BIOPHYSICAL MONITORING PLAN, TSITSA RIVER T35 A-E
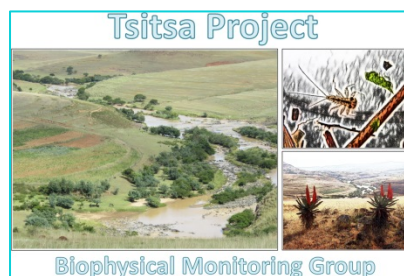
Methodological Outline Report

environmental affairs
Department:
Environmental Affairs
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TABLE OF CONTENTS

List of Figures

List of Tables

INTRODUCTION

This report provides an outline of the methodological framework for the proposed Biophysical Monitoring (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.

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.

Finally, this report is regarded as a living document that will be updated and modified based on experience gained in the 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. This report will be followed by an in depth BM plan for the Tsitsa Project following inputs from relevant stakeholders.

The Tsitsa Project is currently doing restoration work in T35A-E and is referred to as phase 1 and 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 is secured.

Upper Tsitsa River catchment (T35 A-E)
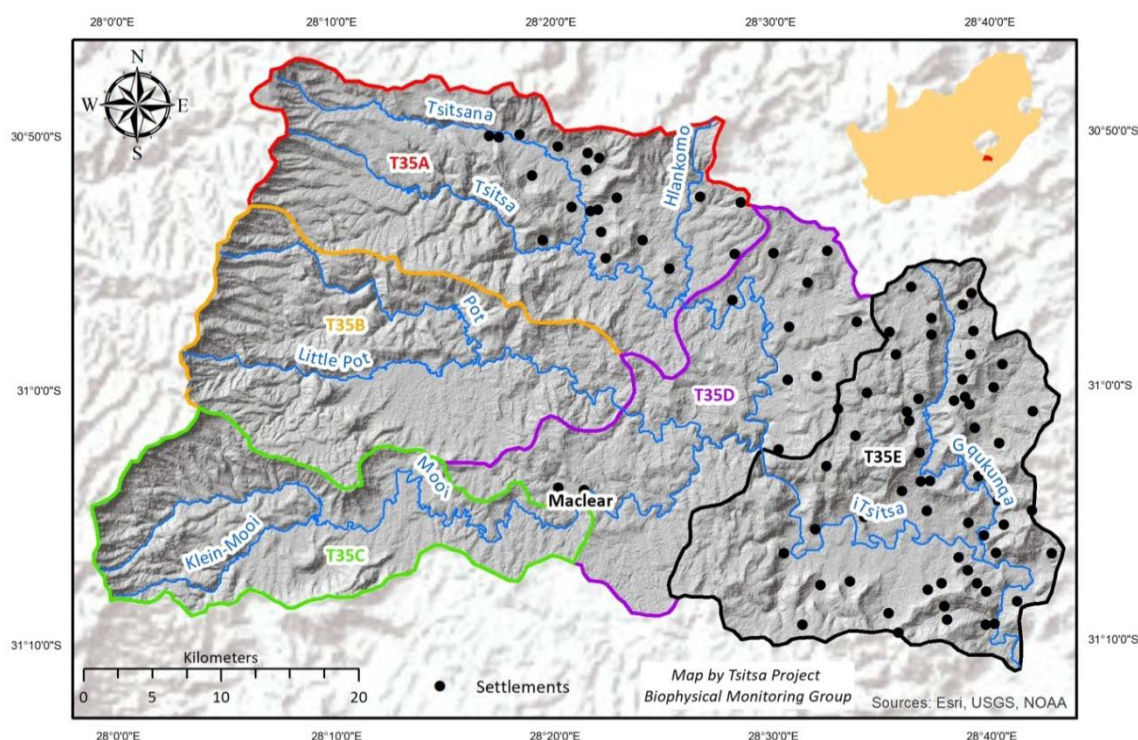
The upper Tsitsa River Catchment (T35 A-E) is in the Eastern Cape province of South Africa. The catchment receives summer rainfall and is characterised by steep topography, with the prominent Drakensburg Escarpment forming the headwaters, followed by a second smaller escarpment in the lower catchment. 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

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

). 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.
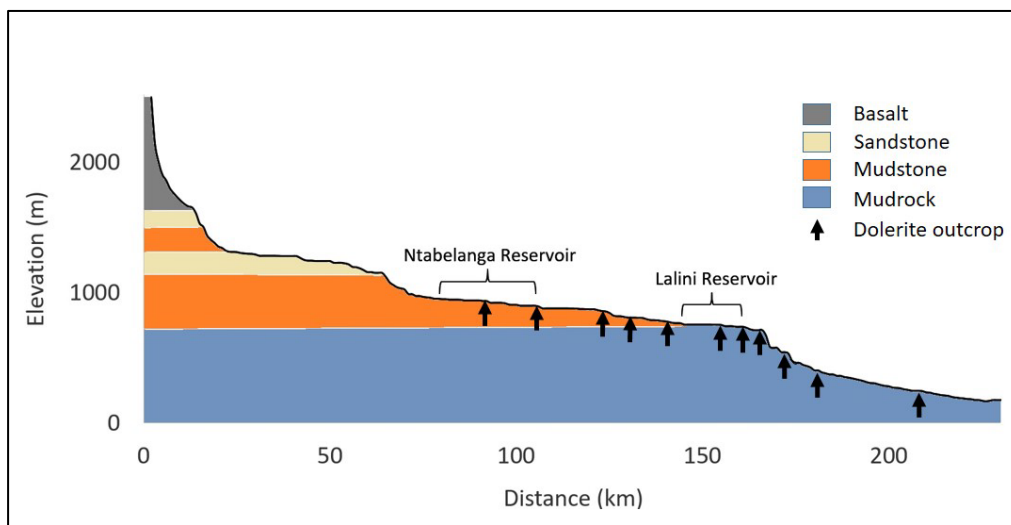
Figure BB: Longitudinal profile of the Tsitsa River showing generalised rock types.

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).

4

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.

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).
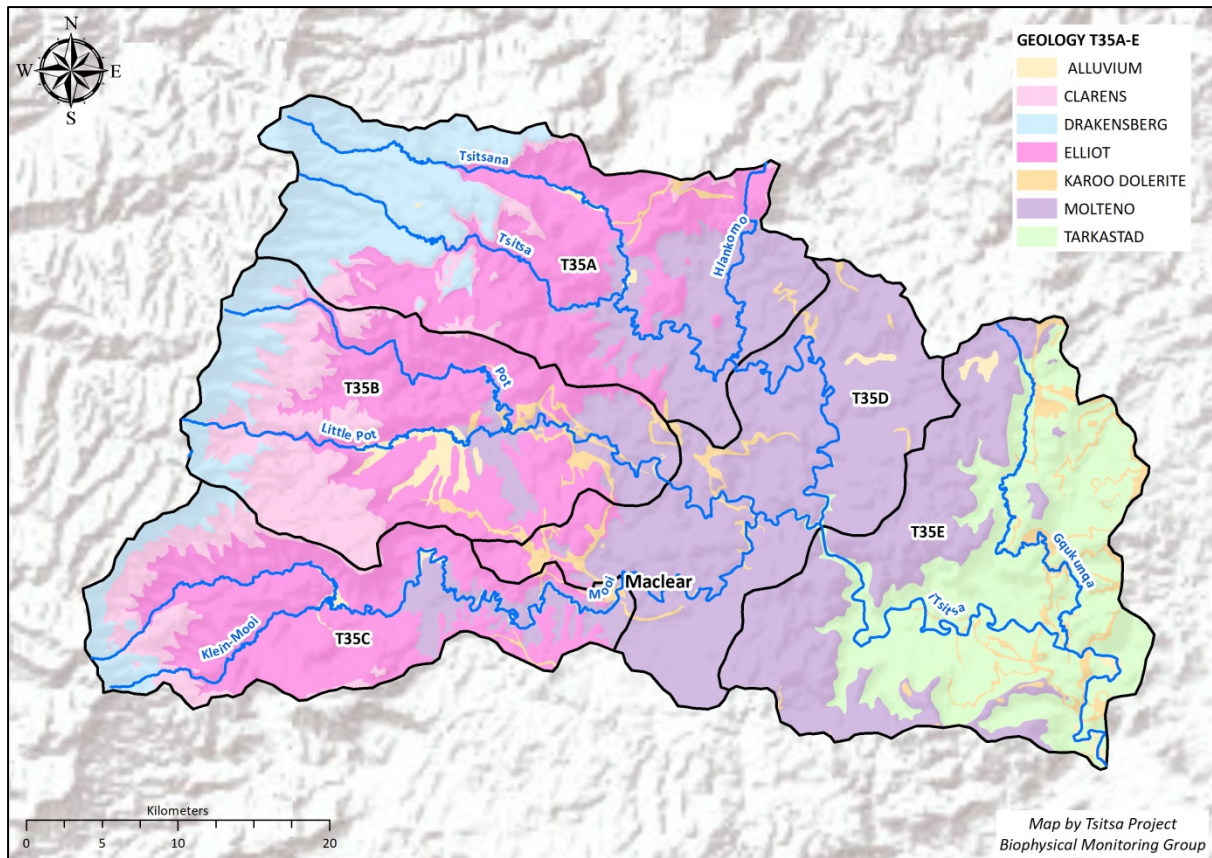
FIGURE 2: GEOLOGY OF CATCHMENT T35 A-E

VEGETATION

Figure 3 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.
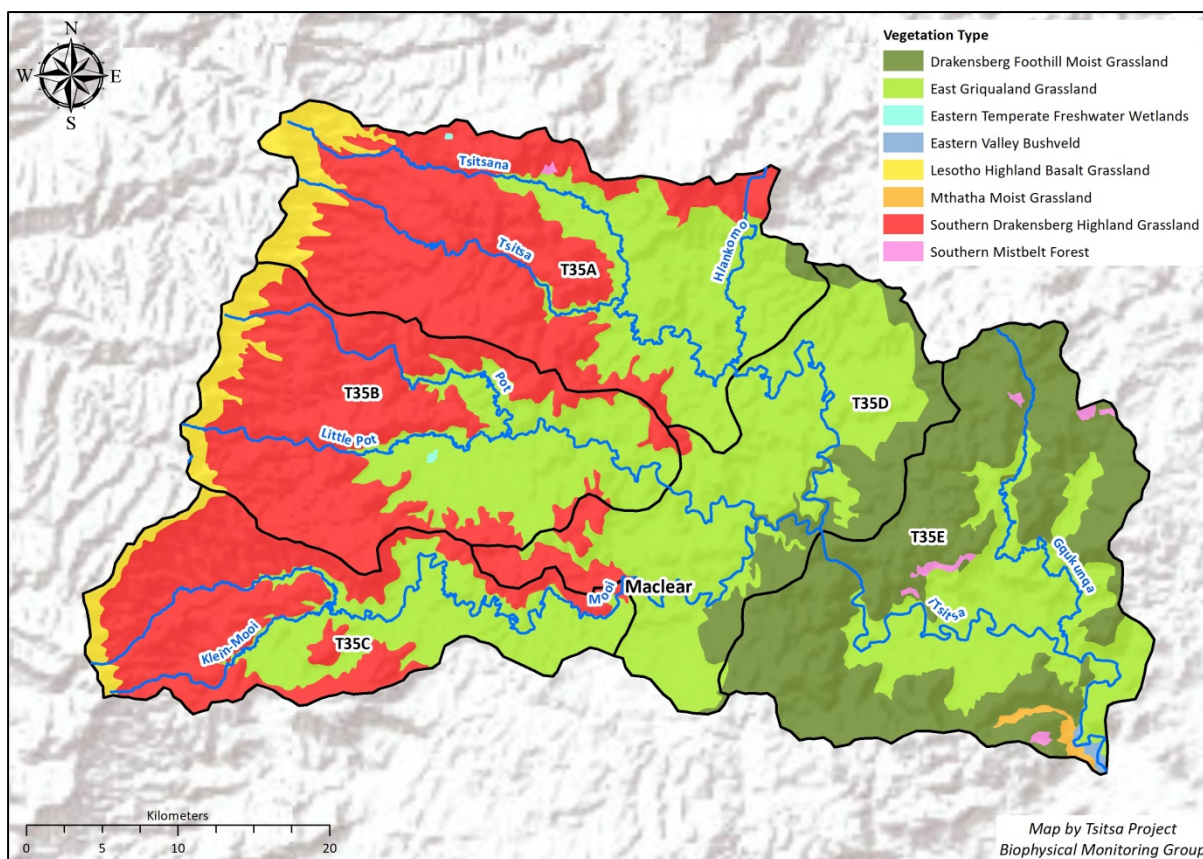
LAND COVER AND LAND USE

Land cover distribution and percentage per land cover type for the Tsitsa River Catchment are given in Table 1, Figure 4 and Figure 5. 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 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
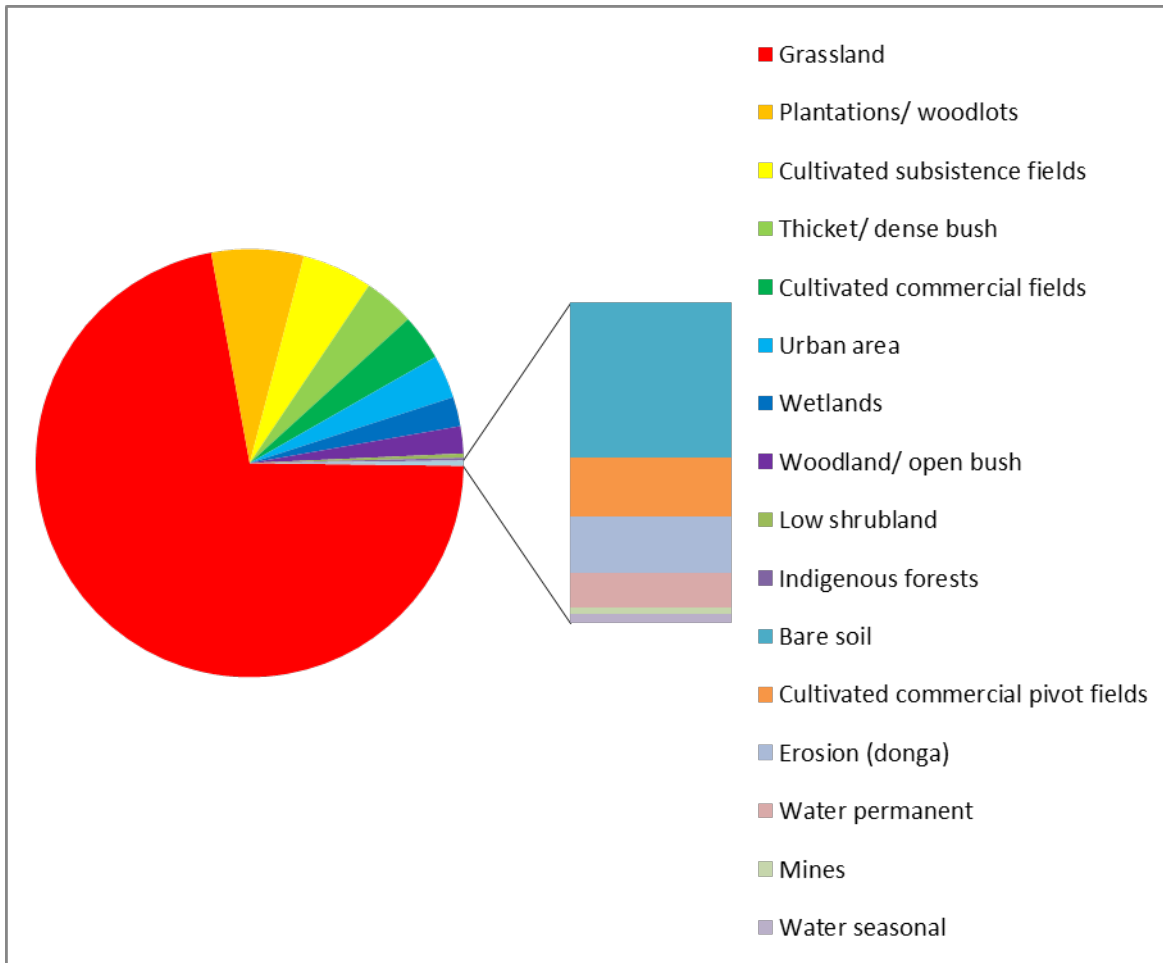
In the lower communal part of the catchment agricultural practices are mostly small scale (household scale) subsistence farming located on household properties or within fenced areas close to villages. Commercial farmers found in the upper part of the catchment predominantly plant maize, potatoes and beans.
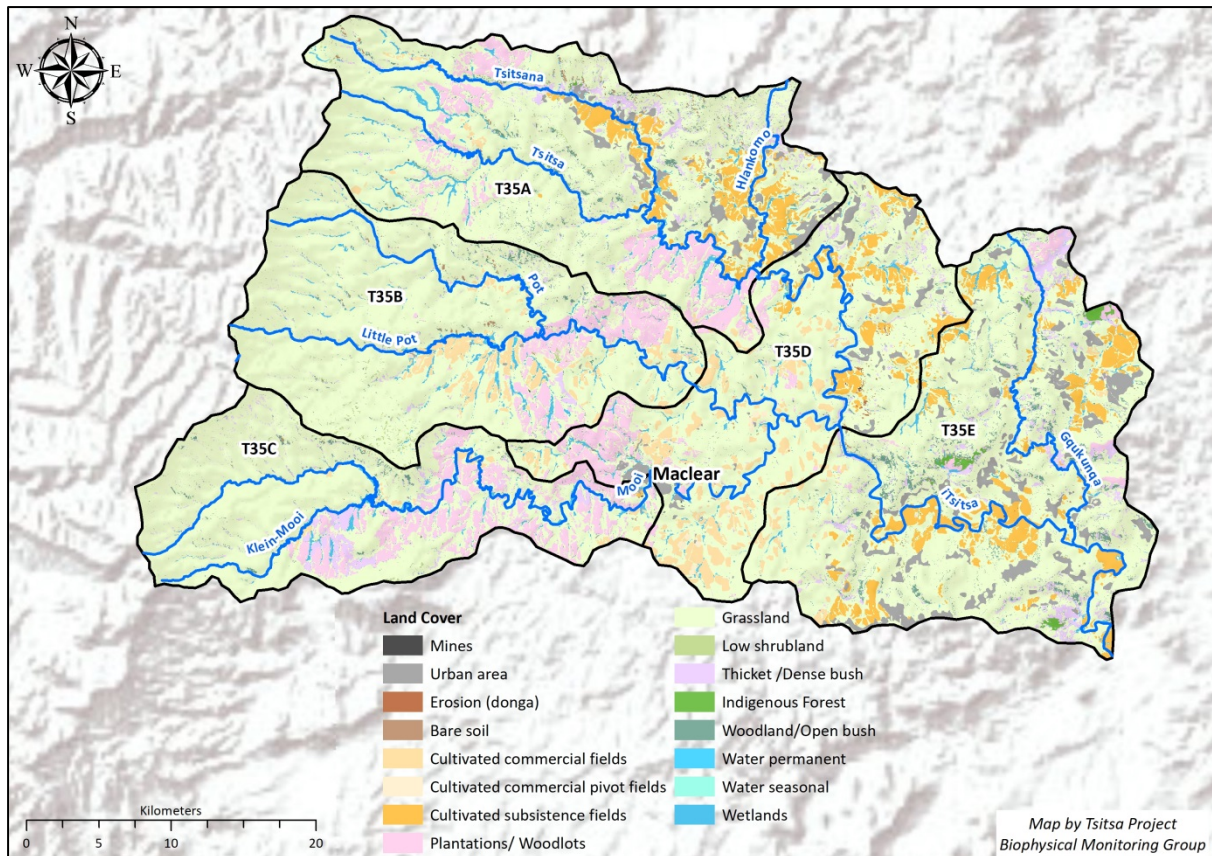
FIGURE 5: LAND COVER CLASSES IN CATCHMENT T35 A-E (GEOTERRAIMAGE, 2015)

OBJECTIVES

The main objectives of the Tsitsa Project Biophysical Monitoring are:

- to measure and describe the biophysical condition and health of the catchment (T35 A-E),
- to provide data to better understand and manage the dynamic nature and condition of the catchment,
- to monitor and evaluate the effects of current and future management practices and restoration programs within the catchment (monitoring), and
- to feed this knowledge gained from measuring biophysical variables to relevant stakeholders.

MONITORING QUESTIONS AN INDICATORS

Effective long-term monitoring is a question-driven process. To acquire meaningful information good questions must be scientifically tractable and linked to objectives and desired conditions from which to measure progress toward restoration. The Tsitsa Project Biophysical Monitoring Group endeavour to achieve this end by formulating questions to evaluate the goals and objectives of the Tsitsa

Project. This will be achieved by monitoring ecosystem infrastructure, ecosystem services and the geomorphic template? That can support sustainable livelihoods. The goals, objectives and questions are grouped into three overarching themes: climate, ecosystems/land cover/land use, and water. The Tsitsa Project Biophysical Monitoring Group has developed a set of initial questions, monitoring indicators, and measured variables based on the objectives.

QUESTIONS

- Has ecological infrastructure improved in catchments T35 A-E?
- Has ecosystem goods and services improved in catchments T35 A-E?
- Have the livelihoods of the people in the catchment been improved by improving ecosystem infrastructure and ecosystem goods and services?

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 (Table 2) 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 (Figure 6) (Texas Coast Ecohealth 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:

1) Reduction of stressors through regulation or other constraints on the drivers and pressures (e.g. land use policies);

2) Remediation, the removal of existing stressors (e.g. removal of Alien Invasive Plant species (AIPs);

3) Restoration of damaged ecosystems (e.g. wetland rehabilitation); and

4) 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.
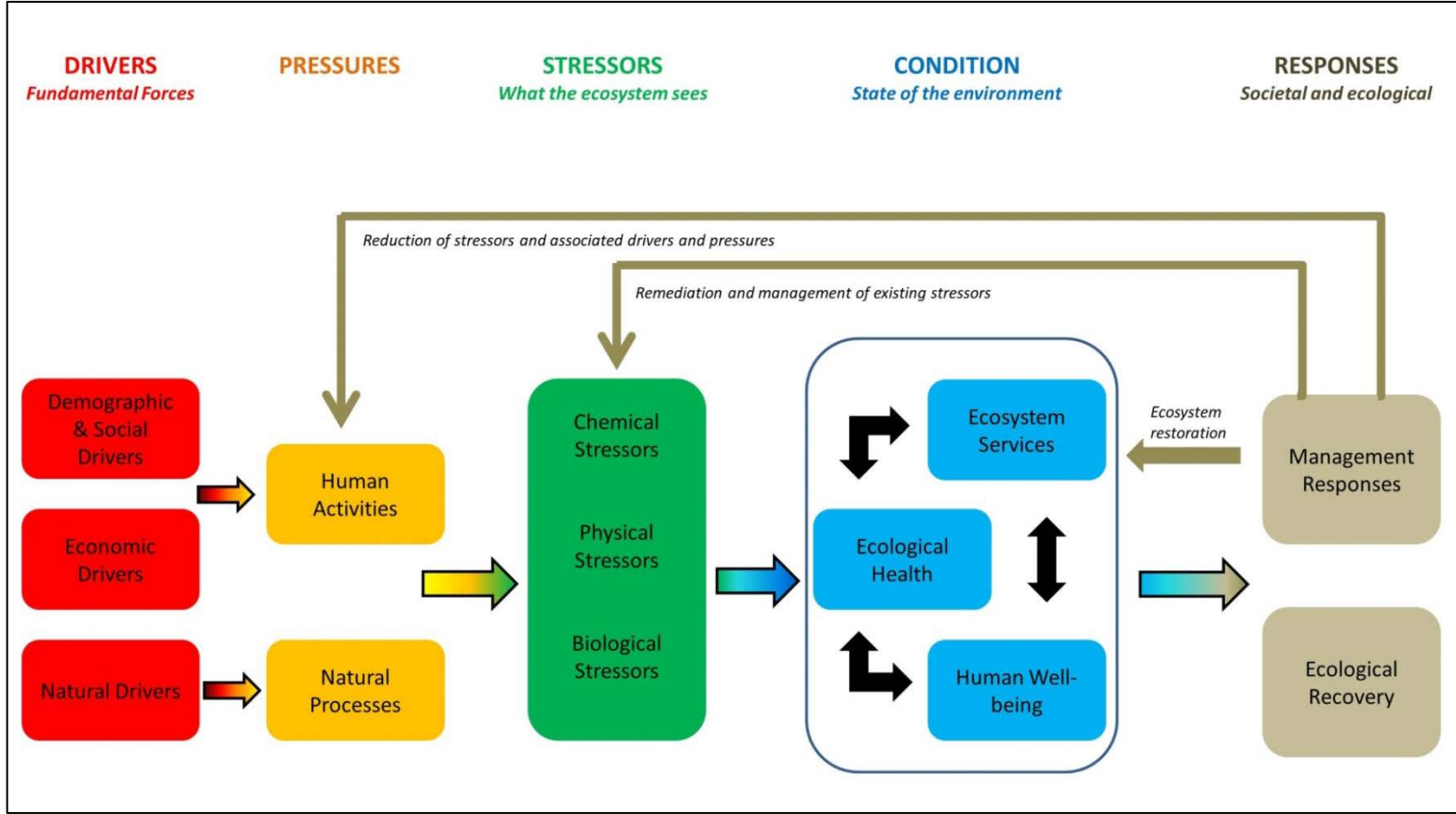
FIGURE 6: THE INTEGRATED MONITORING FRAMEWORK FOR THE TSITSA PROJECT IS BASED UPON THE DRIVERS-PRESSURES-STRESSORS-CONDITION-RESPONSES THAT AFFECT ECOSYSTEMS (BASED ON TEXAS COAST ECOHEALTH METRICS FRAMEWORK AND PROTOTYPE REPORT CARD, 2017)

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 (W/m²) • 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 (SA ecostatus)
	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 (m³) • Flood peaks (m³) • Runoff (m³)
	Water quality	Water quality- chemical and physical	• Nitrates • Phosphates • Total suspended solids (mg/L) • Suspended sediment yield (t/ha/yr) • pH • Dissolved oxygen • Electric conductivity • Turbidity • Temperature
		Aquatic macroinvertebrates and diatoms	• SASSv5 & MIRAI • IHI • VEGRAI

13

DATA INVENTORY

The data inventory shown in Table 3 is the datasets that are currently accessible and pertinent to the Biophysical Monitoring Plan for the Tsitsa Project.

Data Source	Data Type	Scale	Frequen
Department of Water and Sanitation (DWS)	Gauging Stations • T3H006- Current • T3H009- Current • T3H003- Historical • T3H014- Historical • T3H016- Historical	Catchment	6 min co
	Boreholes • Multiple locations, not monitored • Groundwater recharge model	Catchment	
	Water Quality Stations	Catchment	Quarterly
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 • ECBCP- aquatic/ terrestrial • NPAES- focus areas • SKEP • National Freshwater Ecosystem Priority Areas (NFEPA)	National	Once off
Wildlands	Maps and data of • Groundcover • Productivity • Species richness and abundance	Unknown	
Agriculture Research Council (ARC)	Maps and data of • Grazing Capacity • Degraded lands • Weatherstation at Sommerville (lets ask Tony at some point, I might have some data from many moons ago)	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

Method	Measurement	Scale	Frequency
Tsitsa Project Automated loggers for rainfall, discharge and suspended sediment concentration	• Rainfall tipping buckets (0.2 mm, event based) • Level loggers (Flow) • Accoustic Backscatter Sediment probe (Sediment) • Barologgers (air pressure)	Catchment/ Reach/ Plot	Event ba... 20 min 6 min 20 min
Citizen Technicians	Suspended sediment	Sub-catchment/ plot	

GIS maps and data created	• Wetlands
	• Erosion associated with wetlands
	• Alien vegetation
	• Cultivated lands
	• Gullies
	    o Discontinuous gullies
	    o Continuous gullies
	• Roads- Main, arterial, dirt roads, jeeps tracks
	• Livestock tracks
	• Settlements
	• Geology
	• Slope
		Catchment	3 years?
			3 years?
			3 years?
			5 years
			5 years
			
			5 years

METHODOLOGY OUTLINE

SPATIAL SCALES

Monitoring involves repeated measurements. However, the goals of monitoring, such as increasing understanding of ecosystem variability and providing early warning of abnormal conditions, require that such measurements be assessed in relation to potential drivers and responses. For example, changes in vegetation cover may be compared to climatic trends to distinguish between natural and anthropogenic effects. Such analyses can make monitoring data useful to managers. Examining interactions among indicators at multiple spatial and temporal scales is also crucial to understanding trends. Interactions among drivers and stressors force change in biotic communities. In turn, interactions among biotic components can change community structure and composition. Many of these interactions occur as same-scale processes. As such it is important to understand scale dependencies, whereby plot scale processes are facilitated by the spatial and temporal heterogeneity of higher-scale patterns and processes (Wiens, 1999).
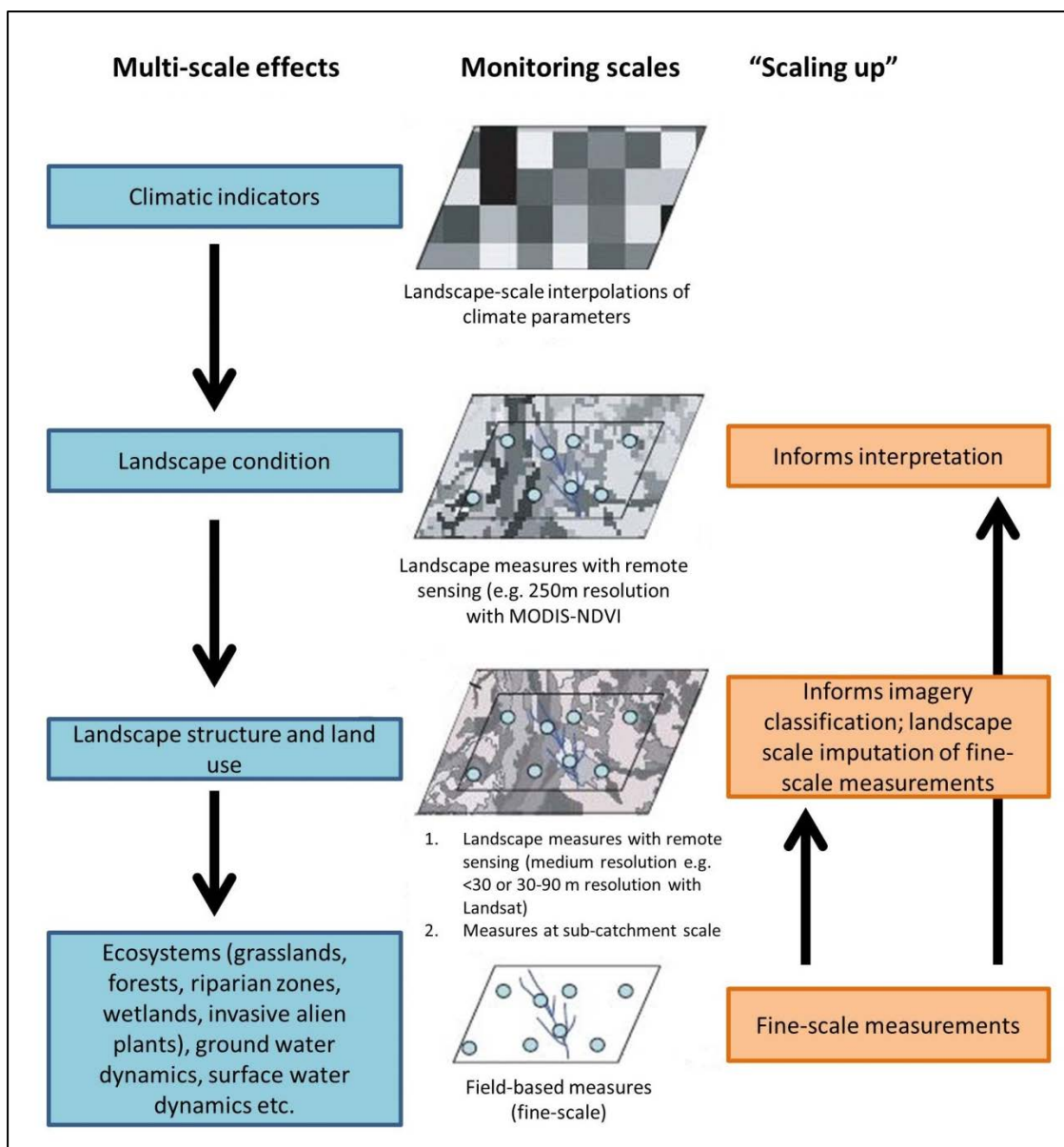
FIGURE 7: SPATIAL SCALES OF THE BIOPHYSICAL MONITORING AND DATA ANALYSIS (FROM: O'DELL *ET AL,*. 2005)

The Tsitsa Project Biophysical Monitoring Plan is designed to monitor scale-dependent processes and to accommodate integration within and among scales. Estimates of climatic parameters derived from regional monitoring networks provide a backdrop for evaluating large-scale changes in abiotic drivers of change. Remotely-sensed information on landscape structure, condition, and land use within the catchment, and at multiple scales, provides key measures of spatial patterns and human pressures. We propose monitoring of the key variables using remotely sensed coarse resolution data at a catchment scale and high resolution data at strategic points in the catchment. Trends in fine-scale attributes are monitored with ground-based field plots. At each scale, the use of synoptic measures will afford better understanding of trends. The spatial hierarchy of monitored attributes

permits understanding of cross-scale interactions; e.g., the effects of regional climatic conditions on patterns and trends in landscape condition, the effects of large-scale climatic conditions and proximate landscape structure on plot-based trends. Additionally, fine-scale data will be used to inform analyses of data collected at coarser scales (e.g., imagery classification, interpretation of land condition), and potentially as the basis for interpolating fine-scale measures to the landscape (e.g., Gradient Nearest Neighbor Imputation [Ohmann & Gregory, 2002]).

CLIMATE

Climate will continue to be monitored at existing weather stations in the region of the catchment. Programs external to the Tsitsa Project Biophysical Monitoring are currently monitoring this, such as the South African Weather Service. 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 and fall outside the catchment boundaries. Many of the climate stations have a long 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.

Within the TP scope (catchments T35 A-K) there are 10 automated tipping buckets collecting rainfall data at the plot scale and two barologgers measuring air pressure in strategic positions in the catchment. Data are available from December 2015 and 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 model (correcting water level measurements).

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 more 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) which is in close proximity and to the Tsitsa River Catchment (Figure 8).

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 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 located in the upper reaches of the Catchment T35 A-E, with sedimentary rocks underlying the middle and lower catchment (see Figure 2).

Suspended sediment is collected using time-integrated samplers (Figure 9) 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.
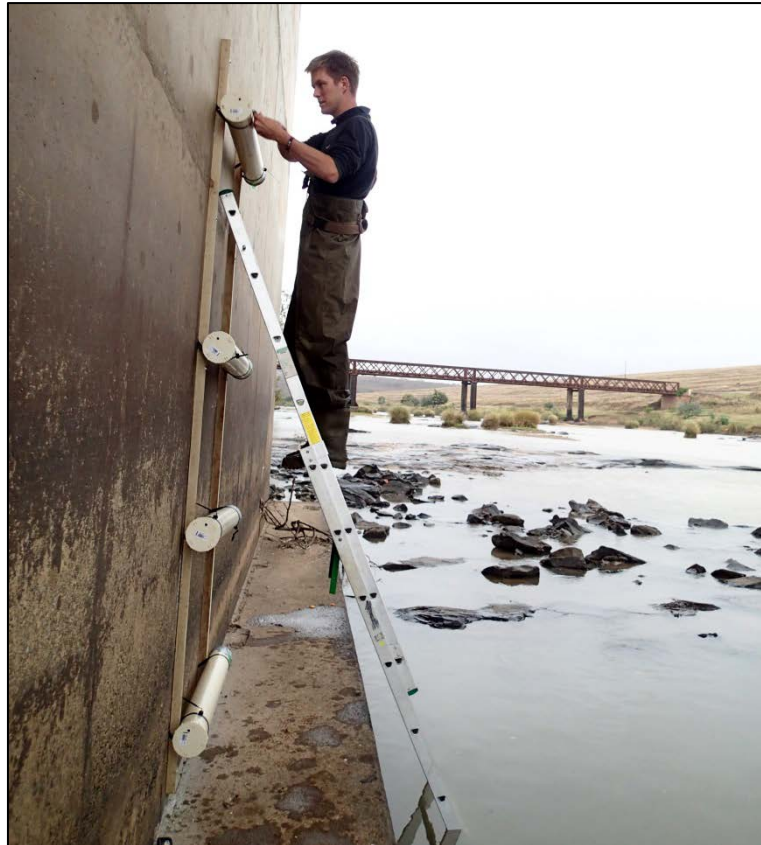
Trollope (2016) identified sources of sediments using sediment tracing techniques in Catchment T35 A-K. Colour and magnetic tracing of sediment captured in time-integrated suspended sediment samplers installed in six tributaries of the Tsitsa River as well as on the Tsitsa River itself showed that the 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 broad areas that are continuously contributing to the suspended sediment load in the Tsitsa River.

FLUVIAL GEOMORPHOLOGY/RIPARIAN 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; Holistic South African scoring system to indicate the system's departure from natural, scores range from A to F) 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
  III. Identification and demarcation of key geomorphic features (e.g. bankfull level), morphological units and linked habitats along survey transects
  IV. 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)
  V. Size distribution of bank material (laboratory analysis)
- The following procedure for each identified morphological unit is recommended by Rowntree (2015) for monitoring purposes:
  VI. Place 1 meter quadrat in the centre of the morphological unit and record the distance along the transect
  VII. 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
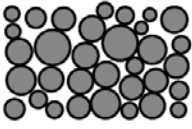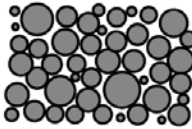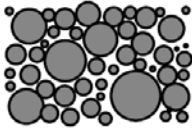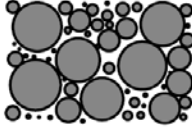
VIII.   Packing is a measure of bed stability and can be assessed using the table below

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

IX.   The sorting index quantifies the range of particle sizes or particle size variability at a point in the channel. Sorting provides an indication of bedload transport processes, such as selective transport during constant flows (well sorted) or sediment dumping during flashy flows (poorly sorted), and is assessed visually using the table below (Table 5).

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	

X.   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 6. 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 ecological integrity of the catchment. Monitoring the soils structural and chemical indicators 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 (Carbon, Nitrogen, Phosphorus) 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.

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. NDVI measures vegetation growth vigour and can be

closely correlated with vegetation cover (Purevdorj *et al.,* 1998). 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 analysis will be done every year as well as a historical analysis 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 & Rutherford, 2006). Grasslands are an important grazing resource for the people living within the catchment. The natural grassland has been heavily affected by poor grazing and fire management (Grass and Fire CoP collaboration). Grass cover and functional types will be monitored by community based officers. The plot data will be used to calibrate NDVI based monitoring that will be done at a catchment level.

Forests: Indigenous forests exist in fire protected pockets along ravines in the Tsitsa River Catchment. 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 remote sensing and aerial images will be used to map the extent of the forests, extent of encroachment of AIPs as well as using historical images to conduct a trend analysis. A study on forest structure and condition was done by Geldenhuis et al in 2015? and will form the basis for ongoing forest monitoring.

Riparian vegetation: Riparian systems perform numerous ecosystem functions important to humans, yet they are one of the most endangered ecosystem types. For the Tsitsa Project Biophysical Monitoring the protocol set out by the River Eco-classification known as the 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 provision of ecosystem services by the wetlands.

Firstly a catchment scale assessment of the wetlands using existing datasets and desktop assessments will be conducted. This will allow the TPBMP to report on the extent, type, and land cover surrounding the wetlands; and the current use and protection of these wetlands. Secondly a rehabilitation prioritisation process will be conducted at the catchment scale using aerial images, mapped data on use, current degradation of the wetlands and vulnerability of the wetlands to erosion. Thirdly a selection of wetlands across the catchment 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. Results from this will allow TPBMP to report on eight indicators, namely:

1. the extent of the wetland;
2. the present state of hydrology;
3. the present state of geomorphology;
4. the present state of vegetation;
5. the present state of water quality;
6. present ecological state based on land use;
7. scores for ecosystem services provided by the wetland;
8. 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 at a 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 reviews 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 catchment wide occurrence and higher resolution monitoring of 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.

WATER
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 overland flow during and after 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 levels. 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 (such as electrical conductivity) (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 are 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 and soils also play a role. By understanding the mechanisms controlling functional wetland seeps, indirect impacts, such as…, can be monitored and management actions can be more accurately applied (Stein *et al.,* 2004).

Van der Kamp & Hayashi (1998) state that small wetlands are also 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.

Seep wetland extent can be monitored over wet and dry periods to as proxy for groundwater levels (e.g. ha over time).

SURFACE WATER FLOW/DISCHARGE

LONGER TERM MONITORING AT DWS GAUGING STATIONS

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 will be sourced from gauging stations T3H006 (Tsitsa River at Xonkonxa; catchment area 4 285 km^2) and T3H009 (Mooi River at Maclear, catchment area 307 km^2). In addition historic flood data will be sourced from gauging stations T3H003 (Tsitsa River at Halcyon Drift; catchment area 482 km^2; data logged from 1949-1959). 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.

SHORTER TERM DISCHARGE MONITORING USING NATURAL CHANNEL GEOMETRY

An additional 10 discharge monitoring sites were established in 2015 in the upper Tsitsa River catchment (Huchzermeyer, 2017; Bannatyne, 2017). Water depth data are recorded at 20 min intervals at known cross sections using pressure sensors. The depth data are converted based on a

rating cure, see section below on developing the rating curve. Discharge data are primarily used to calculate the suspended sediment yield at these monitoring points and hydrodynamic properties of the river channel including floods and baseflows.

Developing a rating curve

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.

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 (not stratified as in lakes) 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 an electrical current, and is enhanced by high salt loads. 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 are measured using a handheld pH and EC meter.

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 & 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/WATER CLARITY

Clastic 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 suspended sediment concentrations 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 water quality for household and irrigation use and lowers light penetration into the water column, 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 by 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 & Graham, 2002). This is a widely used method that integrates water quality over longer time periods (seasonal to annual).

SOUTH AFRICAN SCORING SYSTEM (SASSv5) AND MACROINVERTEBRATE RESPONSE ASSESSMENT INDEX (MIRAI)

A score derived using the South African Scoring System (SASS) (Dickens & Graham, 2002), a widely used technique in South African Rivers, will be calculated for each site by sampling period to look at a rapid assessment of water quality. This gives 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, will be used for sample collection. In addition, fine sediments are sieved through the net and visual observations of substrate and vegetation will be 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.

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 habitat quality, diversity, size and variability are very small.	0.5-1.0
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

DIATOM INDEX

Current biomonitoring tools (such as SASSv5) are best suited for assessing lotic systems and are not suited for assessing wetlands and other lentic water systems (Musa & Greenfield, 2018). Diatoms are ubiquitous and through the use of diatom indexes diatoms can indicate degradation and/or restoration of a variety of aquatic systems.

Diatom indices are based on the principle that the most abundant diatom taxa present are those that are experiencing the least negative effects with regard to water quality (Musa & Greenfield, 2018). Indices are based on an indicator value (*v*) and a taxon's sensitivity to pollution (*s*) (Taylor *et al.*, 2006).

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 management-oriented meetings, professional meetings, and in scientific publications.

THEME	INDICATOR	PROPOSED ANALYSES
Climate	Climate	**Status:** Monthly and annual means of climatic parameters for each climate station in the area; e.g. number of days above 95th percentile and below 5th percentile of air temperature and precipitation, number of days below freezing. **Comprehensive Analysis and Syntheses:** Identification of climatic extremes by descriptive comparisons of current-year climatic parameters with historical trends and distributions on a yearly, monthly, and daily basis; qualitative and quantitative comparisons of annual conditions and trends, and climatic extremes with regional trends.
Ecosystems, Land cover/ Land use	Land cover, landscape connectivity and fragmentation; and fire dynamics	**Status:** Measures of landscape structure (composition, configuration, and connectivity) on the basis of land-cover types (from classified satellite imagery) and derived with FRAGSTATS (McGarigal and Marks 1995). Landscape-structure components resulting from fire highlighted to track status of disturbance-regime attributes. **Comprehensive Analysis and Syntheses:** Change detection among years using spectral comparison methods; quantitative comparison (possibly repeated-measures ANOVA, regression based trend analysis) of changes in landscape-structure metrics (for land-cover classes) within the catchment and within landscape units; correlation of adjacent-land changes with proximate changes in landscape units; correlation of broad-scale climate with changes in landscape structure; qualitative and quantitative comparisons of landscape-structure status and trends within the catchment.
	Land use	**Status:** Amount of area affected by land-use activity and by ownership. **Comprehensive Analysis and Syntheses:** Quantitative or qualitative assessment of trends for individual land use activities, where applicable; spatial-pattern assessment of land use activities, where possible; correlation analyses between land use and other measured indicators logically responsive to specific land use activities; qualitative and quantitative comparisons of status and trends in land use activities within the catchment.
	Land condition	**Status:** Annual trend in MODIS-NDVI and seasonally integrated NDVI. **Comprehensive Analysis and Syntheses:** Quantitative comparisons of seasonally-integrated NDVI of landscape parcels among years (ANOVA, regression-based trend analyses); quantitative comparisons of changes in integrated NDVI.
	Grassland, Forests, Riparian vegetation and wetlands	**Status:** Mean and variance of indicators measures; catchment extrapolations of monitored attributes. **Comprehensive Analysis and Syntheses:** Regression-based trend analysis for each indicator measured using frequentist and Bayesian methods; correlative analyses of trend slopes among indicators measured with broader-scale measures such as localized landscape structure, interpolated climate (2-4 km grain) measures.
	Invasive Alien Plants (AIPs)	**Status:** extent, locations, coverage, density, and age by target species; annual trend in extent or population size of target populations. **Comprehensive Analysis and Syntheses**: Spatial pattern analysis of early detections (correlative analyses with biophysical features, regression analysis using similar factors and interpreted using AIC criterion [Information-Theoretic methods]); Regression-based trend analysis in area or number of detections of newly detected/established exotic plants, where possible.

Water	Groundwater and surface water	**Status:** Mean and variance of indicators measures; catchment extrapolations of monitored attributes. **Comprehensive Analysis and Syntheses:** Regression-based trend analysis for each indicator measured using frequentist and Bayesian methods; correlative analyses of trend slopes among indicators measured with broader-scale measures such as localized landscape structure, interpolated climate (2-4 km grain) measures.
	Water chemistry (physical and chemical)	**Monthly data review:** Quality assurance and control; identify inconsistent values indicating need for re-analysing samples; censor values below method detection limits; flag values exceeding state standards and report to parks. **Status (annual summary):** Summarize site data by season and tabulate values exceeding, and approaching exceedance of standards (20% or less below the applicable standard); summary tables, histograms, and box and whisker plots to show frequency distribution, median and interquartile ranges (for non-normally distributed data), mean and standard deviation (for normally distributed data), and 95% confidence intervals for means and medians of parameters at each site. **Comprehensive analysis and synthesis:** Site level trend analysis adjusted for season and flow for individual constituents. Statistical tests include Seasonal Kendall tests for monotonic trends and Seasonal Rank Sum tests for step trends.
	Integrated biological indicators: Macroinvertebrates and diatoms	**Status:** Mean and variance of measured attributes; catchment level extrapolation of monitored attributes. **Comprehensive Analysis and Syntheses:** Regression-based trend analysis of each measure using frequentist and Bayesian methods; correlative analyses of trend slopes of measures with those of riparian and water-quality measures, and with broader scale measures such as localised landscape structure, and climate (2-4 km grain) measures; qualitative and quantitative comparisons of status and trends among tributaries..

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