BIOPHYSICAL MONITORING PLAN, TSITSA RIVER T35 A- D

TECHNICAL REPORT OUTLINE

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INTRODUCTION

This report provides an outline of the methodological framework for the proposed Biophysical Monitoring Plan 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 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 Biophysical Monitoring Plan as well as the other parts of the PMERL plan. Ultimately, we aspire to establishing rigorous monitoring and evaluation procedures that can be replicated and that facilitate learning. This report will be followed by Biophysical Monitoring Plan for the Tsitsa River Project following inputs from relevant stakeholders.

Setting: Tsitsa catchment (T35 A-D)

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-D) drains an area of approximately 2 000 km². Much of the Tsitsa River catchment lies in the communal areas 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 upper Tsitsa catchment is dominated by rural subsistence farming (found mostly in the middle and lower parts of the catchment), larger commercial farms (found in the upper sections of the catchment), 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, a large part of the catchment fell within the Transkei Homeland. 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 and Rowntree, 2003; Blignaut *et al.*, 2010; van der Waal, 2014).

Topography

The Tsitsa River rises 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 Drakensburg in the north-east, to ~600 m towards the confluence with the Umzimvubu (Le Roux and Weepener 2015). The topography of the study area is typically hilly to rolling with steep escarpment zones in the headwaters and middle catchment.

Once free of its Drakensberg headwaters, the Tsitsa River may be described as 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 Falls waterfall, the Tsitsa River passes through a deep and largely inaccessible gorge as it crosses the middle escarpment. The Pot River, having been joined by the Mooi River, converges with the Tsitsa River within this gorge.

Climate

The climate of the Tsitsa River catchment has been described variously as sub-tropical (Iliso Consulting (Pty) Ltd, 2015), sub-humid (Le Roux and Weepener, 2015), and warm-temperate (Mucina and Rutherford, 2006). Given its altitudinal range the catchment traverses a range of climate types (Mucina and Rutherford, 2006). Iliso Consulting (2015) report 749 mm in the lower catchment area as measured at Tsolo whilst Le Roux and Weepener (2015) put mean annual rainfall in the upper parts of the catchment at 1327 mm. The study area experiences summer rainfall (Mucina and Rutherford, 2006) between October and March (Moore 2016), often in the form of afternoon thundershowers (Mucina and 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. The driest and coldest month is July, with a monthly average rainfall and temperature of ~13 mm and ~0 °C respectively (Mucina and Rutherford, 2006). Snowfalls can be expected during the winter months in the upper part of the catchment, and may occur in other parts (Mucina and Rutherford, 2006). As with precipitation, river flows are highly variable. Mean annual water levels 1951 - 2016 are depicted in Figure 8 which illustrates mean water levels ranging between 0.1 m to 3.5 m. It should be noted that the highest flows would be far greater than this, given that the gauge is overtopped beyond the highest level shown. This variability introduces uncertainties into the estimation of flood durations, particularly in ungauged catchments, which in turn can impact on the effectiveness of the temporal flood sampling design.

Geology and Soils

The upper Tsitsa catchment is underlain by the Tarkastad Subgroup and the Molteno and Elliot Formations of the Karoo Supergroup, which are succeeded towards the headwaters of the catchment by the Clarens Formation. Drakensberg Group basalt caps the sequence, whilst intrusive dolerite sills and dykes occur throughout the catchment (Le Roux and Weepener 2015).

Soils in the catchment vary significantly through the catchment, but, the most prominent soil forms include poorly drained and shallow to moderately deep loams usually with minimal 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 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 and Weepener 2015).

Vegetation

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 and 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 are given below. Grassland constitutes the dominant land cover (71%) found in the catchment, followed by plantations, cultivated fields, indigenous bush/ forests, and villages/ urban centres.

Land cover	Percentage of catchment (%)
Grasslands	71.1
Plantations/ Woodlots	6.9
Cultivated subsistence crops	5.4
Thicket/ Dense bush	4.1
Cultivated commercial annual crops non-pivot	3.5
Settlements	3.3
Woodland/ Open bush	2.3
Wetlands	2.3
Low Shrubland	0.3
Bare Ground	0.3
Indigenous Forest	0.2
Degraded	0.2
Cultivated commercial annual crops pivot	0.1

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

Objectives

The Tsitsa River Project Monitoring Plan main objectives are:

- to measure and describe the condition and health (baseline) of the catchment (T35 A-D),
- to provide data to better understand the dynamic nature and condition of the catchment,

- to evaluate the effects of current and future management practices and programs within the catchment (monitoring), and
- to feed this knowledge gained from measuring biophysical variables to relevant stakeholders.

MONITROING QUESTIONS AND INDICATORS

Effective long-term monitoring is a question-driven process. To acquire meaningful information, however, good questions must be scientifically tractable and linked to objectives and desired conditions from which to measure progress toward restoration. The Biophysical Monitoring team endeavour to achieve this end by formulating questions to evaluate the goals and objectives of the Tsitsa River Project in terms of improving ecosystem infrastructure, improving ecosystem services and improving livelihoods sustainability. The goals, objectives and questions were grouped into three overarching themes: climate, ecosystems/ land cover/ land use, and water. The Biophysical Monitoring team has developed a set of initial questions, monitoring indicators, and measured variables based on the objectives.

Questions

- Has ecosystem infrastructure improved in catchments T35 A-D?
- Has ecosystem goods and services improved in catchments T35 A-D?
- 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 River Project Biophysical Monitoring Groups selection of the catchment indicators began with a review of relevant literature. This review provided a list of catchment biophysical indicators that are used in similar situations elsewhere. The review resulted in indicators that could be summarised along the following themes:

- Climate,
- 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 the Drivers-Pressures-Stressors-Condition-Responses that affect ecosystems (Figure 1). 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: 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 Plan 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.

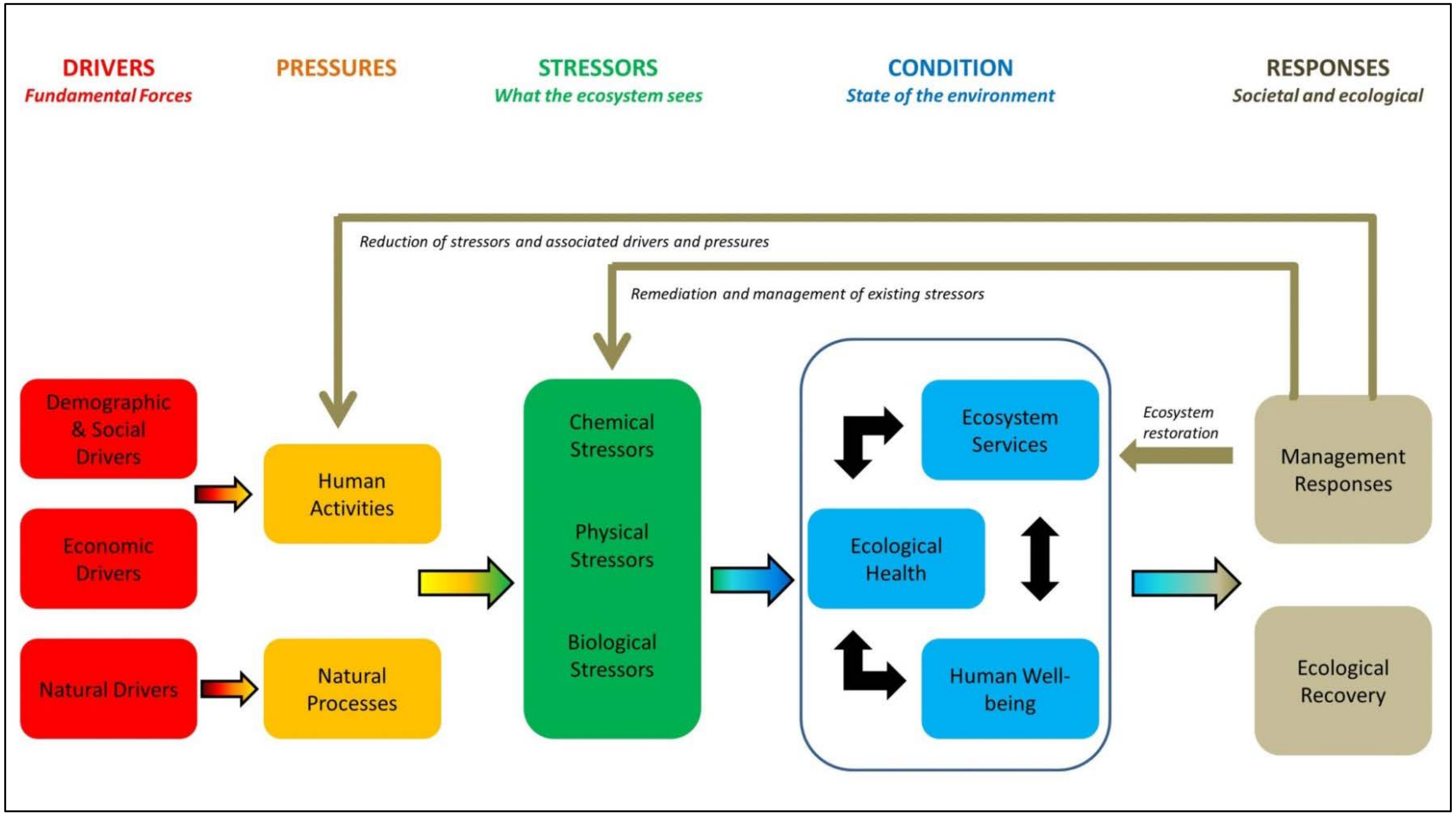


FIGURE 1: THE INTEGRATED MONITORING FRAMEWORK FOR THE TSITSA PROJECT IS BASED UPON THE DRIVERS-PRESSURES-STRESSORS-CONDITION-RESPONSES THAT AFFECT ECOSYSTEMS (BASED ON TEXAS COAST ECOHEALTH METRICS FRAMEWORK AND PROTOTYPE REPORT CARD, 2017)

Table 1: Table showing proposed Indicators and Measured Variables under different Domains and Themes

Theme	Domain	Indicators	Measured Variables
Climate	Regional Weather and climate	Hydro-meteorological trend over time	• Rainfall (mm) • Temperature (°C) • Evaporation (mm/per unit time/ unit area) • Atmospheric pressure (millibar) • Solar radiation • Wind speed (m/s) • Relative humidity (%)
Ecosystems/ Land cover/ Land use	Geomorphology	Hillslope features and process	• Slope (% or gradient) • Connectivity (m) • Erosion (m^3) • Gully expansion (% or ha or m^2)
		River channel characteristics	• Channel classification • Index of channel stability • Index of channel condition
	Soils	Soil quality, function and dynamics	• Soil classification map • Soil Carbon trend (%) • Microbial Activity • Soil infiltration (mm/hr) • Soil erosivity
	Land cover/ Land use	Land cover/ use	• Land cover/ use (% or ha) • Productivity (?)
		Fire dynamics	• Fire frequency, location, extent, severity (% or ha)
	Ecosystems	Grassland	• Cover, composition, functional species (% or ha)
		Forests	• Extent, composition, threatened (% or ha)
		Riparian vegetation	• Extent, composition, condition (% or ha)
		Wetlands	• Size, type, location, health, ecosystem services (% or ha)
		Alien vegetation	• Extent, composition, density, age (% or ha)
Water	Hydrology	Groundwater dynamics	• Borehole water levels (m) • Seep dynamics (wet-dry periods) (ha and time)
		Surface water flow	• Base flow modeling (m^3) • Flood peaks (m^3) • Runoff (m^3)
	Water quality	Water quality- chemical and physical	• Nitrates • Phosphates • Suspended sediment (t/ha/yr) • pH • Dissolved oxygen • Electric conductivity • Turbidity • Temperature
		Aquatic macroinvertebrates and diatoms	• SASSv5 & MIRAI • IHI • VEGRAI

DATA INVENTORY

The data inventory shown in Table 2 is the datasets that are currently accessible and pertinent to the Biophysical Monitoring Plan for the Tsitsa River Project.

TABLE 2: TABLE SHOWING DATA THAT IS CURRENTLY ACCESSIBLE FOR THE TSITSA RIVER PROJECT

Data Source	Data Type	Scale
Department of Water and Sanitation (DWS)	Gauging Stations • T3H006- Current • T3H009- Current • T3H003- Historical • T3H014- Historical • T3H016- Historical	Catchment
	Boreholes • Multiple locations, not monitored	Catchment
	Water Quality Stations	Catchment
Department of Environmental Affairs (DEA- EGIS)	Maps and data of • Land cover (1990 & 2013/2014) • Protected areas	National
South African Weather Station (SAWS)	Weather/ Climate stations • Mthatha • Elliot • Matatiele	Regional
SANBI	Maps and data of • Vegetation • Ecosystems (NBA 2011) • Wetland inventory/ vegetation • ECBCP- aquatic/ terrestrial • NPAES- focus areas • SKEP	National
Wildlands	Maps and data of • Groundcover • Productivity • Species richness and abundance	Unknown
Agriculture Research Council (ARC)	Maps and data of • Grazing Capacity • Degraded lands	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
Automated logger	• Rainfall tipping buckets • Level loggers (Flow) • ABS probe (Sediment) • Barologgers (Pressure)	Catchment/ Reach/ Plot
Citizen Technicians	Suspended sediment	Sub-catchment/ plot
GIS Maps and data created	• Wetlands • Erosion associated with wetlands • Alien vegetation • Cultivated lands	Catchment

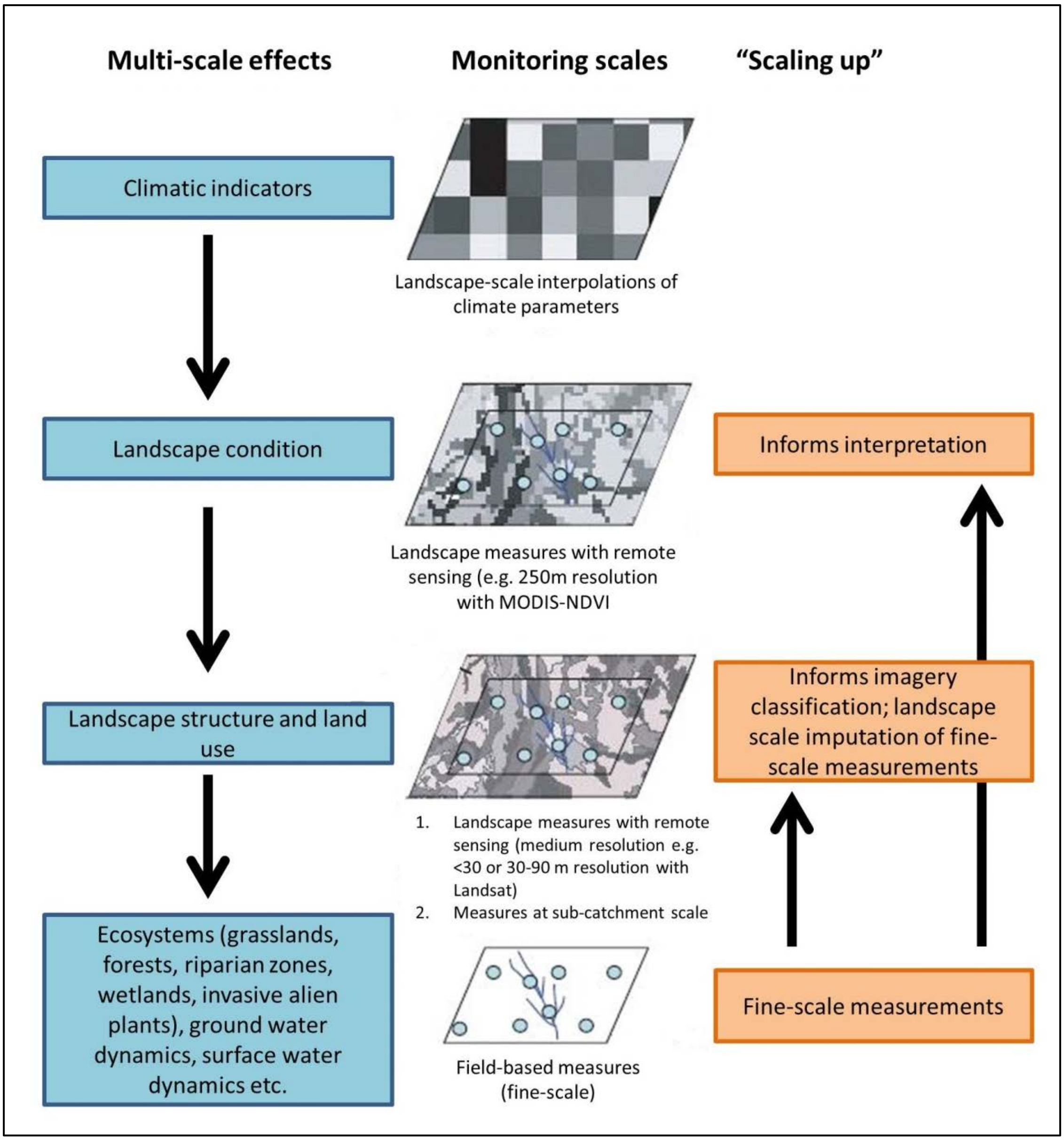
	• Gullies
	  o Discontinuous gullies
	  o Continuous gullies
	• Roads- Main, arterial, dirt roads, jeeps tracks
	• Livestock tracks
	• Settlements
	• Geology
	• Slope	

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).

The Tsitsa River 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 pattern and human disturbance. 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 and Gregory 2002]).



Site Selection

Climate

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

ECOSYSTEMS/ LAND COVER/ LAND USE

GEOMORPHOLOGY

CATCHMENT SCALE GEOMORPHOLOGY

SEDIMENT PATHWAYS AND LANDSCAPE CONNECTIVITY

Landscape connectivity over the past 100 years has been enhanced by the formation of gullies, livestock tracks and roads (Van der Waal & Rowntree, 2017). An increase in both downslope connectivity and across slope connectivity leads to highly increased hillslope to river channel coupling, making water and sediment routing very efficient (Van der Waal & Rowntree, 2017). A high increase in sediment routing and export results as areas that were formerly functioning as water and sediment buffers and sinks are turned into conduits of both water and sediment (Van der Waal, 2015). Van der Waal (2015) summarised the landscape setting, anthropogenic influences, and changes to landscape connectivity and the possible effects of increased vegetation cover and rehabilitation and its effects on sediment dynamics in the Thina River Catchment (Quaternary Catchment T34 A-C) (Figure 2).

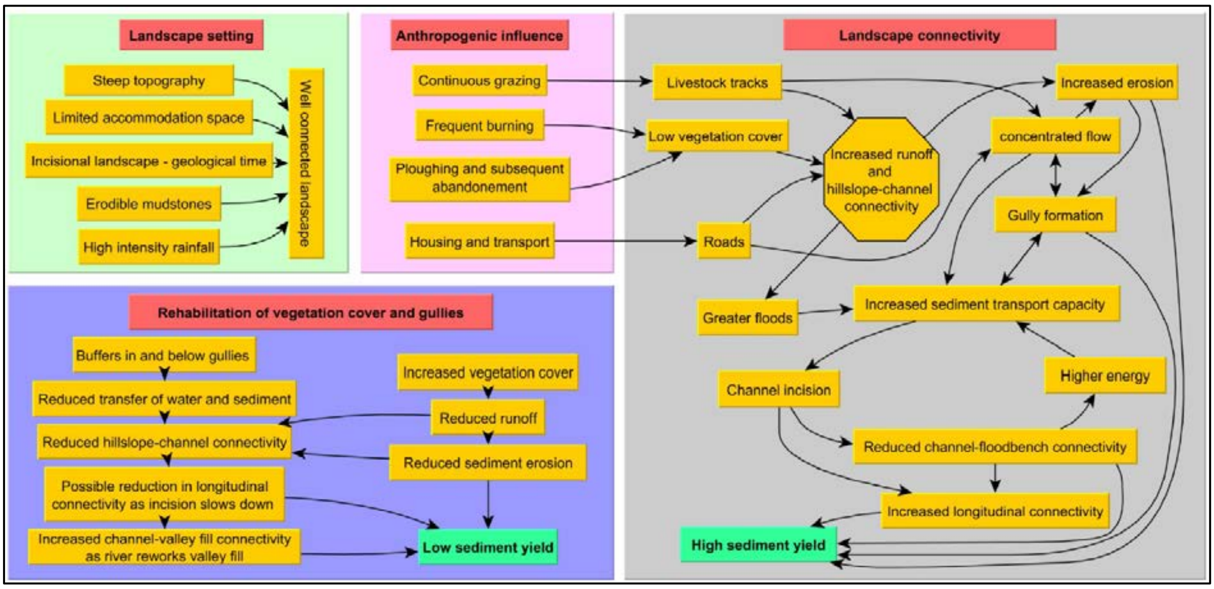


FIGURE 2: CONCEPTUAL DIAGRAM OF HOW LANDSCAPE CONNECTIVITY HAS ALTERED SEDIMENT DYNAMICS IN THE THINA RIVER CATCHMENT (VAN DER WAAL, 2015)

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

Sediment source tracing

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

Suspended sediment is collected using time-integrated samplers (Phillips *et al*., 2000) (Figure 1) that are bolted onto bridges in the river at varying heights. Recently deposited sediment can be collected from sand banks and behind water infrastructure such as weirs using a 30 cm plastic corer.

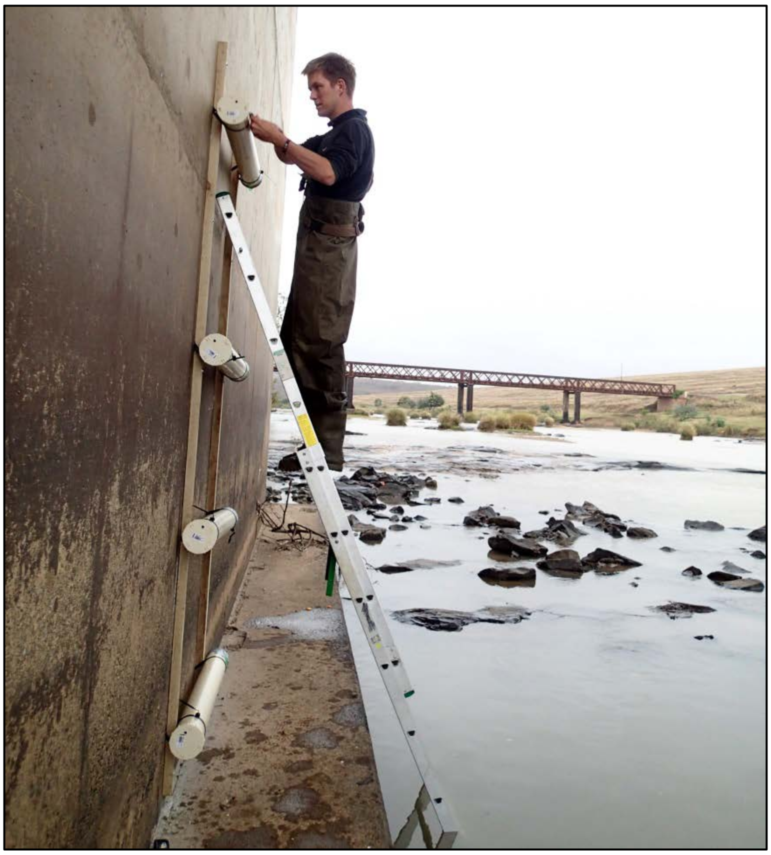


Figure 3: Installing time integrated samplers in the Tsitsa River

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

Fluvial geomorphology/ Geo-habitats

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

The following methods are adapted from Rowntree (2015):

Desktop study

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

Data collection

- Determining the Present Ecological State (PES) using the Geomorphic Assessment Index (Rowntree, 2013):
    I. Map/sketch of channel planform and channel transects with channel dimensions
    II. Channel classification including:
        - reach type,
        - dominant sediment class
        - morphological units
        - geo-habitats.

- description of reference condition
- rating of driver metrics including geomorphic connectivity, sediment supply, channel stability and habitat change related to channel morphology

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

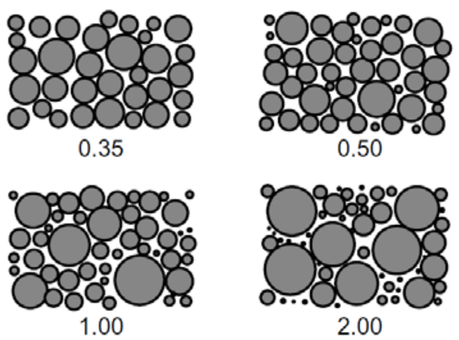
VIII. Packing is a measure of bed stability and cab be assessed using the table below

Table 3: 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. Sorting accesses the range of particle sizes or particle size variability at a point in the channel. Sorting provides an indication of bedload transport processes and is assessed visually using the table below

Table 4: 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 3. The size class of the largest and second largest clast type is recorded to make up the first two digits of the number, and following a full stop the percentage cover of fine sediment is estimated, making up the third digit. For example, a cobble bed with a substrate mixture of small cobble (code 6) and medium gravel (code 3) embedded by 40% fines (0.4) will result in an embeddedness index of 63.4. Bedrock or large boulders with no fines will result in an embeddedness index of 99.0 or when completely embedded by fines an embeddedness index of 91.9. Packing, sorting and embeddedness were quantified at a quadrat scale to set up a table of substrate properties along each transect in each site. The percentage fines (code 3) of the embeddedness index can be monitored seasonally under different flow conditions to monitor patches of fines collecting on the substrate.

Table 5: Substrate description categories for embeddedness values (From: Gordon *et al*., 2004).

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

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

SOILS

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

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

Land cover/ Land use

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

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

Ecosystems

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

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

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

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

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

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

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

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

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

Hydrology

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

Groundwater dynamics

DWS (2016) identified groundwater as a key resource for poverty reduction and economic development of rural and semi-urban areas (Department of Water and Sanitation Strategy: National Groundwater Strategy, Dec. 2016).

Baseflow dynamics indicate groundwater dynamics. See methods below. When analysing flood duration curves the recession curve represents groundwater flow patterns (Gordon *et al*., 2004). If groundwater contributions are significant then the curve at the lower end tends to be flattened whereas a steep curve indicates minor baseflows.

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

Borehole water levels

The Department of Water and Sanitation has a dataset of boreholes in the catchment. However, none of the boreholes in Catchment T35 A-E are currently being monitored by the Department of

Water and Sanitation and no data is available in the National Groundwater Archive for this catchment. If funding permits groundwater level sensors can be installed in various boreholes across the catchment.

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

Hillslope seep wetlands occur where topographic and stratigraphic conditions allow groundwater to intersect the surface (Stein *et al*., 2004) (Stein, E.D., Mattson, W., Fetscher, A.F. & Halama, K.J. 2004. Influence of geologic setting on slope wetland hydrodynamics. *Wetlands* 24: 244-260.). The condition and resilience of hillslope seep wetlands are therefore controlled by their hydrodynamic characteristics and recharge mechanisms. Underlying geology (sedimentary and/or basaltic), underlying deposits (alluvial/colluvial) and presence of faults and dykes will affect the volume and recharge rate of groundwater. Factors such as vegetation cover, which can also be linked to the geology (soils) also play a role. By understanding the mechanisms controlling functional wetland seeps, indirect impacts can be monitored and management actions can more accurately be applied (Stein *et al.,* 2004). Van der Kamp and Hayashi (1998) (van der Kamp, G & Hayashi, M. 1998. The groundwater recharge function of small wetlands in the semi-arid northern prairies. *Great Plains Research* 8:39-56) state that small wetlands are a vital point for groundwater recharge. This can occur on wetlands that occur on shallow slopes where water accumulates such as depression wetlands and floodplain wetlands.

Surface water flow/ Discharge

Flood/peak discharge modelling

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

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

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

Base flow modelling

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

Discharge for each unit is calculated using the following formula:

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

Where:

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

d = depth (m)

l = length of unit (m)

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

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

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

$$Q = VA$$

Where:

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

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

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

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

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

Where:

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

L = known distance (m)

t = travel time (s)

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

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

Where:

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

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

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

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

Water Quality

Physical and chemical water quality

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

Nitrate and phosphate concentrations

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

Electrical conductivity (EC) and pH

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

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

Dissolved oxygen

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

Temperature

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

Turbidity

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

Data will be used from Bannatyne (2017).

Suspended sediment

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

Biological response indices: aquatic macroinvertebrates and diatoms

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

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

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

Index of Habitat Integrity (IHI)

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

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

TABLE 6: METRICS RATING TABLE (KLEYNHAUS ET AL., 2008)

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

RIPARIAN VEGETATION RESPONSE ASSESSMENT INDEX (VEGRAI)

THE SOUTH AFRICAN DIATOM INDEX (SADI)

DATA MANAGEMENT

The Tsitsa River Project Biophysical Monitoring Group is stewards of the irreplaceable 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 TRPBMG. From planning, to field work, and through to analysis, priorities will be place on:

- Data Accuracy

The quality of the ecological 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 TRPBMG 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 TRPBMG will ensure that data sets are migrated to current software and formats, and documentation will accompany all data.

- Data Accessibility

Data will be made available in a variety of formats to any interested and affected stakeholders.

Data Analysis and Reporting

Disseminating results in a useable format for managers and a wide audience is central to the success of the Tsitsa River 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 management-oriented meetings, professional meetings, and in scientific publications.

THEME	
Climate	
Ecosystems, Land cover/ Land use	**Land cover, landscape connecti**
	La
	Grassland, Forests, Ri
	Invasive

Water	**Groundwat**
	Water chemistr
	Macroinver