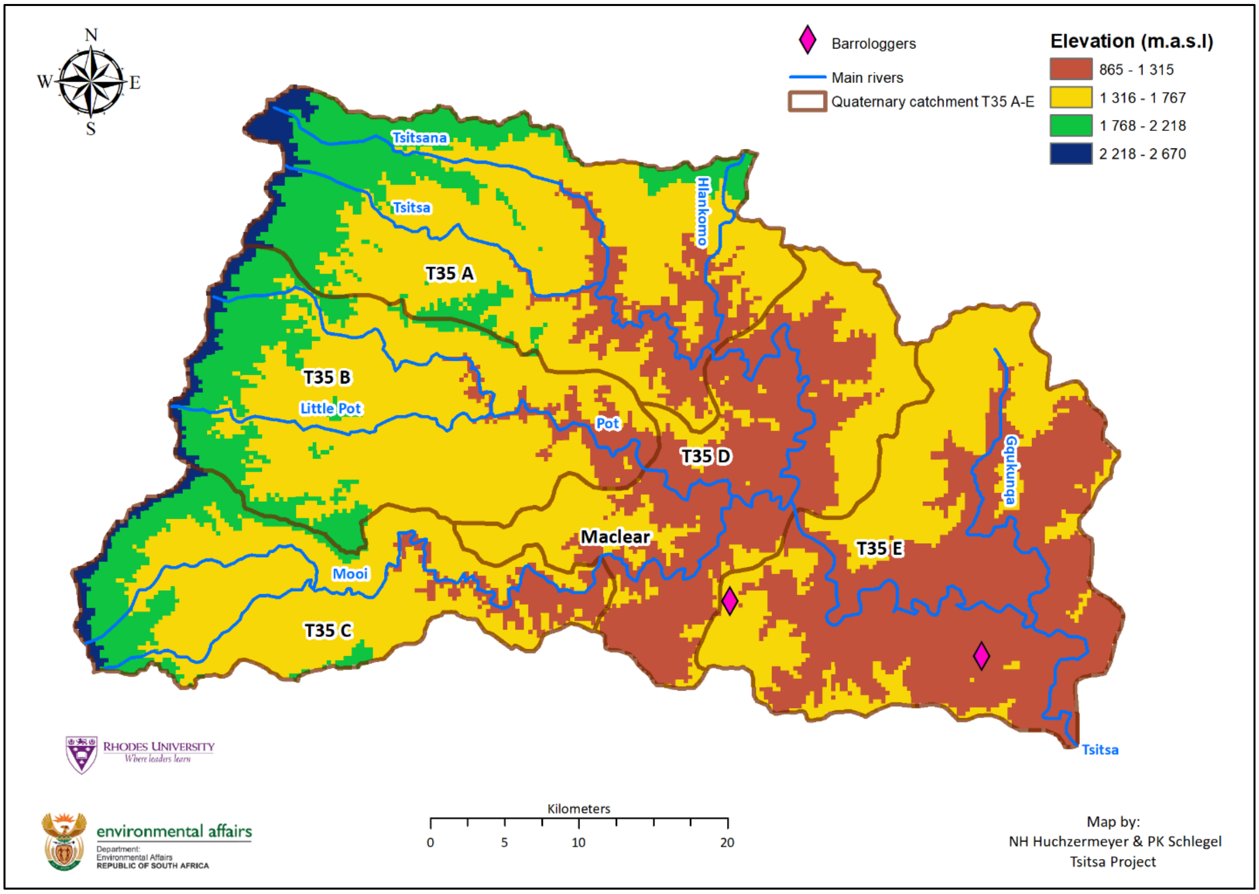


FIGURE 19: LOCATION OF BAROMETRIC LOGGERS IN CATCHMENT T35 A-E

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. Discharge, including baseflow and flood peaks are plotted on a time-series.

Flood peak 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 & Wadeson, 1999).

Current flow data is sourced from gauging stations T3H006 (Tsitsa River at Xonkonxa; catchment area 4 285 km2) and T3H009 (Mooi River at Maclear, catchment area 307 km2).

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.

7.2. 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). Samples are taken in the middle of each site (Figure 17), prior to any other field measurement activities to avoid disturbance or contamination of the sample site. Measurements are taken in the field to avoid contamination of the samples. In addition, turbidity and clarity are measured, habitat diversity assessed and a rapid assessment of water quality is conducted by looking at the macroinvertebrates present. In addition turbidity and suspended sediment concentrations are continuously measured (Bannatyne, 2018). A comparison of trends over time and under different flow conditions can point to either an improved or degraded aquatic ecosystem.

7.2.1. Nitrate and phosphate concentrations

High concentrations of dissolved phosphates and nitrates can be toxic to aquatic organisms. A rapid Machery-Nagel Visocolor ECO colorimetric test kit is used to measure concentrations in mg/l.

7.2.2. 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.

7.2.3. Dissolved oxygen

The maintenance of sufficient DO concentrations (> 80%) is critical for the survival of aquatic organisms. An AZ8403 Dissolved Oxygen probe meter, made available by the Rhodes University Geography Department, was used to measure DO.

7.2.4. 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 & 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). An AZ8403 Dissolved Oxygen probe meter, made available by the Rhodes University Geography Department, was used to measure water temperature (˚C) at each site. The Solinst level loggers at each site record continuous data on water temperature (˚C)

7.2.5. 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.

A combination of qualitative data and quantitative data was used to measure turbidity. Quantitative data was measured in FTU using a Partech 740 handheld turbidity meter, made available by the Rhodes Geography Department, which can be sourced from Partech Instruments. The turbidity meter measures the weakening of a beam of light through a water sample, in other words the instrument measures the absorption and scatter properties of light when it passes through water (Henley *et al*., 2000). Henley *et al.* (2000) state that determining suspended sediment concentrations from recorded turbidity values (in NTU or FTU) should be considered with caution because values from different river systems can be correlated with different suspended sediment concentrations. Less accurate quantitative data was collected using a water clarity tube (GroundTruth, 2013). GroundTruth (2013) state that the clarity tube is one of the few inexpensive methods for testing water clarity and has fewer limitations than its counterparts. This clear graduated plastic tube contains a moveable marker magnetised to the side of the tube. The tube is filled with a representative sample from the river and the magnetic marker is moved up or down until it is no longer visible. A level of clarity (in centimeters) can then be read off the corresponding value on the tube.

Turbidity and water clarity are measured during each field visit at each site in order to observe how turbidity changes over time with the flow hydraulics of a river.

7.2.6. Suspended sediment

A citizen technician based flood focused approach to direct suspended sediment sampling was developed (Bannatyne, 2018) and data collected from this will be used for biophysical monitoring. Hydrographs and rainfall events will be linked to the suspended sediment data.

Annual sediment flux (changes over time) per site will be plotted in relation to rainfall in each sub-catchment.

7.2.7. South African Scoring System (SASSv5)

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 & Graham, 2002).

A score derived using the South African Scoring System (SASS) (Dickens & 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.

7.3. Channel classifications: 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) and will be conducted at river sites during low flow conditions:

- Topographical Survey transects.
- Describe reach geomorphology in terms of visible channel patterns and morphological units.
- Construct a site map of geomorphic characteristics using a drone for high definition photographs, topographical transects and field notes, including:
  - reach type,
  - dominant sediment class,
  - morphological units and
  - geo-habitats.
- Identification and demarcation of key geomorphic features (e.g. bankfull level), morphological units and linked habitats along survey transects.

8. STUDENT PROJECTS

Data collected by the biophysical monitoring team can be used to augment data collected for student projects. For example, Herd-Hoare (2018) is investigating the wet season interaction between rainfall intensity, vegetation cover and sediment flux in different areas of Catchment T35. Rainfall and sediment data is being sourced from the Tsitsa Project biophysical monitoring group for this study.

9. 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. 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. Data will be securely stored.

- Data Longevity.

  Data sets need to be cared for. 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.

- Student data collection warrants an embargo period in which a full dataset cannot be shared until the student has published and released their data.

10. DATA ANALYSIS AND REPORTING

Appendix 1-4 give an overview of data collection forms for biophysical monitoring (note that these are not a comprehensive list of all the forms used).

Disseminating results in a useable format for managers and a wide audience is central to the success of the Tsitsa Project Biophysical Monitoring Program. 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.

Data will be analysed and presented using time-series analysis (trends over time) and relevant statistical analysis will be carried out on the data to pick up relationships between different catchment processes and characteristics.

The results and interpretations will be reported on in a separate monitoring report and will be accompanied by a biophysical database.

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. 2018. *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.

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.

Geldenhuys, C; Funda, O; Aromaye, T; & Mugure, M., 2016. Evaluation of natural forests in the Ntabelanga quaternary catchments in the Maclear area in relation to resource use management (No. FW-04/16). Forestwood CC, Pretoria, South Africa.

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.

GroundTruth. 2013. *GroundTruth: Water, Wetlands and Environmental Engineering.*[Online]. Available: http://www.groundtruth.co.za/equipment/clarity-tube.html [15/07/2015].

Henley, W. F., Patterson, M. A., Neves, R. J. & Lemly, A.D. 2000. Effects of Sedimentation and Turbidity on Lotic Food Webs: A Concise Review for Natural Resource Managers. *Reviews in Fisheries*

Science, 8(2): 125–139.

Herd-Hoare, S. 2019. *The influence of land use and land cover on sediment dynamics in the Tsitsa River catchment.* Rhodes University. MSc in progress.

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).

Huchzermeyer, N.H., Schlegel, P.K. & van der Waal, B. 2018a. *Woody vegetation in Catchment T35 A-E: mapping and classifying the extent of woody vegetation with an emphasis on alien invasive species.* Tsitsa Project: Mapping report.

Huchzermeyer, N.H., Sibiya, S., Schlegel, P.K. & van der Waal, B. 2018b. *Cultivated Lands in the Upper Tsitsa River Catchment T35 A-E. Cultivated land mapping: level of degradation and vulnerability to erosion.* Tsitsa Project: Mapping report.

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.

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.

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.

Ngwenya, M. 2016. Participatory identification of key places and species valued by Shukunxa residents in the Ntabelanga dam catchment. Honours Dissertation. Department of Environmental Science, Rhodes University.

Nyamela, N. 2018. The Suspended Sediment Yield and Provenance of the Inxu River Catchment, Eastern Cape. Rhodes University (Unpublished MSc).

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.

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.

Schlegel, P., Huchzermeyer, N. & Van der Waal., B. 2018a. *Wetlands in Catchment T35 A-E: Wetland type, current condition and rehabilitation prioritisation.* Ecosystem report, Tsitsa Project, Rhodes University.

Schlegel, P., Huchzermeyer, N. & Van der Waal., B. 2018a. *Managing Wetlands in the Upper Tsitsa River (T35 A-).* Management report, Tsitsa Project, Rhodes University.

Schlegel, P., Huchzermeyer, N. & Van der Waal., B. 2019. *Biophysical Monitoring Plan of the Upper Tsitsa River Catchment (T35 A-E)*. Ecosystem report, Tsitsa Project, Rhodes University.

Snyman, G. 2019. *An investigation into the fire regimes of the Upper Tsitsa River catchment.* Rhodes University. MSc in progress.

Trollope, C. 2016. *Identifying sources of sediments through Sediment Tracing in the Tsitsa River Eastern Cape, South Africa.* Rhodes University: Honours thesis.

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

APPENDIX 1: CHECK LIST FOR BIOPHYSICAL MONITORING SITES

	River Sites																
	Catchment T35 A-E											Catchment T35 F-K					
Variable	T2	G	T3	M	P	T4	H	Ta	LP	I	N3	TN2	Nc	Qw	Ng	Um	I/up
Water Quality																	
pH																	
EC																	
Temp.																	
DO																	
N																	
P																	
Turbidity																	
Clarity																	
SASS																	
Date																	
Time																	
Logger																	
Depth to logger																	
Download logger																	
Check data																	
Discharge																	
Fixed point photograph																	
Upstream																	
Downstream																	
Aerial image																	
VEGRAI																	
State of riparian zone																	
Species																	

	Rain gauges										
	Catchment T35 A-E						**Catchment T35 F-K**				
	Gquk.	**GreenV**	**Falls**	**PGBis**	**Tsitsana**	**LitPot**	**Mgosa**	**Ntsiop**	**Tyrika**	**Mont.**	**Morvan**
Clean											
Steady											
Check soldering											
Download											
Check data											
Change battery											

	Veld monitoring							
Variables	1	2	3	4	5	6	7	8
Photographic monitoring								
Species composition								
Biomass								
Multi-criteria visual assessment								
LFA								

	Wetland monitoring			
Variables	1	2	3	4
Photographic monitoring				
Species composition				
Description				

APPENDIX 2: WATER QUALITY CAPTURE SHEET

River site no.	Variable	Reading
	pH	
Date:	EC (µS)	
	Temp. (˚C)	
Time:	DO (%)	
	N (mg/l)	
Comment:	P (mg/l)	
	Turbidity (FTU)	
	Clarity (cm)	

APPENDIX 3: SASSV5 CAPTURE SHEET

SASS Version 5 Score Sheet

Version date: Sept 2005

Date (dd:mm:yr):			(dd.ddddd)		
RHP Site Code:		Grid reference (dd mm ss.s) Lat:	S		
Collector/Sampler:		Long:	E		
River:		Datum (WGS84/Cape):			
Level 1 Ecoregion:		Altitude (m):			
Quaternary Catchment:		Zonation:			
Site Description:	Temp (℃):		Routine or Project? (circle one)	Flow:	
	pH:		Project Name:	Clarity (cm):	
	DO (mg/L):			Turbidity:	
	Cond (mS/m):			Colour:	
	Riparian Disturbance:				
	Instream Disturbance:				

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)		
Stones Out Of Current (SOOC)		
Bedrock		
Aquatic Veg		
MargVeg In Current		
MargVeg Out Of Current		
Gravel		
Sand		
Mud		
Hand picking/Visual observation		

Taxon	QV	S	Veg	GSM	TOT
PORIFERA (Sponge)	5				
COELENTERATA (Cnidaria)	1				
TURBELLARIA (Flatworms)	3				
ANNELIDA					
Oligochaeta (Earthworms)	1				
Hirudinea (Leeches)	3				
CRUSTACEA					
Amphipoda (Scuds)	13				
Potamonautidae* (Crabs)	3				
Atyidae (Freshwater Shrimps)	8				
Palaemonidae (Freshwater Prawns)	10				
HYDRACARINA (Mites)	8				
PLECOPTERA (Stoneflies)					
Notonemouridae	14				
Perlidae	12				
EPHEMEROPTERA (Mayflies)					
Baetidae 1sp	4				
Baetidae 2 sp	6				
Baetidae > 2 sp	12				
Caenidae (Squaregills/Cainfles)	6				
Ephemeridae	15				
Heptageniidae (Flatheaded mayflies)	13				
Leptophlebiidae (Prongills)	9				
Oligoneuridae (Brushlegged mayflies)	15				
Polymitarcyidae (Pale Burrowers)	10				
Prosopistomatidae (Water specs)	15				
Teloganodidae SWC (Spiny Crawlers)	12				
Tricorythidae (Stout Crawlers)	9				
ODONATA (Dragonflies & Damselflies)					
Calopterygidae ST,T (Demoiselles)	10				
Chlorocyphidae (Jewels)	10				
Synlestidae (Chlorolestidae)(Sylphs)	8				
Coenagrionidae (Sprites and blues)	4				
Lestidae (Emerald Damselflies/Spreadwing	8				
Platycnemidae (Stream Damselflies)	10				
Protoneuridae (Threadwings)	8				
Aeshnidae (Hawkers & Emperors)	8				
Corduliidae (Cruisers)	8				
Gomphidae (Clubtails)	6				
Libellulidae (Darters/Skimmers)	4				
LEPIDOPTERA (Aquatic Caterpillars/Moths)					
Crambidae (Pyralidae)	12				

Taxon	QV	S	Veg	GSM	TOT
HEMIPTERA (Bugs)					
Belostomatidae* (Giant water bugs)	3				
Corixidae* (Water boatmen)	3				
Gerridae* (Pond skaters/Water striders)	5				
Hydrometridae* (Water measurers)	6				
Naucoridae* (Creeping water bugs)	7				
Nepidae* (Water scorpions)	3				
Notonectidae* (Backswimmers)	3				
Pleidae* (Pygmy backswimmers)	4				
Veliidae/M...veliidae* (Ripple bugs)	5				
MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)					
Corydalidae (Fishflies & Dobsonflies)	8				
Sialidae (Alderflies)	6				
TRICHOPTERA (Caddisflies)					
Dipseudopsidae	10				
Ecnomidae	8				
Hydropsychidae 1 sp	4				
Hydropsychidae 2 sp	6				
Hydropsychidae > 2 sp	12				
Philopotamidae	10				
Polycentropodidae	12				
Psychomyiidae/Xiphocentronidae	8				
Cased caddis:					
Barbarochthonidae SWC	13				
Calamoceratidae ST	11				
Glossosomatidae SWC	11				
Hydroptilidae	6				
Hydrosalpingidae SWC	15				
Lepidostomatidae	10				
Leptoceridae	6				
Petrothrincidae SWC	11				
Pisuliidae	10				
Sericostomatidae SWC	13				
COLEOPTERA (Beetles)					
Dytiscidae/Noteridae* (Diving beetles)	5				
Elmidae/Dryopidae* (Riffle beetles)	8				
Gyrinidae* (Whirligig beetles)	5				
Haliplidae* (Crawling water beetles)	5				
Helodidae (Marsh beetles)	12				
Hydraenidae* (Minute moss beetles)	8				
Hydrophilidae* (Water scavenger beetles)	5				
Limnichidae (Marsh-Loving Beetles)	10				
Psephenidae (Water Pennies)	10				

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blepharoceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5				
Chironomidae (Midges)	2				
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5				
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ancylidae (Limpets)	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvles)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					
No. of Taxa					
ASPT					

Other biota:

Comments/Observations:

Procedure: Kick SIC & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock for 1 min. Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg 1m². Stir & sweep gravel, sand, mud for 1 min total. * = airbreathers
Hand picking & visual observation for 1 min - record in biotope where found (by circling estimated abundance on score sheet). Score for 15 mins/biotope but stop if no new taxa seen after 5 mins.
Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000 S = Stone, rock & solid objects; Veg = All vegetation; GSM = Gravel, sand, mud SWC = South Western Cape, T = Tropical, ST = Sub-tropical
Rate each biotope sampled: 1=very poor (i.e. limited diversity), 5=highly suitable (i.e. wide diversity) Rate turbidity: V low, Low, Medium, High, Very High

APPENDIX 4: VELD MONITORING CAPTURE SHEETS (VAN OUDTSHOORN, 2015)

Grass Species Transect **Site name:**__________ **Site no.** **:**______________ **GPS:**___° ′ ″S; ° ′ ″E

Date:__________ **Time:**_________ **Assessor:**_____________

	Plant name	Nearest Plant		Nearest Total	Hits	Hits Total		Total	Total (%)
		Hit on bare ground	Hit on a forb						
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
	Total								
	Total (%)								100%

1. SITE DESCRIPTION

Step 1 Complete the site description information below;

Terrain unit ?	Crest	Midslope	Footslope	Valley bottom	
Slope ?	Steep	Medium	Gentle	Flat or even	
Soil texture ?	Sandy	Sandy loam	Loam	Clay loam	Clay
Soil depth ?	Deep	Medium	Shallow	Gravelly / rocky	

Name the common grasses:
(from most to least common)

1. ________________ % 2. ________________ %
3. ________________ % 4. ________________ %
5. ________________ % 6. ________________ %
7. ________________ % 8. ________________ %

Name the common trees/shrubs:
(from most to least common)

1. ________________ % 2. ________________ %
3. ________________ % 4. ________________ %
5. ________________ % 6. ________________ %

Name the common forbs/herbs:
(from most to least common)

1. ________________ 2. ________________
3. ________________ 4. ________________
5. ________________ 6. ________________

Comments:

____

____

Step 2

2. EVALUATION

Apply scores to the following criteria (A – F):

A.	How much grass biomass is present? (quantity grazing)		
1	Very low levels of grass biomass	0 – 3	Score A: ↓
2	Low levels of grass biomass	4 – 7	
3	Moderate levels of grass biomass	8 – 11	
4	High levels of grass biomass	12 – 15	
5	Very high levels of grass biomass	16 – 20	

B.	How many good grazing grasses are present? (quality grazing)		
1	Mainly poor grazing grasses present	0 – 3	Score B: ↓
2	Moderate and poor grazing grasses mixed	4 – 7	
3	Mainly moderate grazing grasses present	8 – 11	
4	Good and moderate grazing grasses mixed	12 – 15	
5	Mainly good grazing grasses present	16 – 20	

C.	How good is the ground cover?		
1	Very poor ground cover	1 – 2	Score C: ↓
2	Poor ground cover	3 – 4	
3	Moderate levels of ground cover	5 – 6	
4	High levels ground cover	7 – 8	
5	Very high levels of ground cover	9 – 10	

D.	How much encroachment by unwanted plants is present?		
1	Heavy encroachment is present	1	Score D: ↓
2	Heavy to medium encroachment present	2 – 3	
3	Medium encroachment is present	4 – 5	
4	Medium to light encroachment is present	6 – 7	
5	Only light encroachment is present	8 – 9	
6	No encroachment present	10	

E.	How is the soil surface condition? (erosion)		
1	Severe levels of topsoil loss	1 – 2	Score E: ↓
2	High levels of topsoil loss	3 – 4	
3	Moderate levels of topsoil loss	5 – 6	
4	Slight levels of topsoil loss	7 – 8	
5	No topsoil loss	9 – 10	

F.	What is the soil type? (agric potential)				
	Texture ↓ Soil depth →	Deep	Shallow	Gravelly	Score F: ↓
1	Sandy soil (< 10% clay)	2 – 4	-3	-5	
2	Sandy loam soil (10 – 15% clay)	5 – 6	-3	-5	
3	Loam soil (15 – 25% clay)	7 – 8	-3	-5	
4	Clay loam soil (25 – 40% clay)	9 – 10	-3	-5	
5	Clay soil (40 – 50% clay)	7 – 8	-3	-5	
6	Heavy clay soil (>50% clay)	5 - 6	-3	-5	

Step 3 Add below all the scores together to get the Veld Condition Score (VCS):

VCS = A + B + C + D + E + F = ___ + ___ + ___ + ___ + ___ + ___ = VCS = ________

Step 4 Use now the Veld Condition Score (VCS), and long-term average rainfall for the area, to get the estimated grazing capacity in ha/LSU or AU from the table below:

RAINFALL (mm/year)		300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750
VCS	Condition	GRAZING CAPACITY (ha/AU/year)																		
20 - 22	Very poor	50.3	45.2	40.2	35.2	32.7	30.2	27.6	26.4	25.1	23.9	22.6	21.4	20.1	18.8	17.6	16.3	15.1	13.8	12.6
23 - 24		45.3	40.7	36.2	31.7	29.4	27.2	24.9	23.8	22.6	21.5	20.4	19.3	18.1	17.0	15.9	14.7	13.6	12.5	11.4
25 - 27		40.2	36.2	32.2	28.1	26.1	24.1	22.1	21.1	20.1	19.1	18.1	17.1	16.1	15.1	14.1	13.1	12.1	11.1	10.1
28 - 29		37.2	33.5	29.8	26.0	24.2	22.3	20.5	19.5	18.6	17.7	16.8	15.8	14.9	14.0	13.1	12.1	11.2	10.3	9.3
30 - 32	Poor	34.2	30.8	27.3	23.9	22.2	20.5	18.8	17.9	17.1	16.2	15.4	14.5	13.7	12.8	12.0	11.1	10.3	9.4	8.5
33 - 34		31.6	28.5	25.3	22.1	20.6	19.0	17.4	16.6	15.8	15.0	14.3	13.4	12.7	11.9	11.1	10.3	9.5	8.7	7.9
35 - 37		29.0	26.1	23.2	20.3	18.9	17.4	16.0	15.3	14.5	13.8	13.1	12.3	11.6	10.9	10.2	9.4	8.7	8.0	7.3
38 - 39		26.9	24.2	21.5	18.8	17.5	16.1	14.8	14.2	13.4	12.8	12.1	11.4	10.8	10.1	9.4	8.7	8.1	7.4	6.8
40 - 42		24.7	22.2	19.8	17.3	16.0	14.8	13.6	13.0	12.3	11.7	11.1	10.5	9.9	9.3	8.6	8.0	7.4	6.8	6.2
43 - 44		23.5	21.1	18.8	16.5	15.2	14.1	12.9	12.4	11.7	11.2	10.6	10.0	9.4	8.8	8.2	7.6	7.1	6.5	5.9
45 - 47	Moderate	22.2	20.0	17.8	15.6	14.4	13.3	12.2	11.7	11.1	10.6	10.0	9.4	8.9	8.3	7.8	7.2	6.7	6.1	5.6
48 - 49		21.1	19.0	16.9	14.8	13.7	12.7	11.6	11.1	10.6	10.1	9.5	9.0	8.5	7.9	7.4	6.9	6.4	5.8	5.3
50 - 52		20.0	18.0	16.0	14.0	13.0	12.0	11.0	10.5	10.0	9.5	9.0	8.5	8.0	7.5	7.0	6.5	6.0	5.5	5.0
53 - 54		19.0	17.1	15.2	13.3	12.4	11.4	10.5	10.0	9.5	9.1	8.6	8.1	7.6	7.2	6.7	6.2	5.7	5.3	4.8
55 - 57	Good	18.0	16.2	14.4	12.6	11.7	10.8	9.9	9.5	9.0	8.6	8.1	7.7	7.2	6.8	6.3	5.9	5.4	5.0	4.5
58 - 59		17.2	15.5	13.8	12.1	11.2	10.3	9.5	9.1	8.6	8.2	7.8	7.4	6.9	6.5	6.0	5.6	5.2	4.8	4.3
60 - 62		16.4	14.7	13.1	11.5	10.6	9.8	9.0	8.6	8.2	7.8	7.4	7.0	6.6	6.1	5.7	5.3	4.9	4.5	4.1
63 - 64		15.7	14.1	12.5	11.0	10.2	9.4	8.6	8.2	7.9	7.5	7.1	6.7	6.3	5.9	5.5	5.1	4.7	4.3	3.9
65 - 67		14.9	13.4	11.9	10.4	9.7	8.9	8.2	7.8	7.5	7.1	6.7	6.3	6.0	5.6	5.2	4.8	4.5	4.1	3.7
68 - 69		14.3	12.8	11.4	10.0	9.3	8.5	7.9	7.5	7.2	6.8	6.4	6.1	5.7	5.4	5.0	4.6	4.3	3.9	3.6
70 - 72	Very good	13.6	12.2	10.9	9.5	8.8	8.1	7.5	7.1	6.8	6.4	6.1	5.8	5.4	5.1	4.7	4.4	4.1	3.7	3.4
73 - 74		13.0	11.7	10.4	9.1	8.4	7.8	7.2	6.8	6.5	6.2	5.9	5.5	5.2	4.9	4.5	4.2	3.9	3.6	3.3
75 - 77		12.3	11.1	9.9	8.6	8.0	7.4	6.8	6.5	6.2	5.9	5.6	5.2	4.9	4.6	4.3	4.0	3.7	3.4	3.1
78 - 79		11.8	10.6	9.5	8.3	7.7	7.1	6.5	6.2	5.9	5.6	5.4	5.0	4.7	4.4	4.1	3.9	3.6	3.3	3.0
80		11.2	10.1	9.0	7.9	7.3	6.7	6.2	5.9	5.6	5.3	5.1	4.8	4.5	4.2	3.9	3.7	3.4	3.1	2.8

NB: Please note that the grazing capacity is an estimate and that rainfall fluctuations and grazing system/management also have an influence on the grazing capacity.
Compiled by Frits van Oudtshoorn. Adapted from Erika A van Zyl (1989) as published in HOËVELDFOKUS Nr 1/89.
Version 11 (for the latest version email frits@alut.co.za)