A baseline survey of channel geomorphology with particular reference to the effects of sediment characteristics on ecosystem health in the Tsitsa River, Eastern Cape, South Africa.

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Supervisor: Professor Kate Rowntree

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ABSTRACT

Fluvial systems are dynamic systems in which variables in a catchment and river channel affect the morphology of river reaches. South African rivers are increasingly being exposed to stresses from a combination of factors, one of the most prevalent being the impacts of damming rivers which result in varying downstream sediment fluxes and flow regimes. The sediment load combined with flow characteristics for respective river channels provides the physical habitat for aquatic ecosystems. The damming of the Tsitsa River, through the construction of the Ntabelanga Dam, will change the overall downstream geomorphology. This creates an opportunity for research in the pre-construction window. The current condition of the Tsitsa River was monitored by completing a baseline survey of the channel geomorphology with specific reference to the influence of sediment on river habitats and ecosystem health. Five sites were established in variable reaches of the Tsitsa River, with Site 1 located above the proposed Ntabelanga Dam inundation and Sites 2-5 below the proposed dam wall. Each site included a range of features that can be monitored for their response to the dam. Physical variables, water quality and biota were monitored seasonally to note changes in habitat quality. A baseline survey of the present geomorphology and associated instream habitats of the selected reaches was set up by conducting cross-sectional surveys of channel topography, water slope surveys, discharge measurements and visual and quantitative assessments of substrate. Level loggers were installed at each site to collect continuous data on variations in depth and temperature. Monitoring surveys, in terms of fine sediment accumulation, were conducted to characterise dynamic habitat arrangements and macroinvertebrate community composition. A taxa related physical habitat score for the Tsitsa River was created. The relationship between water quality, physical and ecological characteristics of the Tsitsa River will aid further research in the area as well as create a better understanding of the influence of sediment on river habitats and ecosystem health. Monitoring sites can be used to monitor the impact of catchment-wide rehabilitation on river health prior to the dam being built. After dam construction, the top site above the dam inundation can still be used as a point to monitor the impact of catchment rehabilitation on ecosystem health in terms of fine sediment accumulation.

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And lastly to my motivators; various role models from the Wild West and more importantly the pioneers of this field, to whom I have adapted this song from an unknown cowboy bard (adapted from 'So Big Texas', The National Geographic Magazine, June 1928):

"Backward, turn backward, oh time on your wheels,
Airplanes, wagons, automobiles;
Dress me once more in a sombrero that flaps,
Spurs, a flannel shirt, slicker and chaps;
Give me a flow meter or two in my hand,
And show me a flood to rope and to brand,
Out where the rivers are dusty and grey,
Make me a cowboy again just for a day."

"Thunder of floods over the range as we ride,
Hissing of iron and smoking of hide;
Bellow of cattle in the catchment,
Wild longhorns from the Tsitsa an attachment;
Turbid flows resulting in taxa interred,
Whistles from the herder, from a villager a friendly word;
Right in the midst of it all I would stay,
Make me a Geomorphologist any day."

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LIST OF ABBREVIATIONS

ASPT	-	Average score per taxa
DEM	-	Digital Elevation Model
DGPS	-	Differential Global Positioning System
DO	-	Dissolved oxygen
EC	-	Electrical conductivity
ER	-	Entrainment ratio
ESRI	-	Environmental Systems Research Institute
FTU	-	Formazin Turbidity Unit
GIS	-	Geographical Information Systems
HMID	-	Hydro-morphological Index of Diversity
Masl	-	Meters above sea level
Mini- SASS	-	Simplified South African Scoring System
NTU	-	Nephelometric Turbidity Unit
Q	-	Discharge
RBS	-	Relative Bed Stability
SASS/ SASS 5	-	South African Scoring System Version 5
SDI	-	Shannon Diversity Index
WRC	-	Water Research Commission

CHAPTER 1: INTRODUCTION

Dams have a multitude of influences on a river system. By damming a river, the downstream flow and sediment characteristics are altered. This in turn affects available habitats and associated biota. It is important to understand the condition of a river before dam construction. This aids management of flows in order to maintain ecosystem services and keep river conditions as close to natural as possible below an impoundment. In this thesis a baseline survey of channel geomorphology was conducted with specific reference to the influence of sediment on river habitats and associated biota, prior to the construction of the Ntabelanga Dam. Macroinvertebrates are the most preferential group of organisms used to study the effects of water quality changes in a river system. In addition macroinvertebrate community composition provides an understanding of the influences of sediment deposition on ecosystem health. In this study macroinvertebrates were used to assess the amount of sediment deposited on the bed of the river by looking at the community structure of macroinvertebrates in habitats with different sediment concentrations. Through this a taxa related physical habitat score for the Tsitsa River was created.

1.1 Background and Motivation

Catchment variables influence river channels and the dynamic morphologies of river reaches. Poff *et al*. (1997) observed that the physical processes in rivers that define the structure of the environment in turn alter the habitat. The natural flow regime is variable and may change over any given time scale including hours, days, seasons, years or longer (Poff *et al.,* 1997; Rowntree & Wadeson, 1999). Furthermore, river's flow regimes display regional patterns that are commonly determined by the size of a river, as well geographic characteristics such as climate, geology, topography and vegetation cover (Poff *et al*., 1997). The movement of water and sediment within the channel and between the channel and floodplain is of utmost importance. The physical habitat is influenced by sediment size and heterogeneity, morphology of the channel and adjacent floodplains as well as other relevant geomorphic features (Poff *et al*., 1997). Fluvial geomorphological processes control aquatic biodiversity in river systems by shaping the physical habitat (Newson, 2002; Chessman *et al*., 2006). The sediment load combined with the flow characteristics for respective river channels determine the quality of the physical habitat for aquatic ecosystems (Poff *et al*., 1997; Puckridge *et al*., 1998; Newson, 2002; Chessman *et al.,* 2006).

Sediment comprises an essential part of the ecosystem, creating habitat and substrate for a variety of organisms (Apitz, 2012). Apitz (2012) notes that changes to the hydrodynamics in a catchment or river channel can affect the stability of soils by altering erosional and depositional patterns of sediments, in turn affecting habitats and in severe cases reducing habitat diversity. Alterations to channel morphology, flow regimes and sedimentation patterns can alter habitats, habitat function and ecosystem services of aquatic species (Apitz, 2012). Habitat alteration occurs due to either an increase in sediment supply and deposition or a decrease in sediment supply which in turn decreases deposition of fine sediment. This can commonly be seen below dam constructions.

Environmental flows (Ecological Reserves) encompass the water needed to maintain the ecological functions of a system so that the long-term sustainability of aquatic ecosystems and their associated organisms are not compromised (King & Louw, 1998; Dube *et al*., 2015). Controlled artificial flows below dam constructions are allocated to maintain the aquatic environment and in turn they indirectly support the livelihoods of people, by maintaining important ecosystem services. Environmental flows, which make up a key element of integrated water resources management and require a thorough baseline of river conditions before dam construction, are an important input for studies of post impoundment impacts (Dube *et al*., 2015). Correct environmental flows are essential for maintaining the channel morphology below dam constructions and studies of sediment dynamics are important to maintain the sediment balance in aquatic habitats after dam construction.

The assessment of benthic macroinvertebrates is an effective means of determining the condition of a river (Dickens & Graham, 2002). A range of effects on macroinvertebrates can be observed through the alteration of stream habitat, ecology or water quality including changes in species composition of aquatic communities (Gordon *et al*., 2004). Biomonitoring techniques such as the South African Scoring System (SASS) have been used to rapidly assess river water quality and health by covering aspects such as the ecological state of aquatic ecosystems, the spatial and temporal trends in ecological state, the impact of developments on a river system as well as predicting changes to ecosystems due to developments (Dickens & Graham, 2002). However, biomonitoring using SASS does not assess the physical habitat conditions in which macroinvertebrates are found.

South African rivers are increasingly being exposed to stresses from a combination of factors, one of the most prevalent being the impacts of dams which result in varying sediment yields and flow regimes (Rowntree & Wadeson, 1999). For example, the Pongolapoort Dam, constructed on the Phongola River in 1973, has had noticeable impact on the hydrological regime downstream of the dam wall and in turn has altered the ecological response of the river (Dube *et al*., 2015). Dube *et al*. (2015) noted that prior to dam construction the environmental flow regime, required to maintain the current biodiversity and ecosystem services of the river, was not established, resulting in a threatened ecological integrity downstream of the Pongolapoort Dam. Controlled flood releases, including the volume, rate, duration and timing of flows, have subsequently been recommended to simulate the original natural floods in an attempt to restore the ecological health of the river. However, these artificial flows are limited due to factors such as the sizes of the sluices on the dam wall and the demand for water by local communities (Dube *et al.,* 2015).

It is vital to ensure that baseline studies of a river's hydrological regime and associated habitats are conducted prior to dam construction. Management strategies for post dam scenarios can then include not only the social needs resulting from the dam construction but also have an insight into the processes behind maintaining a healthy ecosystem in the river after dam construction.

1.2 Mzimvubu Catchment

Rivers in the Mzimvubu catchment are some of the largest undeveloped rivers in South Africa (van Tol *et al.,* 2014a). However, the planned construction of two dams (Ntabelanga Dam and Laleni Dam) in the Tsitsa River, a main tributary to the Mzimvubu River, has potentially imminent impacts through the fragmenting of river ecosystems and the alteration of flow and sediment regimes in the river (Figure 1). The Environmental Impact Assessment for the Mzimvubu Water Project (Muruven & Calmeyer, 2015) provides the following information on the dams. The Mzimvubu Water Project is a Strategic Integrated Project intended for social and economic development in the Mzimvubu Catchment. The two multipurpose dams on the Tsitsa River, namely the Ntabelanga Dam and the Laleni Dam, will supply irrigated agriculture, domestic and industrial water requirements and generate hydropower. The Ntabelanga Dam has a proposed storage capacity of 490 million m^3 with the Mean Annual Runoff of the Tsitsa River at the Ntabelanga Dam being 415 m^3. Therefore the dam storage is 1.2 times the mean annual runoff resulting in a significant impact on the downstream flood frequency. A small hydropower plant will be constructed at the Ntabelanga Dam and flow will be released for hydroelectric generation at the Laleni Dam, in addition to irrigation water, situated downstream from Ntabelanga Dam. This will result in variable water levels in the Ntabelanga Dam and variable flow and a reduced sediment load downstream of the dam. There will be an environmental flow requirement; however details of this are still to be finalised. After dam construction several flow gauging weirs will be constructed above and below the dam in order to monitor the implementation of the environmental flow requirements (Muruven & Calmeyer, 2015).

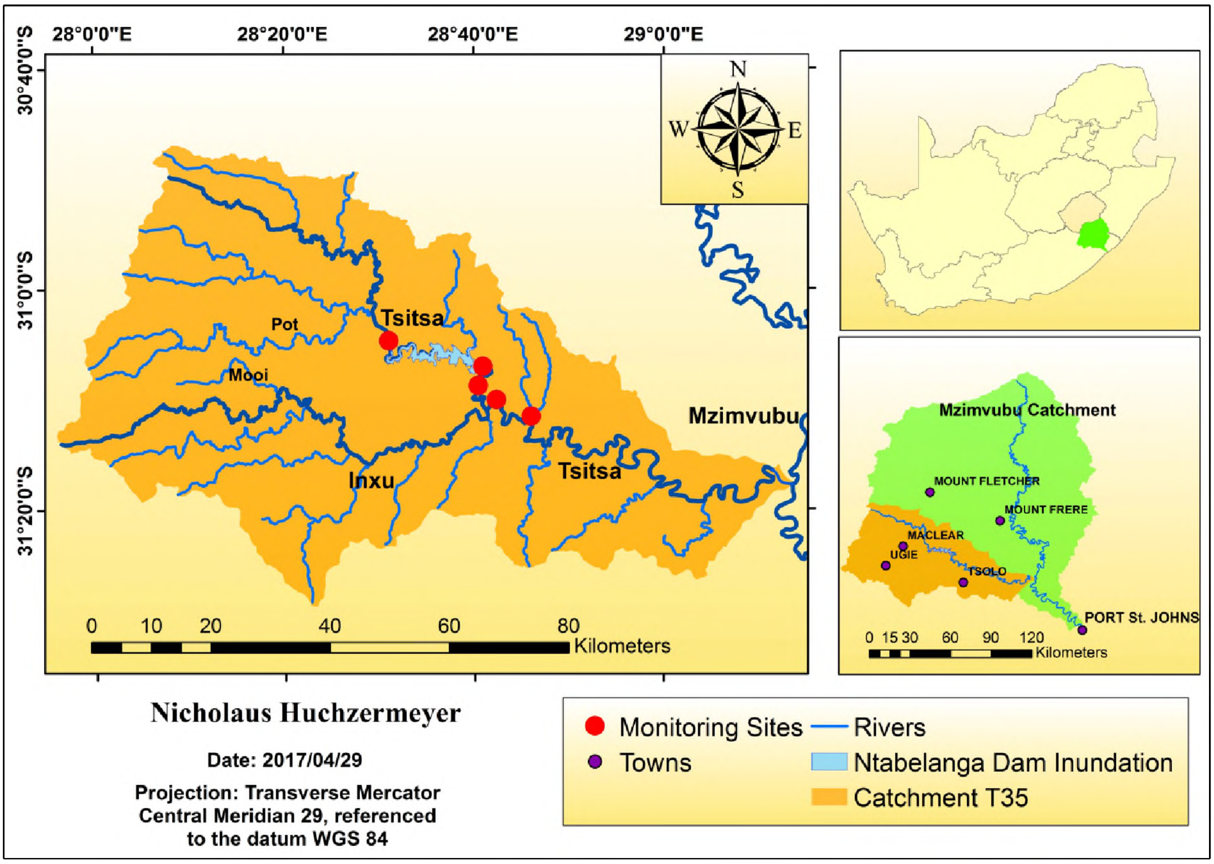


Figure 1: Locality map of the Tsitsa catchment, Eastern Cape, South Africa.

The Mzimvubu catchment is located in the foothills of the southern Drakensberg (Partridge *et al.*, 2010). Rainfall varies temporally from 707-928 mm per year and increases spatially with elevation (Mucina *et al.*, 2006). Precipitation peaks during summer months and often takes the form of intensive thunder showers. Winter precipitation occasionally occurs as snow. Evaporation during summer months can be as high as 1628 mm (Mucina *et al.,* 2006). The flow in the catchment is perennial and peaks in summer after intense thunderstorms.

The Drakensberg Mountain range, covering less than 5% of South Africa's surface area, contains one of South Africa's most strategic sources of fresh water and produces 25% of the country's runoff (Blignaut *et al.*, 2010). The Mzimvubu catchment is underlain by the Karoo Supergroup with the upper regions comprising of Drakensberg Group basalts and Clarens Formation sandstones overlying Elliot mudstones (De Decker, 1981)(Table 1). The Tsitsa catchment, immediately upstream of the proposed Ntabelanga Dam site, is underlain by sandstone and mudstone from the Beaufort Group (Caston, 1979; van Tol *et al.,* 2014a). Groups of isolated dolerite intrusions traverse the catchment (Caston, 1979). Soils derived from this suite of geological formations (Table 1) are highly susceptible to erosion due to their duplex nature (Laker, 2004).

Table 1: Geological formations in the Tsitsa Catchment, from the escarpment until proximal to the proposed Ntabelanga Dam. (Adapted from: Norman & Whitfield, 2006).

Essential Geological Features and Formations of the Stormberg, Drakensberg and Beaufort Groups of the Karoo Supergroup						
AGE	**GROUP**		**THICKNESS**	**MAIN ROCK TYPES**	**ENVIRONMENT OF DEPOSITION**	**SUSCEPTIBILITY TO EROSION**
183 Ma	Drakensberg Group		>2 000 m	Basaltic lava flows, fed by Karoo dolerite dikes	Continental scale rifting and eruption of flood lavas	Low
198 Ma	Clarens Formation	Stormberg Group	<300 m	Fine grained sandstone and siltstone	Wind- blown, dune covered desert with occasional ephemeral riverbeds	Intermediate
215 Ma	Elliot Formation	Stormberg Group	<500 m	Mudstones, with interbedded sandstones	Sinuous river systems on a semi-arid to arid alluvial plain	High due to dispersive soils
240 Ma	Molteno Formation	Stormberg Group	<600 m	Alternating sandstone, mudstone and shale	Braided river systems in a vast floodplain	High due to dispersive soils
250 Ma	**Beaufort Group**		**<7 000 m**	**Mudstones and sandstones**	**Extensive alluvial floodplains**	**Very high due to dispersive soils**

The Tsitsa River is a main tributary in the Mzimvubu Catchment and has its headwaters in the Drakensberg Mountains. The Tsitsa River flows into the Mzimvubu River which discharges into the Indian Ocean at Port St. Johns.

Figure 2 shows the susceptibility of different parts of the Tsitsa catchment to erosion. The potential for erosion as well as the amount of erosion increases down the catchment as the geology changes (Table 1). Therefore sediment sources become more common down the catchment resulting in a cumulative increase in sedimentation down the river system (Figure 2).

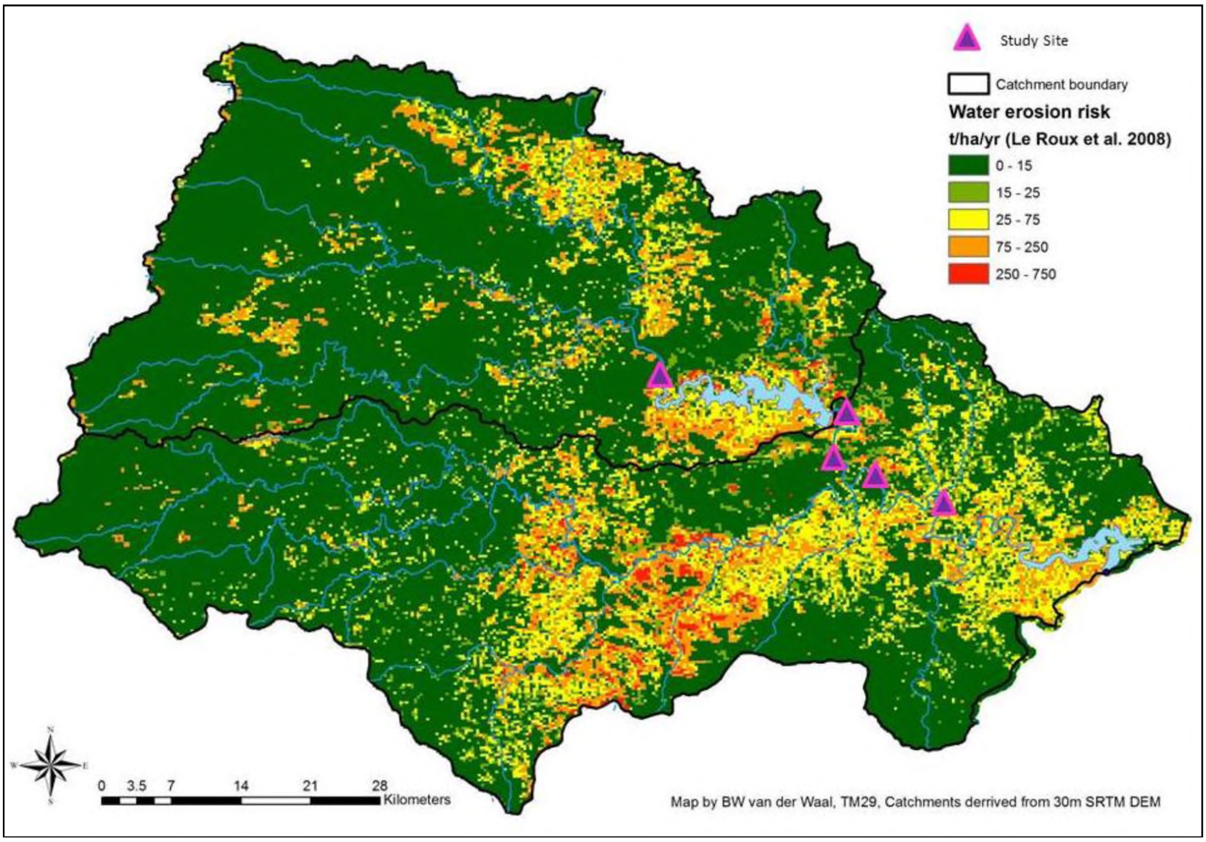


Figure 2: Erosion prediction map for the Tsitsa Catchment (provided by Dr B van der Waal).

Rural communities, which are widespread in the old Transkei homelands including this study area (van Tol *et al.,* 2014a), 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, 2014). Disturbances caused by the settlement of humans on the landscape ultimately result in an increase in sediment sources and pathways on the landscape, causing higher connectivity of hillslopes to the drainage network (van der Waal, 2014). Cultivated lands, abandoned lands (Kakembo *et al.*, 2009) as well as unsuitable grazing management regimes combined with inappropriate stocking rates affect the quality and quantity of water runoff and baseflow (Blignaut *et al.*, 2010; Vetter, 2009).

1.3 Morphology of the Tsitsa River

The baseline study conducted in this research will focus on sites in the Tsitsa River above the proposed Ntabelanga Dam inundation and below the dam wall to below the confluence with the Inxu River, a major sediment source for the Tsitsa River (Figure 2 and 3).

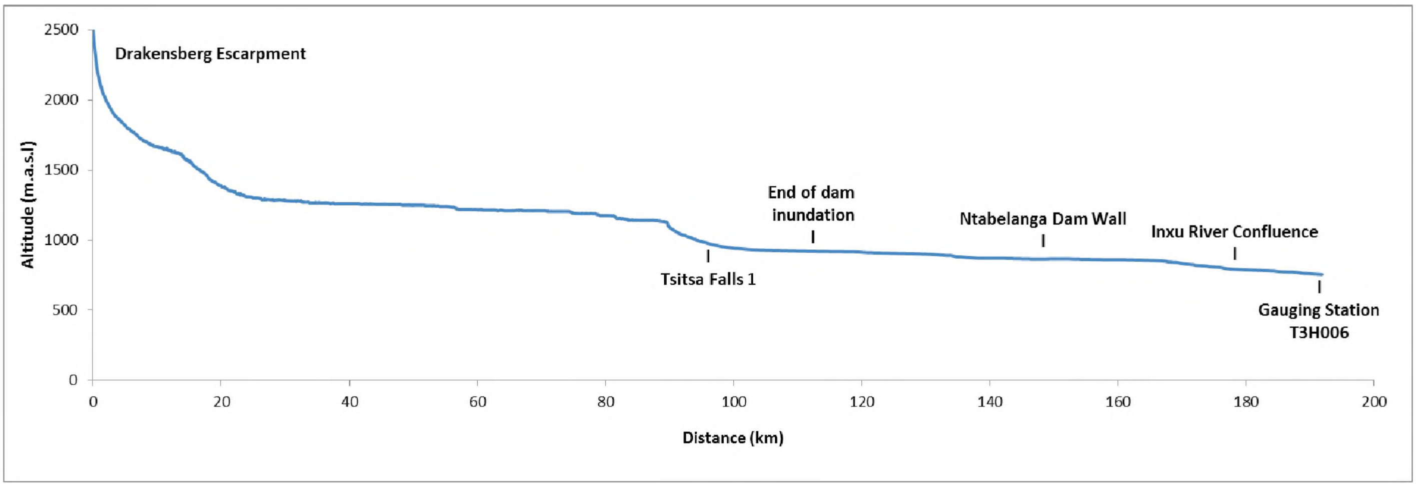


Figure 3: Longitudinal profile of the Tsitsa River from its headwaters in the Drakensberg Mountains to gauging station T3H006.

The damming of the Tsitsa River, through the construction of the Ntabelanga Dam, will change the overall downstream geomorphology. This creates an opportunity for research in the pre-construction window to help understand what the current geomorphic condition of a selection of channel reaches in the Tsitsa River is, above and below the proposed Ntabelanga dam. In addition the Tsitsa catchment is highly susceptible to erosion (Figure 2) resulting in large volumes of sediment being transported by the river system. Predictions of future impacts, through the rehabilitation of the catchment or dam construction, on stream geomorphology and ecosystems can be aided by understanding the current relationship between sediment characteristics and river habitats in the Tsitsa River. In addition this research will aid in the assessment of flows required to maintain the physical quality of aquatic habitats after dam construction.

1.4 Research Aim

The research aim of this study is to monitor the current condition of the Tsitsa River by completing a baseline survey of the channel geomorphology with specific reference to the influence of sediment on river habitats and ecosystem health.

1.5 Research Objectives

1. Establish monitoring sites for the investigation of characteristics of channel morphology.

2. Conduct a baseline survey of abiotic components, channel morphology and associated habitats at the selected sites.

3. Conduct a baseline survey of biotic components to characterise macroinvertebrate community composition.

4. Identify a relationship between biotic and abiotic components to determine the influence of sediment on river habitats and ecosystem health at the selected sites.

5. Discuss likely changes that will occur to channel geomorphology with specific reference to the influence of sediment on river habitats and biota after the dam has been constructed.

6. Make recommendations for future monitoring with particular reference to fine sediment accumulation in the Tsitsa River.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

River ecology has developed into a multi-disciplinary field, combining physical sciences and biology, to create a more inclusive understanding of complex fluvial systems (Hauer & Lorang, 2004). Rivers are shaped by dynamic and diverse processes. Geomorphological processes within a river system, as well as its associated ecological structure and functioning, take place over a range of temporal and spatial scales (Rowntree & Wadeson, 1999; Meyer *et al.*, 2003; Hauer & Lorang, 2004; Poff *et al.*, 1997; Dallas, 2008; Jacobson, 2013). The relationship between geomorphic processes, channel morphology, hydrology and habitat quality needs to be fully understood in order to quantify the current condition of a river.

This chapter reviews the current findings on sedimentation, biotic responses, hydrogeomorphic factors, the impacts of dams and monitoring principles.

2.2 The Relationship Between Sedimentation and Biotic Responses

Natural erosional processes have always contributed to a certain amount of sedimentation in streams. However, anthropogenic impacts on the landscape have augmented the amount of sediment entering fluvial systems. Silt from erosional processes has become a recurring problem (Ellis, 1936; Jones *et al.*, 2011). In areas such as the Tsitsa Catchment, constant disturbances to the land surface such as overgrazing and ploughing on already sensitive soils increases the amount of suspended solids transported into the river system. Van der Waal (2014) showed that the formation of gullies in disturbed areas increased the connectivity between hillslopes and river channels, in turn causing a decreased channel-valley fill connectivity that allows sediment to be exported from the catchment by the river system. Altered sediment dynamics due to connectivity increase turbidity and suspended sediment concentrations in the river system. Sedimentation results from particulates of silt, sand and/or fine gravels, sourced from eroded materials which enter a stream system as suspended sediment from the surrounding landscape (Henley *et al.*, 2000). Sediment is then deposited on the stream bed during periods of reduced water velocity. Sedimentation occurs at various scales depending on the amount of sediment entering a system and the preconditions for deposition. The impacts of sedimentation were already identified by Ellis (1936) in the Mississippi-Ohio-Missouri System. Ellis (1936) recognised that excessive loads of erosion silt have significantly increased the turbidity of streams as well as the amount of sediment and silt being deposited on river substrates, resulting in a marked change in both aquatic habitats and associated biota.

Particulates can be suspended, cover stream bed substrate, fill interstitial spaces and in severe cases cover an entire bed of substrate (Petts, 1988; Henley *et al.,* 2000; Allan, 2004).

It has been recognised by many authors that increased sedimentation and turbidity have a direct impact on ecological health in fluvial systems, and are commonly seen as the most detrimental aquatic pollutant (Ritchie, 1972; Lemly, 1982; Henley *et al*., 2000; Allan, 2004; Jones *et al*., 2011). However, unlike most other pollutants, presence of a certain amount of fine sediment is normal for the natural functioning of a river system and it is only when excess sedimentation occurs that negative impacts arise (Jones *et al*., 2011)(Figure 4). Henley *et al.* (2000) state that excess sedimentation and resulting turbidity in a river system have a direct impact on various aquatic trophic levels, including mortality, reduced physiological functioning and drifting of organisms to seek new niches.

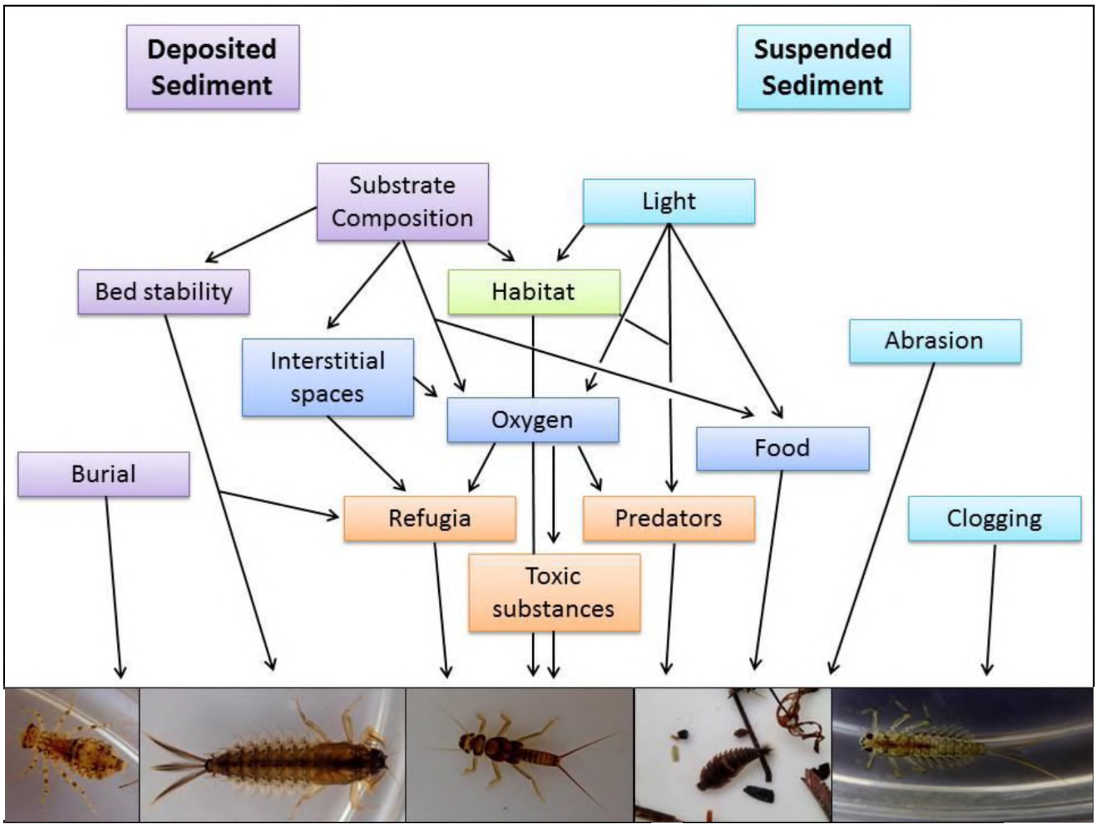


Figure 4: Direct and indirect impacts of fine sediment on macroinvertebrates, caused by both suspended and deposited sediments. Because of the diversity of macroinvertebrates and their range of sensitivities, different taxa and communities respond differently. Some undergo a positive change, others a negative change. (Adapted from: Jones *et al*., 2011).

During turbid flows, sedimentation specifically alters river habitats and associated biota by a combination of the following factors: increased turbidity, decreased light penetration, varied rates of temperature change, scouring and abrasion of substrate, infilling and draping of interstitial spaces between diverse substrates reducing available habitat niches, coating of gills and respiratory surfaces, trapping of organic material and other substances on the stream bed which are unfavourable to aquatic biota, reducing stream depth heterogeneity and reducing marginal vegetation and erosional banks due to deposition (Ellis, 1936; Steinman & McIntire, 1990; Hötzel & Croome, 1994; Allan, 2004). This can result in a change in pool species (reduction in depth and marginal habitats), rocky substrate species (different habitat niches) and species sensitive to water quality changes. In addition the extensive alteration of local scale food webs of aquatic organisms, starting at the primary trophic level, results in reduced rates of growth and reproduction (Henley *et al.,* 2000). Henley *et al.* (2000) state that the effects of sedimentation and turbidity can be directly linked to the amount of sediment entering a system as well as the period over which a system is exposed to high sediment loads.

Natural concentrations of sediment encompasses an essential part of the ecosystem, creating habitat and substrate for a variety of organisms (Apitz, 2012). Apitz (2012) notes that changes to the hydrodynamics in a catchment or river channel can affect the stability of soils both in the catchment, which increases the amount of sediment entering the river system, and in the river channel, which affects bed stability. This in turn alters erosional and depositional patterns of sediments, in turn affecting habitats and in severe cases reducing habitat diversity. Fluvial processes are strongly influenced by two dominant groups of factors, namely those which determine the capacity for sediment in the channel to be eroded or transported and factors responsible for sediment input into the channel (Rowntree & Wadeson 1999). Hauer & Lorang (2004) note that the movement of water and sediment in a river system commonly occurs along longitudinal connections between tributaries and rivers, lateral connections between the river and its adjacent floodplain and vertical water exchanges. Longitudinal connections will be more dominant in confined areas such as gorges where flow is concentrated, whereas the lateral and vertical exchange of sediment and water is more prevalent in floodplain areas that are less confined. Anthropogenic impacts on the river system can disrupt or enhance these connections as well as affect bed and bank stability, the amount of water and sediment coming down the river system and changes to channel shape. In turn all of these factors cause an imbalance in the complexity and dynamics of a river system resulting in a deluge of responses, particularly at a local scale (Allan, 2004).

Macroinvertebrates are the most preferential group of aquatic organisms to use in the biomonitoring of streams (Dickens & Graham, 2002; Türkmen & Kazanci, 2010) as they are able to occupy various specific family related micro-habitats due to a high diversity and a range of sensitivities. Where these micro-habitats are impacted by organic or inorganic pollutants, macroinvertebrates respond by a change in community composition (Gehrke *et al.,* 1995; Türkmen & Kazanci, 2010; Jones *et al.,* 2011). In addition the study of biological and ecological traits of macroinvertebrates, such as body size and shape, life history and behavioural traits, can shed light on the current processes at work and the history of sedimentation within a river system (Allan, 2004).

Quinn and Hickey (1990) found that substrate variability plays an important role in the aquatic health of a stream system. Macroinvertebrate density and diversity are directly linked to the substrate diversity. For example, stable cobble and boulder substrates generally have large interstitial spaces that host a diverse and abundant array of aquatic invertebrates (Quinn & Hickey, 1990; Henley *et al.,* 2000). Quinn & Hickey (1990) also observed that species that construct fixed shelters or inhabit stable beds are more resilient to large flood events. However, with the sedimentation of substrates, the availability of stable beds with large interstitial spaces becomes less common (Quinn & Hickey, 1990; Fryirs, 2003; Chessman *et al.,* 2006). Impermeable sediment barriers form when high concentrations of sediment fills interstitial spaces, in turn causing a reduction in hyporheic oxygen levels due to the inhibition of interstitial water circulation (Gordon *et al.*, 2004). Ryan (1991) linked a 12% to 17% increase in the deposition of interstitial sediments to a 16% to 40% reduction in the total abundance of macroinvertebrates. Habitat alterations, due to sedimentation, often result in a shift in macroinvertebrate community structures from more sensitive families to families that favour burrowing and are tolerant to lower oxygen levels (Ryan, 1991).

Lemley (1982) monitored the effects of inorganic sedimentation and nutrient enrichment on benthic macroinvertebrates in a southern Appalachian stream. Lemley (1982) identified the positions of point sources for different pollutants and assessed the combined effects of sedimentation and organic pollutants on a site as well as the singular effects of inorganic sedimentation on a different site above the point source for organic pollutants. Through this study, Lemley (1982) found that two or more pollutants (organic pollutants and inorganic sedimentation) have a significantly greater impact than a singular pollutant (inorganic sedimentation) in a stream. This implies that pollutants affect stream health synergistically. Sedimentation reduces habitat diversity by filling up interstitial spaces as well as affecting the filter feeding capabilities of various macroinvertebrate taxa (Lemly, 1982). In addition, compounds commonly associated with materials in the bedload of a stream can decompose and depress the pH, eliminating acid sensitive species of macroinvertebrates (Lemly, 1982). In a similar study, Wagener & LaPerriere (1985) found that turbidity was a dominant factor in sedimentation, reducing the density and biomass of macroinvertebrate communities.

Sediment also provides ecological functions such as the production of biomass, food and provision of raw materials (Apitz, 2012). Apitz (2012) states that habitat diversity and in turn diversity of ecosystem services is dependent upon a sediment balance. Therefore the focus of sediment management should start with the understanding of how dynamic interactions of flow and sediment contribute to the sustainability of ecosystems (Apitz, 2012).

Chessman *et al*. (2006) state that in order to accurately predict changes to biological assemblages, geomorphic controls in a river system need to be integrated with environmental drivers. Changes in water quality commonly occur concurrently with geomorphic changes, as the geomorphology of a river system commonly alters due to land uses causing human induced alterations in a catchment, such as removal of riparian vegetation or agricultural practices (Chessman *et al*., 2006). However, geomorphology and water quality can be defined as separate drivers in river processes. For example, diffuse or point inflows can affect water quality and not geomorphology. In turn rehabilitating geomorphology in a degraded stream will have no impact on the water quality unless catchment scale rehabilitation is performed. Therefore the spatial patterns of macroinvertebrate assemblages should be predicted by jointly monitoring the physical structure, hydrology and water quality of fluvial systems (Chessman *et al*., 2006), one of the most critical components affecting the health of aquatic organisms being water quality.

The following details on water quality were taken from (Dallas & Day, 2004):

- Natural variations in **temperature** occur due to daily and seasonal temperature patterns as well as through longitudinal changes along a rivers course. Benthic organisms thrive at certain temperatures or temperature ranges in a river system. Increased sediment supply into a river not only changes the morphology of the river channel affecting habitats but areas of increased sediment deposition become shallower, increasing water temperatures as well as temperature fluctuations. Other anthropogenic triggers of temperature changes in a river system can be caused by altering the flow properties of a river system such as through the construction of a hydroelectric dam. Increased water temperatures result in decreased oxygen solubility as well as increased toxicity of certain chemicals. Changes to temperature regimes in a river system due to anthropogenic influences have a direct influence on aquatic organisms and can prove lethal.

- The natural **pH** of a river system is determined by the surrounding geology as well as atmospheric influences. A pH of a relatively natural stream ranges from 6 to 8. Reduced growth rates and fecundity in aquatic organisms is commonly linked to small changes in pH due to increased energy requirements to survive in more acidic or alkaline waters.
- Material dissolved in water is commonly measured as **conductivity** or salinity. Conductivity is the measure of the ability of a sample of water to conduct a current. Electrical conductivity (EC) is naturally determined by geological or atmospheric conditions; however anthropogenic activities such as effluents from irrigation can increase the conductivity or salinity of water. The rate of change of EC is commonly the most detrimental to aquatic health, impacting juvenile stages of organisms.
- The survival of aquatic organisms critically relies on the maintenance of sufficient **dissolved oxygen** (DO) concentrations. DO levels can fluctuate diurnally and are dependent on the rates of respiration and photosynthesis of aquatic organisms and plants. Continuous exposure to concentrations of less than 80% of saturation can have acute effects on aquatic organisms.
- **Nitrogen and phosphorous** enrichment result in eutrophication of aquatic systems. High nitrogen concentrations are toxic to aquatic organisms. High concentrations of phosphorus are likely to occur in waters that receive sewage or runoff from agricultural lands. High concentrations of nutrients have a significant impact on the structure and functioning of biotic communities.

2.3 Hydrogeomorphic Factors Affecting Sedimentation, Physical Habitats and Biota

Jacobsen (2013) has stressed the importance of understanding the role of habitat dynamics on ecosystem health. Ecosystem structure and function in riverine systems is strongly influenced by the pattern of the physical habitat (Jacobsen, 2013). Jacobsen (2013) defines habitat dynamics as the change in habitat through space and time due to variations in discharge and geomorphology.

The hydrology of a fluvial system creates a unique physiochemical environment. Hydrological pathways transport energy and nutrients through a system (Mitsch & Gosselink, 2007). Water depth, flow patterns including the duration and frequency of flooding events influence the biochemistry of sediments and are a dominant factor for the success of biota (Mitsch & Gosselink, 2007). In turn biotic feedbacks affect the hydrology of a river (Figure 5).

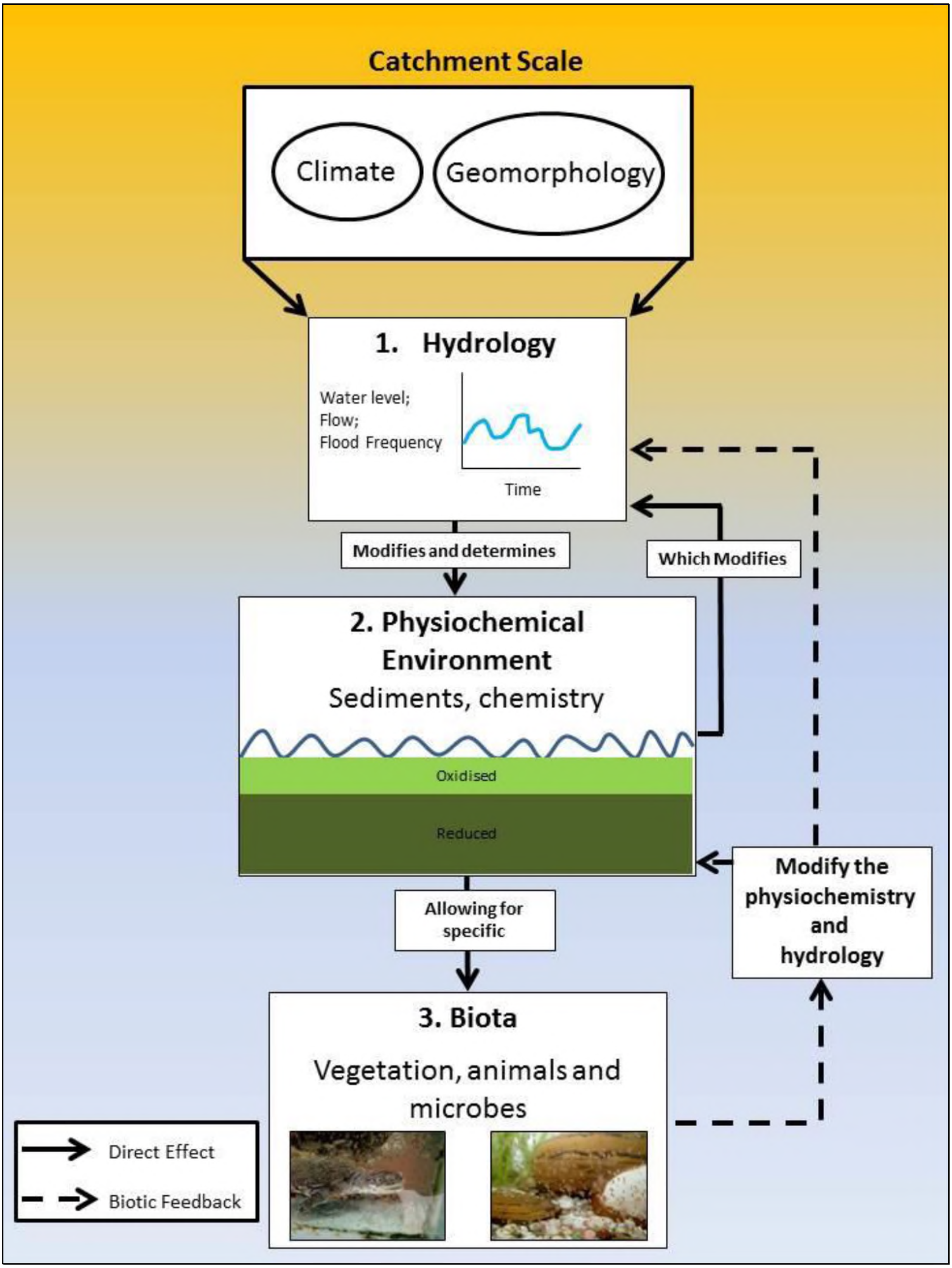


Figure 5: Conceptual diagram illustrating the effects of hydrology on fluvial system function and biotic feedbacks that in turn affect hydrology. (Adapted from: Mitsch & Gosselink, 2007).

Apitz (2012) emphasizes the importance of sediment input and how variable inputs have the capability to change habitats and describes the diverse role that sediments have on ecosystem health (Table 2).

Table 2: Characteristics of sediment deposition locations and transport that influence potential effects of sediment on various endpoints, such as habitat. (From: Apitz, 2012).

Characteristic		Consequence
Location ↑	**Relative location**	Source will not affect upstream endpoint locations; source can potentially impact all downstream endpoint locations over time
	Water depth	Sediment loss; siltation and hydromorphological loss can change water depths required for specific endpoint; reduce habitat diversity; flooding can change habitat
	Hydrologic balance	**Maintains habitat diversity**
	Depositional potential	Potential excessive deposition
Transport ↓	**Suspension/ erosion**	Excessive suspended sediment effects habitat; insufficient suspended sediment causes erosion
	River connectivity	Barriers in rivers reduce sediment transport downstream; induces erosion
	Landscape connectivity	Landscape connectivity affects the amount of sediment transported to a river

One of the most dominant factors controlling the ecological processes in a river system is its natural flow regime (Puckridge *et al*., 1998). The spatial location of river systems (climate, geology, catchment processes) plays an important role in the natural flow variability. Rivers in arid to semi-arid areas will have a significantly larger variation in flow than rivers situated in humid climates that tend to have a constant supply of water (Puckridge *et al*., 1998). This in turn affects the available habitats in a river, the processes occurring within the river and the aquatic organisms. The natural flow regime plays an important role in maintaining sustainable ecosystem health and dynamic ecology in a riverine system (Poff *et al*., 1997). Streamflow characteristics such as quantity and timing are critical components (Poff *et al*., 1997). The streamflow of a river can be linked to physiochemical characteristics such as water temperature, channel geomorphology and habitat diversity (Pennack, 1971; Poff *et al*., 1997). Studies such as those by Pennack (1971), Puckridge *et al.* (1998) and Díaz *et al*. (2008) identify a number of variables which are used to classify stream habitats. These include:

- Width of stream channel,
- Nature of flow (temporary/permanent),
- Flow velocity,
- Type of substrate,
- Summer and winter water temperatures,
- Turbidity,
- Total dissolved organic and inorganic matter,
- Dissolved oxygen,
- Aquatic and marginal vegetation
- pH
- Electrical conductivity

The distribution and abundance of riverine species, in particular macroinvertebrates, are commonly restricted by these variables (Dickens & Graham, 2002). Puckridge *et al.* (1998) recommend that whilst conducting a habitat assessment, eight to eleven variables should be considered depending on the scale of the study. Díaz *et al.* (2008) used up to 39 variables in their large scale habitat assessments including physiochemical, geomorphic and in stream variables. Thorp *et al.* (2010) focus on the physical structure of a river, suggesting possible solutions to assigning natural ecological benefits and anthropogenic ecosystems services in riverine landscapes through hydrogeomorphic classifications of rivers.

Henley *et al.* (2000) recognised that riparian buffer zones play a very important role in the reduction of suspended sediments entering a fluvial system from the surrounding landscape. The restoration of natural vegetation along riparian zones has several positive effects, including channel bank stabilisation and the trapping and deposition of sediments, by reducing the surface velocity of water, before they enter a river channel. This in turn has a significant positive effect on instream habitats and associated biota within an aquatic ecosystem (Henley *et al.,* 2000).

Rivers are complex systems and need to be studied at a range of scales (Allan, 2004). The natural and land use related processes within a river catchment play a pivotal role in ecosystem health and have a dominant influence on habitats within a river as well as its biological diversity. Church (2002) classified several types of geomorphic thresholds in riverine landscapes. The sediment transport regime and character of alluvial deposits along a river channel are determined by the flow regime, sediment yield in the channel and the gradient of the channel. These factors in turn set the threshold conditions in a river which control river channel form (Church, 2002). Church (2002) notes that changes in a riverine system occur systematically along a drainage system as the flow, gradient and sediment characteristics vary. This variation in the landscape results in a characteristic sequence of morphological and habitat types (Church, 2002). Church (2002) emphasises the importance of understanding geomorphic thresholds in rivers as they govern morphology and habitat, and human alterations can significantly impact these features.

River conditions at a local scale are influenced by the river reach as well as processes occurring in the surrounding landscape (Allan, 2004). Figure 6 illustrates that the small-scale (pool/riffle and microhabitat system) creation and maintenance of habitats for aquatic organisms is shaped from channel processes at intermediate scales (segment and reach system). This, in turn, stems from large-scale factors (catchment system), such as geology, climate and topography, which shape channel processes by controlling the geomorphic processes within a river system. Allan (2004) identified that the reach scale morphology is influenced by the catchment slope, input of water and sediment from upstream, valley confinement and bed and bank materials.

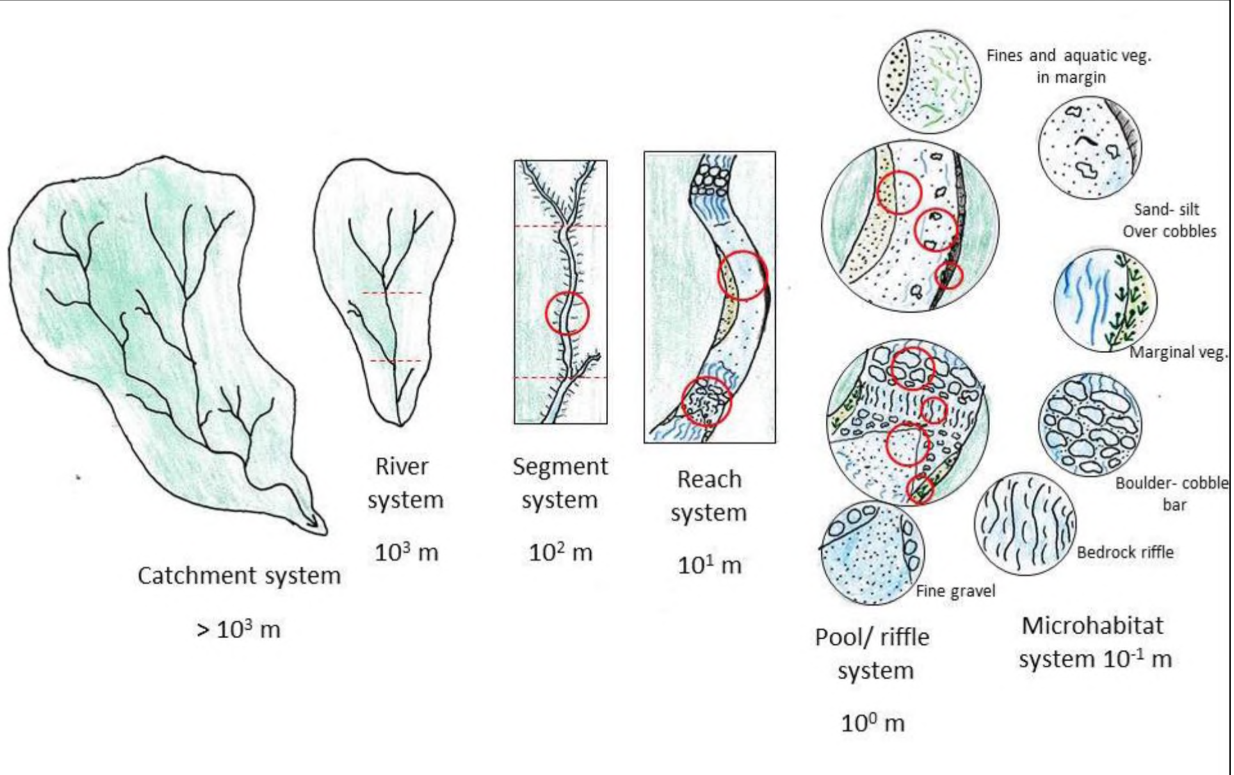


Figure 6: Hierarchical nature of rivers, from a large catchment scale to successively smaller scales of river segments, channel reaches, individual channel units (such as pools and riffles) and microhabitats. (Adapted from: Allan, 2004).

2.4 Downstream Impacts of Dams

Anthropogenic interventions, ranging from impacts at a large catchment scale to impacts at a small reach to sub-reach scale affect flow variability, geomorphic processes, channel morphology and habitat quality (Puckridge *et al*., 1998; Allan, 2004). This is most commonly caused by flow regulation (Puckridge *et al*., 1998) which alters flow duration and amplitude (Grubaugh & Anderson, 1988) and pulse frequencies (Carlson & Muth, 1989).

The geomorphic structure of a river is commonly associated with large flow events that have significant energy to move the bed substrate and change channel bank morphology, in turn reshaping river channels (Church, 1995; Chessman *et al.,* 2006). The frequency of large floods are commonly affected downstream of a dam, having a major effect on the downstream geomorphological and ecological processes (Petts, 1980; Ligon *et al*., 1995; Power *et al*., 1996; Chessman *et al,.* 2006; Petts & Gurnell, 2013). The construction of the Ntabelanga Dam will have severe impacts on downstream flood magnitudes and downstream sediment supply in the Tsitsa River.

2.4.1 Impact of dams on hydrogeomorphic factors

Dams are commonly seen as the most dominant form of anthropogenic impacts on a fluvial system due to their capacity to alter the flow and sediment regimes of rivers (Petts & Gurnell, 2005; Petts & Gurnell, 2013; Poeppl *et al.,* 2013). Petts & Gurnell (2013) note that through the damming of a river both low and high flows are captured resulting in direct downstream impacts. Poeppl *et al*. (2013) observed that channel changes occurred downstream of active dams in the form of channel degradation. However, armouring of the streambed through a change in geomorphic processes can reduce habitat availability for species living downstream of an impacted area (Poff *et al.*, 1997; Petts & Gurnell, 2013).

Each dam has a unique set of flow release policies depending on various factors including location, environment, substrate, released water and sediment. Changes to downstream hydrological regimes therefore vary from dam to dam according to flow input from the dam (Brandt, 2000). The relationship between the transport capacity of flow released from a dam and its sediment load, combined with the erodibility of the river banks, determines changes to river morphology (Brandt, 2000). Stream power, which is directly dependent on the product of discharge and channel gradient, affects a river's flow regime and is responsible for the amount of sediment transport, sediment deposition or erosion of the channel bed. Rowntree and Wadeson (1999) have shown that short-term changes to fluvial systems, such as changes to flow hydraulics, can be identified when focusing on river morphological units, bed forms and sediment grain sizes as they are likely to change. Dam construction will result in a disruption of this intrinsic interaction of processes making up the natural flow regime of a river.

This section describes changes that occur to fluvial systems due to dam constructions. The flow regime of a river, downstream of a dam wall, is altered in turn affecting channel morphology and aquatic habitats.

Hydrology

The natural flow regime is variable and may change over any given time scale including hours, days, seasons, years or longer (Poff *et al*., 1997, Rowntree & Wadeson, 1999). Local and regional flow patterns are determined by the variability in precipitation (intensity, timing and duration) combined with the effects of topography, soil texture and vegetation on the hydrologic cycle. These regional patterns are commonly determined by the size of a river as well as geographic characteristics such as climate, geology, topography and vegetation cover (Poff *et al*., 1997). Furthermore, five critical components of the flow regime control river ecosystems and their ecological integrity. These components are magnitude, frequency, duration, timing and rate of change of hydraulic conditions (Figure 7) (Poff *et al.*, 1997).

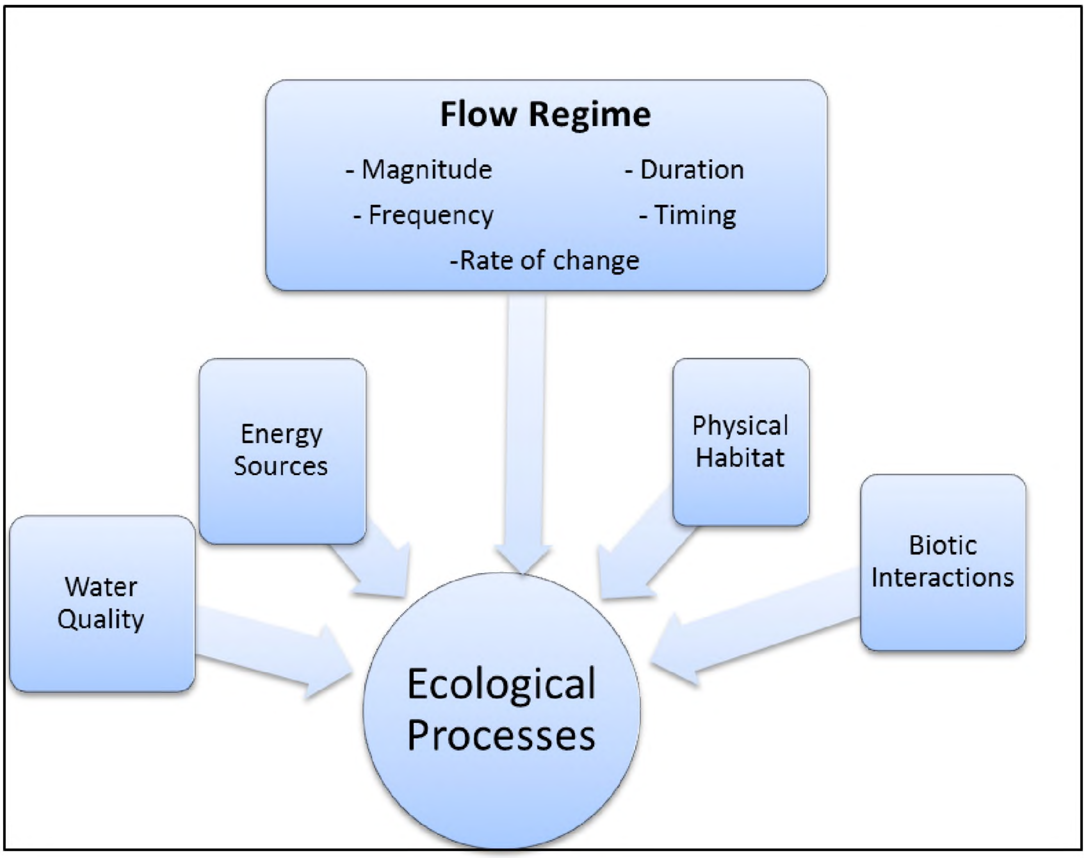


Figure 7: Critical components of the flow regime that control river ecosystems and their ecological integrity. (From: Poff *et al.,* 1997).

Habitat dynamics on which species depend can be changed by anthropogenic alterations to the natural flow regime, in a river system, which has the potential to change established patterns of natural hydrologic variations (Poff *et al.,* 1997). Flow regulations, through the construction of dams, can affect the flow variability and sediment supply at several scales (Puckridge *et al.*, 1998). Furthermore, absence of floods in a river system below an impoundment may result in increased sediment deposition from tributaries (Williams & Wolman, 1984). This affects both gemorphic processes and available habitat (Williams & Wolman, 1984; Poff *et al.*, 1997; Petts & Gurnell, 2013).

CHANNEL MORPHOLOGY AND HABITAT

Geomorphic features in a river system create habitat for aquatic and riparian species. The relative success of species in an ecosystem is dependent on the spatial and temporal patterns of habitat dynamics which in turn can be changed by major impacts such as dam construction (Poff *et al.*, 1997). Flow regulation through dam construction reduces the overall lateral and vertical connectivity of a river (Dube *et al.,* 2015). Channel morphology is largely determined by processes occurring within a catchment (Figure 8).

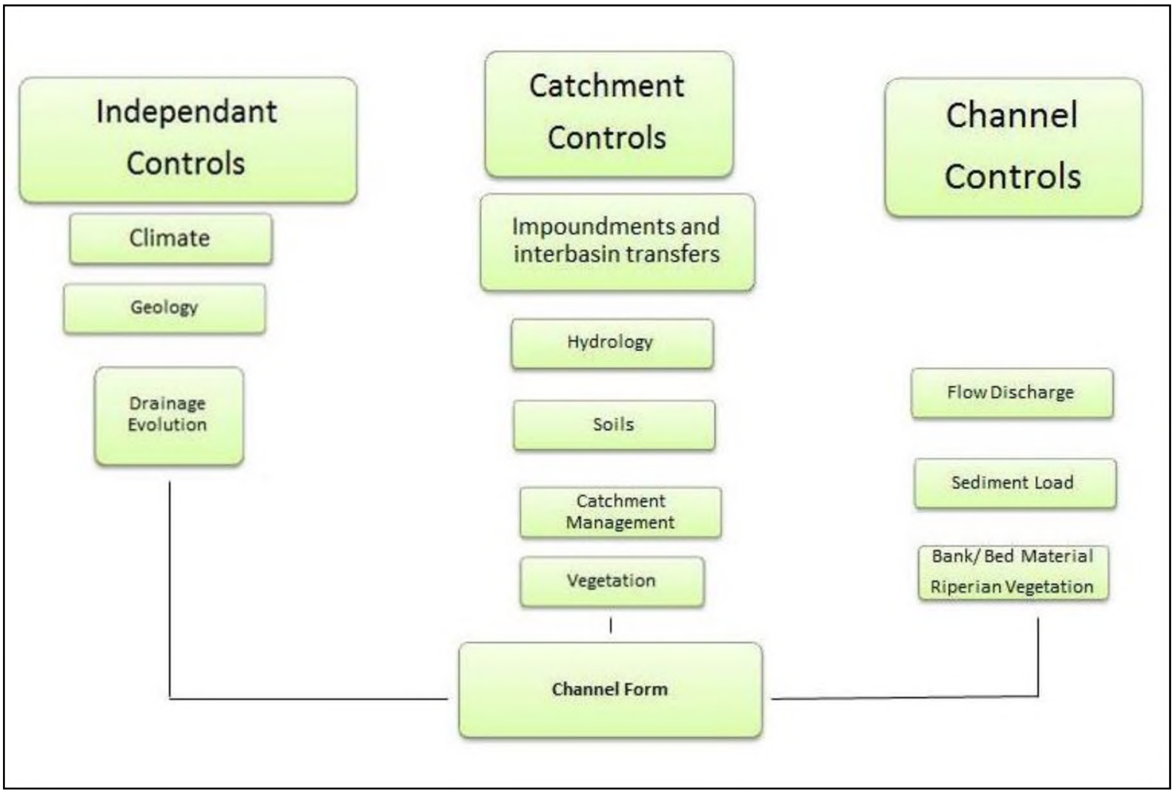
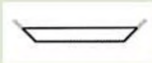
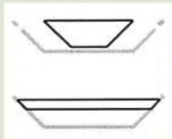
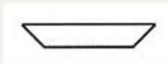
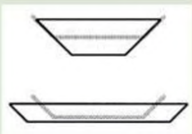
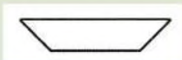
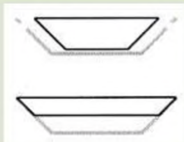


Figure 8: Examples of variables in a catchment that ultimately affect channel form in a fluvial system. (From: Rowntree & Wadeson, 1999).

The balance between water discharge, sediment load, grain size and river slope shapes the cross-sectional geomorphology of a channel (Brandt, 2000). Dams have the ability to disrupt the natural balance between the above mentioned variables. Table 3 illustrates estimated cross-sectional geomorphology by looking at changes in released water flow and released sediment loads relative to the transport capacity of the flow (Brandt, 2000).

Table 3: Examples of possible cases in which cross-sectional geomorphological changes occur, downstream of a dam. This takes place after changes in water discharge (Q) and changes to the relation between sediment load and sediment transport capacity occurs. Grey lines represent channel cross-sections before the construction of a dam and black lines represent cross-sections after dam construction. (From: Brandt, 2000).

	Load < Capacity	**Load = Capacity**	**Load > Capacity**
Decreased Q	Case 1 	Case 2 	Case 3 
Equal Q	Case 4 	Case 5 	Case 6 
Increased Q	Case 7 	Case 8 	Case 9 

Poeppl *et al*. (2013) investigated the impact of dam construction on sediment connectivity and channel morphology in two river systems, using a combination of Digital Elevation Model (DEM) analyses, field surveys and landscape evolution modelling. Poeppl *et al.* (2013) found that river reaches characterised by fine river bed sediment facies were linked to low sediment connectivity and were found upstream of active dams. In contrast river reaches dominated by course sediment facies were accompanied by significant channel degradation and located downstream of active dams.

2.4.2 Impact of dams on ecology

Disturbances alter habitat dynamics by disrupting the movement of water and sediment in a catchment and river system. This creates new conditions for the re-establishment of biota (Apitz 2012). Puckridge *et al.* (1998) indicate that variations in flow at different temporal scales will affect aquatic biota differently. Large scale alterations to the flow regime are reflected in the development of the different life stages of aquatic biota. Variations in the flow history can be reflected in the community and population dynamics of aquatic biota. Small scale variations in flow, such as variations in the characteristics of a given flood pulse, commonly affects community dynamics in the long term. Furthermore, in the time span of a single flood pulse, the impact of flow variations can be observed in the physiological and behavioural responses of aquatic biota.

Alterations to channel morphology, flow regimes and sedimentation patterns alter habitats, habitat functions and ecosystem services of aquatic species (Apitz, 2012). An increase in sediment supply and deposition may create habitat whereas a decrease in sediment, as a result of a dam construction, may put downstream reaches at risk of losing habitat availability through decreased deposition and increased erosion of fine sediment. Commonly the response of geomorphic processes, which shape the river system, respond to these anthropogenic impacts in a negative manner, resulting in consequences such as a general degradation of habitats and a gradual decrease in heterogeneity (Allan, 2004).

Hydrological modifications to a river system result in a change in the natural flow regime which has a direct impact on ecological health. Areas of rivers that are periodically inundated and exposed, due to dam constructions and hydroelectric projects, are unsuitable for macroinvertebrate colonisation which in turn has a major impact on aquatic biota (de Moor *et al.*, 2000). Restoration of aquatic habitats goes hand in hand with restoring a river's natural hydrograph as far as possible (Duerdoth *et al.*, 2015). Puckridge *et al.* (1998) therefore emphasize the importance of combining ecological studies with hydrological analyses to obtain biologically significant aspects of a river's flow regime.

2.5 Monitoring the Impacts of Dams

Brandt (2000) states that downstream changes to a newly constructed dam can easily be anticipated if water and sediment flow records are established in a period before dam construction. To correctly predict downstream changes, studies need to include an analysis of existing geomorphology, including the variation in slope, as well as a record of seasonal flow hydraulics and variability (Poff *et al.*, 1997; Brandt, 2000; Dube *et al.*, 2015). This framework will be used as a guide during this study.

Petts & Gurnell (2005) review the developments of monitoring techniques over the past 20 years and suggest a basis for future research, concentrating around three main themes namely: channel dynamics, the role of riparian vegetation and channel change as the driver of ecological change. When specific thresholds are exceeded, fluvial systems stay open systems in a continuous state of flux and variability, and the understanding of the spatio-temporal heterogeneity of channel dynamics with their respective ecological interactions in unaltered rivers needs to be further developed (Church, 2002; Petts & Gurnell, 2005).

2.5.1 Monitoring changes to channel morphology and habitat quality

Jacobsen (2013) categorises the temporal aspects of riverine habitat dynamics into hydrodynamics and morphodynamics. Hydrodynamic assessments evaluate variations in habitat due to changes in discharge with a minimal change to sediment transport rates and insignificant changes to channel morphology. Morphodynamic assessments evaluate variations in habitat caused by infrequent changes to the substrate conditions and channel or floodplain morphology. Jacobsen (2013) states that hydrodynamic assessments are useful in conditions of relatively high flow exceedance or high critical sheer stress, whereas morphodynamic assessments are critical when channel and floodplain conditions have been significantly changed, for example after a rare flood event or dam construction.

Habitat dynamics on hydrodynamic timescales can be assessed in a similar manner to the natural flow regime, by developing relationships between discharge and habitat, and time series of habitat availability that can be estimated according to magnitude (area and volume), duration, frequency, rate of change and timing (Poff *et al.*, 1997; Jacobsen, 2013). Habitat dynamics on morphodynamic (erosion and deposition) timescales are less common but are associated with human impacts and can be particularly important in the life stages of organisms (Jacobson, 2013).

2.5.2 MONITORING CHANGES TO ASSOCIATED AQUATIC ORGANISMS

The bulk of research and management of a river's suspended sediment (not deposited sediment) focuses on a uniform approach to all river systems which does not take into consideration the variability of conditions (flow, depth, morphology) of different river systems (Jones *et al.*, 2011). Therefore it is important to undertake studies at the sub-reach scale, taking into account all the factors that may influence the sensitivity of a river system.

Jones *et al.* (2011) report that the majority of impacts on macroinvertebrates due to fine sediments are related to the deposition of material, that can be linked to local hydraulic, hydrological and geomorphological conditions. However, current management targets are frequently defined in terms of the suspended sediment concentration at a particular time (Jones *et al.*, 2011). The impact of fine sediment on macroinvertebrates is clear but each study quantifies its own set of targets which cannot be replicated, in particular at the scale of river catchment management, across a range of river types (Jones *et al.*, 2011). Jones *et al.* (2011) propose that studies are required that gather data covering community level responses of macroinvertebrates to current river conditions including fine sediment deposition, hydrology and geomorphic parameters, over a range of river types.

2.5.3 KEY PRINCIPLES FOR MONITORING

In order to analyse changes in a river system it is of utmost importance to establish a reference condition (Du Preez & Rowntree, 2006; Dube *et al.*, 2015). The reference condition can be used to monitor present and/or altered river conditions (Du Preez & Rowntree, 2006). This can be achieved by conducting a baseline study of the river channel prior to large anthropogenic impacts, such as impoundments, and can aid in management decisions. A baseline study needs to include a range of conditions that reflect the natural processes occurring in the river system which can be continuously monitored to pick up changes. Using the baseline data as a reference, anthropogenic impacts can be separated from natural processes occurring in the river (Du Preez & Rowntree, 2006).

The overall reference condition for a river system should include flow hydraulics, geomorphology, water quality, habitats and associated biota. When selecting sites for a baseline study and future monitoring it is important to create a relationship between the flow hydraulics and morphological characteristics of a river and identify sites in a range of river reaches (Chapman, 1996; Rowntree & Wadeson, 1999). Geomorphic factors at work in a river system are recognised as being important in determining the structure of river habitats and the functioning of ecosystems (Tharme & King, 1998; Du Preez & Rowntree, 2006). Erosional and depositional processes influence channel form and river substrates. River discharge plays an important role in determining the amount of organic and inorganic pollutants carried by the river (Chapman, 1996). Generally with an increase in discharge point sources of pollutants are diluted whereas diffuse sources of pollutants show an increase in concentration. Therefore, discharge can aid in the diagnostics of the origin of pollutants. Following a baseline study, viable management objectives for future monitoring can be set up (Du Preez & Rowntree, 2006).

River channels below a dam construction should be subdivided into different micro-reaches based on channel gradient, inputs from tributaries and channel morphology (van Tol *et al*., 2014b). To set up baseline monitoring prior to dam construction the following actions should be conducted at sites, that represent each reach, identified along the river (Chapman, 1996; Du Preez & Rowntree, 2006; van Tol *et al.,* 2014b):

- Define the physical structure of the river through channel cross-sections.
- Describe substrate types by looking at depositional features, pebble counts and fine substrate distribution.
- Conduct hydraulic surveys to establish a relationship between flow hydraulics, channel form and the potential of flow to carry sediment.
- Establish a stage-discharge relationship by drawing up rating curves at selected cross-sections. These should be linked to data from a gauging weir if possible.
- Define water quality variables under different flow conditions.
- Characterise communities of macroinvertebrates at each site which act as an indicator of water quality and physical habitat.

From the above, the habitat condition at each site can be interpreted. After dam construction the following monitoring actions should be conducted to monitor these habitat conditions (Chapman, 1996; van Tol *et al.,* 2014b):

- Continued hydraulic monitoring at a range of flows.
- Repeat surveys of channel cross-sections at the end of the wet season.
- Continuous monitoring of biota. Any changes in the biological communities can point to changes in either the river structure or water quality due to anthropogenic impacts.

2.6 Conclusion

It can be seen that common features in a river system are derived from and supplemented by available sediments from the catchment, organic matter and other transportable materials that are either transported or deposited by flow (Poff *et al.*, 1997). A change in flow characteristics and availability of transportable material results in variable habitat conditions among rivers as well as river sections. For example, the construction of a dam results in a disruption of processes in a river, in turn initiating the alteration of habitats, such as those in interstitial spaces in river substrate (Petts, 1988).

In South African river systems approaches to determine river health and environmental flows rely on suitable baseline studies that can be used as a reference condition of a river after large anthropogenic developments, such as impoundments, impact a river (Du Preez & Rowntree, 2006). Therefore, to facilitate management decisions these baseline studies should include a combination of river components such as geomorphology, water quality, physical habitats and associated biota.

From relevant literature it is hypothesised that the effects of the proposed Ntabelanga Dam are likely to gradually change downstream of the dam wall (Petts, 1980; Williams & Wolman, 1984; Ligon *et al.*, 1995; Power *et al.*, 1996; Petts & Gurnell, 2005; Petts & Gurnell, 2013). Between the dam and the confluence with the Inxu River, a severe loss of sediment and a reduction in flood magnitude are anticipated causing one or more of the following: channel widening due to bank erosion, channel deepening due to bed incision, armouring of the bed through the loss of fines and loss of gravel bars. The main impact on habitats will be the loss of fine substrate and reduced flow in an extended channel. Below the confluence, it is anticipated that the reduction in flood magnitude combined with a continued sediment input from the Inxu River will have one or more of the following effects: sediment deposition in a tributary bar immediately downstream of the confluence and an increased formation of channel bars downstream, channel narrowing and/or reduction in depth and increased embeddedness of coarse substrate.

Furthermore, rehabilitation in the upper Tsitsa Catchment may result in a loss of sediment. Changes, after dam construction, can be monitored in the gorge above the proposed Ntabelanga Dam. A reduced sediment supply without a reduction in flood magnitude will result in less sediment deposition and decreased embeddedness of coarse substrate.

CHAPTER 3: MATERIALS AND METHODS

Study sites (Figure 1), were monitored on a seasonal basis. Monitoring surveys took place in July 2015, October 2015 (only Sites 2, 3 and 4), February 2016, April 2016 and August 2016. Physical variables, flow hydraulics, water quality and biological variables, and the relationship between these variables, was studied in order to create a baseline for future monitoring and to quantify the current impact of sediment on ecosystem health in the Tsitsa River. Table 4 gives a breakdown of how often an analysis was conducted at each site and at what scale (site or quadrat) it was conducted. Sites 2-4 were the most easily accessible whereas Site 1 was not easily accessible by road and Site 5 was the furthest distance to travel. Therefore, Sites 2-4 were monitored more frequently, especially during rising and receding stages of floods.

Table 4: Breakdown of sampling strategy

	Surveying (site scale)			Hydraulics (site scale)		Substrate		
	Cross-sections	Longitudinal profile	Water slope for site	Water level and temp.	Measured discharge	Substrate (visual, quadrat scale, assessment)	Disturbance Sample (quadrat scale)	Pebble count (site scale)
July 2015	Site 1-5	Site 1-5	Site 1-5	Installed	Site 1-5	Site 1-5	Site 1-5	n/a
October 2015	n/a	n/a	n/a	Continuous	Site 2-4	Site 2-4	Site 2-4	Site 2-4
February 2016 (rising stage)	n/a	n/a	Site 2-5	Continuous	Site 2-5	Site 1-5	Site 1-5	n/a
February 2016 (receding stage)	n/a	n/a	Site 1-4	Continuous	Site 1-4	Site 1-5	Site 1-5	n/a
April 2016 (rising stage)	n/a	n/a	Site 1, 2 and 5	Continuous	Site 1, 2 and 5	Site 1-5	Site 1-5	n/a
April 2016 (receding stage)	n/a	n/a	Site 3 and 4	Continuous	Site 3 and 4	Site 1-5	Site 1-5	n/a
August 2016	Site 1-5	n/a	All	Removed	Site 1-5	Site 1-5	Site 1-5	Site 1 and 5

	Water Quality (site scale)					SASS (site scale)	Patch analyses (quadrat scale)		
	pH and EC	Water temp. and dissolved oxygen	Phosphate concentration	Suspended sediment concentration	Water clarity and turbidity	SASS protocol	Macroinvertebrates	Depth	Velocity
July 2015	Site 1-5	Site 1-5	Site 1-5	Site 1-5	Site 1-5	Site 1-5 (mini-SASS)	Site 1-5 (class)	Site 1-5	Site 1-5
October 2015	Site 2-4	Site 2-4	Site 2-4	Site 2-4	Site 2-4	Site 2-4 (mini-SASS)	Site 2-4 (class)	Site 2-4	Site 2-4
February 2016 (rising stage)	Site 2-5	Site 2-5	Site 2-5	Site 2-5	Site 2-5	Site 2-5 (SASS)	Site 2-5 (family)	Site 2-5	Site 2-5
February 2016 (receding stage)	Site 1-4	Site 1-4	Site 1-4	Site 1-4	Site 1-4	Site 1-4 (SASS)	Site 1-4 (family)	Site 1-4	Site 1-4
April 2016 (rising stage)	Site 1, 2 and 5	Site 1, 2 and 5	Site 1, 2 and 5	Site 1, 2 and 5	Site 1, 2 and 5	Site 1, 2 and 5 (SASS)	Site 1, 2 and 5 (family)	Site 1, 2 and 5	Site 1, 2 and 5
April 2016 (receding stage)	Site 3 and 4	Site 3 and 4	Site 3 and 4	Site 3 and 4	Site 3 and 4	Site 3 and 4 (SASS)	Site 3 and 4 (family)	Site 3 and 4	Site 3 and 4
August 2016	Site 1-5	Malfunction	Site 1-5	Site 1-5	Site 1-5	Site 1-5 (SASS)	Site 1-5 (family)	Site 1-5	Site 1-5

In the Tsitsa River three main reaches (Figure 9), proximal to the proposed Ntabelanga Dam, have been identified (in terms of gradient, substrate and sediment accumulation) (Table 5).

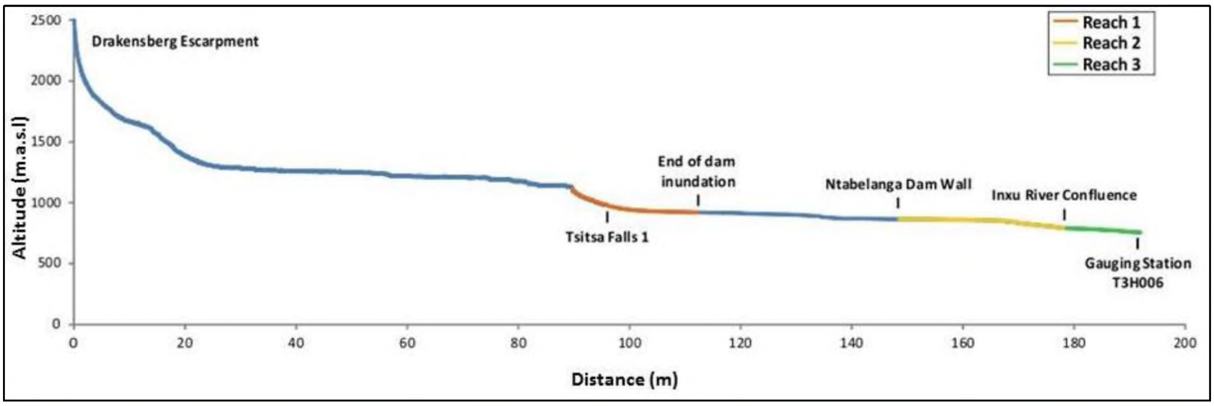


Figure 9: Longitudinal profile of the Tsitsa River showing the locations of identified reaches.

Table 5: Approximate gradients for reaches of the Tsitsa River

Reach	Energy slope
1	0.016
2	0.008
3	0.003

The gorge (Reach 1), above the dam, is characterised by a steep gradient with an input of coarse material from the side walls and low potential for the deposition of fine sediments. The channel downstream of the dam (Reach 2) is characterised by a lower gradient. The channel downstream of the Inxu River (Reach 3) is characterised by an additional sediment input which affects the channel morphology and has a low gradient.

Monitoring sites, for the investigation of characteristics of channel morphology, were identified in each reach using 2009 and 2013 digital aerial photographs. Two monitoring sites were identified in both Reach 2 and 3 to monitor the impacts of dam construction; two sites took account of differences within a reach. Aerial photographs were made available by the Rhodes University Geography Department who source the images from National Geo-Spatial Information, Cape Town. These photographs have a suitable resolution (1: 10 000 orthophotos, with 50 cm resolution) in the area of interest. Longitudinal profiles of the river channel in the area of interest were plotted using 5 meter contour lines and aerial photographs (sourced from National Geo-Spatial Information, Cape

Town). These were used to identify distinct changes in gradient which point to different process sets. The desktop study based on aerial photography was supported by a field survey in May 2015, in which sites were verified.

The final site locations were selected in the field. Five fixed sites (Table 6) were established in variable reaches of the Tsitsa River. Each site represented the channel reach in which it was located (Figure 10). Four sites were established in the downstream reach and one in the upstream reach proximal to the proposed Ntabelanga Dam (Figure 11). Sites were chosen to be long enough to include a characteristic range of channel morphologies such as pools, riffles and rapids and range from 150-300 meters in length (Rowntree & Wadeson, 1999; Heritage *et al.*, 2000). The general site characteristics are described in Chapter 4.

Table 6: Site coordinates of monitoring sites in the Tsitsa River, Eastern Cape.

Site	X coordinates	Y coordinates
1	31°4'46.821"S	28°30'59.573"E
2	31°7'7.656"S	28°40'56.268"E
3	31°8'53.045"S	28°40'23.098"E
4	31°10'8.616"S	28°42'20.32"E
5	31°11'39.512"S	28°46'0.389"E

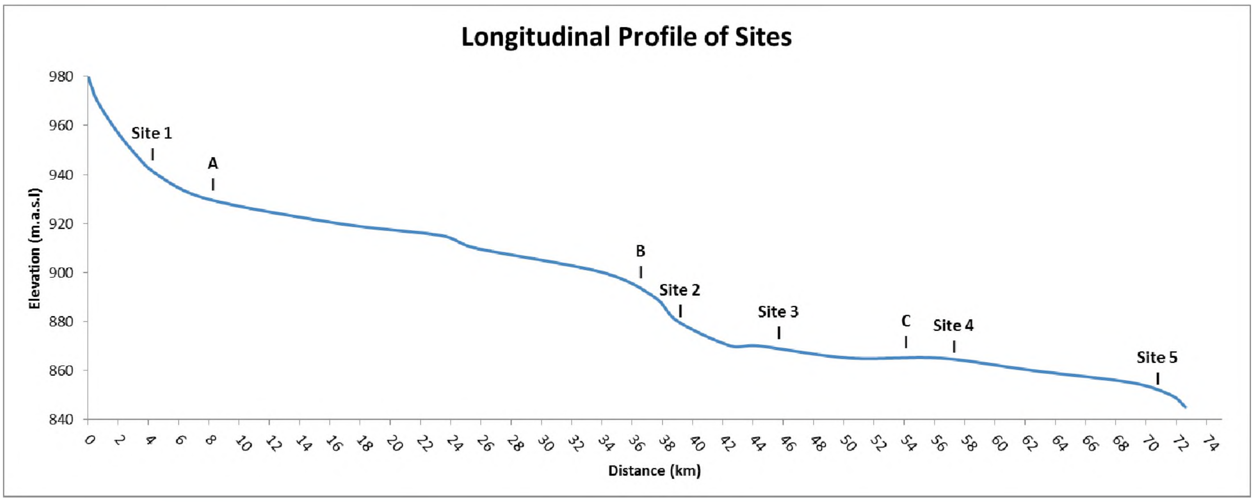


Figure 10: Longitudinal profile of the selected sites along the Tsitsa River reach, ranging from the gorge to below the confluence with the Inxu River. A: End of dam inundation, B: Dam Wall, C: Confluence with Inxu River.

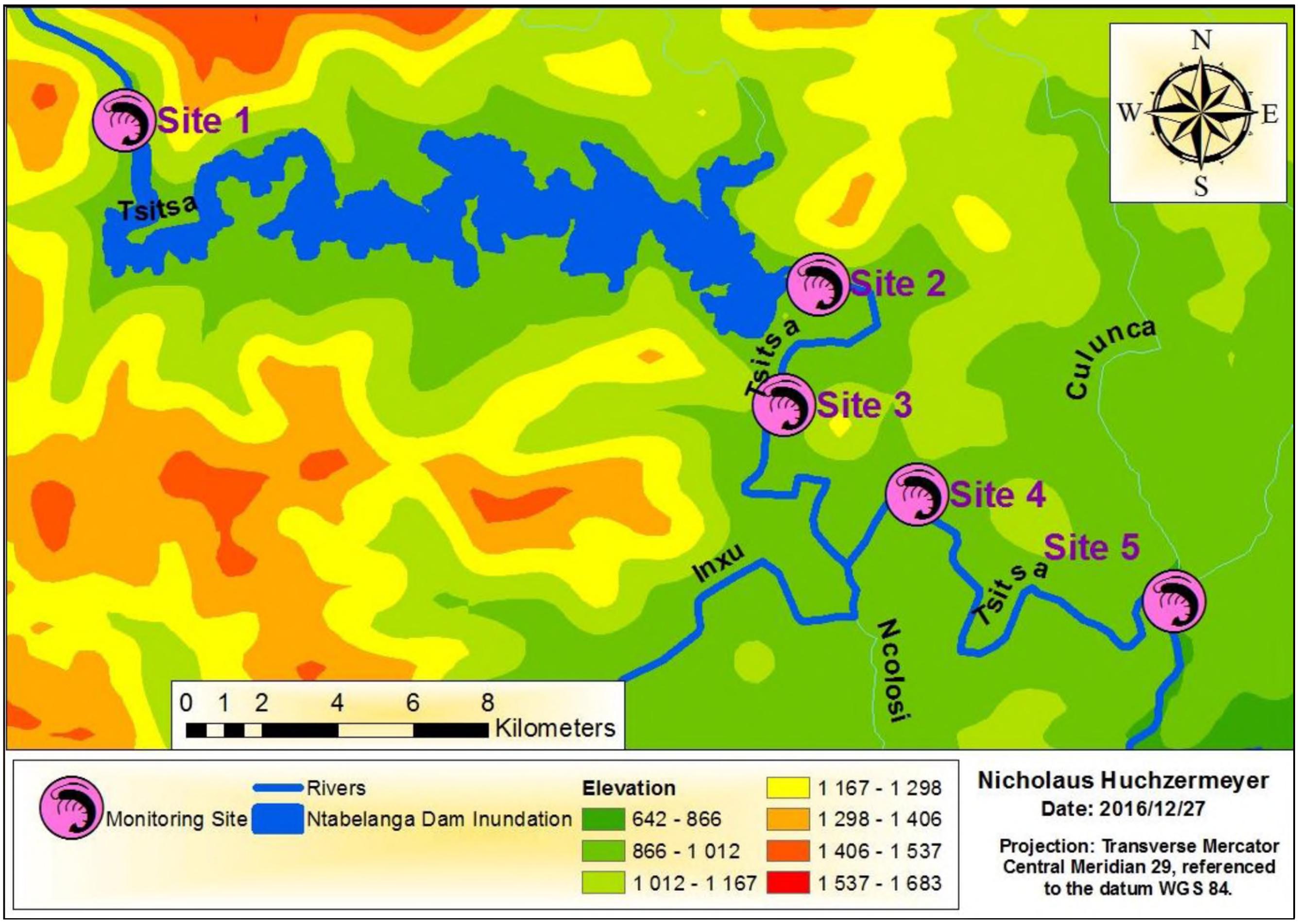


Figure 11: Locality map of monitoring sites in the Tsitsa River, Eastern Cape.

3.2 Hydrology

3.2.1 Discharge

Discharge is an important variable determining channel response over time (Rowntree & Wadeson, 1999). High discharges are required for significant sediment entrainment and transport.

Flood data was sourced from three gauging stations for two rivers in the Mzimvubu catchment (Department of Water and Sanitation, 2015). The Tsitsa River has a catchment area of 4 285 km^2 above the gauging station (situated below the proposed Ntabelanga Dam) and the Thina River, a tributary of the Mzimvubu River, has a significantly smaller catchment area above the gauging stations (2 957 km^2). Flood frequency curves were drawn to show the relationship between flood magnitude (peak discharge) and the recurrence intervals of floods in the two sub-catchments to observe if catchment size affects flood magnitude. Annual peak discharges from gauging station T3H006, between the period from 2000-2016, were plotted against the two year and ten year floods to look if flows over the study period were above or below average.

Measurements of discharge in relation to current water levels were monitored over time to investigate the current stream condition. Discharge measurements were taken along one known cross-sectional transect at each site, with the most uniform flow and stable bed, using a Marsh McBirney Flo-Mate 2000 portable flow meter, made available by the Rhodes University Geography Department. The total width of the channel along each transect was measured and the width of the channel was divided into 20 equal units. At the mid-point in each unit the depth and velocity was measured. Discharge was calculated using the Velocity-Area Method (Gordon *et al.*, 2004).

Discharge for each unit was 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 = flow velocity ($m.s^{-1}$)

The total discharge ($m^3.s^{-1}$) for the site was 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 were used to collect continuous flow data, including floods and baseflows, to calculate hydrodynamic properties of the river channel. Level loggers were installed at each site to collect continuous data on variations in depth (water pressure above the logger) and temperature. A barometric compensation was carried out on the level logger data using a Solinst Barologger which was installed in the catchment proximal to the level loggers.

Readings of discharge versus water level were 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. The measured depths to the loggers were also used to validate the level logger data. The level logger data can be used to extrapolate the highest discharge by applying the Manning's equation (Gordon *et al.,* 2004) (section 3.3.2). The Manning's equation calculates discharge from the cross-sectional area of the flow, hydraulic radius, water surface slope and roughness. The highest level was used to work out the cross-sectional area of the flow and hydraulic radius from known topographical cross-sections across or in the vicinity of the logger. Water slope and roughness were estimated for the highest discharge by comparing known measurements at lower discharges. Because the highest discharge is extrapolated using the Manning's equation and not measured in the field, slight over or underestimations of the highest discharge might occur. Therefore a logarithmic regression, rather than a straight line, was used to create a formula from the rating curves. This formula was used to calculate discharge from the known levels. Fluctuations in flow properties for each site were picked up by plotting line graphs of the discharges over time. These graphs give an indication of the condition of the river before and after each field visit.

3.3 Sediment Mobility

3.3.1 Water slope

Channel long profiles and water slope can be used to work out what processes might come into effect at different water levels. Measurements of the water slope were conducted using a DGPS. Water level readings on the edge of the bank were taken during each site visit covering each morphological channel unit (i.e. pool and riffle), starting at the upstream point of each site and ending at the downstream point.

3.3.2 Manning's roughness

From measured water surface slope and discharge readings the roughness (Manning's n) for each site was calculated (Rowntree & Wadeson, 1999; Gordon *et al.*, 2004) using the following formula:

$$Q = \frac{1}{n} A R^{2/3} S^{1/5}$$

Where:

Q= discharge (m^3/s)

n= Manning's roughness coefficient

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

R= hydraulic radius (m)

S= slope

3.3.3 Sediment mobility

Sediment entrainment, transport and deposition are a fundamental response of a channel to an altered flow regime. The potential movement of sediment at varying flows was calculated by working out Relative Bed Stability (RBS) and Shear Stress using variables including water slope, water depth, median particle diameters and flow velocities (Gordon *et al.*, 2004). As flow velocity was measured along a single transect in each site, the RBS shows the bed stability along the transect and bed stability may vary along the site. Shear Stress values provide an indication of the overall bed stability in each site and do not take into account changes in bed stability within the site.

Relative Bed Stability can be calculated using the following formula (Gordon *et al.*, 2004):

$$RBS = Vc/Vb$$

Where:

Vc= critical velocity needed to move a particle ($Vc = 0.155\sqrt{d}$ where d is the median particle diameter)

Vb= near bed velocity at a given discharge ($Vb = 0.7V$ where V is the velocity for the cross- section in m/s)

If values for RBS are greater than 1.0, the value at which particles would be expected to move (Gordon *et al.*, 2004), the bed would be considered stable. If the value is less than 1.0 the bed is considered unstable and movement is possible.

Shear stress (τ) is the stress that water exerts on the bed (Rowntree, 2015). Shear stress increases with discharge but is unevenly distributed within a channel. Shear stress can be calculated from the following formula (Gordon *et al.,* 2004):

$$\tau = pgdS$$

Where:

τ= shear stress

p= specific weight of water

g= gravitational acceleration

d= water depth

S= energy slope

Critical shear stress (τ_c) is the shear stress required to initiate the movement of particles on the river bed (Gordon *et al.*, 2004). Grains smaller than the median (D_{25}) are shielded by larger particles whereas grains larger than the median (D_{75}) are more likely to be mobilised.

Critical shear stress can be calculated from the following formula (Komar, 1996):

$$\tau_c = 0.045(p_s - p)gD_x{}^{0.6}D_{max}{}^{0.4}$$

Where:

τ_c= critical shear stress

p_s= specific weight of the sediment

p= specific weight of water

g= gravitational acceleration

D_x = particle diameter (D_{25}/D_{75})

D_{max} = diameter of the maximum particle size that can potentially move

Rowntree (2015) used an entrainment ratio derived as the ratio between the bed shear stress and the critical shear stress (for both D_{25} and D_{75}) which can be used to estimate the relative bed movement at different discharges. The ER can be calculated using the following formula (Rowntree, 2015):

$$ER = \tau/\tau_c$$

Where:

ER= entrainment ratio

τ= calculated shear stress

τ_c= calculated critical shear stress

If the ER is less than 1 there should be no bed movement. If the ER is greater than 1 then there is bed movement (Rowntree, 2015).

The potential for bed movement was calculated for each site during each monitoring survey. In addition the potential movement during the highest flood peak over the monitoring period was obtained by taking the maximum measured water level from the level logger data and slope was assumed to be the same as measured for the highest discharge.

3.4 Physical Variables

Physical variables define the geomorphology of a stream. Rivers vary spatially allowing for a variety of habitats, each supporting a range of biota. Physical variables were monitored seasonally to set up a baseline of the current condition of the river. These included cross-sectional surveys (transects across each site), substrate and turbidity. The basic sampling unit for substrate was a 1 meter by 1 meter quadrat. In most cases three to five quadrates were placed along the surveyed transects, covering all biotopes. Measurements were taken in different biotopes (flow, depth, substrates), along each known transect in each site, in the middle of a quadrat in which a visual and biological assessment was conducted.

3.4.1 Cross-sectional surveys

Cross-sectional surveys of channel topography, in the form of transects, were conducted at the sub-reach scale, using a Geomax Zenith 10/20 Differential Geo Positioning System (DGPS), made available by the Rhodes University Geography Department. Four to six cross-sectional surveys were conducted per site. The number of cross-sectional surveys varied according to the number of channel morphology features present in each respective site so as to obtain accurate channel dimensions. Cross-sectional surveys are important in setting up a baseline of the channel to monitor changes to morphology as well as well as acting as a guide for sampling of variables such as substrate within each site. Future monitoring of channel morphology should be conducted along the same transect positions as the baseline survey. The location of cross-sections for Site 5 is shown in Figure 12. Other sites are shown in section 4.4.2. Repeat monitoring of cross-sectional transects was conducted approximately a year after the first transects were conducted to see if there had been a seasonal change in channel topography due to sedimentation or lack thereof.

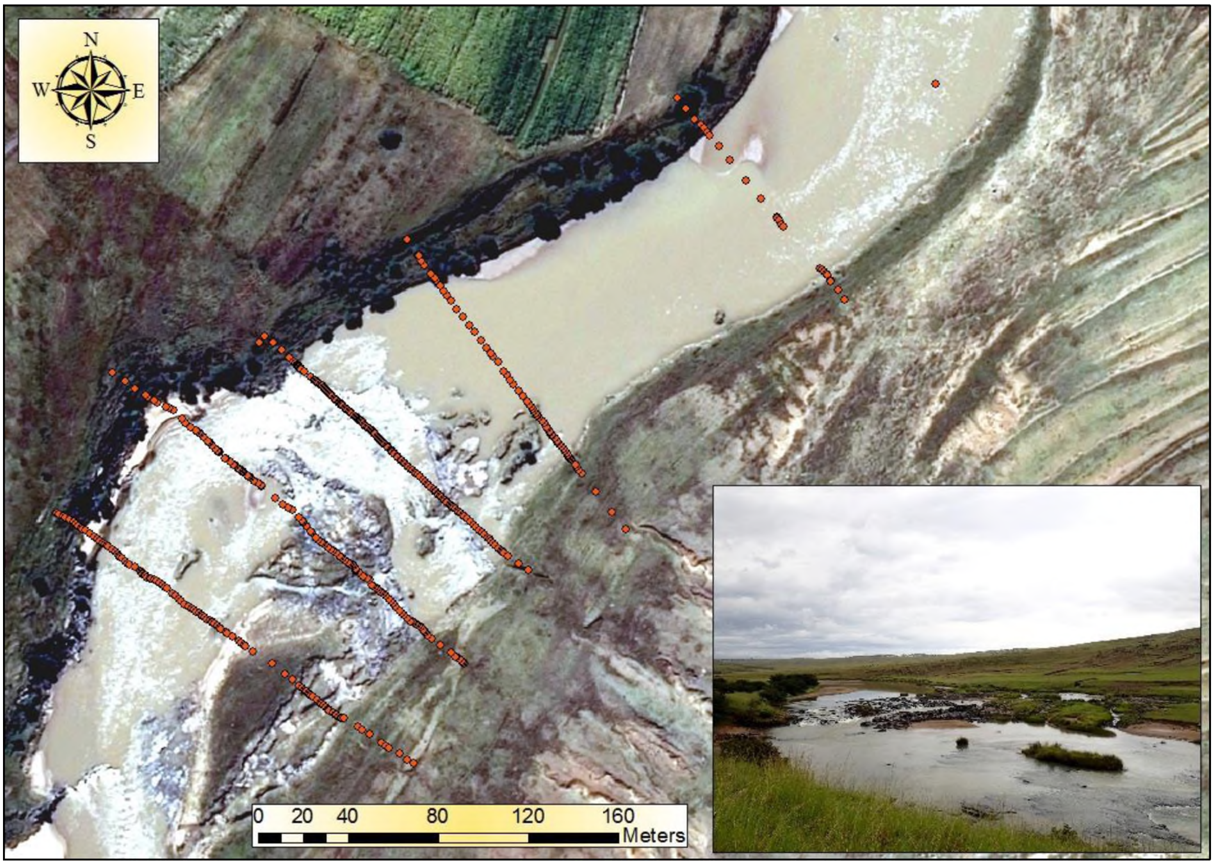


Figure 12: The location of cross-sectional surveys (transects) for Site 5, below the confluence with the Inxu River, to monitor increased embeddedness of coarse substrate and channel narrowing and or reduction in depth after dam construction.

3.4.2 Substrate

Substrate, an important driver of habitat type, was measured using both visual and objective assessments.

A visual assessment was conducted according to methods taken from Gordon *et al.* (2004). Substrate properties, including packing, sorting and embeddedness, were assessed using Table 7, 8 and 9. Packing gives a measure of bed stability (Table 7) ranging from loosely packed, which implies a soft unstable bed, to highly imbricated, which refers to the tiling of the bed material and implies a stable bed. The sorting category provides a measure of the range of particle sizes and the variability of particle sizes at certain points in the channel (Table 8). Quadrats dominated by bedrock or fines were not given a packing or sorting category. An embeddedness index after Bovee (1982) was calculated following methods set out in Gordon *et al.* (2004). The Brusven Index was 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 9. The size class of the largest and second largest clast type was recorded to make up the first two digits of the number, and following a full stop the percentage cover of fine sediment was 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 was monitored seasonally under different flow conditions to monitor patches of fines collecting on the substrate.

Table 7: 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

Table 8: 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	

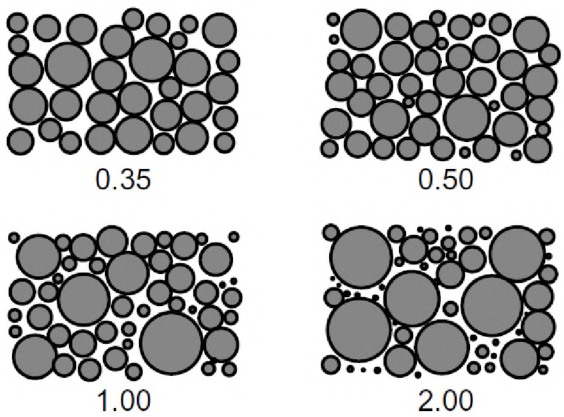


Table 9: Substrate description categories for embeddedness values (From: Gordon *et al.*, 2004).

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)

A once-off survey was conducted 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, was conducted by measuring the particle diameters of a minimum of 100 clasts. In addition, during each field visit clast sizes found within each quadrat were used to establish the dominant particle size distribution along each transect. Following this the median particle size (D_{50}) values were extracted and the percentage distribution by clast type (Table 9) for each site was calculated.

An objective assessment of substrate was conducted by following methods taken from Lambert & Walling (1988) and Duerdoth *et al.* (2015). By taking disturbance samples of fine sediment stored on the stream bed (surface and subsurface) an assessment of the variation in fine sediment accumulation over time was conducted. A cylindrical bucket, 31 cm high, with the bottom removed, was placed over the substrate on the channel bed. The diameter of the bucket was 33 cm permitting for a known area of 0.086 m^2 to be sampled for each disturbance. The depth of the water level in the bucket was recorded. The disturbance sampling was undertaken in two steps. First the fine bed sediments on the bed surface were disturbed by vigorously stirring the water with a stick, without touching the river bed, for 60 seconds. A water sample was taken. Subsequently a further 30 seconds of disturbance was conducted by stirring up and digging in the top 10 cm of the bed substrate to raise any subsurface fine sediment into suspension. Samples of both the surface and subsurface deposited fine sediments were collected for each disturbance to quantify the combined surface drape and subsurface fine sediment deposits. The sampling strategy across the site took into account that deposited fine sediment is unlikely to be evenly distributed across a river bed

(Duerdoth *et al.*, 2015). In several cases the disturbance technique was limited to fine gravels and sands as the bucket could not be firmly fixed into coarse gravels or cobble beds without flow of water into or out of the bucket. However, where the bucket could be firmly fixed to the substrate, including coarse gravels, cobbles and bedrock, disturbance samples were taken. In the case of bedrock only a surface sample could be taken. Coarse gravels and cobble beds found in fast flowing rapids were not suitable for disturbance samples as they were expected not to be conducive to the deposition of fine materials (Tharme & King, 1998). During high flow, disturbance samples could only be taken in quadrats where water depth did not exceed the depth of the bucket which was commonly limited to areas of reduced flow near the edges of the bank.

The above analyses combined with field observations and photographs were used to create maps of channel features at a large scale. Channel features were digitised using ArcMap 10.3, a programme written by the Environmental Systems Research Institute (ESRI). Channel features included bedrock, boulder/ cobble bed, gravel bar, sand bar, vegetated bar/ island, flood bench and pools. Pools are generally dominated by fine substrates due to reduced flow velocity in these areas.

Grab samples of suspended sediment were taken at each site in highly turbulent areas. Samples were taken during every field visit in order to link the sediment data to seasonal hydraulic processes. During periods of fluctuating summer flows such as February and April 2016, two samples were taken at the most accessible sites during the rising and lowering stages of floods. However, in most cases, a single sample was taken per site during each field visit. This method was limiting and only gave suspended sediment concentrations during each field visit and no data was obtained for sediment concentrations between field visits. However, sediment transport rates for 2016 measured at gauging station T3H006, approximately 25 kilometres downstream of Site 5, were provided by L. Bannatyne, Geography Department, Rhodes University. This data gives an indication of sediment concentrations between field visits.

A laboratory analysis of the water samples of surface drape, subsurface fine sediment deposits and suspended sediments collected was conducted after each field visit. The concentration of sediment was measured by using the filtration method from Gordon *et al.* (2004). In the filtration method, a water sample, with a known volume, is filtered and the amount of sediment trapped on the filter is weighed after drying. Sediment concentration was determined by passing an entire water sample through a vacuum filtration setup. Weighed 90 mm diameter Macherey-Nagel glass fibre filter paper disks, with an average pore size of 0.6 µm, were used (Gurnell *et al.,* 1992). The filter paper and sediment were dried in the oven at a temperature of 50 ˚C for a minimum of 24 hours or until it was dry. The sediment was not dried overnight at 105 ˚C due to the availability of ovens and this may lead to marginal overestimations in sediment weight (van der Waal, 2014). However, this will vary according to sediment type. After drying, the filter paper and extracted sediment were cooled to room temperature and weighed again.

The sediment concentration was calculated using the following formula (Gordon *et al.,* 2004):

$$C_s = \frac{(Mass\ of\ filter + Sediment) - (Mass\ of\ Filter)}{Volume\ of\ water\ sample}$$

Where:

C_s = sediment concentration (g.l^{-1})

Mass in grams

Volume (in litres) of water sample (weight of water, calculated by subtracting the empty bottle from the weight of the full water sample bottle, was converted to volume assuming 1 kilogram = 1 litre).

The sediment concentrations were determined by first calculating the volume of water in the bottle, the weight of the extracted sediment and then dividing the sediment weight by the volume of water.

The depth of water measured in the bucket was used to convert the laboratory weights to a mass of fine-grained sediment per square meter of river bed sampled (Lambert & Walling, 1988; Collins & Walling, 2007; Duerdoth *et al*., 2015). The following formula was used to estimate the weight of sediment stored (Collins & Walling, 2007):

$$B_r = \frac{C_s\,W_v}{A}$$

Where:

B_r= fine sediment per unit surface area of channel bed (g.m^{-2})

C_s = sediment concentration (g.l^{-1})

W_v= volume of water enclosed in the sampling bucket (l)

A= surface area of bucket (m^2)

These weights were used as a measure of sediment storage for comparative analyses as the area sampled was constant.

3.5 WATER QUALITY

Water quality variables are an important driver of the health of aquatic habitats. Five variables (Pennack, 1971; Díaz *et al.,* 2008) were identified for a short term habitat assessment, namely water temperature, pH, electrical conductivity, dissolved oxygen content and dissolved nitrogen and phosphate concentration. In rivers that are well mixed a rapid assessment of the average water quality for a river reach can be measured by taking a single representative sample (Gordon *et al.*, 2004). Samples were taken in the middle of each site, prior to any other field measurement activities to avoid disturbance or contamination of the sample site. Measurements were taken in the field to avoid contamination of the samples. In addition turbidity and clarity were measured, habitat diversity assessed and a rapid assessment of water quality was conducted by looking at the macroinvertebrates present.

3.5.1 PHOSPHATE CONCENTRATIONS

High levels of dissolved phosphate concentrations can be toxic to aquatic organisms. Phosphate concentration (mg/l) was measured using a Machery-Nagel Visocolor ECO colorimetric test kit made available by the Rhodes University Geography Department. Dissolved nitrate concentration was also measured; however the available Visocolor alpha colorimetric Nitrate test kit was inadequate to produce accurate results. The NO_3^{-2} substance in the test kit had exceeded its shelf life and no longer dissolved adequately in the water sample. New test kits were requested but only received after field monitoring had ceased.

3.5.2 DISSOLVED OXYGEN (DO)

The maintenance of sufficient DO concentrations (>80%) is critical for the survival of aquatic organisms. An AZ8403 Dissolved Oxygen probe meter, made available by the Rhodes University Geography Department, was used to measure DO. However, for the last monitoring survey, in August 2016, the DO probe was malfunctioning and it was decided to exclude the data.

3.5.3 TEMPERATURE

The thermal characteristics of a river system vary due to natural and anthropogenic hydrological, climatic and structural changes within a river channel and catchment area (Dallas & Day, 2004). In turn this directly affects the life cycle patterns (reproductive periods, rates of development and emergence times) and metabolic processes in aquatic organisms. Water should not be allowed to vary from the background daily average water temperature, considered to be normal for a site, at the specific time of day or season, by >2 ˚C (DWAF, 1996). An AZ8403 Dissolved Oxygen probe meter, made available by the Rhodes University Geography Department, was used to measure water temperature (˚C) at each site. Level loggers at each site also recorded continuous data on water temperature for the monitoring period.

3.5.4 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, made available by the Rhodes University Geography Department, which can be sourced from Hanna instruments.

3.5.5 Turbidity

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

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

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

3.5.6 Hydro-morphological Index of Diversity (HMID)

Although not a water quality parameter, habitat diversity, affecting macroinvertebrate communities, based on different flow velocities and depths, was assessed using the Hydro-morphological Index of Diversity (HMID) (Gostner, 2012). Flow velocity and depth were both measured at the quadrat scale. A single flow velocity reading was taken in the middle of each quadrat, at a depth of 0.6 in the water column. Water depth was recorded in the same location.

The HMID was obtained by calculating the coefficient of variation (CV) of flow velocities and water depth readings for all quadrats at each site by using the following formula (Gostner, 2012):

$$HMID_{quadrat} = \left(1 + \frac{\sigma_v}{\mu_v}\right)^2 \times \left(1 + \frac{\sigma_h}{\mu_h}\right)^2$$

Where:

$HMID_{quadrat}$= Hydro-morphological Index of Diversity per quadrat

σ= standard deviation

μ= mean

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

h= depth (m)

Table 10 was used to interpret the HMID values. Higher HMID values correspond to higher hydromorphological heterogeneity

Table 10: Interpretation of HMID values (Adapted from: Gostner, 2012).

HMID value	Description
< 5	Very little variability in hydraulic variables
5 - 9	Moderate variability in hydraulic variables
> 9	High variability in hydraulic variables

3.5.7 MACROINVERTEBRATES

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

The ASPT for the first two monitoring surveys (July and October 2015) were calculated using Mini-SASS methods (Graham *et al.*, 2004) that go down to order level. Following the completion of a SASS 5 biomonitoring course and SASS 5 accreditation the remainder of the monitoring surveys (February, April and August 2016) were done following SASS 5 methods going down to family level. Because the SASS method goes down to family level, a higher number of taxa are expected to be found at each site providing a higher corresponding SASS score. However, when the SASS score is divided by the number of taxa found, the ASPT varies only slightly from the ASPT calculated using Mini-SASS protocol (Figure 13). Therefore, for this study, a comparison between the ASPT derived by Mini-SASS methods in the first two monitoring surveys and the ASPT derived by SASS methods in the remaining monitoring surveys was justified. However, this may not be the case for other river systems. Water quality status using both SASS and Mini-SASS data was derived from Table 11.

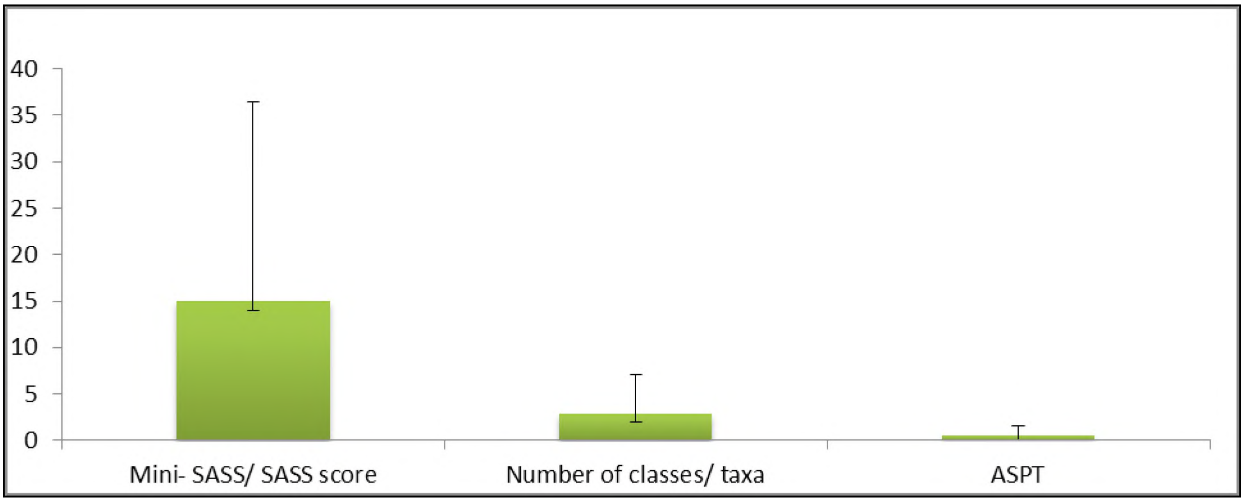


Figure 13: Average differences between scores derived from Mini-SASS and SASS for the Tsitsa River.

Table 11: Ecological categories and sensitivity scores used to interpret SASS data for this study (Adapted from: Graham *et al*., 2004; Dallas, 2007).

Ecological category	Ecological category name	Description	Sensitivity score (ASPT)	
			Sandy habitat	Rocky habitat
A	Natural	Unmodified, natural	> 6.9	> 7.9
B	Good	Largely natural with few modifications	5.8 - 6.9	6.8 - 7.9
C	Fair	Moderately modified	4.9 - 5.8	6.1 - 6.8
D	Poor	Largely modified	4.3 - 4.9	5.1 - 6.1
E	Very poor	Seriously modified	< 4.3	< 5.1

3.5.8 Time based statistical analyses of water quality and habitat conditions

A time based analyses of measured variables affecting water quality and habitat conditions was conducted to find out which independent variables correlate most (positively or negatively) with the site based water quality ASPT of sensitive macroinvertebrates during each monitoring survey. Independent variables included the HMID, phosphate concentration (mg/l), DO (%), temperature (˚C), pH, EC (µs), clarity (cm) and turbidity (FTU).

3.6 Sensitivity of Biota to Fine Sediment Drape

Macroinvertebrates provide barometers of river health as they are the first to register ill effects of negative impacts on a river system. Changes in habitat result in changes in types of organisms and give a clear indication of the current condition of a river channel.

The macroinvertebrate community structure was established at a family level using a variation of the Mini-SASS technique (Graham *et al.*, 2004) combined with adaptions from the South African Scoring System (SASS) (Dickens & Graham, 2002). Sampling was undertaken at a quadrat scale, rather than at a site scale as in section 3.5.7, and the data from all the sites and monitoring surveys were combined to conduct a once off assessment. The overall relationship between macroinvertebrates and habitat conditions was identified based on a ranking and scoring system by identifying macroinvertebrate families in different habitat types (substrate, flow, depth, embeddedness etc.). 13 key macroinvertebrate classes have been identified in South African rivers by Graham *et al.* (2004) (Table 12).

Table 12: Macroinvertebrate classes found in South African rivers (Graham *et al.*, 2004).

Code	Macroinvertebrate class
1	**Annelida-Hirudinea** (Leeches)
2	**Turbellaria** (Flat worms)
3	**Crustacea** (Crabs or shrimps)
4	**Mollusca** (Snails or Limpets)
5	**Odonata- Zygoptera** (Damselflies)
6	**Plecoptera** (Stoneflies)
7	**Trichoptera** (Cased and uncased caddisfly)
8	**Ephemeroptera** (Mayflies excluding Baetidae)
9	**Hemiptera or Coleoptera** (Bugs or beetles)
10	**Annelida- Oligochaeta** (Worms)
11	**Odonata – Anisoptera** (Dragonflies)
12	**Ephemeroptera- Baetidae** (Minnow mayflies)
13	**Diptera** (Flies)

Sample collection was conducted following an adaption of the SASS 5 protocol laid out by Dickens & Graham (2002). Samples were taken across known transects in each site. Each family of macroinvertebrate found was listed; abundance was noted as well as the proportion of each macroinvertebrate class (Table 12). The corresponding physical habitat was noted as well as the proportions of each substrate category (Table 9). The flow velocity and depth (Tharme & King, 1998) was measured in each sampling location (quadrat) as explained in section 3.5.6. The number of samples per transect depended on the channel width as well as the number of biotopes present.

Across a site, samples were taken on all biotopes present, including stones in and out of the current, bedrock, marginal vegetation in and out of the current, aquatic vegetation and gravel, sand and mud/silt. Sample sites corresponded to the same location as for the substrate measurements. The ASPT and sensitivity to sediment drape (ASPTsed) was calculated for the macroinvertebrates in each sample location as described below.

SASS scores, as explained in the section 3.5.7, are based on the sensitivity of macroinvertebrates to changes in water quality but there are no available taxa and sediment related scores relevant to South African rivers. Studies such as Extence *et al*. (2011) and Murphy *et al*. (2015) look at the macroinvertebrate species as indicators of fine sediment accumulation focusing on rivers in the United Kingdom. However, these studies go down to species level which is not conducive to a rapid assessment. In order to use SASS methodology to assess the quality of physical habitat, it was necessary to create a score based on the sensitivity/ tolerance of macroinvertebrates to fine sediment accumulation (hereafter referred to as ASPTsed) in the Tsitsa River under current conditions. Fine sediment accumulation in terms of sediment drape (section 3.4.2) was seen as representative of current habitat condition. A fine sediment habitat score was calculated by ranking the sensitivity of different families of macroinvertebrates (the sample size comprised of a total number of 540 individuals and 47 families of macroinvertebrates) by the accumulation of sediment drape (g/m^2) in which they were observed. The macroinvertebrate families were then ranked from least sensitive to most sensitive to surface sediment drape and assigned a sensitivity score (Table 13). The higher the sensitivity score the more sensitive the macroinvertebrate family is to surface sediment drape. For example, macroinvertebrate families only found in quadrats where the maximum concentration of surface sediment drape falls between 100.1-200.0 g/m^2 are assigned a score of 9 whereas macroinvertebrate families found in quadrats where the maximum concentration of surface sediment drape falls between 8 000.1-10 000.0 g/m^2 are assigned a score of 2 (Table 13). These sensitivity scores were then used to create a scoring sheet (Table 48, section 4.6) This score sheet was used to carry out a rapid assessment, under the current conditions (water quality and flow variability) in the Tsitsa River, to look at the impacts on fine sediment drape on macroinvertebrate families. An ASPTsed was calculated over the monitoring periods and used for further analyses. Macroinvertebrate families with higher sensitivity scores are less tolerant to fine sediment drape which causes less favourable habitat conditions for them. An increase in occurrences and abundance of these macroinvertebrates implies less fine sediment drape.

Table 13: Sensitivity scores assigned to macroinvertebrates occurring in different concentrations of surface sediment drape in the Tsitsa River.

Sensitivity score	Surface sediment drape (g/m^2)
1	>10 000.1
2	8 000.1 – 10 000.0
3	4 000.1 – 8 000.0
4	2 000.1 – 4 000.0
5	1 000.1 – 2 000.0
6	800.1 – 1 000.0
7	400.1 – 800.1
8	200.1 – 400.0
9	100.1 – 200.0
10	<100

The percentage distribution of macroinvertebrate classes and families found in different concentrations of surface drape sediments was calculated. Surface drape conditions were divided into three categories namely; low (<100 g/m^2), medium (100-1000 g/m^2) and high (>1000 g/m^2) and the percentage distribution of macroinvertebrate classes and families was calculated for each according to the number of observations of the relevant macroinvertebrate class and family present.

3.7 Biotic and Abiotic Interactions

3.7.1 Shannon Diversity Index

For this study the Shannon Diversity Index (SDI) as described by Boyero (2003) was used to assess both the heterogeneity of substrate (substrate diversity) and macroinvertebrate types (macroinvertebrate diversity) found in each quadrat along each transect. The SDI is based on the number of types present as well as the proportion of each type present in a specified site (Boyero, 2003) and is usually used for ecological studies. However, for this study it was adapted as a tool for geomorphic studies in which substrate types were assessed. The diversity for substrate score (H'_{sub}) was calculated using the 9 substrate description categories (Table 9) with the addition of two further substrate categories namely, bedrock as the 10th substrate category and vegetation (both aquatic and marginal vegetation) making up the 11th category. The maximum possible score for substrate diversity in this study is 2.4 H'_{sub}. The diversity score for macroinvertebrates (H'_{bio}) was calculated using 13 macroinvertebrate classes (Table 12). The proportion of each macroinvertebrate class was estimated by observed abundances in the field. The maximum possible score for macroinvertebrate diversity in this study is 2.6 H'_{bio}.

The maximum possible score is obtained when each substrate category is equally presented within a quadrat. The following formula is used to calculate the SDI (Boyero, 2003):

$$H'_{sub/bio} = \sum -(P_i \ln P_i)$$

Where:

H'_{sub}= Shannon Diversity Index (heterogeneity score) for substrate

H'_{bio}= Shannon Diversity Index (heterogeneity score) for macroinvertebrates (biota)

P_i= Proportion of the i^{th} substrate/macroinvertebrate type

3.7.2 PATCH SCALE ANALYSES

Statistical methods offer a means to aid in the interpretation of relationships between drivers of sediment processes and the impact of sediment on habitat (Piégay & Vaudor, 2016).

A patch scale analyses was conducted to tease out relationships between macroinvertebrate taxa and physical habitat conditions. The analysis was divided into three reaches, namely Reach 1 (Site 1 above the proposed dam), Reach 2 (Site 2 and 3 between the dam and the Inxu River confluence) and Reach 3 (Site 4 and 5 below the confluence). Separate analyses were conducted for habitats dominated by coarse substrates (rocky), fine substrates (fines) and marginal and aquatic vegetation (vegetation).

Variables measured at the quadrat scale were substrate diversity (H'_{sub}), surface sediment drape concentration (g/m^2) and subsurface sediment concentration (g/m^2), depth (m), flow velocity (m/s^1) and macroinvertebrate diversity (H'_{bio}), and the sediment sensitivity score of macroinvertebrates. Box and whisker plots of the above variables were drawn to show the variability of sampled data, as well as outliers, for each habitat in each reach. A correlation analysis was undertaken to identify the relationship between substrate diversity and macroinvertebrate diversity on the ASPTsed respectively.

CHAPTER 4: RESULTS

4.1 Desktop Analysis: Monitoring Sites

The results of the desktop analysis used to select the monitoring sites are presented in this section.

A significant factor affecting channel morphology was the gradient of the river bed. Sites chosen on the Tsitsa river had varying bed gradients (Table 14), each pointing to different process sets in the river channel. The gradient of the river bed determined the energy slope of the site at different discharges and affected sediment deposition or entrainment and channel shape.

Table 14: Bed gradients and site lengths for monitoring sites on the Tsitsa River.

Site	Bed gradient	Site length (m)
1	0.006	151
2	0.007	180
3	0.008	166
4	0.002	257
5	0.003	334

The gorge reach, represented by Site 1 (Figure 14 and 15) above the proposed dam, was characterised by a confined channel dominated by a bedrock substrate and input of coarse material from the side walls. Hydraulic biotopes, defined by Rowntree & Wadeson (1999), were predominantly bedrock runs, including both fast and slow runs, which turn into bedrock rapids down the site (Figure 16). Fines were deposited over the bedrock along the right bank where flow was less concentrated.

Figure 14: Upstream view of Site 1.

Figure 15: Downstream view of Site 1.

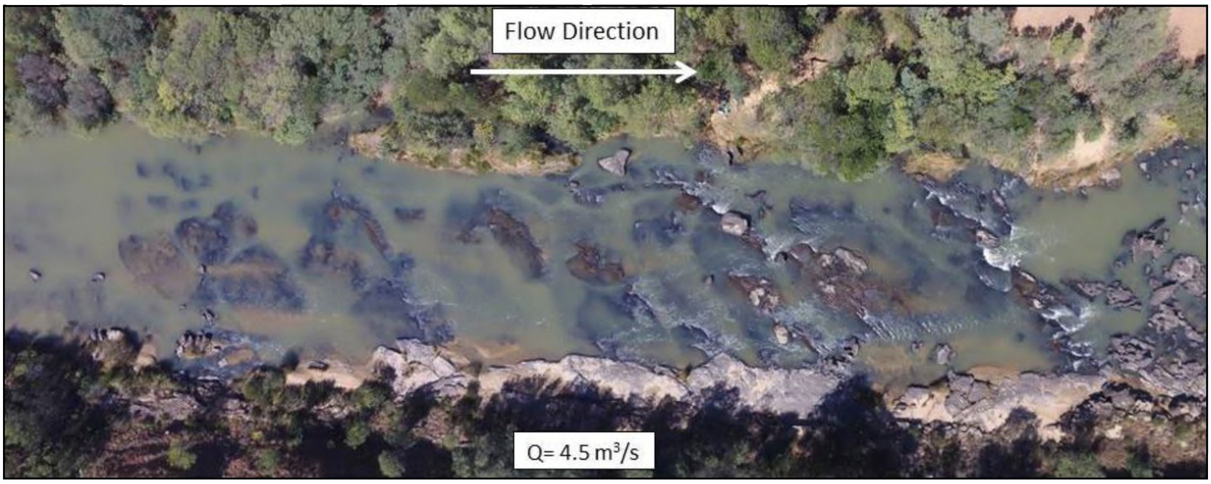


Figure 16: Aerial view of the channel at Site 1.

The channel gradient downstream of the dam was variable. Two sites were chosen in this reach, the first immediately downstream of the dam (Figure 17) and the second (Figure 18) upstream of the confluence of the Tsitsa River with the Inxu River.

Figure 17: Downstream view of Site 2.

Figure 18: Downstream view of Site 3.

The hydraulic biotopes present in site 2 followed a pool-rapid sequence (Figure 19). The pool at the top end of the site was followed by a rapid on the left of the channel and a bedrock cascade on the right of the channel. This was followed by a further pool which turned into a riffle.

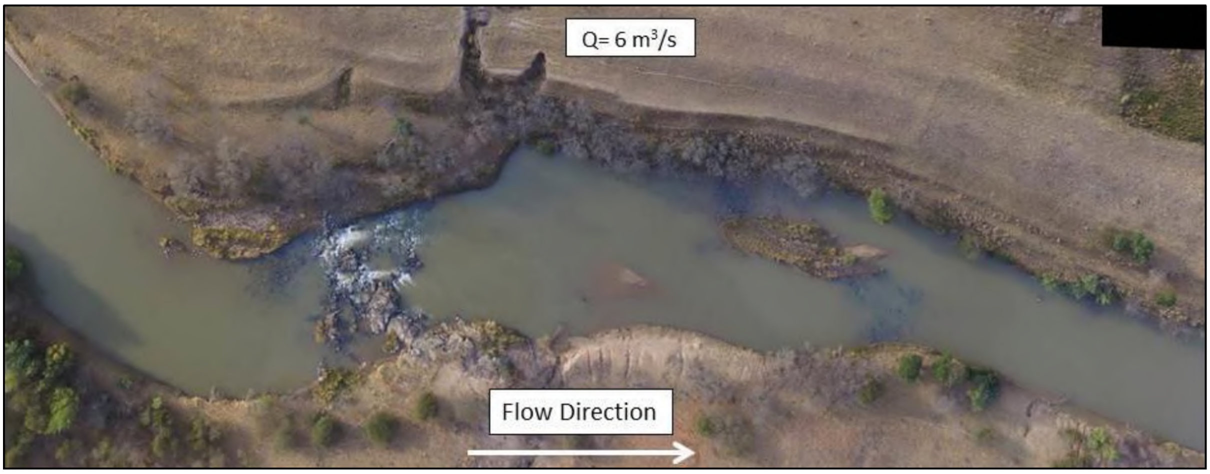


Figure 19: Aerial view of the channel at Site 2.

The hydraulic biotopes present in Site 3 also followed a pool-rapid sequence (Figure 20). The pool at the top of the site was followed by a rapid which turned into a riffle before again becoming a pool. Flow was confined towards the bottom of the site due to an inpinging aluvial fan, causing channel scouring.

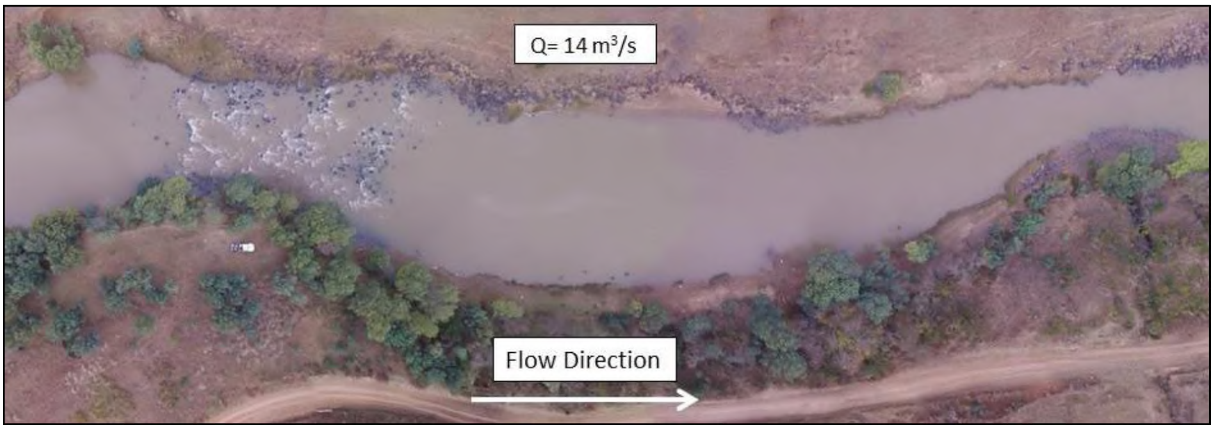


Figure 20: Aerial view of the channel at Site 3.

The Inxu River is a tributary flowing into the Tsitsa River (Figure 21 and 22), below the proposed Ntabelanga Dam, that acts as an important sediment source and is anticipated to provide continued sediment input into the Tsitsa River after the dam has been constructed.

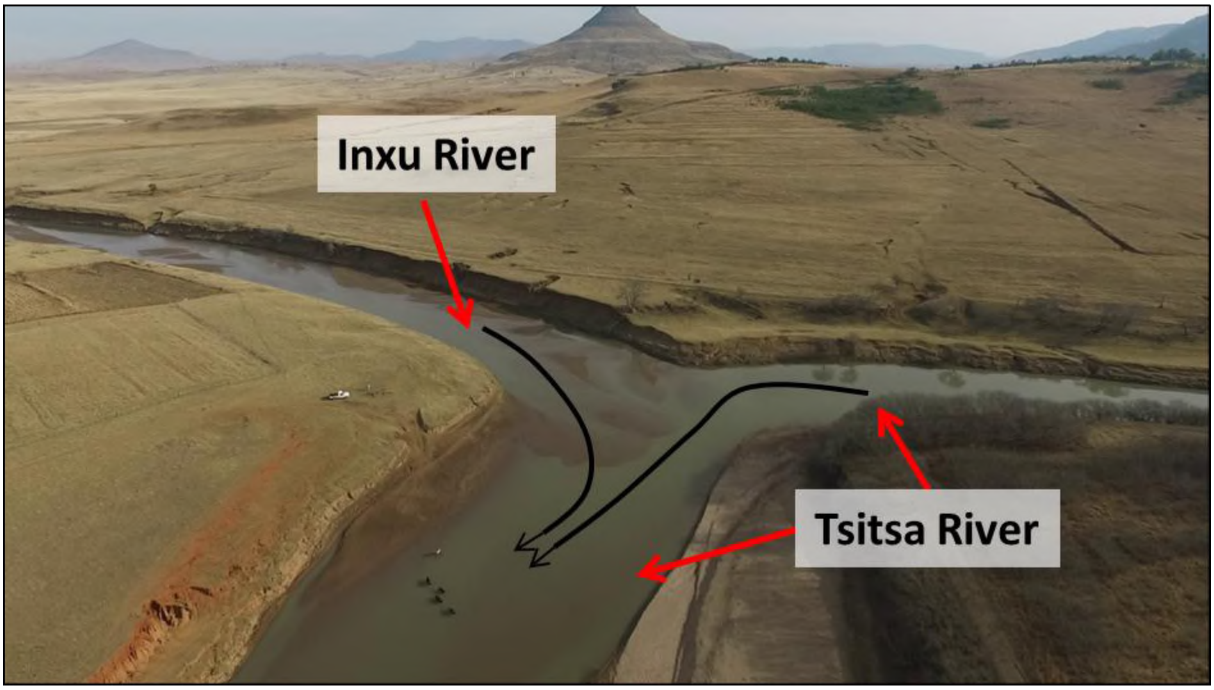


Figure 21: Confluence of the Inxu River with the Tsitsa River.

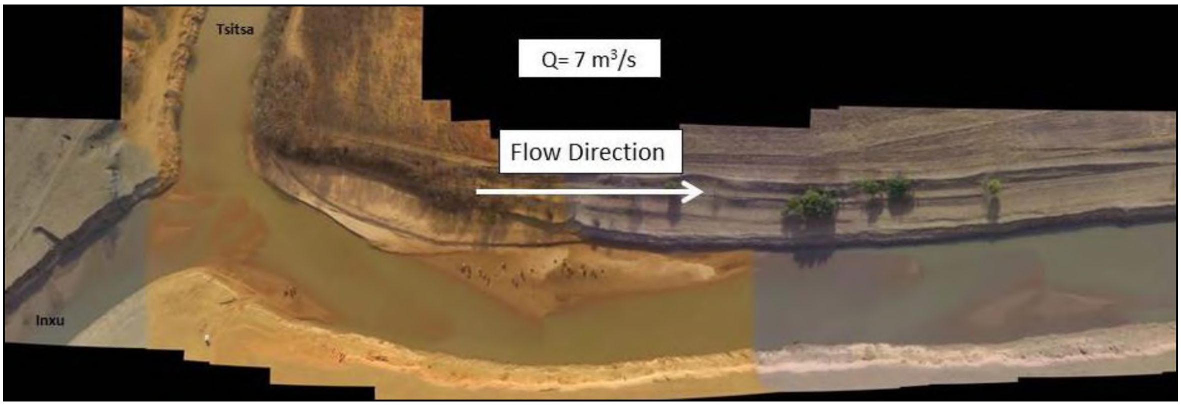


Figure 22: Aerial view of the confluence between the Tsitsa River and the Inxu River.

The channel downstream of the Inxu River was characterised by an additional sediment input. Two sites were chosen below the confluence. The first, Site 4 (Figure 23 and 24), was a lower gradient site where increased sediment deposition is anticipated to form pronounced in-channel bars.

Figure 23: Upstream view of Site 4.

Figure 24: Downstream view of Site 4.

Site 4 had the lowest overall gradient with the dominant hydraulic biotope being a sandy glide with a uniform flow (Figure 25). A small bedrock outcrop was present on the outer edge of the bend. When the site was selected, sand mining operations were not present. However, over the monitoring period sand mining operations were initated due to low river levels, and affected channel stability and morphology.

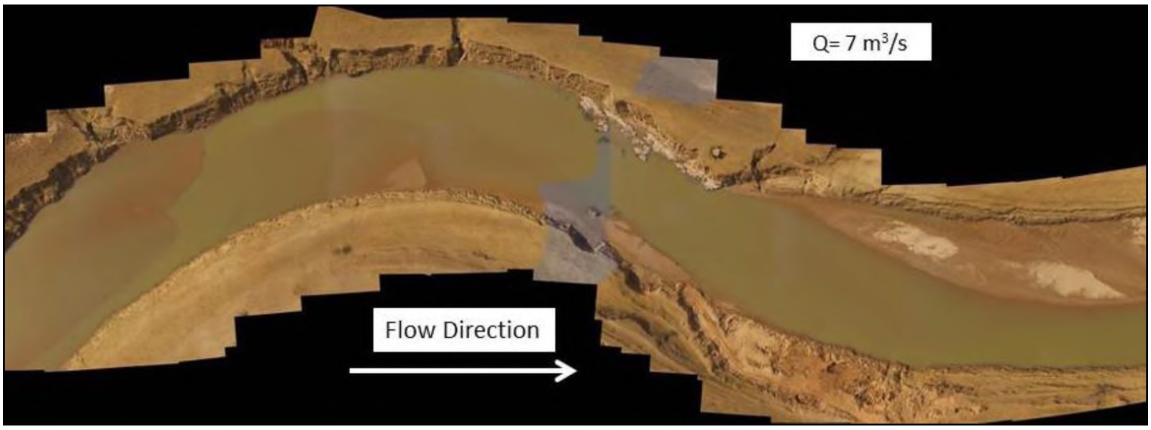


Figure 25: Aerial view of the channel in Site 4.

The second site below the Inxu confluence, Site 5, was a complex site containing coarse substrate that could be monitored to see the effect of sediment deposition on embeddedness in cobble and boulder beds (Figure 26). The overall gradient was low due to the length of the chosen site, however the gradient in the site varied with the middle of the site showing an increase in gradient over a rapid.

Figure 26: Upstream view of Site 5

The site consisted of a complex range of hydraulic biotopes including pools, backwater, slack water, rapids and riffles (Figure 27).

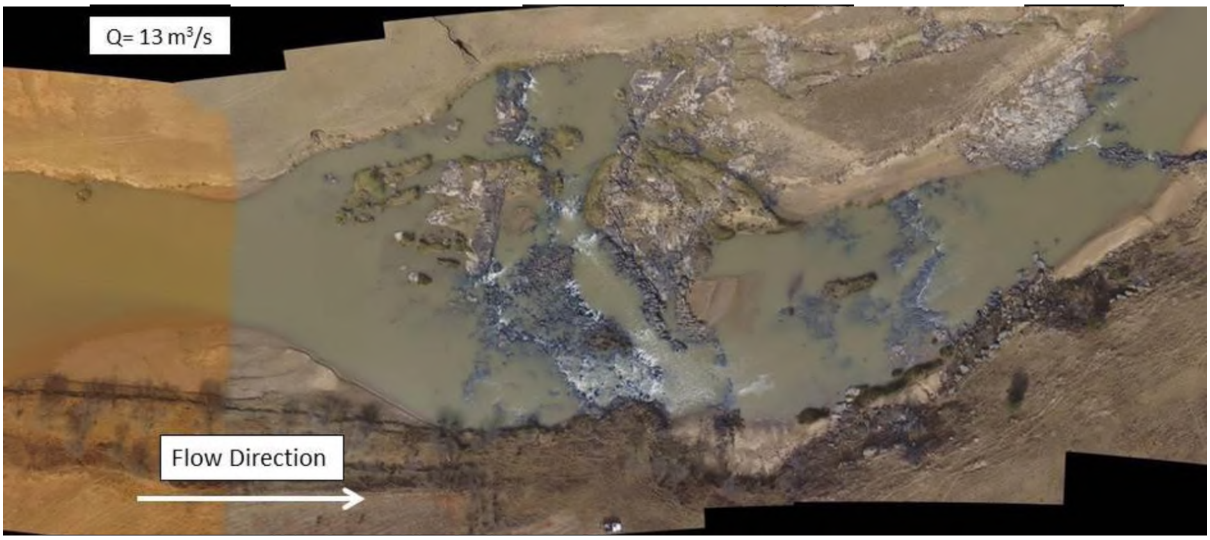


Figure 27: Aerial view of the channel in Site 5.

4.2 Hydrology and Sediment Flux

4.2.1 Discharge

In this section the data collected from level loggers is presented and put into perspective with the flow history of the Tsitsa River obtained from gauging station T3H006. Flow hydrographs for all the sites can be found in Appendix 4.

The Tsitsa River, above gauging station T3H006, has a high peak discharge at the 10 year flood recurrence interval and the 10 year flood will occur when peak discharges are equal to or exceed 935 $m^3.s^{-1}$ (data sourced from the Department of Water and Sanitation). Floods with very large peak discharges fell outside of the rating curves and were not included in the analysis. Figure 28 illustrates that a larger catchment area, such as that of the Tsitsa River (4 285 km^2), will result in a bigger mean annual flood and therefore peak discharges (in the 10 year flood interval) compared to the Thina River (which has a smaller catchment area (2 957 km^2). However high discharges are not accurate as each gauging station has a limit above which large floods are estimated.

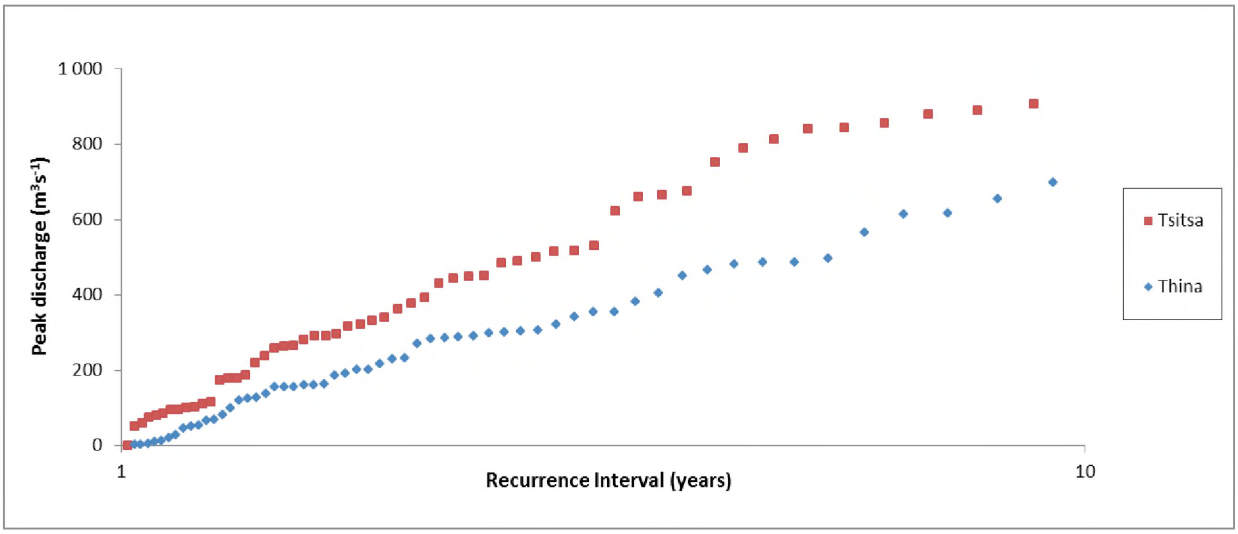


Figure 28: Flood frequency curves for two rivers in the Mzimvubu catchment (data sourced from the Department of Water and Sanitation).

Table 15 shows catchment areas for each site. Discharge and flow velocities played an important role in sediment mobility and the stability of beds. Discharge and flow velocities are expected to be higher in sites with larger catchment areas.

Table 15: Approximate catchment areas for each site on the Tsitsa River.

Site	Catchment area (km^2)
1	1 830
2	1 988
3	2 016
4	3 683
5	3 861

Figure 29 shows the seasonal variation of discharges measured at the monitoring sites on the Tsitsa River during the study period. Winter months, with little or no rainfall, generally had low discharge values (July 2015). The lowest discharges were measured in October 2015. The highest discharges were measured in February 2016 and April 2016 due to heavy rains in the catchment. August 2016 also experienced a relatively high discharge for winter months due to snow melt in the catchment.

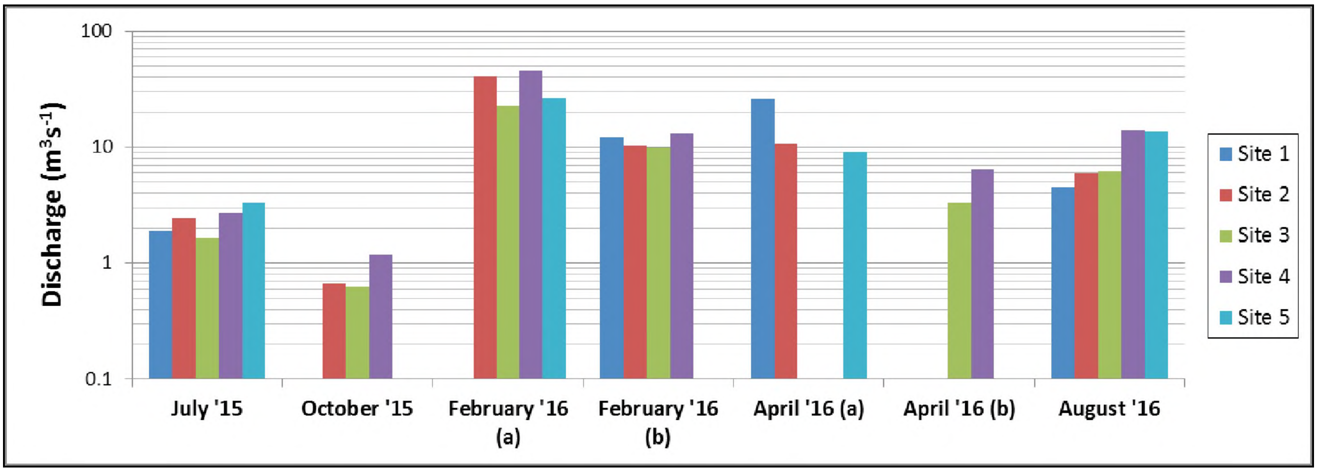


Figure 29: Variation in seasonally measured discharges at each site in the Tsitsa River. a= rising stage, b= receding stage. Logarithmic scale used.

Seasonally measured discharges (Figure 29) and known depths to the river bed, at the level loggers, were used to create rating curves (Figure 30). The highest discharge was estimated using the Manning's equation and cross-sectional profiles over the logger. The rating curves were then used to extrapolate level logger readings to instantaneous discharges which were plotted to show seasonal fluctuations in flow properties as well as peak discharge (Figure 31, 32 and Appendix 4).

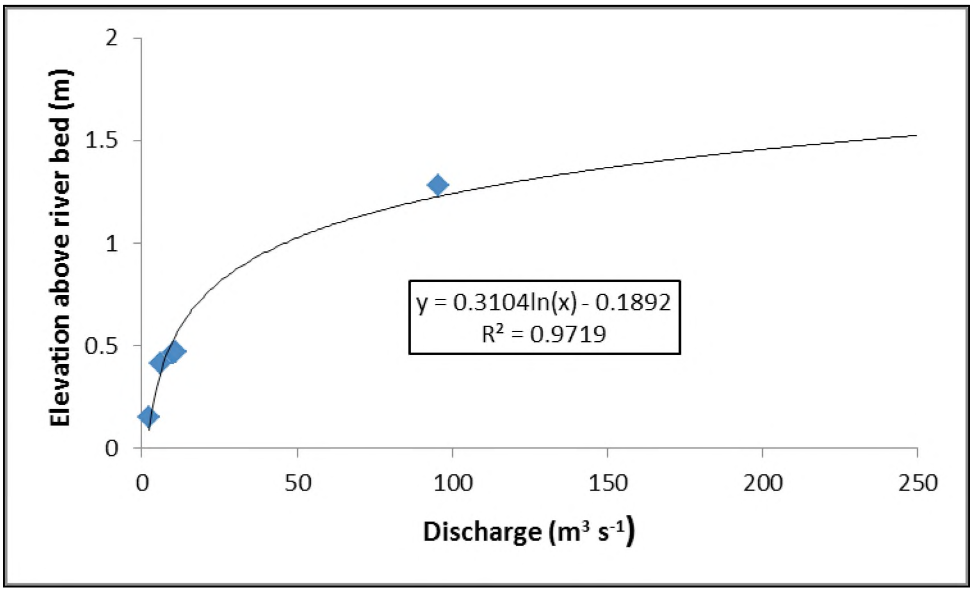


Figure 30: Example of a rating curve for Site 2.

A complete set of rating curves used for each site can be found in Appendix 3.

The sites illustrated in Figure 31 and 32 show similar trends in discharge fluctuations over time down the river channel with discharge increasing further down the catchment, particularly below the confluence with the Inxu River (Site 4). Months with little or no rainfall generally have low discharge values (July – December 2015, May – July 2016). The lowest discharges were experienced during October 2015 (Appendix 4). Discharge peaked during summer months due to heavy rains in the catchment, resulting in several large floods exceeding 50 $m^3.s^{-1}$. A flood peaking in February 2016 can be seen in Site 2 and Site 4 but not in Site 1, implying that local rainfall events can increase the discharge significantly. August 2016 also experienced a period of relatively high discharge for winter months due to snow melt in the catchment. However, discharges experienced during the monitoring period were well below average (Figure 33), possibly accounting for the lack of change in channel morphology. It was important to note the flow conditions before each field sampling trip as these affected the condition of the river at the time of sampling. Sampling in July 2015 fell in a period of low discharges with little variation. Following July 2015, the baseflow was low but discharge increased occasionally probably due to small, local rainfall events. Discharge started to pick up at the end of December 2015 with large flood peaks and high baseflows before the February 2016 sampling. Prior to the April 2016 sampling, baseflow remained high with two periods of increased discharges. After April 2016 the river returned to low baseflows and peaked during the August 2016 sampling trip due to snowmelt in the catchment.

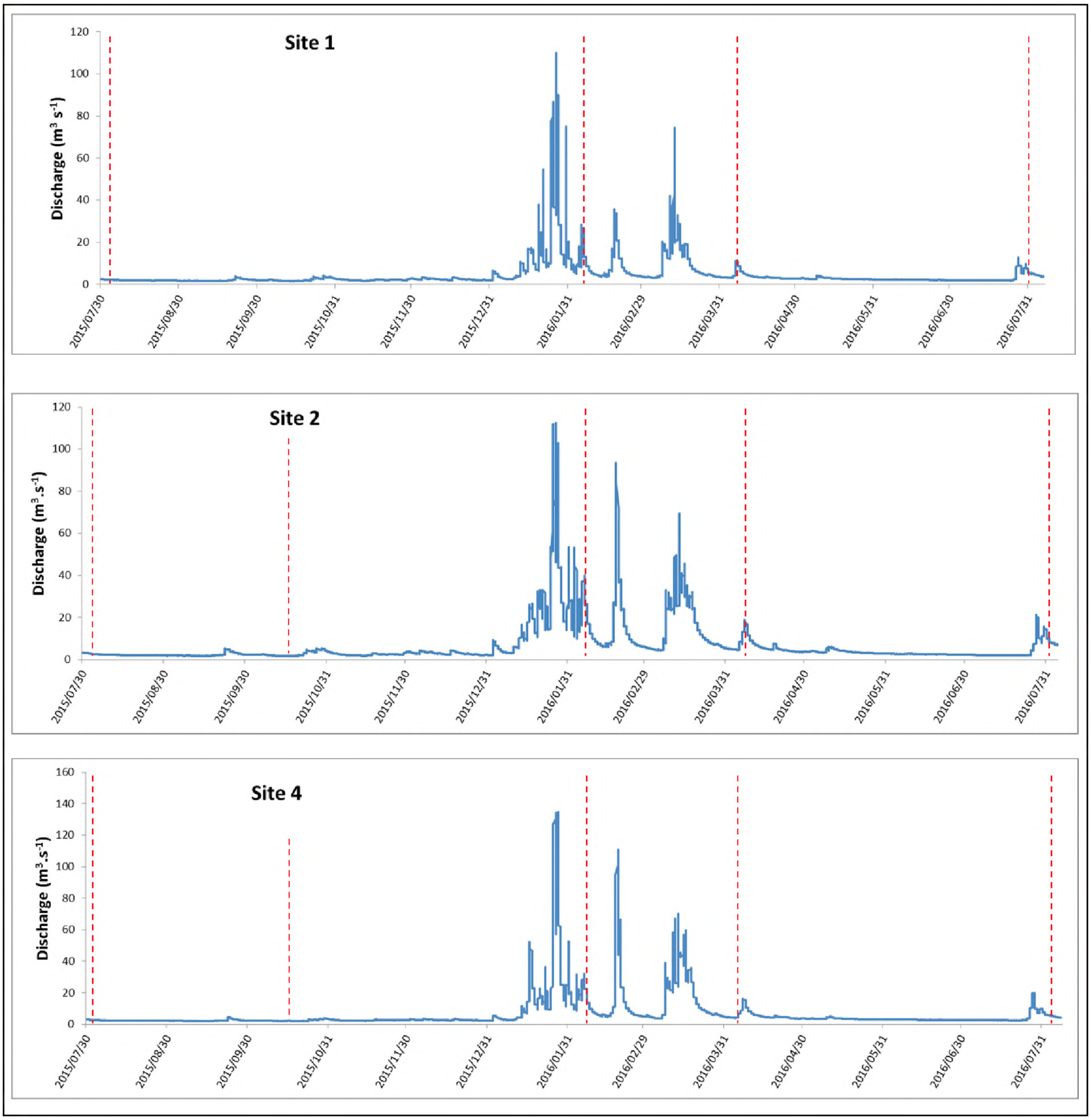


Figure 31: Twenty minute discharges for Site 1, above the proposed dam inundation, Site 2, between the dam wall and the Inxu River confluence, and Site 4, below the Inxu confluence, showing fluctuations in flow properties over time in blue and approximate field sampling times in red.

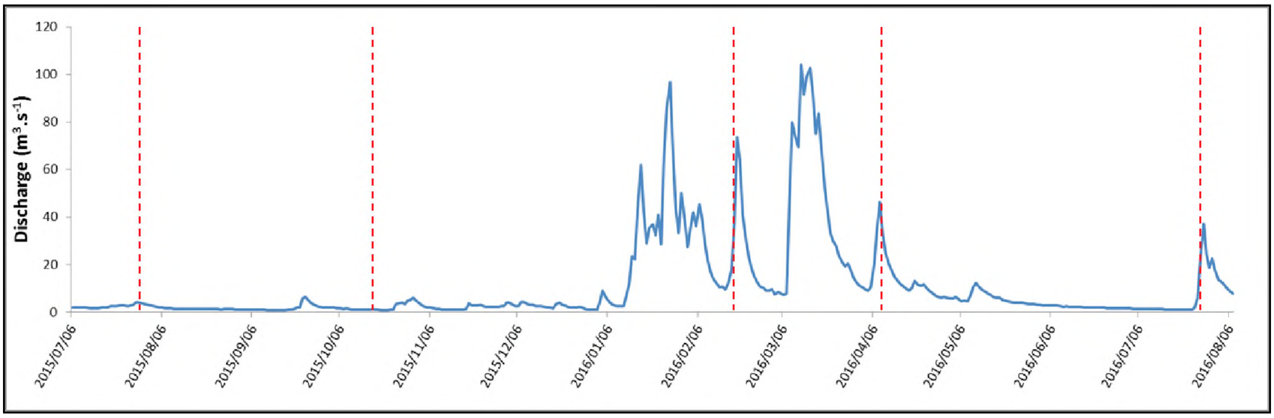


Figure 32: Daily average flows from gauging station T3H006, approximately 25 kilometres downstream of Site 5, showing fluctuations in flow properties over time in blue and approximate field sampling times in red.

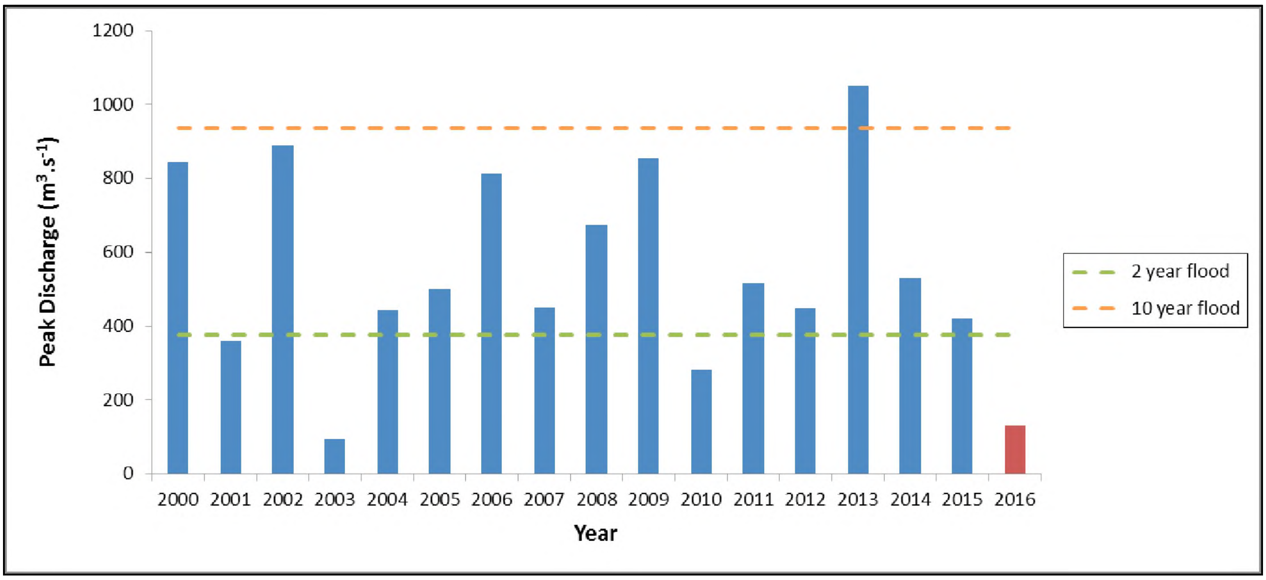


Figure 33: Annual peak discharges, plotted against the two year and ten year floods, from gauging station T3H006 (data obtained from the Department of Water and Sanitation). Data may be skewed as outliers such as 2013 have not been audited.

4.2.2 Suspended Sediment

This section presents data on suspended sediment concentrations which give an indication of how much sediment is being carried by the river.

In the Tsitsa catchment, high rainfall events cause erosion of the highly dispersive soils. This increased the suspended sediment concentrations (Figure 34). Field observations showed that the rising stages of floods carried a higher concentration of suspended sediment than the receding stages. This implied that the flood had a higher energy slope for sediment entrainment as it approached its peak and was carrying more suspended sediment sourced from erosion by rainfall in the catchment. As the flood receded, sediment was deposited back onto the bed as surface drape and less sediment was fed into the river system from the surrounding landscape.

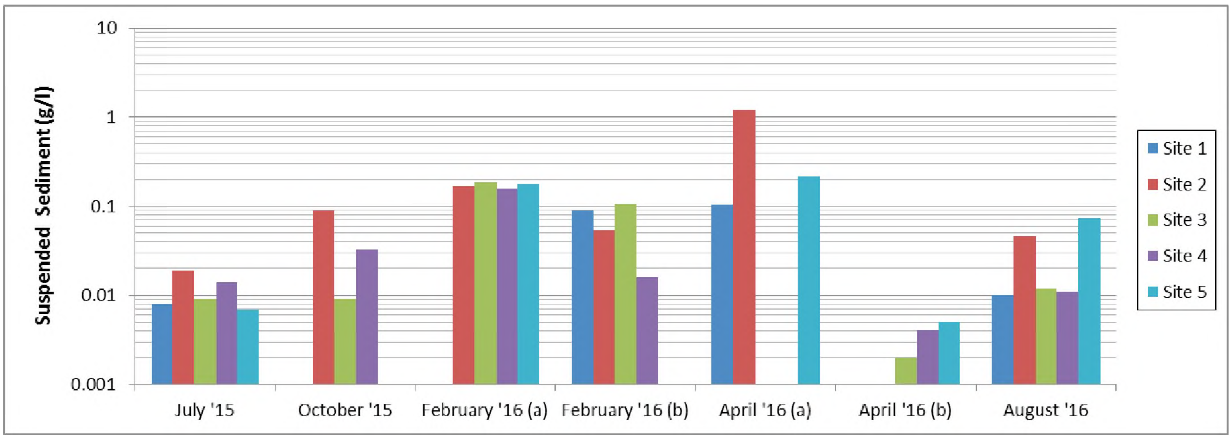


Figure 34: Variation in suspended sediment concentrations in the Tsitsa River. a= rising stage of a flood, b= receding stage of a flood. Drawn with a logarithmic scale to account for outliers.

Figure 35 shows the sediment transport rates for 2016. Prior to the February 2016 field survey the river carried high loads of suspended sediment which peaked during corresponding floods. The period between February 2016 and April 2016 was characterised by two periods with very high suspended sediment concentrations. Between these peaks, concentrations of suspended sediment in the river returned to normal. April 2016 to August 2016 showed very little variation in suspended sediment concentration which remained relatively low. In August 2016 there was a peak in suspended sediment concentration due to the snowmelt in the catchment.

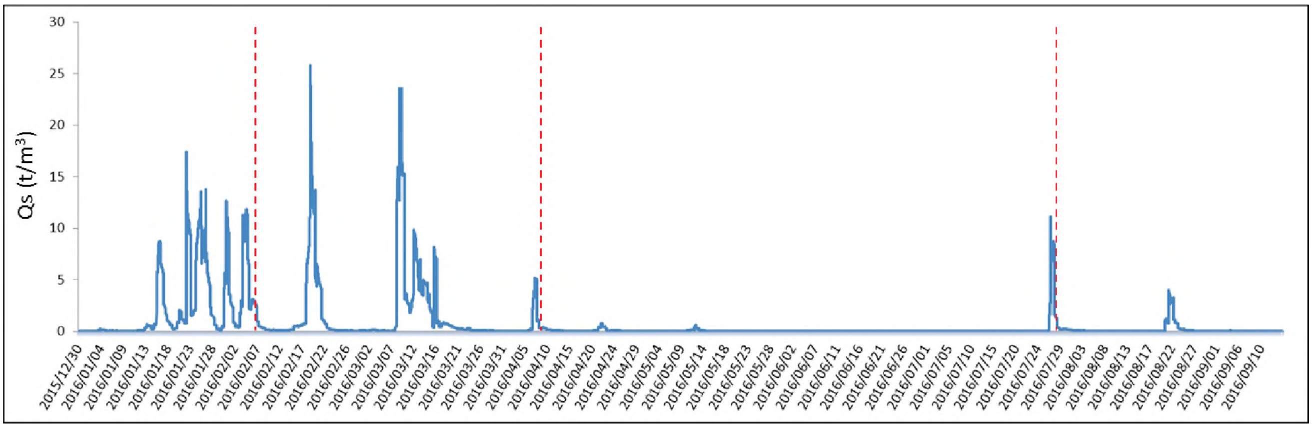


Figure 35: Sediment transport rates for 2016, showing approximate field sampling times, measured at gauging station T3H006, approximately 25 kilometres downstream of Site 5 (data provided by L. Bannatyne, Geography Department, Rhodes University).

4.3 Sediment Mobility

4.3.1 Factors affecting mobility

Sediment entrainment, transport and deposition are a fundamental response of a channel to an altered flow regime. Channel long profiles and water slope can be used to work out what processes might come into effect at different water levels. From measured water surface slope and discharge readings the roughness for each site was calculated. The potential movement of sediment at varying flows was calculated by working out Relative Bed Stability and Sheer Stress using variables such as water slope, water depth, median particle diameters and velocities.

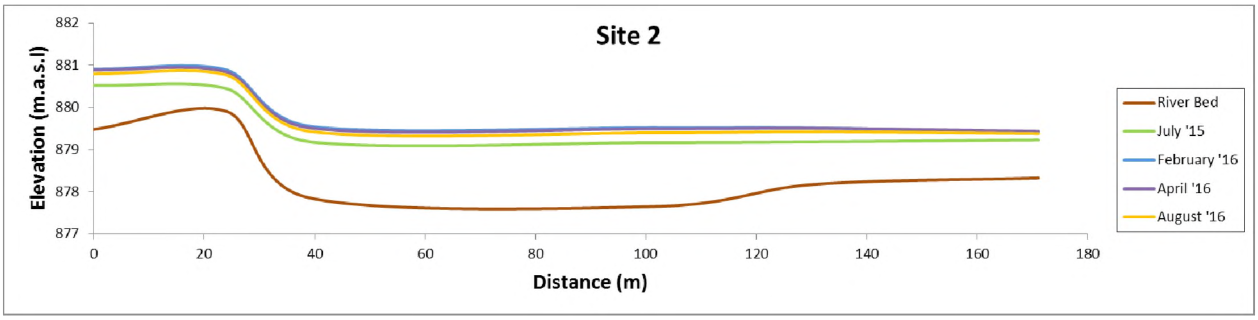
4.3.2 Hydraulic factors

Water slope

This section presents data on channel long profiles and water slope which give an indication of the energy exerted on the bed of the river at different water levels. Longitudinal profiles, and their corresponding energy slopes at different discharges, are presented in Appendix 5. For analysis, the overall site gradients were used. These varied seasonally with discharge (Table 16). Sites with a high bed gradient that varied throughout the site, such as Site 2, exerted significantly more energy on the bed at differing water levels than sites with gentler more uniform gradients such as Site 4 (Figure 36).

Table 16: Energy slope for each site during each field survey.

	Site 1	Site 2	Site 3	Site 4	Site 5
July 2015	0.0049	0.0087	0.0093	0.00064	0.0059
February 2016	0.0041	0.0084	0.0064	0.00051	0.0046
April 2016	0.0041	0.0081	0.0087	0.00050	0.0066
August 2016	0.0046	0.0087	0.0081	0.00042	0.0061



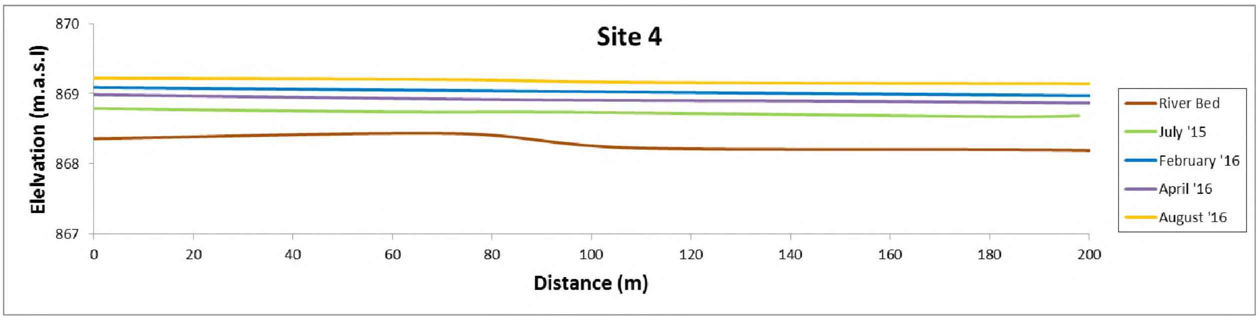


Figure 36: Example of a change in energy slope, with changes in discharge, at two sites with different bed gradients.

MANNING'S ROUGHNESS

This section presents results on the roughness values of the river bed at each site. Roughness values varied seasonally depending on flow velocity conditions and submerged substrates. Results from all sites are presented in Table 17.

Table 17: Roughness values for each site in the Tsitsa River.

	July '15	February '16	April '16	August '16
Site 1	0.17	0.11	0.04	0.15
Site 2	0.2	0.14	0.2	0.33
Site 3	0.19	0.15	0.12	0.19
Site 4	0.03	0.04	0.03	0.03
Site 5	0.05	0.07	0.2	0.12

Site 1 had a high gradient with a confined channel and uniform bedrock bed. Site 1 (Figure 37) exhibited a strong relationship between roughness values and discharge with roughness decreasing with an increase in discharge. Site 2 and 3 had relatively high gradients and confined channels and diverse substrates which resulted in higher roughness values, especially at low flows. A relationship between roughness values and discharge, with roughness decreasing with an increase in discharge, was evident at Site 2 (Figure 38). Site 3 (Figure 39) shows no relationship between roughness values and discharge, with roughness values staying fairly constant. Site 4, below the confluence, had a very low gradient and a correspondingly low roughness factor. This site (Figure 40) showed a slight increase in roughness with an increase in discharge. This could be due to the formation of dunes on the river bed during higher flows. Site 5 was the widest and least confined site resulting in variable roughness factors at different flows. This site (Figure 41) exhibited no relationship between roughness values and discharge. This may have been due to the submerging of wide shallow banks at high discharges and a range of substrates at lower discharges.

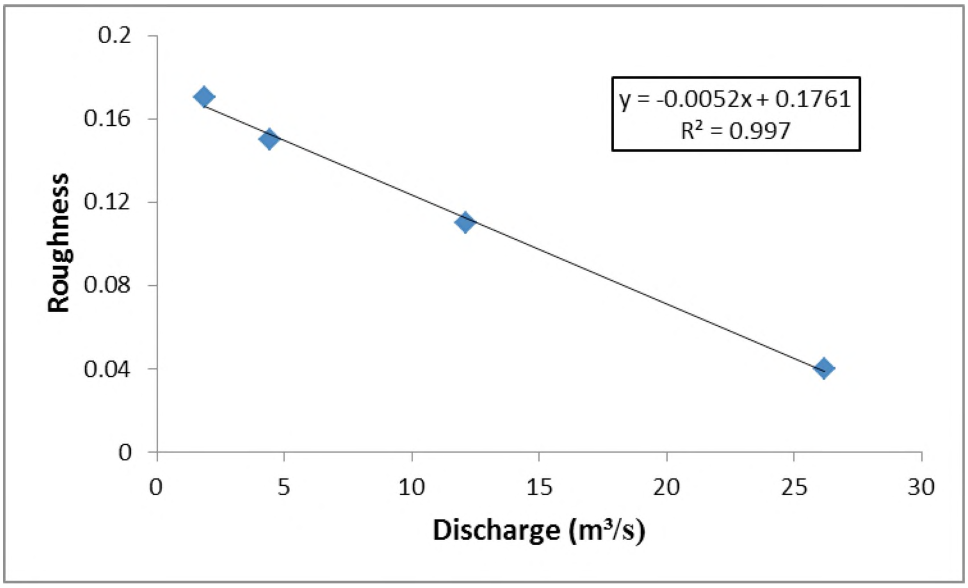


Figure 37: Site 1. Relationship between roughness values and discharge.

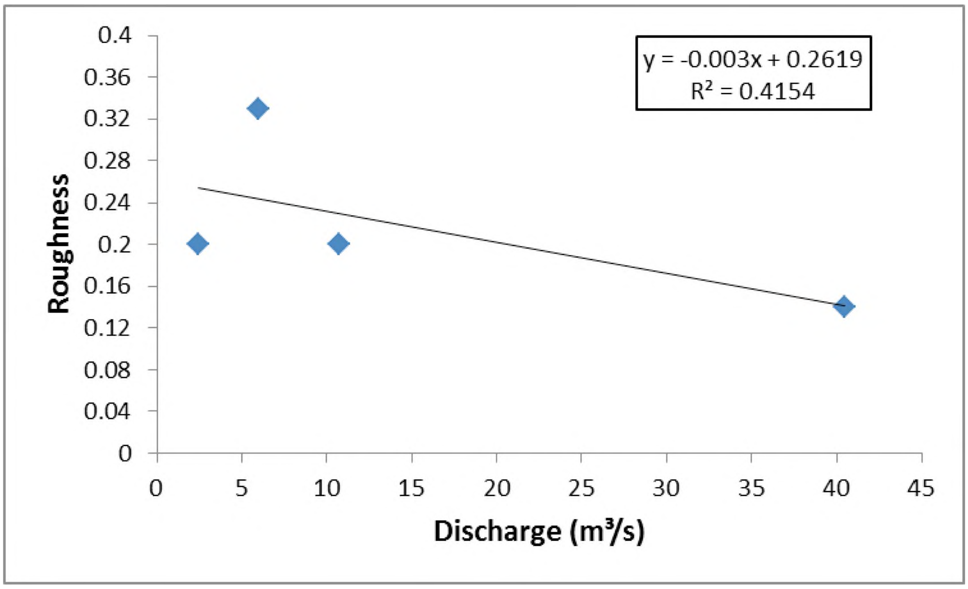


Figure 38: Site 2. Relationship between roughness values and discharge.

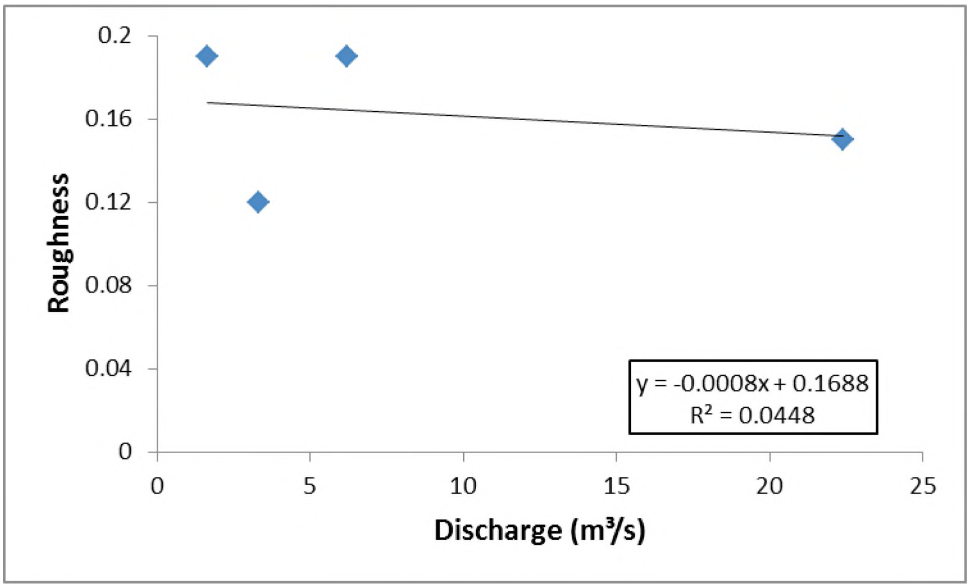


Figure 39: Site 3. Relationship between roughness values and discharge.

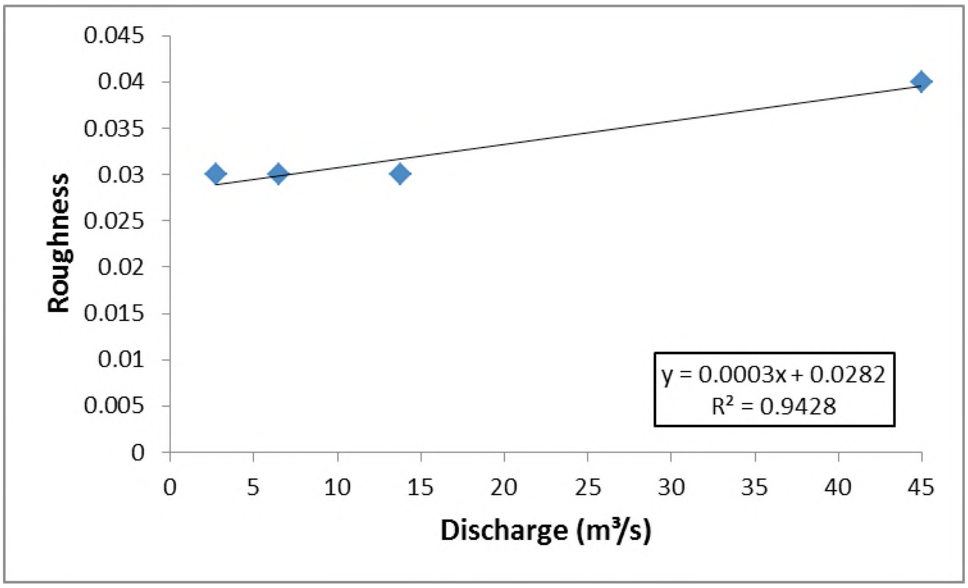


Figure 40: Site 4. Relationship between roughness values and discharge.

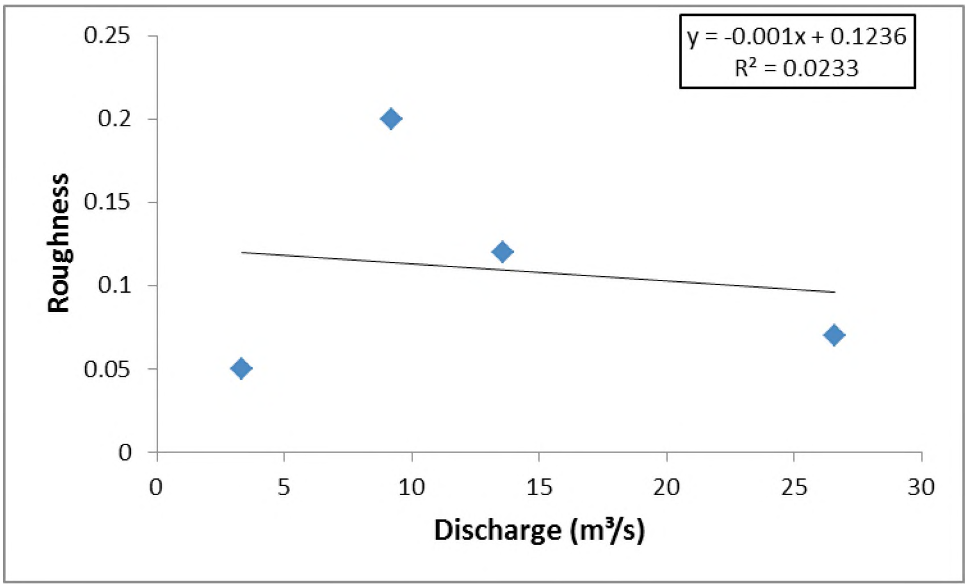


Figure 41: Site 5. Relationship between roughness values and discharge.

4.3.3 Sediment Mobility

This section presents data on the stability of bed substrates and potential movement thereof in each site during each monitoring survey. The RBS illustrated in Table 18, reflects the potential movement of coarse substrates (> 4mm and excluding bedrock outcrops) along a representative transect in each site. The larger the value the more stable the bed along the transect. In Site 4, the river bed became less stable at higher flows with low bed stability and particle movement during high summer flows.

Table 18: Relative Bed Stability for selected sites (a= rising stage, b= receding stage).

	July '15	October '15	February (a) '16	February (b) '16	April '16	August '16
Site 1	14.15	n/a	n/a	6.83	3.34	11.43
Site 2	13.14	14.28	13.46	5.47	12.16	18.25
Site 3	12.48	13.79	6.39	5.46	7.49	9.03
Site 4	1.48	1.37	0.78	1.37	1.53	1.27
Site 5	5.58	n/a	n/a	5.6	17.08	9.15

Tables 19 - 23 show the overall bed movement of coarse substrates in each site. The closer to 1 the ER is the less stable the bed. Where the value is greater than 1, bed movement is possible. Site 1 and 5 showed an extremely stable bed due to the dominant substrates and morphological characteristics with potential movement of D_{25} particle sizes. Site 2 and 3 show less stable beds with movement of D_{25} particle sizes during the peak discharge over the monitoring period and potential movement of

D_{75} particle sizes at high discharges. Site 4 had the least stable bed dominated by sand and fine gravel. Sediment movement of both D_{25} and D_{75} occurred during high summer flows (February 2016) and peak discharges.

Table 19: Bed movement in Site 1.

	July '15	February '16	April '16	August '16	Peak discharge (2016/01/26)
Shear stress	13.94	31.76	27.74	20.75	65.89
Particle size D_{25}					
Critical shear stress	99.3	99.3	99.3	99.3	99.33
Entrainment ratio	0.14	0.32	0.28	0.21	0.65
Bed movement	None	None	None	None	Potential
Particle size D_{75}					
Critical shear stress	175.42	175.42	175.42	175.42	175.42
Entrainment ratio	0.08	0.18	0.16	0.12	0.37
Bed movement	None	None	None	None	None

Table 20: Bed movement in Site 2.

	July '15	February '16	April '16	August '16	Peak discharge (2016/01/26)
Shear stress	36.69	**104.62**	54.81	54.61	**116.14**
Particle size D_{25}					
Critical shear stress	101.33	**101.33**	101.33	101.33	**101.33**
Entrainment ratio	0.36	**1.03**	0.54	0.54	**1.15**
Bed movement	None	**Movement**	Potential	Potential	**Movement**
Particle size D_{75}					
Critical shear stress	209.45	209.45	209.45	209.45	209.45
Entrainment ratio	0.18	0.50	0.26	0.26	0.55
Bed movement	None	Potential	None	None	Potential

Table 21: Bed movement in Site 3.

	July '15	February '16	April '16	August '16	Peak discharge (2016/01/26)
Shear stress	35.57	62.14	43.51	54.02	**114.17**
Particle size D_{25}					
Critical shear stress	81.50	81.50	81.50	81.50	**81.50**
Entrainment ratio	0.44	0.76	0.53	0.66	**1.4**
Bed movement	None	Potential	Potential	Potential	**Movement**
Particle size D_{75}					
Critical shear stress	150.38	150.38	150.38	150.38	150.38
Entrainment ratio	0.24	0.41	0.29	0.36	0.76
Bed movement	None	None	None	None	Potential

Table 22: Bed movement in Site 4.

	July '15	February '16	April '16	August '16	Peak discharge (2016/01/27)
Shear stress	1.88	**6.60**	1.81	2.06	**9.95**
Particle size D_{25}					
Critical shear stress	2.80	**2.80**	2.80	2.80	**2.80**
Entrainment ratio	0.67	**2.36**	0.65	0.74	**3.55**
Bed movement	Potential	**Movement**	Potential	Potential	**Movement**
Particle size D_{75}					
Critical shear stress	7.34	**7.34**	7.34	7.34	**7.34**
Entrainment ratio	0.26	**0.90**	0.25	0.28	**1.36**

Table 23: Bed movement in Site 5.

	July '15	February '16	April '16	August '16	Peak discharge (2016/01/27)
Shear stress	22.57	29.77	40.78	32.95	79.93
Particle size D_{25}					
Critical shear stress	143.48	143.48	143.48	143.48	143.48
Entrainment ratio	0.16	0.21	0.28	0.23	0.56
Bed movement	None	None	None	None	Potential
Particle size D_{75}					
Critical shear stress	253.61	253.61	253.61	253.61	253.61
Entrainment ratio	0.09	0.12	0.16	0.13	0.32
Bed movement	None	None	None	None	None

4.4 Physical Variables

Through the monitoring of physical variables, including cross-sectional morphology and substrates a baseline of the current river condition was set up. This section presents results on the baseline survey conducted in this study which will allow for the assessment of the long term impacts of the Ntabelanga Dam.

4.4.1 Cross-sectional surveys

Cross-sectional transects were surveyed for each site using a Differential GPS (0.001 m vertical and horizontal accuracy) during July 2015. Transects (Figure 42) were used as a reference for the current condition of the Tsitsa River before the construction of the Ntabelanga Dam. Cross-sectional transects for all the sites, including distribution of substrates, geo-habitats and July 2015 water levels are presented in Appendix 1.

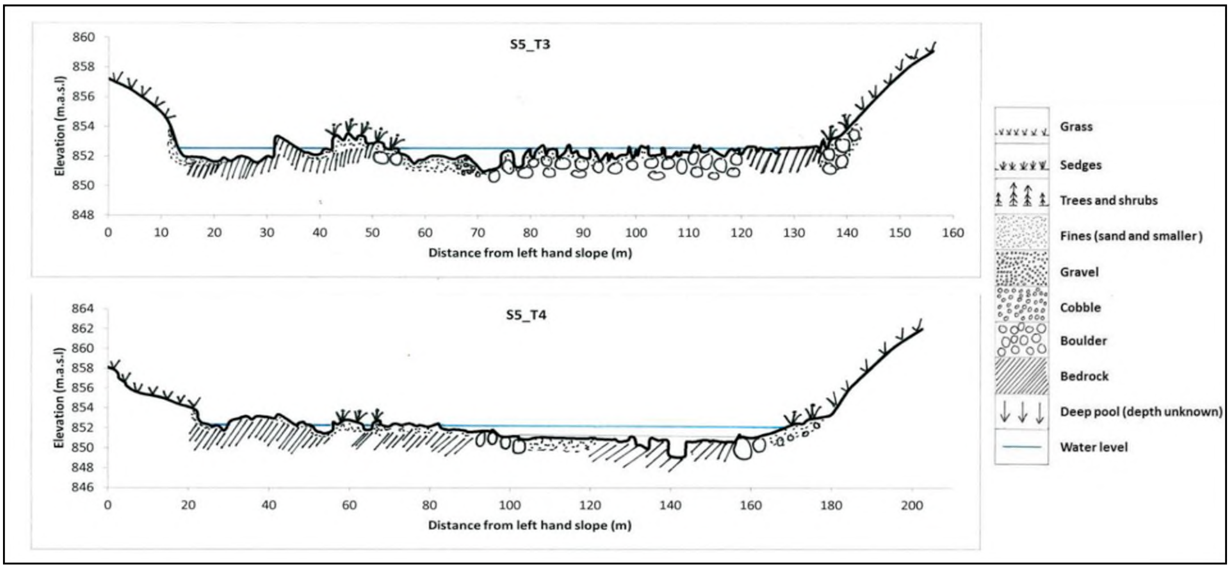


Figure 42: Example of cross-sectional transects of the Tsitsa River, with corresponding substrates and geo-habitats, surveyed in July 2015.

In August 2016, approximately a year after the first cross-sectional transects were surveyed, all the transects were resurveyed to pick up any significant changes in channel morphology after a single wet and dry season. The majority of sites did not undergo any major changes in channel morphology (Figure 43). Small changes were evident on silt and sand banks that were easily entrained during high flows or deposited in low flows. Some of the changes can be accounted for by surveyor bias. This occurred on boulder morphologies where the position of surveying points varied. However, these changes were minor. A full record of the comparison between July 2015 and August 2016 cross-sectional transects can be found in Appendix 2.

A data set of cross-sectional surveys can be found on a compact disc (CD) at the end of the thesis. This includes GIS shapefiles and spreadsheets of the cross-sectional data including the coordinates of each point along the transects. If the channel and the surrounding banks have changed so significantly that they become unrecognisable from descriptions in this baseline study, one can overlay the GIS shapefiles on the most recent aerial images of the area to get an idea of where the transects are located.

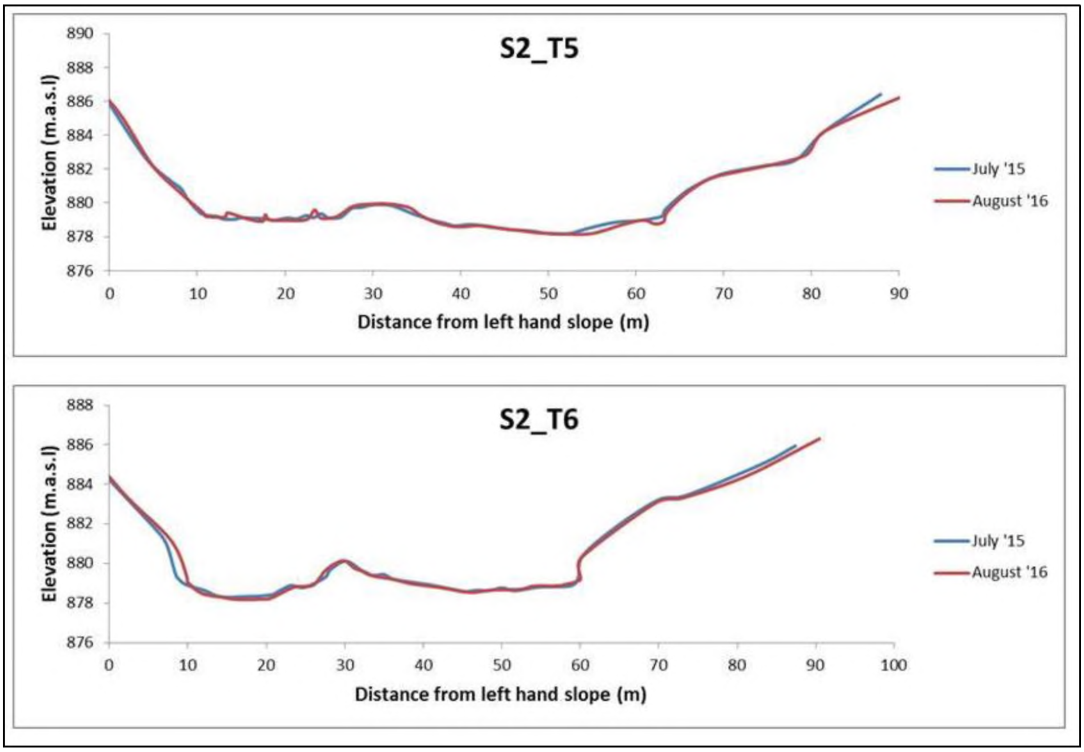


Figure 43: Example of cross-sectional transects showing little or no seasonal change to channel topography.

The only site that underwent a significant change in channel morphology was Site 4 (Figure 44). It is important to note that these changes occurred primarily due to anthropogenic impacts, in the form of sand mining operations, on the river sand bars and channel banks. These activities are likely to continue after the construction of the Ntabelanga Dam and may continue to change the morphology in sites that have easily accessible sand banks, such as Site 4. All of the sites contained sand banks and Site 4 was dominated by fine sediments. Several of the sites exhibited small changes to sand bars and banks. Such sand bars and banks can be entrained and transported at high discharges and deposited at low discharges. These sections of the river are susceptible to major pattern changes irrespective of the construction of the Ntabelanga Dam.

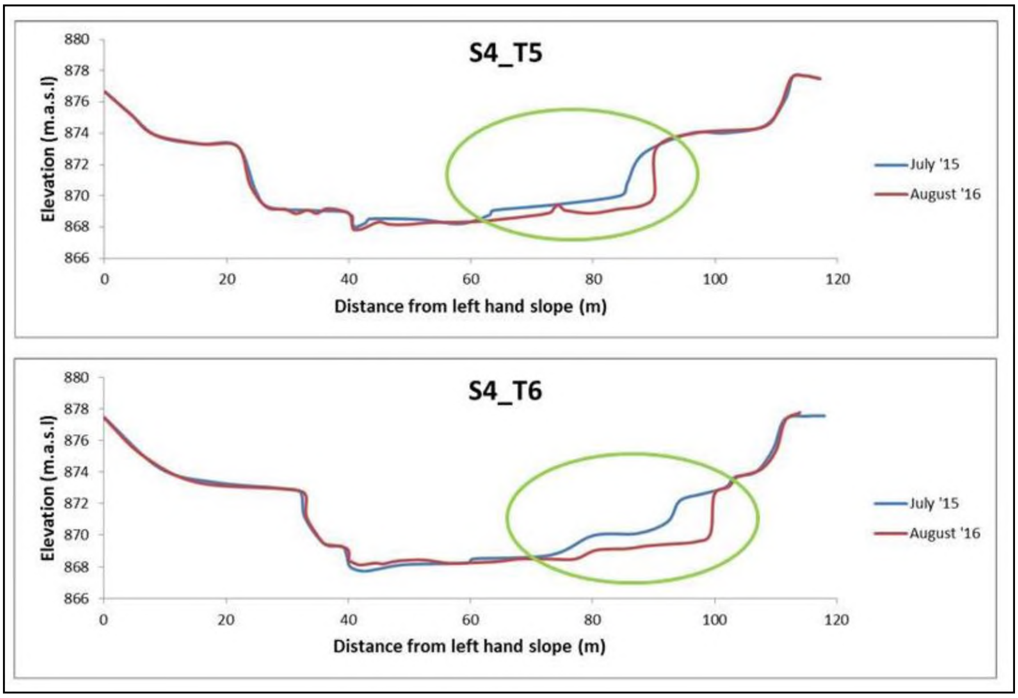


Figure 44: Example of cross-sectional transects that have undergone a seasonal change in topography. In this case changes have occurred due to sand mining at low flows.

4.4.2 SUBSTRATE

The magnitude of sedimentation of substrates can be measured in numerous ways including the area in which the streambed is covered and the types of clasts being embedded.

BED CONDITIONS

This section presents information on the bed conditions in terms of coarse substrates in each site. A summary of the overall bed conditions at each site is given in Table 24.

Table 24: Summary of bed conditions at each site in the Tsitsa River.

Site	D_{50} (mm)	Dominant bed material (>4mm and excluding bedrock)
1	380	Large cobble to large boulders
2	260	Medium gravel to small boulders
3	350	Fines to small boulders
4	6	Fines and small gravels
5	56	Fines to large boulders

Site 1 was dominated by bedrock runs which made up the majority of the site (Figure 45). This site was situated in the gorge reach of the Tsitsa River with a relatively high gradient and confined channel and consequently with little deposition of fines. Measured coarse substrates that can be entrained (>4 mm and excluding bedrock) were predominantly cobbles and boulders (Table 25 and 26) situated in the lee of bedrock slabs and in slower flow along the river banks. Table 27 shows that the bed conditions changed from the left to the right of the channel as the flow velocity became shallower and slower. Embeddedness values on the left and in the middle of the channel were low whereas in shallower water to the right of the channel embeddedness increased due to the collection of fines, mostly in the lee of bedrock boulders.

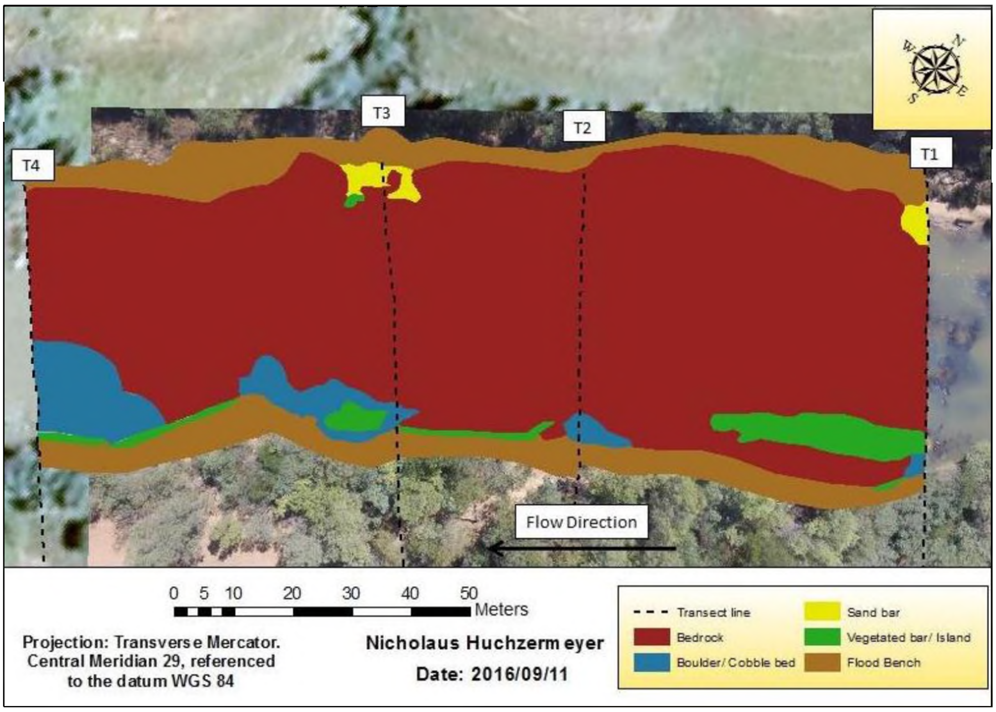


Figure 45: Channel features at a large scale for Site 1.

Table 25: Percentage distribution of clasts in Site 1.

Clast category	Diameter range (mm)	Percentage distribution
Small gravel	4 – 25	2
Medium gravel	25 – 50	8
Large gravel	50 – 75	13
Small cobble	**75 – 150**	**24**
Medium cobble	150 – 225	10
Large cobble	225 – 300	10
Small boulder	**300 – 600**	**25**
Large boulder	> 600	8

Table 26: Bed conditions along each transect in Site 1.

Transect	D_{50} (mm)	Dominant substrate
1	380	Small boulder
2	295	Large cobble
3	550	Small boulder
4	600	Large boulder

Table 27: Substrate properties for Site 1.

Position on transect	Dominant substrate	Embeddedness	Packing	Sorting
Transect 1				
Left of channel	Small boulder	87.1	Normal	Poorly sorted
Mid-channel	Bedrock	99.0	n/a	n/a
Right of channel	Bedrock	91.6	n/a	n/a
Transect 2				
Left of channel	Large cobble	75.1	Normal	Poorly sorted
Mid-channel	Bedrock	91.1	n/a	n/a
Right of channel	Bedrock	91.9	n/a	n/a
Transect 3				
Left of channel	Small boulder	98.1	Normal	Poorly sorted
Mid-channel	Bedrock	91.2	n/a	n/a
Right of channel	Bedrock	91.8	n/a	n/a
Transect 4				
Left of channel	Large boulder	98.1	Poorly sorted	Normal
Mid-channel	Bedrock	91.1	n/a	n/a
Right of channel	Bedrock	91.8	n/a	n/a

Site 2 had a variety of morphologies starting in a pool, with sand and bedrock substrates, ranging through a boulder, cobble and bedrock rapid into a low gradient pool and back into a boulder and cobble riffle (Figure 46). The dominant coarse substrates distributed across the site were small cobbles and small boulders (Table 28). The dominant substrates varied along the transects ranging from gravel to boulders (Table 29). Table 30 shows that Transect 1 was stable on the left of the channel with a decrease in embeddedness due to increased flow velocity. The right of the channel collected fines and was highly embedded. Transect 2 and 3 were situated across the rapid where flow velocity was confined, forming a stable bed with low embeddedness values. Transect 4 was situated in a pool in which reduced flow velocity resulted in an increase in embeddedness values. The left of the channel at Transect 5 and 6, between the vegetated island and the left hand bank, was not part of the main channel and only received flow at higher discharges. Transect 5 was more confined, again reducing embeddedness values. An increase in embeddedness values on the left of the channel in Transect 6 was due to the collection of fines in slack water below a boulder bed that only received flow at high discharges.

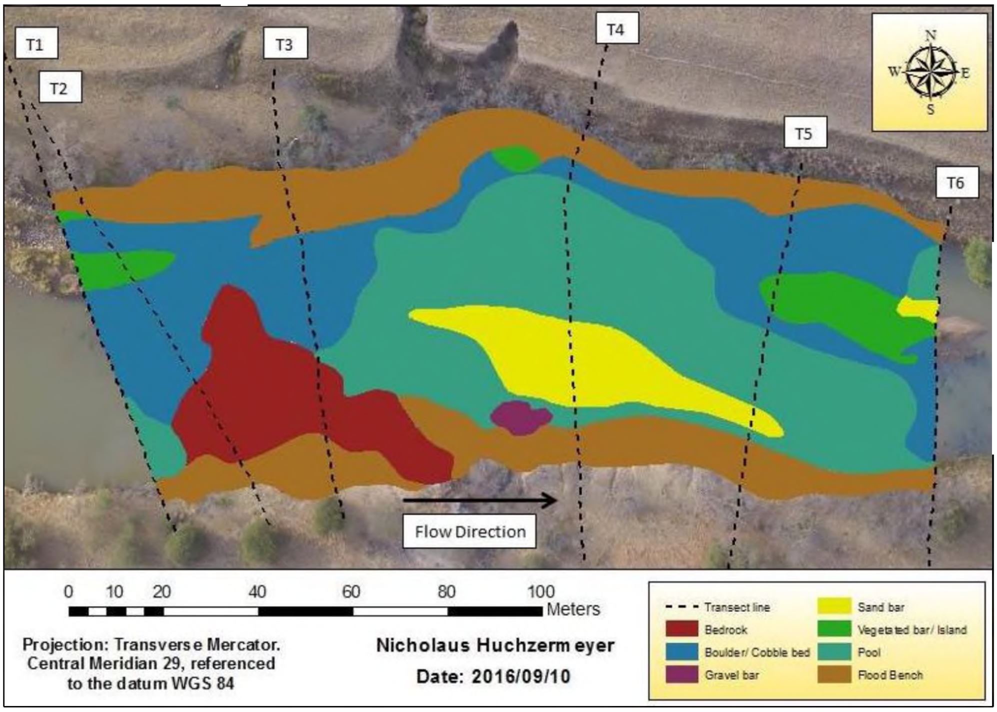


Figure 46: Channel features at a large scale for Site 2. Pools were dominated by fine substrate.

Table 28: Percentage distribution of clasts in Site 2.

Clast category	Diameter range (mm)	Percentage distribution
Small gravel	4 – 25	6
Medium gravel	25 – 50	13
Large gravel	50 – 75	6
Small cobble	**75 – 150**	**18**
Medium cobble	150 – 225	8
Large cobble	225 – 300	13
Small boulder	**300 – 600**	**25**
Large boulder	> 600	11

Table 29: Bed conditions along each transect in Site 2.

Transect	D_{50} (mm)	Dominant substrate
1	580	Small boulder
2	380	Small boulder
3	260	Large cobble
4	33	Medium gravel
5	295	Large cobble
6	315	Small boulder

Table 30: Substrate properties for Site 2.

Position on transect	Dominant substrate	Embeddedness	Packing	Sorting
Transect 1				
Left of channel	Small boulder	98.3	Highly imbricated	Poorly sorted
Right of channel	Fines in lee of boulder	91.9	Closely packed	Very poorly sorted
Transect 2				
Left of channel	Small boulder	87.3	Highly imbricated	Poorly sorted
Right of channel	Bedrock	91.3	n/a	n/a
Transect 3				
Left of channel	Large cobble	87.3	Highly imbricated	Poorly sorted
Right of channel	Bedrock	91.3	n/a	n/a
Transect 4				
Left of channel	Fine gravel	21.5	Normal	Moderately sorted
Right of channel	Medium gravel	42.5	Normal	Poorly sorted
Transect 5				
Left of channel	Small boulder	98.2	Highly imbricated	Poorly sorted
Mid-channel	Large cobble	87.2	Closely packed	Poorly sorted
Transect 6				
Left of channel	Fines	11.9	n/a	n/a
Mid-channel	Small boulder	88.1	Closely packed	Moderately sorted
Right of channel	Medium Cobble	77.3	Normal	Moderately sorted

Site 3 had the highest bed gradient of all the sites and was more confined than Site 2. It varied from bedrock at the top through a boulder and cobble rapid into a low gradient pool with deposits of fine sediments (Figure 47). The dominant coarse substrates across the site were large gravels, commonly from surrounding alluvial fans, as well as small cobbles (Table 31). The bed conditions along the transects were highly variable and ranged from fines to small boulders (Table 32). Table 24 shows that Transect 1 ranged across a pool with low embeddedness values in the middle of the channel and high embeddedness values along the right bank where fines were deposited in an area of reduced flow velocity. Transect 2 and 3 were situated across the rapid with closely packed and highly imbricated boulders forming a stable bed along Transect 2, and Transect 3 being dominated by cobbles with low embeddedness values implying very little deposition of fines in the rapids. Transect 4 was highly embedded due to the deposition of fines in areas of reduced flow velocity making up the pool. Embeddedness values along Transect 5 were reduced as flow velocity increased due to channel confinement by an impinging alluvial fan.

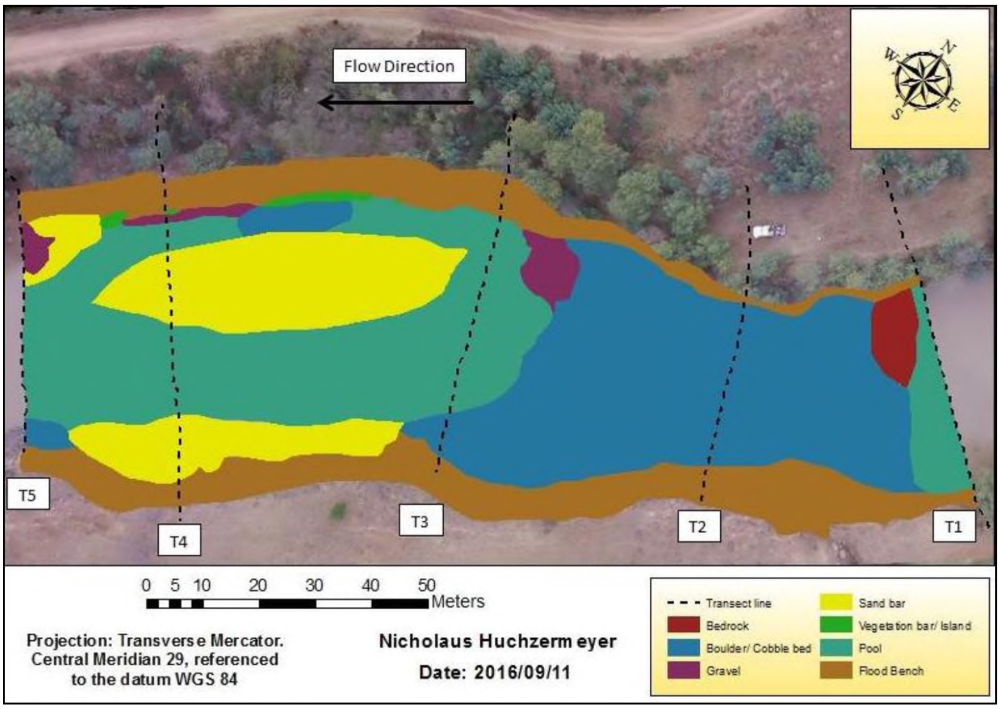


Figure 47: Channel features at a large scale for Site 3. The pool was dominated by fine substrate.

Table 31: Percentage distribution of clasts in Site 3.

Clast category	Diameter range (mm)	Percentage distribution
Small gravel	4 – 25	1
Medium gravel	25 – 50	5
Large gravel	**50 – 75**	**17**
Small cobble	**75 – 150**	**30**
Medium cobble	150 – 225	8
Large cobble	225 – 300	10
Small boulder	300 – 600	14
Large boulder	> 600	15

Table 32: Bed conditions along each transect in Site 3.

Transect	D_{50} (mm)	Dominant substrate
1	± 4	Fines
2	240	Small boulder
3	280	Large cobble
4	620	Medium gravel
5	295	Large cobble

Table 33: Substrate properties for Site 3.

Position on transect	Dominant substrate	Embeddedness	Packing	Sorting
Transect 1				
Mid-channel	Bedrock	91.1	n/a	n/a
Right of channel	Fines	11.9	n/a	n/a
Transect 2				
Left of channel	Small boulder	98.3	Poorly sorted	Closely packed
Mid-channel	Large boulder	99.1	Moderately sorted	Highly imbricated
Transect 3				
Mid-channel	Medium cobble	76.1	Poorly sorted	Normal
Right of channel	Large cobble	85.2	Poorly sorted	Normal
Transect 4				
Left of channel	Large boulder	98.6	Poorly sorted	Closely packed
Mid-channel	Fines	11.9	n/a	n/a
Right of channel	Small gravel	21.8	Well sorted	Normal
Transect 5				
Left of channel	Large boulder	98.4	Poorly sorted	Closely packed
Mid-channel	Small gravel	21.6	Well sorted	Normal
Right of channel	Large cobble	54.3	Moderately sorted	Normal

Site 4 had a low gradient with a wide but incised channel (Figure 48). Sand bars made up the greatest proportion of the substrate (Table 35), with a small section of bedrock (Table 34) on the outside edge of the channel where conditions were less susceptible to deposition of fines (Figure 48). Table 36 showed that Transect 1 to 5 were dominated by high embeddedness values implying deposition of fines in areas of reduced flow velocity due to the low gradient of the site.

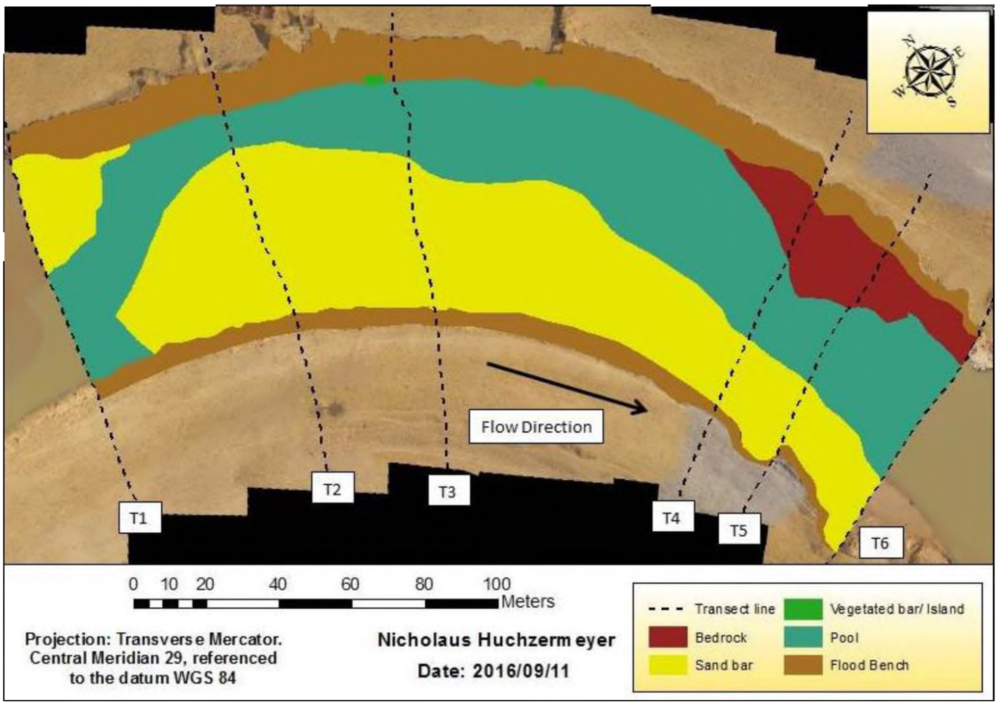


Figure 48: Channel features at a large scale for Site 4. The pool was dominated by fine substrate.

Table 34: Percentage distribution of clasts in Site 4.

Clast category	Diameter range (mm)	Percentage distribution
Small gravel	**4 – 25**	**80**
Medium gravel	25 – 50	0
Large gravel	50 – 75	0
Small cobble	75 – 150	0
Medium cobble	150 – 225	0
Large cobble	225 – 300	0
Small boulder	300 – 600	0
Large boulder	**> 600**	**20**

Table 35: Bed conditions along each transect in Site 4.

Transect	D_{50} (mm)	Dominant substrate
1	5.5	Small gravel
2	± 4	Fines
3	± 4	Fines
4	± 4	Fines
5	± 4	Fines
6	± 4	Fines

Table 36: Substrate properties for Site 4.

Position on transect	Dominant substrate	Embeddedness	Packing	Sorting
Transect 1				
Left of channel	Fines	11.9	n/a	n/a
Mid-channel	Small gravel	21.9	Well sorted	Normal
Right of channel	Fines	11.9	n/a	n/a
Transect 2				
Left of channel	Fines	11.9	n/a	n/a
Mid-channel	Fines	11.9	n/a	n/a
Right of channel	Fines	11.9	n/a	n/a
Transect 3				
Left of channel	Fines	11.9	n/a	n/a
Mid-channel	Fines	11.9	n/a	n/a
Right of channel	Small gravel	21.9	Well sorted	Normal
Transect 4				
Left of channel	Bedrock	91.8	n/a	n/a
Mid-channel	Fines	11.9	n/a	n/a
Right of channel	Fines	11.9	n/a	n/a
Transect 5				
Left of channel	Bedrock	91.7	n/a	n/a
Mid-channel	Fines	11.9	n/a	n/a
Right of channel	Fines	11.9	n/a	n/a
Transect 6				
Left of channel	Bedrock	91.9	n/a	n/a
Mid-channel	Fines	11.9	n/a	n/a
Right of channel	Fines	11.9	n/a	n/a

Site 5 was a highly complex site with a wide channel meandering over a variety of substrates (Figure 49). Boulders represented the most dominantly distributed coarse substrate across the site (Table 37). The site ranged from a low gradient pool dominated by fines into a boulder and cobble rapid, with gravels deposited at the foot of the rapids. The rapids extended into a bed with a lower gradient dominated by a cobble and bedrock substrate (Table 38). Table 39 shows that Transect 1 ranged across a pool with high embeddedness values due to reduced flow velocity. Transect 2 was situated along the bottom edge of the pool with the right of the channel being highly embedded and the mid-channel less embedded as a bedrock outcrop characterises the start of a rapid sequence. Increased flow velocity reduced the embeddedness values. Transect 3, 4 and 5 ranged across a multitude of flow velocities and channel features. Embeddedness values increased in areas of reduced flow velocity or where fines accumulated in the lee of boulders or bedrock slabs. Flow velocity increased over imbricated boulder rapids reducing embeddedness and exhibited a stable bed.

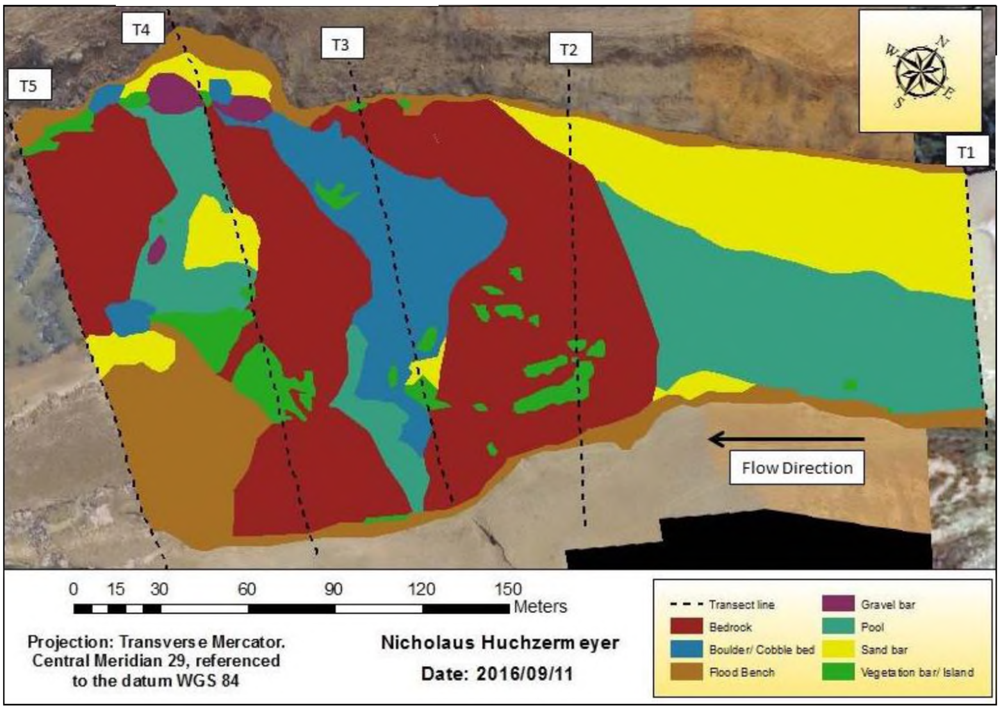


Figure 49: Channel features at a large scale for Site 5. The pool was dominated by fine substrate.

Table 37: Percentage distribution of clasts in Site 5.

Clast category	Diameter range (mm)	Percentage distribution
Small gravel	4 – 25	3
Medium gravel	25 – 50	7
Large gravel	50 – 75	6
Small cobble	75 – 150	14
Medium cobble	150 – 225	16
Large cobble	225 – 300	13
Small boulder	**300 – 600**	**22**
Large boulder	**> 600**	**19**

Table 38: Bed conditions along each transect in Site 5.

Transect	D_{50} (mm)	Dominant substrate
1	± 4	Fines
2	> 600	Bedrock
3	805	Large boulder
4	28	Medium gravel
5	300	Large cobble

Table 39: Substrate properties for Site 5.

Position on transect	Dominant substrate	Embeddedness	Packing	Sorting
Transect 1				
Left of channel	Fines	11.9	n/a	n/a
Mid-channel	Fines	11.9	n/a	n/a
Right of channel	Fines	11.9	n/a	n/a
Transect 2				
Mid-channel	Bedrock	91.5	n/a	n/a
Right of channel	Fines	11.9	n/a	n/a
Transect 3				
Mid-channel	Large boulder	99.3	Moderately sorted	Highly imbricated
Right of channel	Bedrock	91.5	n/a	n/a
Transect 4				
Mid-channel	Small gravel	33.1	Well sorted	Normal
Right of channel	Medium gravel	44.1	Well sorted	Normal
Transect 5				
Mid-channel	Bedrock	91.5	n/a	n/a
Right of channel	Bedrock	90.0	n/a	n/a

Fine Substrate

This section presents the data on fine sediment accumulation and its variation within and between sites during the monitoring period.

The Brusven Index, described in section 3.3.2, gives an indication of embeddedness due to the accumulation of fine sediment at each site (Figure 50a). The general trend from the figure is that embeddedness values increased during lower discharges, implying deposition of fine materials with a reduction in flow velocity. During very high flow velocities (such as in February 2016) embeddedness values decreased implying entrainment of fines.

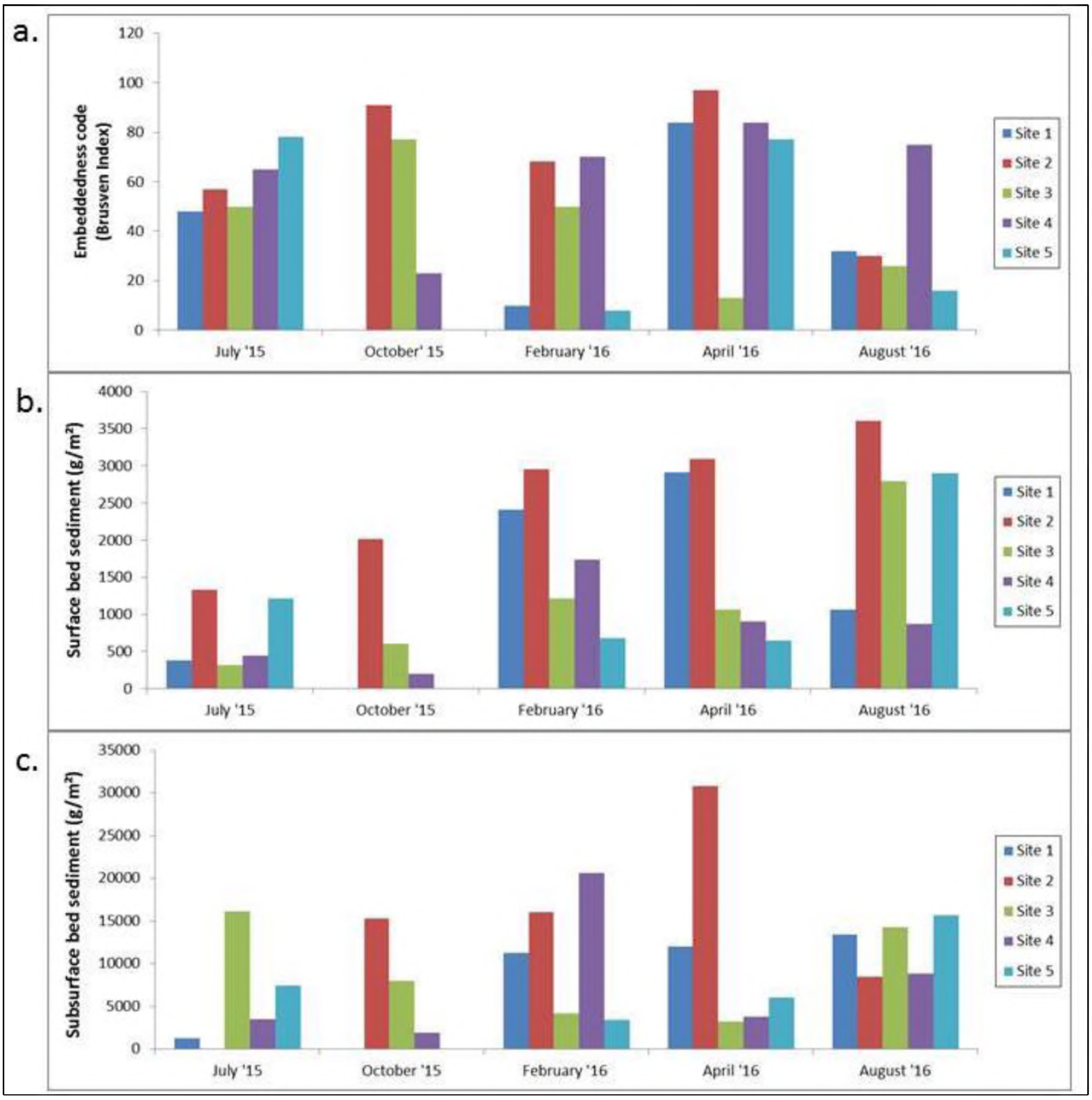


Figure 50: Seasonal variation of the, a. percentage fines in the embeddedness values, b. surface fine sediment accumulation and c. subsurface fine sediment accumulation, across each site in the Tsitsa River.

Disturbance samples of fine sediment stored on the stream bed (surface and subsurface) vary over time. From Figure 50b it can be seen that fine sediment accumulation differed between sites and did not necessarily follow discharge trends alone. Generally, fine sediment accumulation increased the more turbid the flows were (February 2016). Summer baseflows were likely to entrain sediment (April 2016, Site 3, 4 and 5) whereas medium, turbid flows (April 2016, Site 1 and 2) were more likely to deposit sediment on the bed, increasing surface disturbance concentrations. During periods of low flow the energy slope was insufficient to entrain fine sediments resulting in higher disturbance concentrations (July 2015, October 2015 and August 2016). Small local rainfall events increased the turbidity of the river but not the flow (October 2015, Site 2), which in turn increased the amount of sediment deposited on the bed (Figure 51). Surface drape was more easily deposited or entrained than subsurface deposits.

Figure 51: Turbid flood pulse during low flow at Site 2, October 2015.

Samples of both the surface and subsurface deposited fine sediments were collected for each disturbance to quantify the combined surface drape and subsurface fine sediment deposits. Subsurface fine sediment deposits (Figure 50c) followed a similar trend to those of surface sediment deposits; however, subsurface deposits were also affected by the gradient of specific sites as well as the dominant substrate present. A site with a highly stable or imbricated bed (Site 5) or a bedrock dominated site with a relatively high gradient (Site 1) had a low potential for the deposition of subsurface deposits. Sites with diverse substrates, including sand bars, gravel and cobble beds (Site 2) were more likely to have higher subsurface deposits in areas of reduced gradient.

A more in depth habitat scale analysis of surface and subsurface fine sediment accumulation is presented in section 4.7.

Measured values of water quality variables (phosphates, DO, temperature, pH, EC, clarity and turbidity), HMID values and the ASPT derived using SASS 5 methodology for each site during each monitoring survey are presented in Tables 40 – 44.

Table 40: Measured water quality variables for July 2015.

Site	1	2	3	4	5
Phosphates (mg/l)	0	0.3	0	0	0
Dissolved oxygen (%)	72	83	75	91	97
Temperature (˚C)	9.6	13.4	10.3	11	9.5
pH	8.2	8.1	8.1	7.9	8.1
Electric conductivity (µS)	60	59	67	95	85
Clarity (cm)	94	48	49	33	37
Turbidity (FTU)	40	60	80	100	100
HMID	12.3	9.8	10.5	7.6	10.8
ASPT	5.4	6.3	5.9	4.3	5.9

Table 41: Measured water quality variables for October 2015.

Site	2	3	4
Phosphates (mg/l)	1.3	0.2	0
Dissolved oxygen (%)	81.2	84.4	81.7
Temperature (˚C)	19	20.9	15.6
pH	8.0	8.2	8.1
Electric conductivity (µS)	85	87	127
Clarity (cm)	6.5	37	10.5
Turbidity (FTU)	130	30	98
HMID	22.1	8.0	4.0
ASPT	6	6.1	5.6

Table 42: Measured water quality variables for February 2016.

Site	1	2	3	4	5
Phosphates (mg/l)	0.5	0.3	0.7	1	0.5
Dissolved oxygen (%)	89.5	85.8	89.6	87.3	86.3
Temperature (˚C)	21.3	20.8	25.4	25.7	22.7
pH	8.1	8.2	8.0	7.9	8.1
Electric conductivity (µS)	31	23	28	31	28
Clarity (cm)	17	7	9.5	6	6
Turbidity (FTU)	74	150	120	230	216
HMID	5.9	6.1	5.9	3.6	11.5
ASPT	7.4	5.8	6.8	5.0	6.7

Table 43: Measured water quality variables for April 2016.

Site	1	2	3	4	5
Phosphates (mg/l)	0.3	No data	0.4	1	0.5
Dissolved oxygen (%)	81.9	82.4	89	77.8	85.5
Temperature (˚C)	14.7	16.9	19.5	25.5	19.9
pH	7.6	7.5	8.3	7.4	7.5
Electric conductivity (µS)	43	16.9	58	62	65
Clarity (cm)	7	0.2	53	41	38
Turbidity (FTU)	128	> 2000	54	50	58
HMID	8.4	8.6	9.5	3.4	6.7
ASPT	6.4	6.0	6.8	6.2	6.4

Table 44: Measured water quality variables for August 2016.

Site	1	2	3	4	5
Phosphates (mg/l)	0.3	0	0.2	0.3	0.2
Dissolved oxygen (%)	No data	No data	No data	No data	No data
Temperature (˚C)	6.9	7.5	7.4	8.2	9.5
pH	7.7	7.5	7.5	7.8	7.8
Electric conductivity (µS)	41	35	38	47	43
Clarity (cm)	63	26	30	18	23
Turbidity (FTU)	74	88	90	104	102
HMID	15.5	9.2	11.5	6.9	9.3
ASPT	6.3	6.2	4.9	4.3	6.4

Water quality at different sites was affected by external factors such as the underlying geology, point sources of pollutants and sediment inputs into the channel and played an important role in the condition of habitats for the colonisation of macroinvertebrates. Discharge also had an important effect on the water quality of a site and dictated the availability of different habitats. During monitoring surveys not all the sites were measured under the same discharge or on the same day (Figure 29). There was a general trend between water quality measured in seasons with low discharges (Table 40, 41 and 44) and those measured in seasons with higher discharges (Table 42 and 43).

At low discharges during the winter months, phosphate levels were very low, ranging from 0 – 0.3 mg/l in July 2015 and August 2016. October 2015 experienced higher levels of phosphates at low discharge, ranging from 0 – 1.3 mg/l. The highest measured phosphate level was found in Site 3 after a small rainfall event bringing a small but turbid flood pulse through the site. Summer months, February and April 2016, with high discharges and turbid waters had phosphate levels ranging from 0.3 – 1 mg/l. The trend of an increase in phosphate levels after rainfall events, implied that runoff in the catchment was bringing phosphates into the river system, which was then carried down the system by floods. However, phosphate levels were never high enough to have a noticeable impact on macroinvertebrates.

Measured dissolved oxygen (DO) concentrations generally remained greater than 80% of saturation with no significant difference between varying discharges. The lowest measured DO was 72% measured in Site 1 at low discharges in July 2015. None of the DO concentrations fell below 50%, which is defined as sub-lethal to aquatic organisms (DWAF, 1996). Therefore, concentrations of DO were not expected to have any significant impacts on biotic health in the Tsitsa River over the monitoring period.

Water temperatures measured in winter months at all sampling sites ranged from 9.5 – 13.5 ˚C in July 2015 and 6.9 – 9.5 ˚C in August 2016. August 2016 had lower temperatures due to snow melt in the catchment. During the summer months, water temperatures ranged from 14.7 – 25.7 ˚C. These were measured at different times of the day. It was difficult to establish whether the water temperatures impacted on aquatic biota negatively, due to the spatial differences in the times of temperature measurements and the differences in temperature tolerances of biota. A baseline of fluctuations in temperatures over the monitoring period (Figure 52), measured using level loggers, is presented in Appendix 6. The lowest temperatures were found in Site 1, possibly due to the river course being shaded by the side walls of a gorge for most parts of the day. The highest temperatures were found in Site 4 which was the shallowest site with the slowest moving water, allowing for higher but more variable water temperatures.

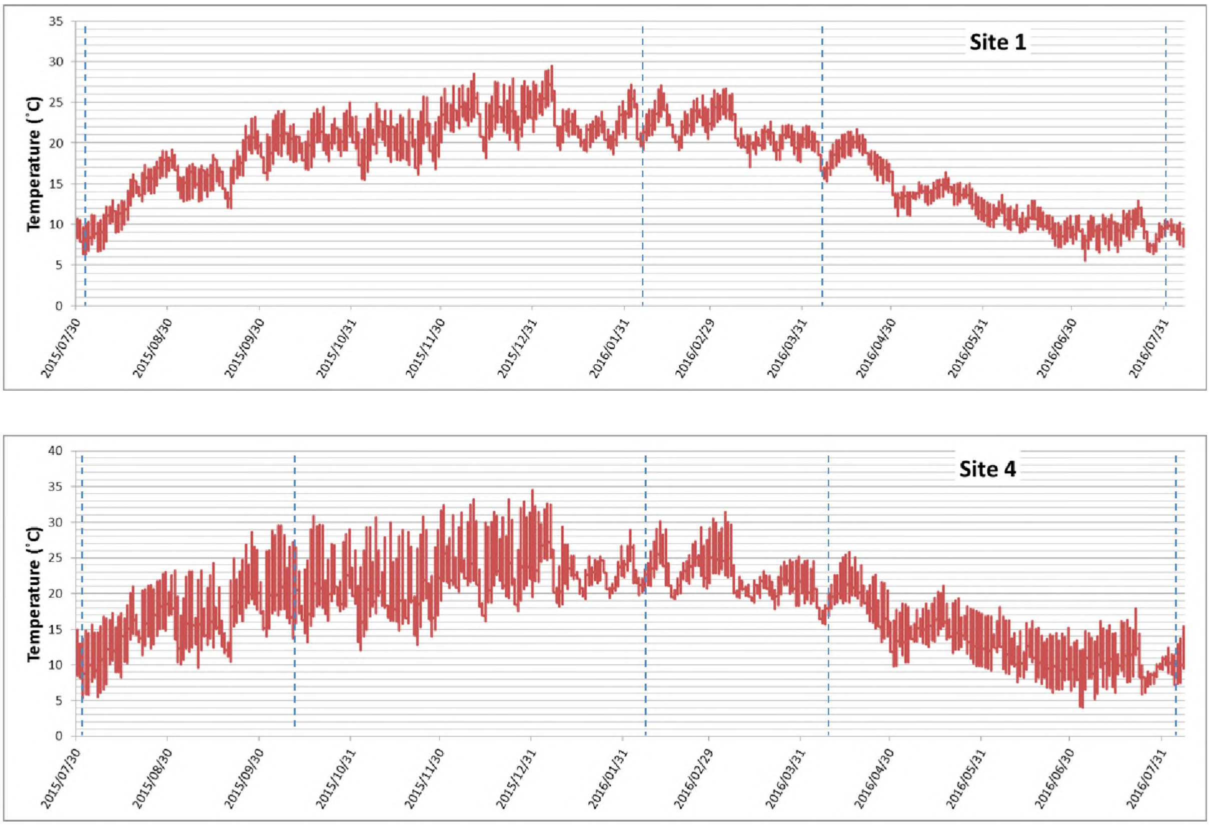


Figure 52: Fluctuations in water temperatures over the monitoring period, at Site 1 and 4, in the Tsitsa River showing approximate field sampling times.

In Site 1, measured pH varied from 7.7 – 8.2, Site 2 from 7.5 – 8.2, Site 3 from 7.5 – 8.3, Site 4 from 7.4 – 8.1 and Site 5 from 7.5 – 8.1. This indicated a balanced system reflecting anticipated seasonal fluctuations in pH.

Electric Conductivity (EC) levels seasonally ranged from 16.9 – 127 µs/cm, showing a generally decreasing trend with an increase in turbidity and flow.

Across all sampling sites, Site 1 generally had the highest clarity values (Figure 53i). The clarity of the water can be linked to rainfall events in the catchment resulting in an increased runoff and turbidity within the river which decreases clarity. Site 1 was the highest up in the catchment and clarity progressively decreased down the river system, implying a cumulative decrease in clarity.

A similar trend was found when looking at turbidity (Figure 53ii). Turbidity increased progressively down the river system, with a marked increase evident in Site 4 and 5 below the Inxu River confluence, depending on the flow conditions. Turbidity peaked during high discharges when runoff from rainfall in the catchment increased the amount of sediment entering the river system.

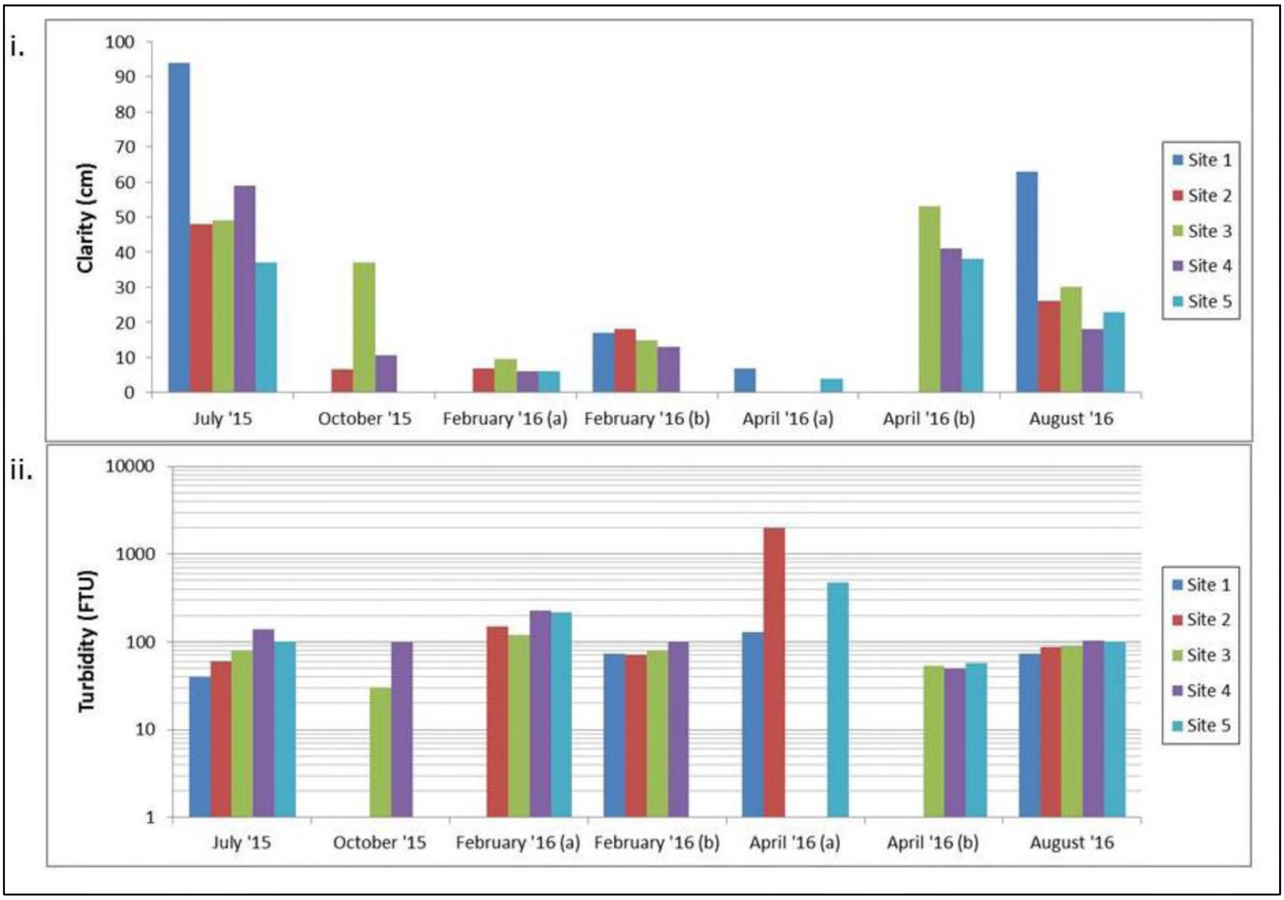


Figure 53: Variation in i. clarity and ii. turbidity in the Tsitsa River. a= rising stage of a flood, b= receding stage of a flood. Turbidity drawn with a logarithmic scale to account for outliers.

Although not technically a water quality parameter, the HMID gave an indication of the variability within hydraulic variables which in turn influenced availability of aquatic habitats and macroinvertebrate communities. The HMID measured during low discharges was very high showing a high variability in hydraulic variables. Months which were sampled under high discharges had lower HMID scores falling between moderate to high variability in hydraulic variables. However, it was expected that during higher discharges there should be a larger range of hydraulic variables (flows and depths), but due to practical reasons, the middle of the channel was not accessible during high discharges making it impossible to sample the hydraulic variability in the middle of the channel. Therefore, at low discharges a larger proportion of the channel was sampled for hydraulic variability. Site 1-3 and 5 showed variable HMID scores over different discharges with a general trend of high HMID scores. Site 4 had the lowest HMID scores. The site was characterised by a homogenous bed with a low gradient which may have affected the number of macroinvertebrate families present in this site.

SASS data sheets for February, April and August 2016 can be found in Appendix 7. The ASPT gave a rapid indication of the ecological state of the river in terms of water quality (Table 45). The ASPT in

Site 1 ranged from 5.4 to 7.4 implying a fair to natural ecological state. Site 2 (ASPT range from 5.8 to 6.3), Site 3 (ASPT range from 5.9 to 6.8) reflected a good ecological state. Site 4, dominated by a sandy habitat, ranged from 4.3 to 6.2, implying a poor to good ecological state. Site 5 ranged from 5.4 to 6.7, implying a moderate to good ecological state. A rapid assessment of the Tsitsa River showed that the state of the Tsitsa River changed depending on the season and the reach. Reach 1, running through the gorge, ranged from moderately modified to unmodified (ecological category A-C). Reach 2, between the dam wall and the Inxu River confluence, was largely natural with few modifications (ecological category B). Reach 3, the Tsitsa River below the confluence of the Inxu River, ranged from largely modified (Site 4) to largely natural with few modifications (Site 5) (ecological category A-D).

Table 45: Site based ASPT scores for each monitoring survey.

Site	1	2	3	4	5
July 2015	5.4	**6.3**	5.9	4.3	5.9
October 2015	No Data	6	6.1	5.6	No Data
February 2016	**7.4**	5.8	**6.8**	5.0	**6.7**
April 2016	6.4	6.0	**6.8**	**6.2**	6.4
August 2016	6.3	6.2	6.2	4.9	6.4

Statistical correlations between water quality variables and ASPT provide insight to understanding the impact of these variables on macroinvertebrates. Correlations between water quality variables and ASPT are presented in Table 46. No significant correlations were identified between the water quality variables and the ASPT. The degree of variability within the variables was insufficient to show a clear relationship. This implies that additional variables, such as the impacts of sediment, are also affecting the ASPT values.

Table 46: Correlation between ASPT of macroinvertebrates, derived using SASS 5 methodology, and measured water quality and habitat variables across all sites and sampling events.

Independent Variables	Correlation to ASPT
HMID	$r(21) = 0.102, p > 0.05$
Phosphate (mg/l)	$r(20) = 0.192, p > 0.05$
Dissolved oxygen (%)	$r(16) = 0.107, p > 0.05$
Temperature (˚C)	$r(21) = 0.294, p > 0.05$
pH	$r(21) = 0.036, p > 0.05$
Electric conductivity (µs)	$r(21) = 0.363, p > 0.05$
Clarity (cm)	$r(21) = 0.057, p > 0.05$
Turbidity (FTU)	$r(21) = 0.035, p > 0.05$
Discharge (m^3/s)	$r(21) = 0.039, p > 0.05$

4.6 Sensitivity of Biota to Fine Sediment Drape

The results of an evaluation of biotic variables established at a quadrat scale across all sites and sampling events are presented in Figure 54 and Table 47. These reflect the community structure of different macroinvertebrate classes and families respectively occurring in habitats with varying fine sediment drape concentrations (Low = < 100 g/m^2; Medium = 100-1 000 g/m^2; High = > 1 000 g/m^2).

Each class of macroinvertebrates and the families in each class, found in the Tsitsa River, are reviewed in section 5.4.

Table 48 provides a list of macroinvertebrate families with corresponding sediment sensitivity scores The fine sediment habitat score was calculated by ranking the sensitivity of different families of macroinvertebrates by the accumulation of sediment drape (g/m^2) in which they were observed. The macroinvertebrate families were then ranked from least sensitive to most sensitive to surface sediment drape and assigned a sensitivity score from Table 13. The higher the score the more sensitive the macroinvertebrate is to fine sediment drape and correspondingly it occurs in lower abundance in habitats with high sediment concentrations (Table 47). Sediment scores derived from Table 48 (ASPTsed) were subsequently used as an input into the analysis of biotic-abiotic interactions. The ASPTsed is the total sensitivity score for all the families found, divided by the number of families found.

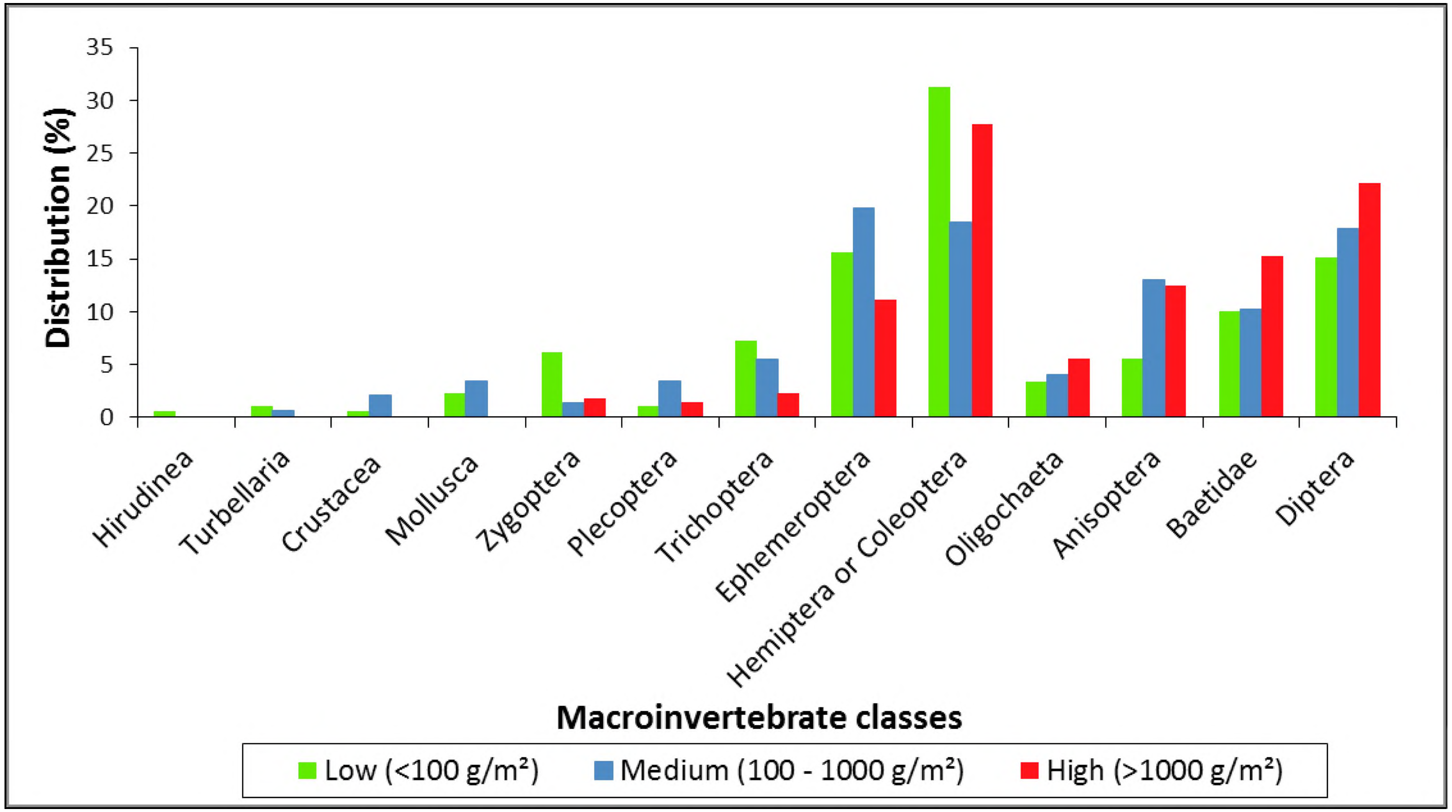


Figure 54: Percentage distribution of different macroinvertebrate classes occurring in different concentration of surface sediment dra pe in the Tsitsa River.

Table 47: Percentage distribution of different macroinvertebrate families occurring in different concentrations (low, medium and high) of surface sediment drape in the Tsitsa River.

Class	Family	% dist. in low (<100 g/m²)	% dist. medium (100 - 1000 g/m²)	% dist. high (>1000 g/m²)
Annelida-Hirudinea (Leeches)	Hirudinea	1	0	0
Turbellaria (Flat worms)	Planaria	1	1	0
Crustacea (Crabs or shrimps)	Potamonautidae	1	2	0
Mollusca (Snails and Limpets)	Ancylidae	2	2	0
	Sphaeriidae	0	1	0
Odonata-Zygoptera (Damselflies)	Coenagrionidae	**6**	1	2
Plecoptera (Stoneflies)	Perlidae	1	3	1
Trichoptera (Cased and uncased caddisfly)	Ecnomidae	1	1	0
	Hydropsychidae 1sp	3	3	0
	Hydropsychidae >2 sp	1	0	0
	Leptoceridae	3	2	2
Ephemeroptera (Mayflies excluding Baetidae)	Caenidae	**5**	**6**	**6**
	Heptageniidae	2	2	1
	Leptophlebiidae	**4**	**5**	3
	Oligoneuridae	2	1	0
	Prosopistomatidae	2	3	0
	Tricorythidae	1	2	0
Hemiptera (Bugs)	Belostomatidae	1	1	0
	Corixidae	3	2	**8**
	Gerridae	1	0	0
	Naucoridae	**4**	**5**	**6**
	Nepidae	1	1	0
	Notonectidae	2	1	2
	Veliidae	**4**	2	**4**

Class	Family	% dist. low (<100 g/m²)	% dist. medium (100 - 1000 g/m²)	% dist. high (>1000 g/m²)
Coleoptera (Beetles)	Dytiscidae	1	0	3
	Elmidae	3	3	0
	Gyrinidae	**6**	3	2
	Hydrophilidae	**4**	0	2
	Psephenidae	2	2	0
Annelida-Oligochaeta (Worms)	Oligochaeta	3	**4**	**6**
Odonata–Anisoptera (Dragonflies)	Aeshnidae	1	2	0
	Corduliidae	1	0	1
	Gomphidae	2	**10**	**10**
	Libellulidae	2	1	1
Ephemeroptera-Baetidae (Minnow mayflies)	Baetidae 1sp	1	3	7
	Baetidae 2 sp	**6**	**7**	**6**
	Baetidae >2 sp	3	1	2
Diptera (Flies)	Athericidae	0	1	0
	Ceratopogonidae	2	**4**	**5**
	Chironomidae	**7**	**6**	**11**
	Culicidae	1	0	1
	Dixidae	0	1	0
	Muscidae	1	1	0
	Psychodidae	0	1	0
	Simuliidae	**5**	3	3
	Tabanidae	0	1	0
	Tipulidae	1	1	1

Table 48: Sediment sensitivity score sheet for macroinvertebrate families found in the Tsitsa River.

Macroinvertebrate Class	Macroinvertebrate Family	Sensitivity Score
Annelidae (Leeches)	Hirudinea	9
Turbellaria (Flat worms)	Planaria	8
Crustacea (Crabs or shrimps)	Potamonautidae	7
Mollusca (Snails or Limpets)	Ancylidae	6
	Sphaeriidae	8
Odonata- Zygoptera (Damselflies)	Coenagrionidae	3
Plecoptera (Stoneflies)	Perlidae	4
Trichoptera (Cased and uncased caddisfly)	Hydropsychidae 1 sp	6
	Hydropsychidae 2 sp	7
	Hydropsychidae > 2sp	9
	Ecnomidae	5
	Leptoceridae	4
Annelidae (Worms)	Oligochaeta	1
Ephemeroptera (Minnow mayflies)	Baetidae 1 sp	1
	Baetidae 2 sp	2
	Baetidae >2 sp	4

Macroinvertebrate Class	Macroinvertebrate Family	Sensitivity Score
Ephemeroptera (Mayflies excluding Minnow mayflies)	Caenidae	1
	Heptageniidae	4
	Leptophlebiidae	4
	Oligoneuridae	9
	Prosopistomatidae	7
	Tricorythidae	4
Diptera (Flies)	Athericidae	5
	Ceratopogonidae	4
	Chironomidae	1
	Culicidae	1
	Dixidae	8
	Muscidae	3
	Psychodidae	8
	Simuliidae	1
	Tabanidae	6
	Tipulidae	5

Macroinvertebrate Class	Macroinvertebrate Family	Sensitivity Score
Hemiptera and Coleoptera (Bugs and beetles)	Belostomatidae	8
	Corixidae	2
	Dytiscidae	1
	Elmidae	6
	Gerridae	10
	Gyrinidae	5
	Hydraenidae	8
	Hydrophilidae	2
	Naucoridae	2
	Nepidae	8
	Notonectidae	4
	Psephenidae	6
	Veliidae	4
Odonata- Anisoptera (Dragonflies)	Aeshnidae	5
	Corduliidae	2
	Gomphidae	1
	Libellulidae	4

An analysis of biotic and abiotic variables and their interactions is presented in this section. Increased sedimentation and turbidity combined with a reduction in habitat conditions have a direct impact on ecological health in a river (Ritchie, 1972; Lemly, 1982; Henley *et al.*, 2000; Allan, 2004; Jones *et al.*, 2011).

The more diverse substrate is on the river bed the more habitat types are available for colonisation by macroinvertebrates. Figure 55 shows that for Reach 1 (Site 1) substrate diversity was highly variable in the rocky habitat, ranging from a low diversity in bedrock dominated habitats to more diverse substrates in cobble beds. Reach 2 (Site 2 and 3) and Reach 3 (Site 4 and 5) had high overall substrate diversity in the rocky habitats. The fines in all three reaches showed less variability with the majority of the data exhibiting no substrate diversity. Vegetation showed the least variation in substrate diversity, commonly occurring along the banks as marginal vegetation and alongside fine sediments. The variability can be accounted for by the proportions of each habitat present within a quadrat. The more equally present each substrate type, the higher the $'H_{sub}$ score.

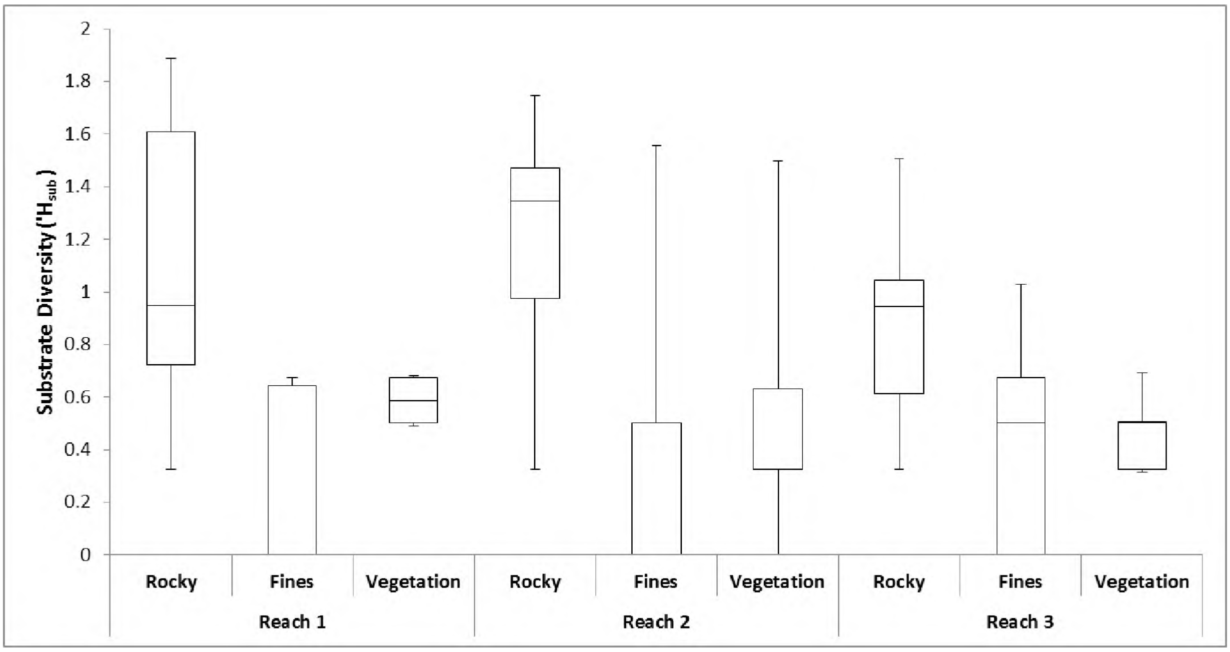


Figure 55: Box and whisker plots of substrate diversity for different habitats in each reach.

Figure 56 shows that the concentrations of fine sediment drape in rocky habitats had less variability, and were generally lower than the concentrations of fine sediment found in habitats dominated by fines. Rocky habitats were generally found in faster flowing water which is less suitable for the deposition of sediment whereas habitats dominated by fines were found in areas of the river where deposition took place due to reduced flow conditions. Reach 1 had the lowest concentration of fine sediment drape in rocky habitats, implying little deposition of sediment. Habitats dominated by fines had a higher concentration of fine sediment drape. In Reach 1 rocky habitats were found in the middle of the channel in fast flowing water, whereas habitats dominated by fines were found in areas of reduced flow velocity on the edge of the channel. Reach 2 and 3 had similar variability in fine sediment deposition, but Reach 2 had higher concentrations of fine sediment drape. Outliers in habitats dominated by fines in Reach 2 and 3 were sampled on thick silt banks which were very fine and exhibited a high concentration of fine sediment drape. Therefore, sediment drape concentrations increased in areas of reduced flow velocity, covering the stream substrate, resulting in habitats that were dominated by fine material.

The combined surface and subsurface sediment fills interstitial spaces between bed substrates or in severe cases covers an entire bed of substrate. Subsurface sediment is deposited during prolonged periods of reduced water velocity and is not as easily entrained as surface sediment drape. Figure 57 shows trends similar to those of surface sediment drape concentrations, however subsurface sediment concentrations were significantly higher. The subsurface sediment concentration in rocky habitats in Reach 1 and 3 had very little subsurface fine sediment deposits, implying very little deposition of fines in this habitat. There was a higher variability of subsurface sediment concentrations in rocky habitats in Reach 2 and habitats dominated by fines in Reach 1, 2 and 3 possibly due to the variability in the depths of fine sediment deposits as well as the grain size of the fine sediment.

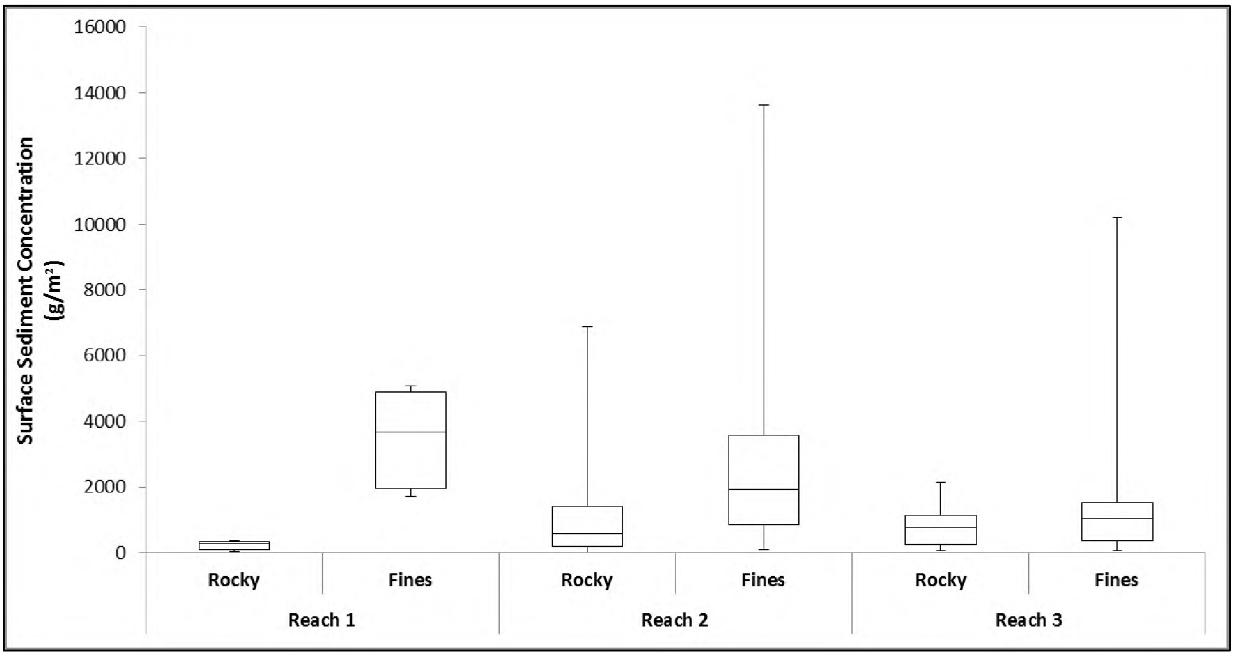


Figure 56: Box and whisker plots of sampled surface sediment concentration for different habitats in each reach.

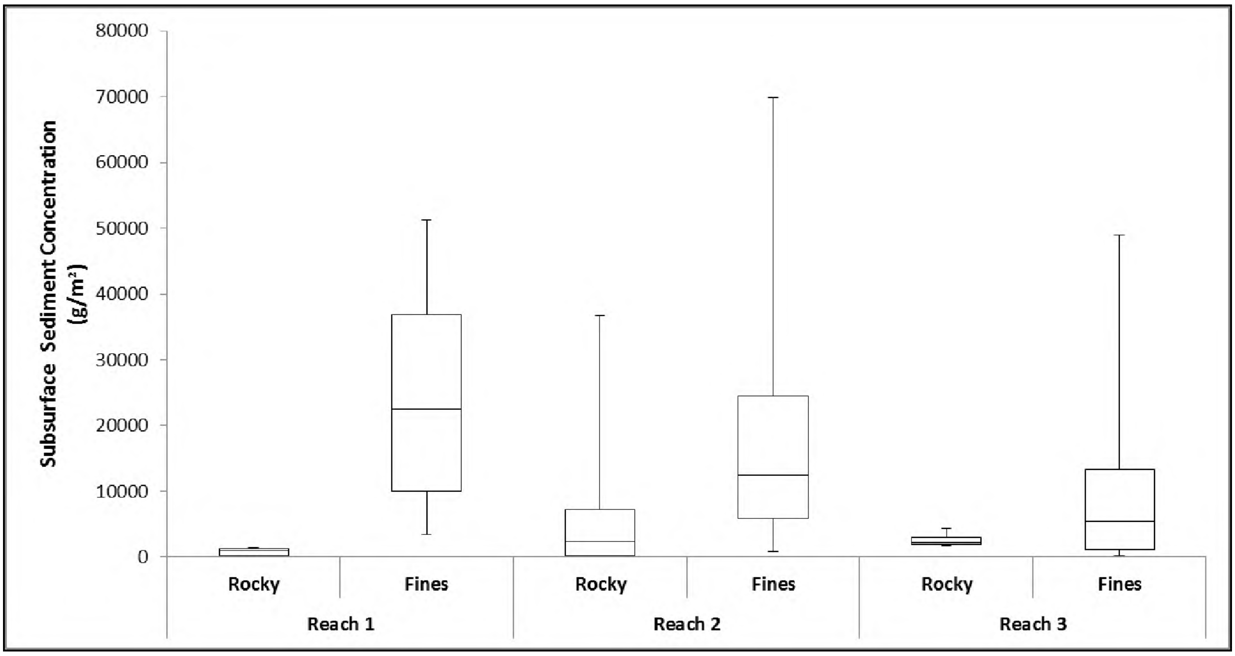


Figure 57: Box and whisker plots of sampled subsurface sediment concentration for different habitats in each reach.

More turbid flows generally occur due to an increase in suspended sediment concentrations sourced from eroded materials which enter the river system. Excessive suspended sediment concentrations affect both river habitats and associated biota. Figure 58 shows suspended sediment concentrations for each reach. Reach 1 and 2 had similar trends with lower concentrations in Reach 1. Reach 3 showed higher concentrations of suspended sediment due to inputs from the Inxu River. The outlier in Reach 2 was sampled during the peak stage of a very turbid flood.

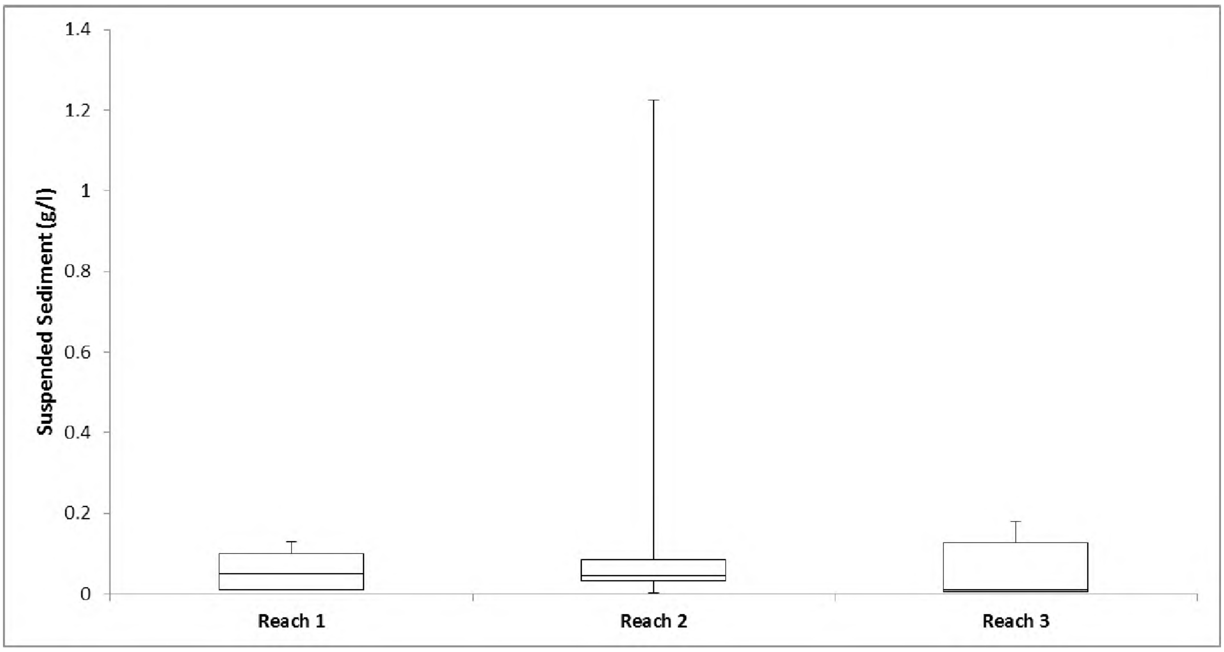


Figure 58: Box and whisker plots of sampled suspended sediment concentrations in each reach.

Different water depths allow for different habitat conditions. A more variable water depth results in more diverse habitats. Figure 59 shows that Reach 1 had more variable depths in the rocky and vegetation habitats, with the highest variability found in the vegetation habitat. Reach 2 showed similar trends however; overall, the depths were less. Reach 2 was less confined than Reach 1. Reach 3 showed the least variability and shallowest depths. Reach 3 was characterised by a lower gradient and wider channel resulting in a more homogenous channel bed.

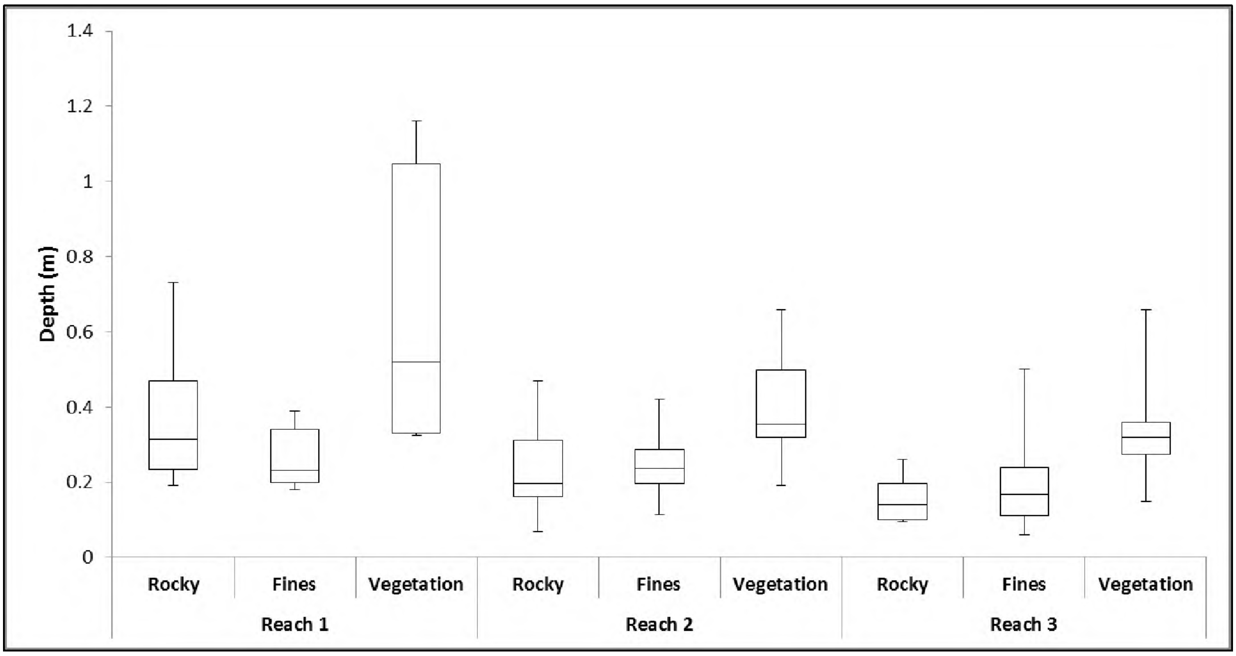


Figure 59: Box and whisker plots of sampled depths for different habitats in each reach.

Different flow conditions affect aquatic biota differently. Flow velocity can be closely linked to sediment regimes, such as deposition of sediment, entrainment of sediment and the period that the river remains turbid. Different flow velocities allow for different habitat conditions. Figure 60 shows a general trend of higher variability and higher flow velocities in both rocky and vegetation habitats. The fines habitat had less variability and lower flow velocities reflecting that fines were deposited under reduced flow velocity conditions.

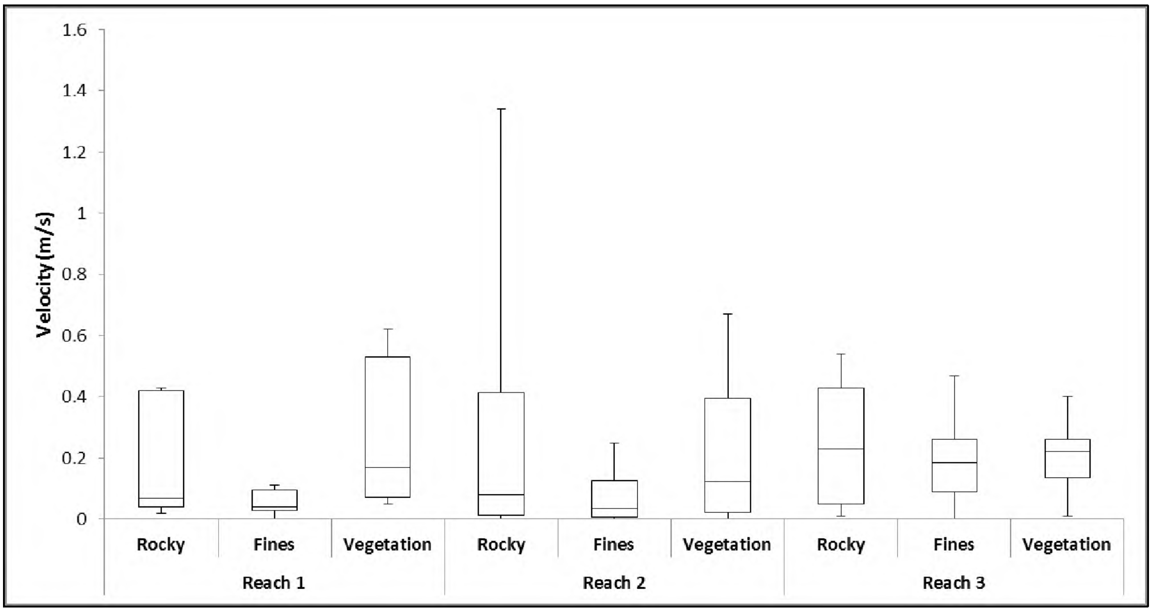


Figure 60: Box and whisker plots of sampled flow velocity for different habitats in each reach.

Macroinvertebrate diversity shows the abundance and proportion of different types of macroinvertebrates present in each habitat. Figure 61 shows that rocky habitats, in particular in Reach 1, had the highest variability of macroinvertebrate diversity. Bedrock dominated habitats are expected to have a lower diversity of macroinvertebrates whereas cobble beds will have a higher diversity of macroinvertebrates due to a higher diversity of available habitat. There were no significant differences in the medians of different habitat types. In the Tsitsa River sampling sites this implied that different macroinvertebrate communities inhabited different habitat types, with none of the habitats being significantly more suitable for macroinvertebrate diversity.

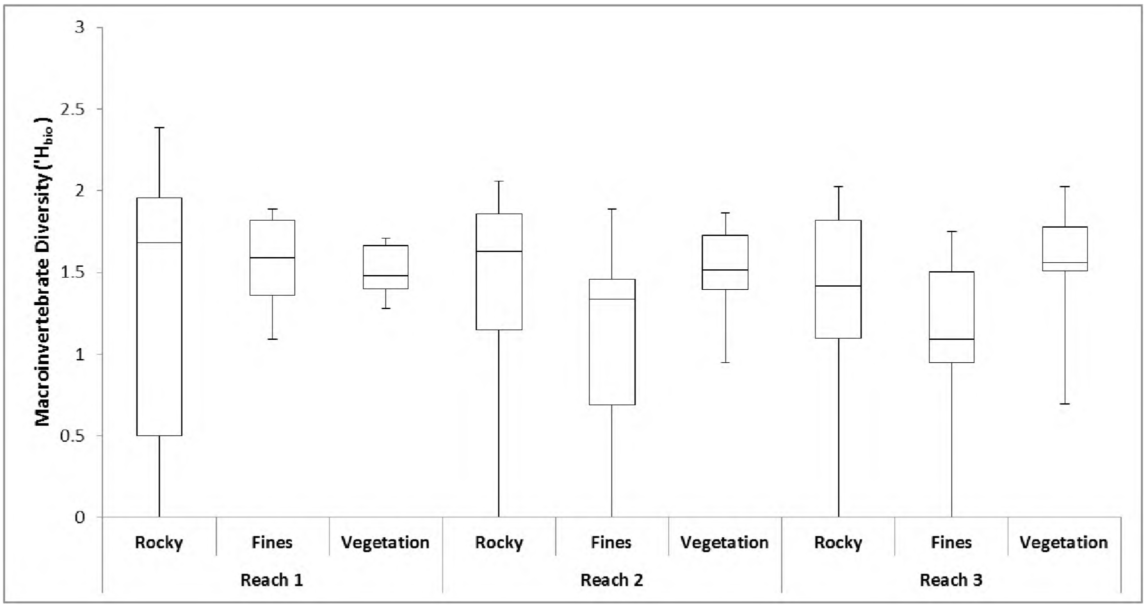


Figure 61: Box and whisker plots of macroinvertebrate diversity for different habitats in each reach.

Different macroinvertebrate families have differing tolerances to fine sediment accumulation. A higher ASPTsed implies a larger occurrence of macroinvertebrates that are sensitive to fine sediment accumulation. Figure 62 shows that rocky habitats, particularly in Reach 1, were inhabited by sediment sensitive macroinvertebrate families. Macroinvertebrate families occurring in vegetation were also intolerant to high sediment concentrations. As expected, habitats dominated by fines were inhabited by macroinvertebrates that were less sensitive to sediment accumulation. The ASPTsed score can be related to channel condition. A very low score implies that there is excessive sedimentation and presence of insensitive macroinvertebrates and a higher score implies less sedimentation and presence of sensitive macroinvertebrates. However, further research is required to ascertain the balance between sediment concertation and channel condition to see under what sediment concentrations the optimal abundance of macroinvertebrates will be found.

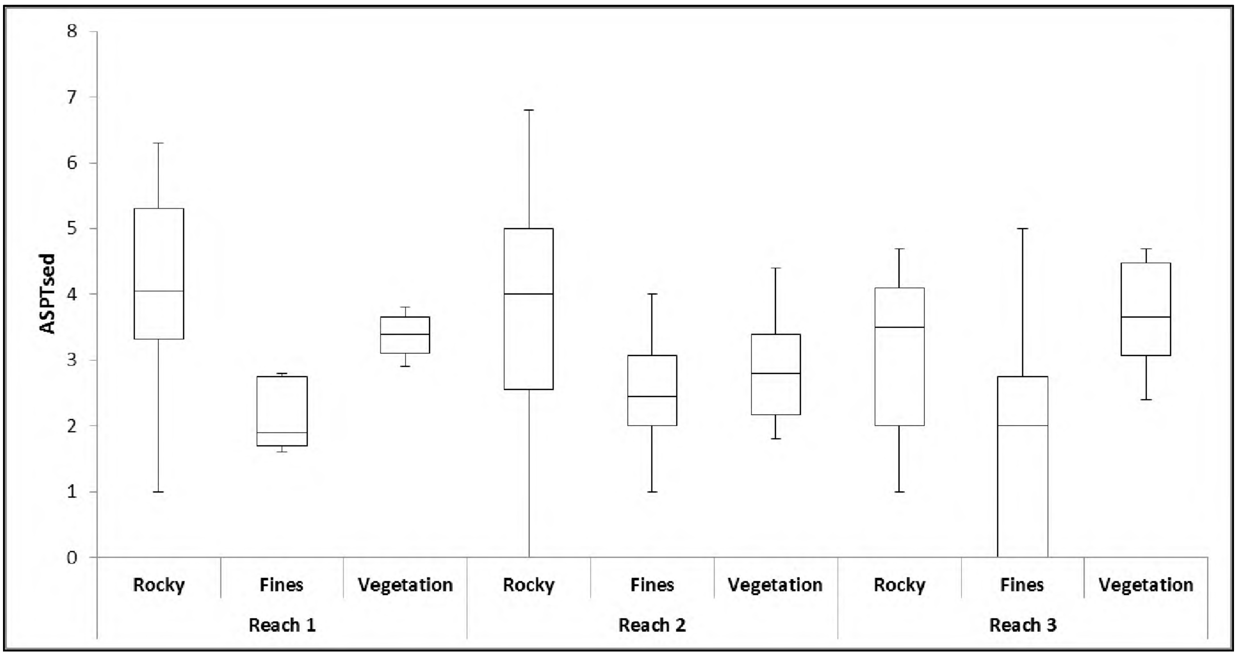


Figure 62: Box and whisker plots of ASPTsed for sediment sensitive species for different habitats in each reach.

The above variables (surface and subsurface sediment concentration, suspended sediment concentration, flow velocity and depth) influence substrate diversity and macroinvertebrate diversity. The influence of substrate diversity and macroinvertebrate diversity on the ASPTsed differed in each habitat type in each reach depending on the characteristics of the reach (Table 49). Different reaches were monitored over the same time period; however flow in the Tsitsa River was highly variable especially in summer months. Not all the sites could be monitored at the exact same time or conditions during each field visit. Changes in correlations were chiefly due to differences in morphology but partially also due to sampling periods and sample size.

Table 49: Degrees of freedom, correlation coefficient and statistical significance of substrate and macroinvertebrate diversity to ASPTsed.

Independent variable	Correlation to ASPTsed								
Reach	Reach 1			Reach 2			Reach 3		
Habitat	Rocky	Fine substrate	Vegetation	Rocky	Fine substrate	Vegetation	Rocky	Fine substrate	Vegetation
Substrate Diversity (H'_{sub})	**$r(16) = 0.75$, $p < 0.05$**	**$r(3) = 0.97$, $p < 0.05$**	$r(3) = 0.26$, $p > 0.05$	**$r(45) = 0.45$, $p < 0.05$**	$r(24) = 0.26$, $p > 0.05$	$r(6) = 0.12$, $p > 0.05$	**$r(19) = 0.41$, $p < 0.05$**	**$r(38) = 0.31$, $p < 0.05$**	$r(4) = -0.19$, $p > 0.05$
Macroinvertebrate Diversity (H'_{bio})	**$r(16) = 0.72$, $p < 0.05$**	**$r(3) = -0.91$, $p < 0.05$**	$r(3) = 0.64$, $p > 0.05$	$r(45) = 0.18$, $p > 0.05$	$r(24) = -0.17$, $p > 0.05$	$r(6) = -0.08$, $p > 0.05$	**$r(19) = 0.47$, $p < 0.05$**	**$r(38) = 0.50$, $p < 0.05$**	$r(4) = 0.58$, $p > 0.05$

Table 49 shows that the ASPTsed in rocky habitats in Reach 1, 2 and 3 increased with an increase in substrate diversity. The higher the substrate diversity in fine habitats in Reach 1 and 3 the higher the ASPTsed implying that sediment sensitive species occurred in greater abundance in fine substrate habitats with more diverse substrates. In the fine substrate habitat in Reach 2 there was no significant correlation between substrate diversity and the ASPTsed.

In the rocky habitat in Reach 1 and 3 the ASPTsed increased with an increase in macroinvertebrate diversity implying that a diversity of sediment sensitive species was present in the rocky habitats. In the fine habitat in Reach 1 the correlation between macroinvertebrate diversity and ASPTsed was negative implying that there were more sediment sensitive species present in habitats dominated by fines. However, this data could be skewed due to a small sample size. The fine substrate habitat in Reach 3 showed a positive correlation between macroinvertebrate diversity and the ASPTsed implying that a diversity of sediment sensitive species was present. Reach 2 showed no significant correlation between macroinvertebrate diversity and the ASPTsed.

Vegetation habitats in Reach 1, 2 and 3 showed no significant correlation between macroinvertebrate diversity and the ASPTsed implying that macroinvertebrates with a range of sensitivities to sediment occurred in this habitat. Vegetation, in the form of marginal vegetation, was influenced by suspended sediment rather than fine sediment drape.

Rocky habitats were found to be the most conducive to substrate diversity and macroinvertebrate diversity allowing for a range of sediment sensitive macroinvertebrate families.

CHAPTER 5: DISCUSSION

5.1 MONITORING SITES

Through this study, a baseline has been established of the current condition of the Tsitsa River by setting up monitoring sites in the vicinity of the proposed Ntabelanga Dam. Dube *et al*. (2015) have stressed the importance of creating a good understanding of processes at work in a river channel prior to dam construction. The capacity for sediment in the channel to be eroded or transported and factors responsible for sediment input into the channel are controlled by dynamic fluvial processes (Rowntree & Wadeson, 1999). Changes in a riverine system occur systematically along a drainage line as the flow, gradient and sediment characteristics vary (Church, 2002). River conditions at a local scale are influenced by the characteristics of the river reach and the processes occurring in the surrounding landscape (Allan, 2004). Three reaches were identified. Each monitoring site represented the reach in which it was located and can be used to monitor the impacts of the dam after construction. Although not the intention of this study, these monitoring sites can also be used to monitor the impact of catchment wide rehabilitation on river health prior to the dam being built. After dam construction the top site, above the dam inundation can, still be used as a monitoring point for rehabilitation.

Site 1 (Reach 1) was located above the proposed dam inundation and was characterised by a confined bedrock dominated channel. Site 1 is suitable as a reference site after dam construction to monitor channel conditions above the dam inundation.

Site 2 and 3 were located in Reach 2 which extended from the proposed dam wall to the confluence of the Tsitsa River with the Inxu River. Site 2 and 3 followed a pool-rapid sequence and had diverse substrates which were ideal to monitor fine sediment accumulation in the channel. After dam construction it is anticipated that Reach 2 will be affected by the cut-off of both flow and sediment supply.

Site 4 and 5 were located in Reach 3, below the confluence of the Tsitsa River with the Inxu River and were characterised by a low gradient and continuous input of sediment from the Inxu River. Site 4 was characterised by a sandy glide with a wide and shallow channel. After dam construction, this site is expected to show development of in-channel bars, channel narrowing and reduction in depth as flow is cut off from the Tsitsa River due to the dam wall while a continuous sediment supply is anticipated to enter the Tsitsa River from the Inxu River. Site 5 had a low overall site gradient, but within the site, the gradient varied considerably with a steep rapid in the middle. Due to the presence of diverse channel features this site can be monitored for increased embeddedness of coarse substrates, channel narrowing and reduction in depth after dam construction.

5.2 Baseline Survey

5.2.1 Relationship between hydrology and physical variables

River channel form is controlled by the flow regime, sediment yield in the channel and the gradient of the channel (Church, 2002). A change in the balance between water discharge, sediment load, grain size and water slope affects the morphology of the channel.

Channel morphology in the Tsitsa River was shaped by the past and current flow hydraulics and physical variables (Figure 63). Catchment features such as relief affect rainfall patterns. Rainfall timing and intensity in turn affect the catchment features. The flow regime of the river is dependent on the amount of rainfall in the catchment. Both natural (e.g. underlying geology and vegetation) and anthropogenic catchment features (e.g. erosion and connectivity) have shaped the sediment yield entering the Tsitsa River system and dictate the bed gradient. The channel gradient, sediment yield and flow regime affect the dominant substrate type present in different reaches of the river. The flow regime and the channel gradient dictate the water slope which in turn shapes channel morphology by driving processes such as sediment entrainment, transport and deposition. Confined channels, with a higher gradient, are prone to entrain sediment at higher discharges and therefore exhibit coarse substrates with very few or no fine substrates. Low gradient sites, with a high sediment yield and low flow velocities result in embeddedness or draping of coarse substrates forming a channel dominated by finer substrates. A change in flow characteristics and availability of transportable material, following the construction of the Ntabelanga Dam, is consistent with expected changes caused by a decrease in flow and sediment immediately downstream of a dam wall, resulting in variable conditions affecting the channel morphology of river reaches (Poff *et al.*, 1997).

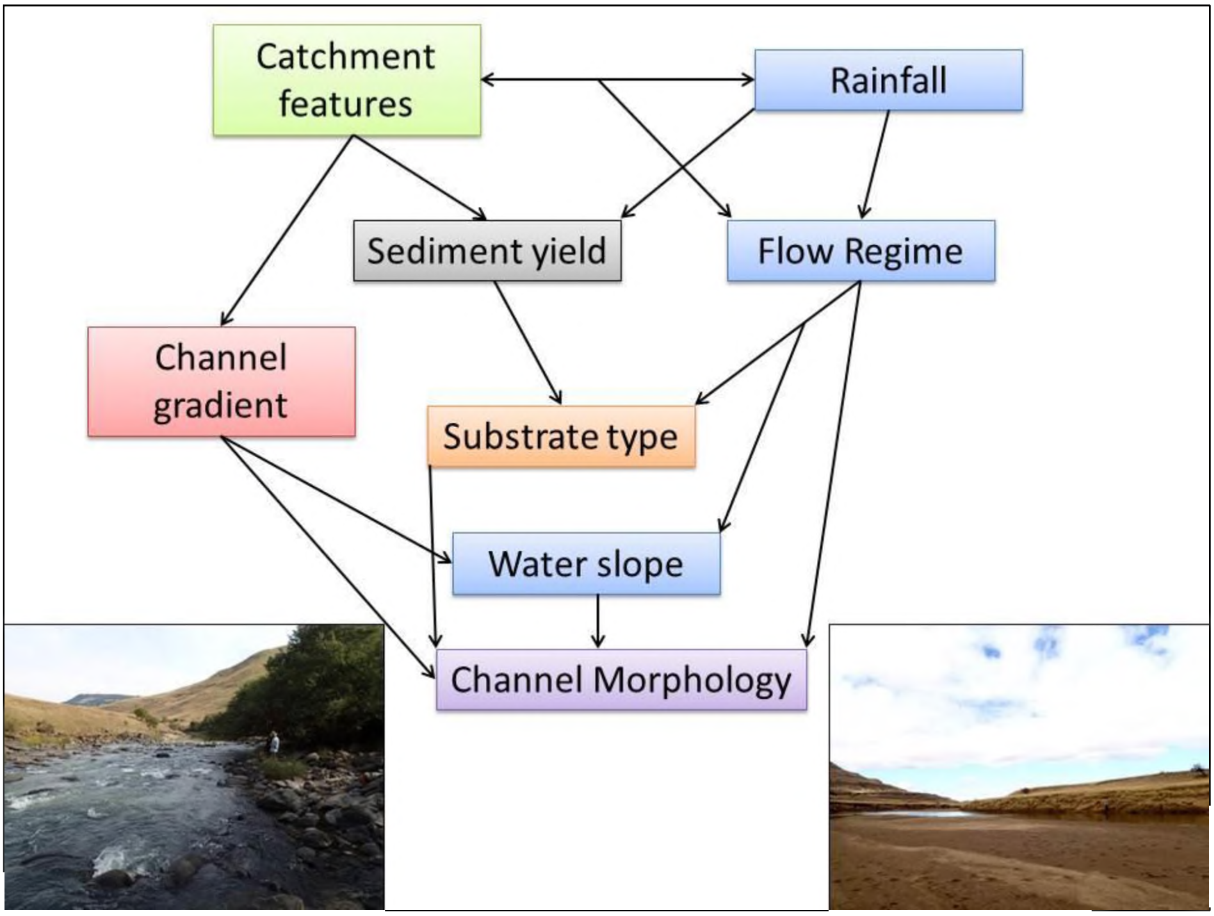


Figure 63: Conceptual model of the relationship between flow hydraulics and physical variables impacting on the Tsitsa River.

5.2.2 HYDROLOGY

The natural flow regime of a river is variable and can change over any given time scale (Poff *et al.,* 1997; Rowntree & Wadeson, 1999). The magnitude, frequency, duration, timing and rate of change of hydraulic conditions control river ecosystems and habitat conditions (Poff *et al*., 1997). In the Tsitsa River, discharge varied considerably over the monitoring period. Drier months received lower discharges, apart from in August 2016 when snowmelt raised the level of the river, whereas summer months had highly variable discharges with several flood peaks (Figure 32). Flood peaks, following rainfall events, carried an elevated concentration of suspended sediment (Figure 35). Sediment deposition on the edge of the channel was observed after periods of lower discharges (Figure 64). A flood with a large peak discharge has the ability to entrain the sediment deposited in areas such as depicted in Figure 64. However, over the monitoring period, the peak discharge was well below the 2 and 10 year flood (Figure 33). This resulted in a less marked effect of flushing the sites clear of sediment as might occur with a peak discharge of a higher magnitude. The overall energy slope in each site varied seasonally with changes in discharge. Sites with higher energy slopes that vary across diverse morphologies exerted a more significant stress on the bed of the river, whereas in sites with gentle bed gradients water slope played less of a role in entraining sediment (section 4.3.2). However, apart from water slope, substrate type and size plays an important role in the stability of the bed (section 4.3.3). Sites 1, 2, 3 and 5 were dominated by stable beds with a high roughness factor. Site 2 and 4 showed potential bed movement under higher discharges in February 2016 with Site 4 showing the greatest potential for bed movement. However, the Tsitsa River is capable of much higher discharges than measured over the monitoring period which could result in potential bed movement in all the sites. In areas of reduced flow, sand banks and bars are present, particularly in pools and on the edge of the channel. Site 4, which had a low gradient, was dominated by fine sediments which formed unstable sand banks and bars. Sand banks and bars are easily entrained due to their low roughness values and bed stability. These areas of the channel are prone to major channel changes irrespective of dam construction.

Figure 64: An example of channel change due to the deposition of sediment in an area of reduced flow in the Tsitsa River (Site 2; transect 1, right hand bank).

Flow variability should be monitored continuously to help understand the condition on the bed and the stress exerted by different discharges on the bed. After dam construction flow hydraulics should be monitored at Site 3 below the dam wall and again below the confluence at Site 5.

5.2.3 PHYSICAL VARIABLES

The cross-sectional profiles show the current morphology of the river channel. This is shaped by the current flow hydraulics and sediment inputs (Brandt, 2000; Apitz, 2012). Cross-sectional profiles of each site in the Tsitsa River provide a comprehensive depiction of the current physical structure of the Tsitsa River (Appendix 1). Geo-habitats are habitat features that are directly linked to the physical structure of the channel (Rowntree, 2013). No significant seasonal changes were found to occur to the cross-sections (section 4.4.1). After dam construction, changes in water release downstream of the dam wall will affect the cross-sectional morphology by changing the relationship between sediment load relative to the transport capacity of flows (Brandt, 2000). Anticipated changes are described in section 5.5.

A baseline of channel features, percentage distribution of clasts, bed conditions and substrate properties was established for each site (section 4.4.2). Sites characterised by higher gradients and diverse morphologies (Site 1, 2, 3 and 5) had higher substrate diversity. In these sites, areas of reduced flow, such as along river banks and in pools, showed increased embeddedness values with increasing deposition of fines. Areas characterised by an increased flow, such as the middle of the channel, entrained fine sediment exhibiting stable or imbricated beds dominated by coarse substrates. Fine substrate deposition showed seasonal changes. An increase in turbidity (section 4.5) in summer months occurred due to higher rainfall events in the catchment (section 4.2). Deposited fines (Figure 36 and 38) during summer months varied according to the stages of a flood (Figure 29). Fines were entrained during the rising stage of a flood and deposited during the receding stage. High baseflows with low turbidity entrained sediment, reducing embeddedness of substrates, whereas low baseflows such as those found in winter months lacked the energy to entrain sediment. Low velocity floods from small or local rainfall events, occurring towards the end or start of summer, increased the turbidity of the river despite no marked increase in the flow velocity. Fine sediment was deposited on the river bed in areas of reduced flow velocity rather than being carried down the river system. This is consistent with excessive loads of erosion silt that significantly increase the turbidity of streams as well as the amount of sediment and silt being deposited on river substrates, resulting in a marked change in aquatic habitats (Ellis, 1936; Jones *et al*., 2011). Therefore, sediment concentrations can be used as an indicator to monitor aquatic habitat health.

Changes in water quality and habitat conditions are commonly associated with geomorphic changes, as the geomorphology of a river system commonly alters due to land uses causing human induced alterations in a catchment such as removal of riparian vegetation or agricultural practices (Chessman *et al*., 2006). Water quality (section 4.5) in the Tsitsa River was found to be close to natural with the exception of levels of nutrients such as phosphates increasing after rainfall events. Runoff from the catchment was the most likely source of this increase as levels of phosphates did not stay elevated for prolonged periods. An increase in phosphate concentrations was likely to occur due to leaching of sewage from pit latrines or runoff from cultivated lands (Dallas & Day, 2004). Rivers with healthy amounts of marginal and aquatic vegetation take up phosphates, regulating spikes in phosphate levels experienced during floods (DWAF, 1996). Concentrations of phosphates needed to be considerably higher than those found in the Tsitsa River to have had a significant impact on biotic health (Dallas & Day, 2004). None of the DO concentrations fell below 50%, which is defined as sub-lethal to aquatic organisms (DWAF, 1996). Therefore, concentrations of DO were not expected to have any significant impacts on biotic health in the Tsitsa River over the monitoring period. A well buffered South African river will be expected to have a pH ranging between 6 and 8, but fluctuations occur due to a changes in temperature, photosynthetic activity or biotic respiration and decomposition of organic matter (DWAF, 1996; Dallas & Day, 2004). The Tsitsa River showed no unusual fluctuations in pH. According to Dallas & Day (2004) very little information is available on the tolerance of aquatic organisms to increased conductivity. The rate of change rather than the absolute change is important in assessing the effects on organisms. EC showed a general decrease with an increase in turbidity and flow which was likely due to the influx of rain water into the stream network. Turbidity increased and clarity decreased progressively down the river system which can be linked to an increase in the erosion potential of the surrounding catchment (Figure 2).

Macroinvertebrates are the most preferential group of aquatic organisms to use in the biomonitoring of streams due to a range of family related sensitivities (Dickens & Graham, 2002; Türkmen & Kazanci, 2010). Macroinvertebrate community structure and abundance changed seasonally. Summer months naturally showed the highest abundance of macroinvertebrates due to increased water temperatures despite the presence of highly turbid flows. These turbid flows only affected the river channel for short periods of time after which the river ran clearer again (Figure 35). Within the range of parameters monitored over the study period, water quality could be discounted for having any noticeable effects in altering the types of macroinvertebrates that would naturally occur in the river. This corresponds to the findings of Madikizela & Day (2003) in the Mzimvubu River and its tributaries including the Tsitsa River. Madikizela & Day (2003) established that macroinvertebrate families in the Mzimvubu River and its tributaries were not found in abundance however, species sensitive to poor water quality were present. Madikizela & Dye (2003) identified that the secondary effects of sedimentation and reduction in habitat played an important role in the ecological health of a river and might cause a reduction in the abundance of certain macroinvertebrate families. Over the monitoring period in the Tsitsa River, the combination of low discharges (section 4.2.1) causing an increase in bed sediment storage (section 4.4.2) and the lack of influence from water quality variables (section 4.5) on macroinvertebrate community structure made conditions ideal for researching the effect that bed sediment was having on macroinvertebrates.

5.4 Biotic and Abiotic Interactions at the Quadrat Scale

When exposed to a change in habitat, for example due to an increase in sediment deposition on the river bed or suspended sediment concentration, macroinvertebrates respond with a change in community structure (Türkmen & Kazanci, 2010; Jones *et al.*, 2011). By looking at the distribution of different macroinvertebrate families occurring under varying concentrations of bed sediment drape, a scoring sheet (Table 48) was established from this study to score macroinvertebrates according to their sensitivity to bed conditions (section 4.6). Abiotic variables such as substrate diversity, bed sediment, suspended sediment, flow velocity and depth affected the bed conditions which shaped the available habitats for macroinvertebrates (section 4.7). Different macroinvertebrate families (Table 47) in each class (Figure 57) were found to have varying tolerance to fine sediment concentrations. This resulted in a shift in the community structure associated with a change in the concentration of fine sediment drape. The different macroinvertebrate classes and their constituent families are reviewed below. A statement of the optimal habitat in which each macroinvertebrate class occurs is given, followed by the conditions, with regard to fine sediment concentration, in which each family found in the Tsitsa River was observed. Macroinvertebrates found in the least abundance will be reviewed first, followed by macroinvertebrate classes more tolerant to fine sediment concentrations.

Hirudinea (Leeches) are found in shallow pools or areas of the river with reduced flow (Gerber & Gabriel, 2002). Hirudinea commonly latch onto substrate and are found under stones. In the Tsitsa River, shallow pool areas and areas of reduced flow were highly embedded with high concentrations of sediment drape and are therefore not suitable for Hirudinea. A low abundance of Hirudinae were found in habitats with a low concentration of surface sediment drape.

Turbellaria (Flatworms), such as Planaria, are sensitive to strong light, and are found under stones or other solid objects (Gerber & Gabriel, 2002). In the Tsitsa River a low abundance of Turbellaria were found in habitats with less embeddedness of coarse substrates and a low to medium concentration of sediment drape. Turbellaria also clung onto vegetation.

Crustacea, such as Potamonautidae, are found under or among rocks (Gerber & Gabriel, 2002). In the Tsitsa River a low abundance of Crustacea were found in rocky habitats with low to medium concentrations of surface sediment drape.

Mollusca, such as Ancylidae, occur on rocks or any other submerged object whereas families such as Sphaeriidae occur in coarse sands and fine gravels (Gerber & Gabriel, 2002). In the Tsitsa River Ancylidae were found in rocky habitats with low to medium concentrations of fine sediment drape, with a higher abundance in low concentrations. Sphaeriidae occurred in medium concentrations of fine sediment drape. However, Mollusca were not found in habitats with high concentrations of fine sediment drape.

Zygoptera (Damselflies) are found in vegetation or organic matter in slower moving water (Gerber & Gabriel, 2002). In the Tsitsa River only the Coenagrionidae family was found in a low, medium and high concentrations of fine sediment with abundance being lower at a higher concentration.

Plecoptera (Stoneflies), such as Perlidae, occur under stones in rocky habitats (Gerber & Gabriel, 2002). Plecoptera are very sensitive to pollutants and make useful indicators of water quality. In the Tsitsa River Perlidae were found in low, medium and high concentrations of surface sediment. Perlidae were not found in high abundance.

Trichoptera (Caddisflies) including Ecnomidae, Hydropsychidae species and Leptoceridae are found in rocky habitats, under stones, or in vegetation (Gerber & Gabriel, 2002). In the Tsitsa River Ecnomidae were found under stones in habitats with low to high concentrations of fine sediment drape. There are several types of Hydropsychidae species in the Hydropsychidae family. In the Tsitsa River more species were found in habitats with low fine sediment drape concentrations, with only one species occurring in medium concentrations of fine sediment drape. The highest abundance was found in rocky habitats with low fine sediment drape concentrations. Leptoceridae construct cases from plant material and occur in vegetation. In the Tsitsa River Leptoceridae were found under varying fine sediment concentrations with an increase in abundance at lower sediment concentrations.

Ephemeroptera (Mayflies) including Caenidae, Heptageniidae, Leptophlebiidae, Oligoneuridae, Prosopistomatidae and Tricorythidae vary greatly in shape and size, with each family being well adapted to suit the variety of habitats in which they occur (Gerber & Gabriel, 2002). Ephemeroptera generally prefer habitats with lower fine sediment concentrations, however different families have different tolerances to sediment concentrations. Caenidae occur in stones or muddy habitats in slow water (Gerber & Gabriel, 2002). In the Tsitsa River they were found to be relatively tolerant to high sediment concentrations and occurred relatively abundantly. Heptageniidae occur in fast flowing habitats with stone substrates or amongst submerged coarse organic matter (Gerber & Gabriel, 2002). In the Tsitsa River Heptageniidae were found in habitats with a high sediment concentration, however their abundance was higher the lower the concentration of fine sediment drape. Leptophlebiidae occur in gentle flow in rocky substrates (Gerber & Gabriel, 2002). In the Tsitsa River Leptophlebiidae were found in relatively high abundance in low to high concentrations of sediment drape; however abundance decreased with an increase in the concentration of fine sediment drape. Oligoneuridae occur in fast flowing streams in patches of coarse sand or gravels (Gerber & Gabriel, 2002). In the Tsitsa River Oligoneuridae were found in summer in patches of gravel in fast flowing areas of the river. Oligoneuridae were not found in habitats with a high concentration of fine sediment drape. Prosopistomatidae occur under stones in fast flow (Gerber & Gabriel, 2002). In the Tsitsa River Prosopistomatidae were found in habitats with a low to medium concentration of fine sediment drape. Tricorythidae occur in fast flow under or around rocky substrates (Gerber & Gabriel, 2002). In the Tsitsa River Tricorythidae were found in habitats with a low to high concentration of fine sediment drape, with abundance decreasing with an increase in sediment concentration.

Hemiptera (Bugs) including Belostomatidae, Corixidae, Gerridae, Naucoridae, Nepidae, Notonectidae and Veliidae are only partly adapted to aquatic habitats. Some types occur on the surface of the water and have respiratory characteristics of terrestrial insects while others live below the surface but are air breathers and need to go to the surface at intervals for oxygen (Gerber & Gabriel, 2002). Belostomatidae occur in shallow pools and slow moving areas of the river (Gerber & Gabriel, 2002). In the Tsitsa River Belostomatidae were found in low abundance in low to medium concentrations of fine sediment. Corixidae occur in shallow pools and muddy areas of the river (Gerber & Gabriel, 2002). Corixidae were found in low to high concentrations of fine sediment with the highest abundance found in habitats with a high sediment concentration. Gerridae occur on the surface of pools in shaded areas (Gerber & Gabriel, 2002). Gerridae were found in low abundance in habitats with low concentrations of fine sediment. Naucoridae occur in dense vegetation in shallow water (Gerber & Gabriel, 2002). Naucoridae were found in low to high concentrations of fine sediment with an increase in abundance with an increase in sediment concentration. Nepidae occur in vegetation in pools or shallow water (Gerber & Gabriel, 2002). Nepidae were found in low abundance in habitats with low to medium concentrations of fine sediment. Notonectidae occur in pools and backwaters (Gerber & Gabriel, 2002). Notonectidae were found in habitats with low to high concentrations of fine sediment with little variation in abundance between the different habitats. Veliidae occur in pools alongside vegetation and commonly run along the surface of the water (Gerber & Gabriel, 2002). Veliidae were found in habitats with low to high concentrations of fine sediment and their abundance was not affected by an increase in sediment concentration.

Coleoptera (Beetles), including Dytiscidae, Elmidae, Gyrinidae, Hydrophilidae and Psephenidae, occupy a variety of habitats, from fast flowing streams to backwater ponds (Gerber & Gabriel, 2002). Several Coleoptera are aquatic in both their larval and adult stages and many are air breathers. Dytiscidae occur on the edges of streams in vegetation as well as in pools with reduced flow (Gerber & Gabriel, 2002). In the Tsitsa River Dytiscidae were found in vegetation habitats with low and high concentrations of sediment with an increase in abundance with an increase in the concentration of surface sediment drape. Elmidae occur in rocky substrates in fast flows (Gerber & Gabriel, 2002). In the Tsitsa River Elmidae were not found in habitats with a high sediment concentration. Gyrinidae occur on the surface of the water in slow moving water and pools (Gerber & Gabriel, 2002). In the Tsitsa River Gyrinidae were found in habitats with low to high concentrations of sediment with a low abundance in habitats with a high sediment concentration. Hydrophilidae occur in vegetation and muddy patches along river banks in slow moving water or pools (Gerber & Gabriel, 2002). Hydrophilidae were found in similar abundance in low and high concentrations of fine sediment. Psephenidae occur on rocks in shallow fast flowing water (Gerber & Gabriel, 2002). Psephenidae were found in habitats with low to medium concentrations of fine sediment drape.

Due to the ability of some families of Hemiptera and Coleoptera to breath air as well as live on the surface of the water they show a general trend of being tolerant to or not affected by different levels of sediment concentrations and occur abundantly.

Oligochaeta (Worms) occur in fine substrates in pools and areas of little flow in a river (Gerber & Gabriel, 2002). In the Tsitsa River Oligochaeta were found in sandy habitats with low to high concentrations of fine sediment concentration with an increase in abundance with an increase in sediment concentration.

Anisoptera (Dragonflies), including Aeshnidae, Corduliidae, Gomphidae and Libellulidae, occur both under stones and in sandy habitats (Gerber & Gabriel, 2002). In the Tsitsa River Anisoptera show a general trend of being more abundant in habitats with medium to high concentrations of fine sediment concentrations. Aeshnidae occur under stones in varying flows (Gerber & Gabriel, 2002). Aeshnidae were found in low to high concentrations of fine sediment. Corduliidae occur in sand and stones in areas of reduced flow (Gerber & Gabriel, 2002). A low abundance of Corduliidae were found in low and high concentrations of fine sediment. Gomphidae occur on sand banks on the edge of the river (Gerber & Gabriel, 2002). Gomphidae were found in very high abundance in sandy habitats with low to high concentrations of fine sediment. Libellulidae occur amongst stones and coarse sand in areas of reduced flow (Gerber & Gabriel, 2002). Libellulidae were found in low to high concentrations of fine sediment with an increase in abundance with a decrease in fine sediment concentrations.

Species of Baetidae (Minnow Mayflies) occur in a variety of habitats including rocks, sand and vegetation (Gerber & Gabriel, 2002). Baetidae were found in low to high concentrations of fine sediment concentration. However, only 1 -2 species were found in abundance in habitats with high concentrations of fine sediment. The presence of more than 2 species indicated a habitat with lower fine sediment concentrations.

Diptera (Flies) including Athericidae, Ceratopogonidae, Chironomidae, Culicidae, Dixidae, Muscidae, Psychodidae, Simuliidae, Tabanidae and Tipulidae occur in a wide variety of habitats from stagnant pools to areas of high flow (Gerber & Gabriel, 2002). In the Tsitsa River Diptera occur in abundance in low to high concentrations of fine sediment. Athericidae occurs in vegetation and organic matter (Gerber & Gabriel, 2002). In the Tsitsa River a low abundance of Athericidae were found in medium concentrations of fine sediment. Ceratopogonidae occur in sand and mud at the edges of a river (Gerber & Gabriel, 2002). Ceratopogonidae were found in low to high concentrations of fine sediment with an increase in abundance with an increase in fine sediment concentration. Chironomidae are commonly found in any water body and in rivers are generally found in pools (Gerber & Gabriel, 2002). A high abundance of Chironomidae were found with an increase in abundance with an increase in fine sediment concentration. Culicidae floats under the surface of a water body and commonly occurs in pools or temporary puddles (Gerber & Gabriel, 2002). A low abundance of Culicidae were found in low and high concentrations of fine sediment. Dixidae occurs in slow streams and backwater areas of fast flowing rivers (Gerber & Gabriel, 2002). A low abundance of Dixidae were found in medium concentrations of fine sediment. Muscidae occur in shallow water commonly with the presence of organic matter or algae (Gerber & Gabriel, 2002). A low abundance of Muscidae were found in low to high concentrations of fine sediment. Psychodidae occur in various habitats in streams (Gerber & Gabriel, 2002). A low abundance of Psychodidae were found in medium concentrations of fine sediment. Simuliidae attach themselves to substrates in shallow areas with increased flow (Gerber & Gabriel, 2002). Simuliidae were found in areas of low to high concentrations of fine sediment, with an increase in abundance with a reduction in the concentration of fine sediment. Tabanidae occur in muddy areas of pools (Gerber & Gabriel, 2002). A low abundance of Tabanidae were found in low to medium concentrations of fine sediment concentration. Tipulidae species are habitat specific and occur at the bottom of streams, muddy edges of streams or in aquatic vegetation (Gerber & Gabriel, 2002). Tipulidae were found in medium to high concentrations of fine sediment.

The general trend showed that in areas where flow velocity was sufficient to wash away fines (eg. cobble riffles), macroinvertebrate abundance and diversity increased (higher ASPTsed) and the river maintained a more natural condition. Macroinvertebrates seek refuge in aquatic and marginal vegetation during highly turbid flows. Presence of vegetation in sites containing fine sediment deposits increased the ASPTsed. Lack of vegetation, low flows and depths and high concentrations of fine sediment with a low substrate diversity decreased the ASPTsed. In rocky habitats in the Tsitsa River, the presence of diverse macroinvertebrate families was found to be mainly affected by substrate diversity. The more diverse the substrate the more habitats are available for colonisation by macroinvertebrate families. However, excessive deposition of fine sediment on the bed of the river decreased the substrate diversity and available habitats, in turn reducing the number of macroinvertebrate families present that were sensitive to sediment drape and in some cases increasing the number of less sensitive families. In habitats dominated by fines macroinvertebrate families that were less sensitive to fine sediment drape become more abundant. In patches where fine sediment accumulation was excessive, such as on thick silt deposits, macroinvertebrate abundance was observed to decrease. Excessive sedimentation in a river system has a direct impact on various aquatic trophic levels (Henley *et al.,* 2000). Macroinvertebrates that naturally occur in rocky habitats decreased in abundance with an increase in fine sediment accumulation, due to a reduction of habitats through the filling of interstitial spaces and rocky substrates becoming draped by fine sediment. Macroinvertebrates that naturally occur in sandy habitats and crawl along substrate or are air breathers, diving in the water column or thriving on the surface of the water, are less affected and are possibly benefited by an increase in fine sediment accumulation.

5.5 Impact of Dam Construction on Channel Geomorphology with Specific Reference to the Influence of Sediment on River Habitats and Biota

Dams have the capacity to completely alter downstream flow and sediment regimes and have been recognised as the most dominant form of anthropogenic impact on a fluvial system (Poeppl *et al.*, 2013; Petts & Gurnell, 2005; Petts & Gurnell, 2013). Floods in the Mzimvubu catchment (Figure 28) are capable of mobilizing a large amount of sediment including bedloads, in turn altering the form of the bed of the river. High magnitude floods can mobilise and transport bigger particle sizes. However, more frequent, lower magnitude floods play an important role in moving smaller particles. The frequency of these smaller floods results in a cumulative effect of sediment transport down the river system (Figure 35). However, with the construction of the Ntabelanga Dam it is likely that the attenuation of floods will lead to the reduction of the overall magnitude of flood peaks particularly in smaller flood events, as they get captured behind the dam wall. In turn dam construction affects downstream channel morphology and associated habitats on various levels (Figure 65). Habitat alteration may occur due to either an increase in natural concentrations of sediment supply, a decrease in sediment supply, as a result of a dam construction and constant flow releases, or due to decreased deposition and increased entrainment of fine sediment. Depending on the catchment characteristics, input of flow and sediment from tributaries (both large and small) progressively cumulate downstream. However, the combined flow is commonly not sufficient to entrain sediment resulting in increased deposition of fine sediments.

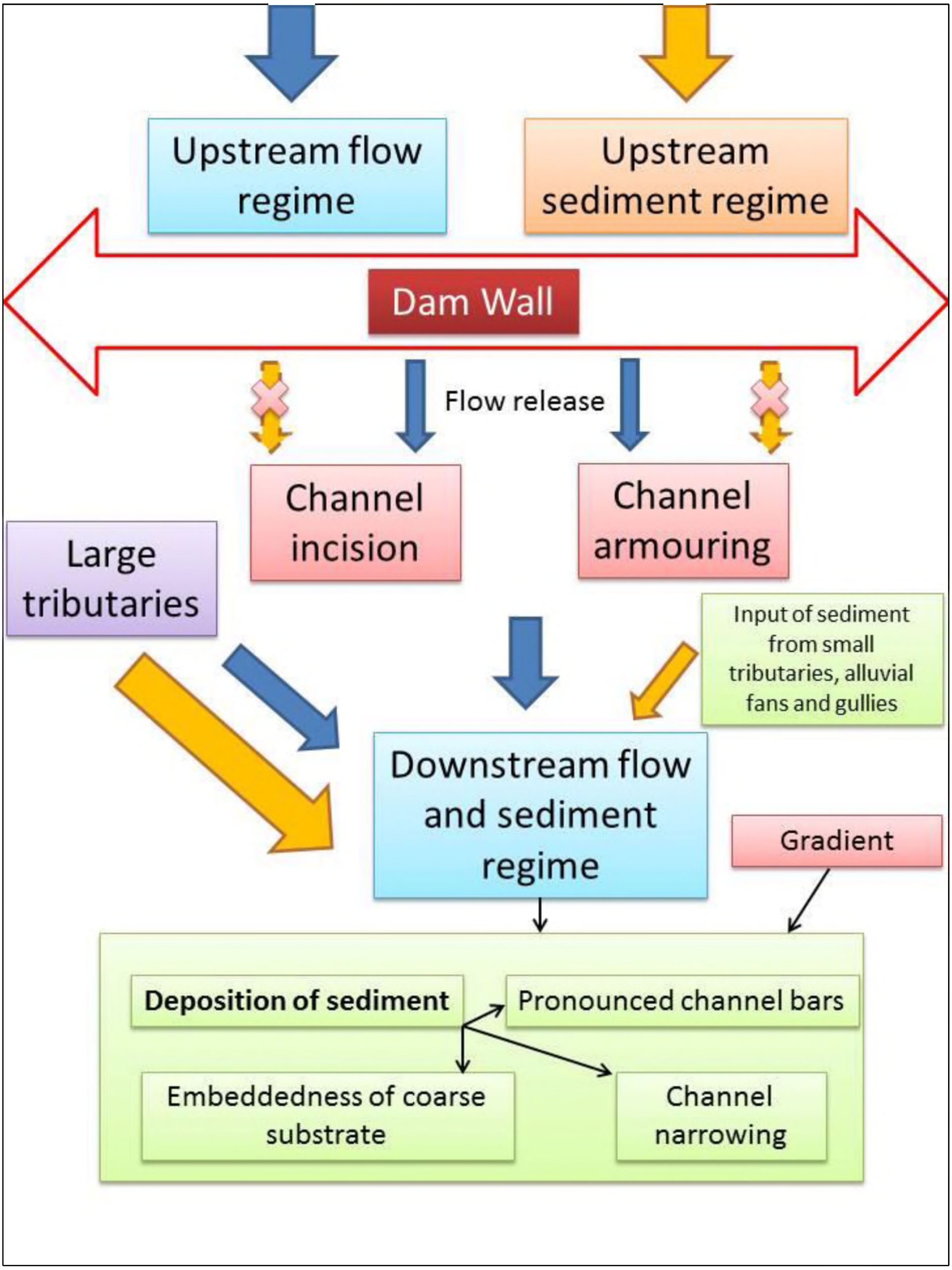


Figure 65: Conceptual model of the impact of dam construction on channel morphology in river systems like the Tsitsa River. Blue arrows represent discharge and yellow arrows represent sediment concentrations as observed in the Tsitsa River (based on information from Williams & Wolman, 1984).

Sites located between the dam wall and the Inxu River confluence are expected to undergo changes to the cross-sectional morphology due to the specified flow release, absence of large floods and lack of sediment which will be captured behind the dam wall. It is hypothesised that channel armouring will occur between the dam wall and the Inxu River confluence (Site 2 and 3) due to sediment being trapped behind the dam wall. Channel armouring occurs due to the removal of fines, by a more constant flow, leaving a coarse bed which is highly imbricated and stable (Figure 66). Figure 66 illustrates an example of channel armouring due to reduced flow and sediment below the Churchill Dam wall in the Eastern Cape. A reduction in sand banks and scouring of pools, which are currently present in Site 2 and 3, are expected to reduce the habitat diversity within these sites affecting the macroinvertebrate communities. Bedrock outcrops are present in both sites and are likely to become more prominent with a reduction in upstream sediment sources. The presence of bedrock will limit incision below the dam wall, once the deposited sediment has been carried downstream, leaving the bedrock channel features exposed. It is possible that accommodation adjustment (no observed further channel change) (Petts & Gurnell, 2013) may occur in these sites as bedrock becomes more dominant and stable and the only impact of the dam is a change in the discharge patterns. Site 2 is seen to be the site most affected by channel armouring and habitat reduction due to its proximity to the dam wall. As in the case elsewhere, the armouring effects are expected to become less and bed variability will increase further away from the dam wall (Williams & Wolman, 1984). At Site 3 this will occur due to sediment inputs from small tributaries, alluvial fans and gullies. The impact is anticipated to be greatest at Site 2 and reduce towards Site 3.

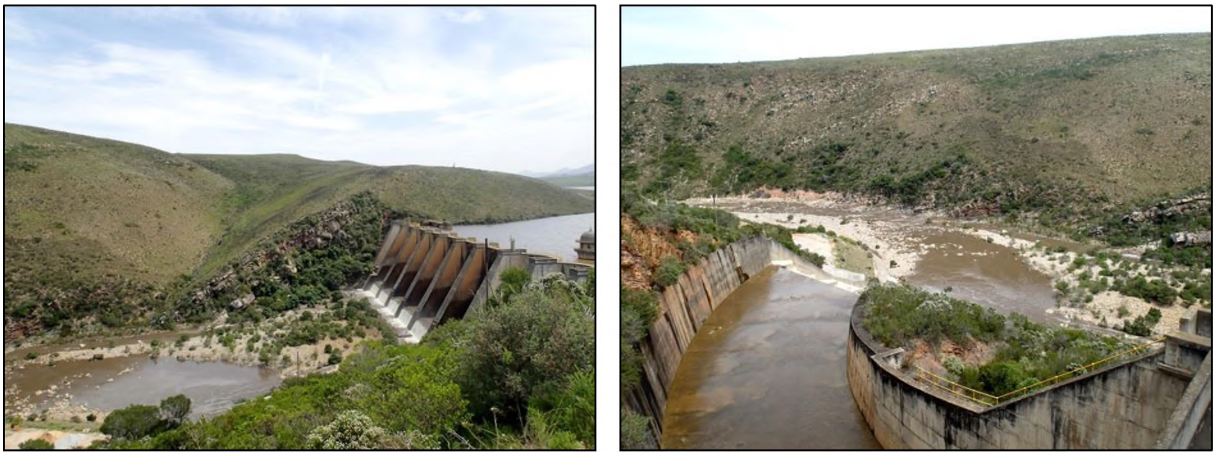


Figure 66: Channel armouring below the Churchill Dam, Eastern Cape.

The absence of floods below a dam may result in increased sediment deposition from tributaries (Puckridge *et al.,* 1998). The Inxu River is a large tributary that will bring sediment into the Tsitsa River after dam construction. The river channel below the Inxu confluence is characterised by a low gradient (Site 4 and 5). A reduction in floods in the Tsitsa River below the dam wall will result in increased sediment deposition from the Inxu River, causing channel narrowing and reduction in depth due to deposition of sediment and pronounced sand bars in channel reaches with a constant gradient and reduced flow (such as Site 4). Coarse substrates including bedrock outcrops (more commonly found in Site 5) will become increasingly embedded, reducing available habitat for macroinvertebrate communities.

After dam construction, the cross-sectional morphology in each reach should be established annually to monitor the impact of the dam. It is recommended that Site 3 be used to monitor Reach 2 as it is easily accessible and not likely to be altered due to anthropogenic impacts associated with the construction of the dam wall. Site 5 is suitable to monitor Reach 3 as Site 4 has been jeopardized by sand mining operations since the initiation of monitoring at the site. These mining operations affect channel morphology and are not representative of downstream impacts of dams. Site 1 in Reach 1 is not likely to change due to the dam construction and is characterised by a stable bedrock channel.

The health of a river is affected by the interaction between variables in a river such as flow, water quality, channel geomorphology and habitat (Pennack, 1971, Poff *et al*., 1997). The state of ecological health in the Tsitsa River is predicted by the intrinsic interaction between these variables (Figure 67).

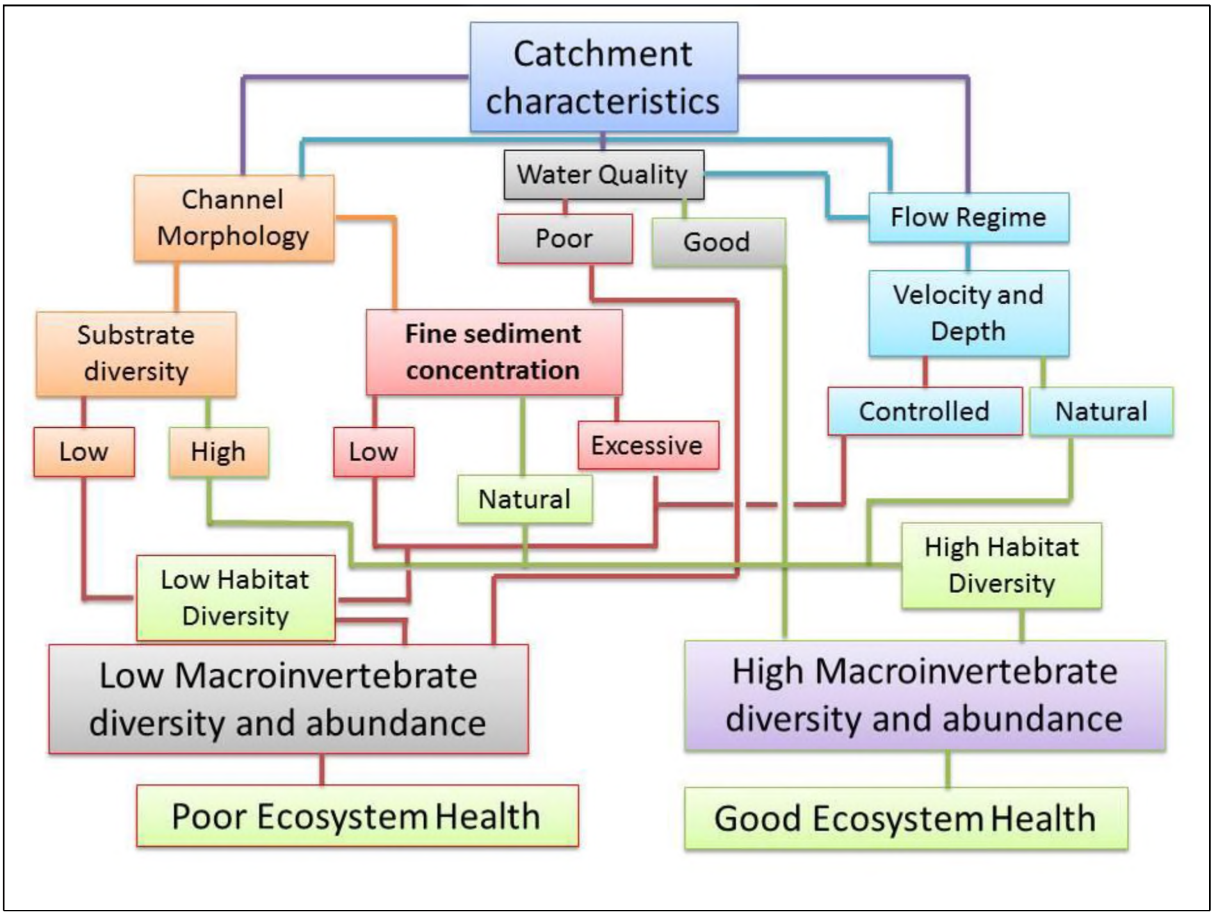


Figure 67: Conceptual model of the variables predicating the state of ecological health in the Tsitsa River.

Figure 67 presents a conceptual model that portrays the links between ecological health of the Tsitsa River and catchment and channel variables. The different relationships are described below.

Catchments are characterised by factors such as climate, geology, vegetation and anthropogenic impacts. These factors affect the flow regime, water quality and channel morphology in different reaches of the river (Figure 67). The natural ecological state of a river is controlled by the natural flow variability (Puckridge *et al*., 1998). In the Tsitsa River, the natural flow variability plays an important role in maintaining the current habitat conditions in different reaches of the river. However with the construction of the Ntabelanga dam, the downstream flow variability will be controlled according to the needs of the dam infrastructure with a secondary focus on the environmental flow requirement. The change to the natural flow variability of a river has a direct impact on ecological health as available habitats are continuously changed (Puckridge *et al.*, 1998). Rivers downstream of dam constructions, in particular hydroelectric projects, are unsuitable for macroinvertebrate colonisation due to the periodic unnatural fluctuation in flows (De Moor *et al.,* 2000).

Different stages of the natural flow regime affect the water quality in the Tsitsa River. High flows sourced from runoff in the catchment carry higher loads of nutrients such as phosphates and are commonly highly turbid, reducing water quality if this persists for an extended period of time. High baseflows with no point sources of pollution will flush the river system of excess nutrients and generally increase water quality. Low baseflows are less capable of flushing out pollutants which may accumulate in areas of reduced flow, in turn reducing water quality. Therefore, water quality depends on the flow regime as well as processes occurring in the catchment. The Tsitsa River catchment has very little industry and point sources of pollutants are scarce. The main aquatic pollutants are phosphates sourced from pit latrines and turbid flows. Future water quality changes in the river system can be caused by altering the flow properties (Dallas & Day, 2004) and may be expected through the construction of the Ntabelanga dam.

In the monitoring sites the channel morphology and associated geo-habitats provide niches for different aquatic species. The flow regime and channel gradient affect sediment entrainment or deposition, playing an important role in shaping the channel morphology (section 4.2 and 4.4). The higher the diversity of substrates present (such as in Site 2, 3 and 5), the more habitats are available for colonisation by different aquatic species. The fine sediment concentration on the bed of the river is partly controlled by the amount of sediment entering the river system from the catchment as well as the channel morphology in different reaches of the river. A certain amount of fine sediment is needed for the natural functioning of a river system and it is only when excess sedimentation occurs that negative impacts arise (Jones *et al*., 2011). Excessive sediment loads, caused by an increase in the sediment yield and channel conditions conducive to the deposition of sediment, will decrease available habitat niches (such as in Site 4). The lack of a sediment input into the river system will result in a highly imbricated and stable bed, once again reducing the available habitat niches. This is anticipated to occur downstream of the proposed Ntabelanga Dam wall. Natural sediment loads provide habitat or substrate for ecological functions such as the production of biomass, food and provision of raw materials (Apitz, 2012). A sediment balance is crucial for maintaining diverse habitats and ecosystem services which constitute a healthy ecosystem.

A high diversity and abundance of macroinvertebrates represents a healthy ecosystem whereas a low diversity and abundance of macroinvertebrates represents a poor ecosystem (Figure 67). Quinn and Hickey (1990) found that substrate variability plays an important role in the aquatic health of a stream system. Macroinvertebrate abundance in the study was directly linked to the substrate diversity (section 4.7). Macroinvertebrate families that were least tolerant to fine sediment surface drape optimally occurred in sites where embeddedness was low and interstitial spaces were present, creating habitat in a rocky substrate. Substrates free of excessive fine sediment drape are more suitable for attachment and found in areas of increased flow such as over rapids. Due to high embeddedness in areas of reduced flow the abundance of these species was very low. In the Tsitsa River macroinvertebrate families naturally occurring in marginal vegetation and sandy habitats were more tolerant to an increase in sediment concentrations, from both suspended sediment and fine sediment drape, whereas families occurring in rocky substrates that were easily embedded were less tolerant to the change in habitat due to an increase in fine sediment accumulation.

5.6 Recommendations for Future Monitoring with Particular Reference to Fine Sediment Accumulation in the Tsitsa River

Table 50 shows a recommended time scale for monitoring the impacts of the Ntabelanga Dam on the Tsitsa River. Site 1, 3 and 5 are the most optimal sites to monitor these changes. Site 1, situated above the dam inundation can be used as a reference site of the Tsitsa River before it enters the dam. Site 1 can also be used to monitor the effects of catchment rehabilitation upstream of the site by measuring changes in sediment accumulation. Site 3 can be used to monitor the impacts below the dam wall. The site is easily accessible and has a range of substrates and morphologies that can be monitored for their response to the dam. Site 5 below the Inxu confluence also has a range of substrate types that can be monitored for their response to an increased sediment load from the Inxu River and reduced flow from the Tsitsa River after dam construction. The sediment load for the Inxu River, above the confluence with the Tsitsa River, is currently being monitored. It is important that this sediment monitoring continues to monitor the effects of catchment rehabilitation in the Inxu catchment. All the monitoring variables should be compared seasonally and yearly to identify changing trends in the river condition due to the construction of the Ntabelanga Dam. The effectiveness of the environmental flow requirement after the dam has been constructed can be monitored using these methods and locations.

Table 50: Recommended time scale to monitor the impact of the Ntabelanga Dam on the condition of the Tsitsa River.

		Summer	Autumn	Winter	Spring
Physical variables	Cross-sectional surveys	n/a	n/a	Once annually during low discharges	n/a
	Coarse substrate	n/a	n/a	Once annually during low discharges	n/a
	Fine substrate	Yes	n/a	n/a	Yes
	ASPTsed	Yes	Yes	Yes	Yes
	Turbidity, clarity and suspended sediment	Yes	Yes	Yes	Yes
Flow hydraulics	Measured discharge	Yes	Yes	Yes	Yes
	Water level (level loggers)	Continuous	Continuous	Continuous	Continuous
	Water slope	Yes	Yes	Yes	Yes
Water Quality	Temperature	Yes	n/a	Yes	n/a
	Electrical conductivity and pH	Yes	n/a	Yes	n/a
	Dissolved oxygen	Yes	n/a	Yes	n/a
	Nutrient concentrations	Yes	n/a	Yes	n/a
	SASS 5	Yes	Yes	Yes	Yes

Cross-sectional surveys should be carried out annually at each site following the same transect lines in order to monitor changes to the channel morphology after the dam construction (GIS shapefiles of each transect line with coordinates can be found on the attached CD). It is important to monitor the shape of the channel particularly if the mean annual flood is significantly reduced by the dam wall.

Coarse substrates in each site provide an indication of the bed conditions. Channel features, percentage distribution, bed conditions along each transect and substrate properties should be monitored annually during periods of reduced flow to pick up any changes to bed conditions.

The ASPTsed score can be used to infer fine sediment accumulation. By using the score sheet set out in this study (Table 48) a rapid assessment can be carried out which gives an indication of fine sediment accumulation as an ASPTsed score. The ASPTsed score can be calculated from the same macroinvertebrates sampled for a SASS assessment. A high ASPTsed score indicates low accumulation of fines whereas a low score shows a higher concentration of fine sediment. Fine substrate accumulation using disturbance samples should be carried out twice a year, once during summer months when baseflows are high to establish if flow is sufficient to entrain and transport sediment down the river system and, secondly in a period with lower baseflows to see how much sediment accumulation is occurring. Both the ASPTsed data and the disturbance sample data should be compared between years to see whether any trends can be identified or if the sediment concentration is remaining stable.

Turbidity, clarity and suspended sediment concentrations should be monitored seasonally to give an indication of how much sediment is being carried by the river. Comparing the trends will be important for rehabilitation projects to see if catchment wide rehabilitation is reducing the amount of sediment entering the river system.

Discharge should be continuously to investigate the current condition of the river and how this alters seasonally. Continuous level logger data combined with seasonally measured known discharges will help to create an accurate idea of the hydrology of the Tsitsa River after dam construction and how close this is following the natural condition found at Site 1. Gauging weirs are planned to be constructed both above and below the proposed Ntabelanga Dam which will provide continuous data on discharge. Level loggers at Site 1-4 have been left in the river and can data can be used for future monitoring.

Water slope should be calculated each time discharge is measured at a site. This helps to quantify the energy exerted by the water on the bed of the river at different discharges and can be used to calculate the Manning's roughness of the bed as well as potential bed movement.

Water quality variables should be measured twice a year. Variables measured in summer months will reflect the water quality changes due to influx of nutrients from runoff. Variables measured in winter months will show if there are any critical water quality issues at low discharges. Water quality will not necessarily change due to the physical construction of the dam; however, with increased irrigation (provided by the dam) for agriculture, there may be an influx of agricultural waste and other pollutants associated with anthropogenic impacts. Macroinvertebrates should be monitored seasonally using SASS 5 methodology providing a rapid assessment of stream health. If any discontinuities are found in the SASS results, a more in depth water quality analyses should be conducted in addition to the twice yearly monitoring. Combining the SASS 5 monitoring with the ASPTsed is recommended as the sensitivity of macroinvertebrates to water quality differs from their sensitivity to sedimentation.

It is proposed that the Ntabelanga dam will act as a source of water for downstream hydroelectric generation at the Laleni Dam. Therefore flow releases out of the Ntabelanga Dam will be variable depending on the downstream requirements for the hydroelectric plant. Monitoring the above variables will be imperative in ensuring that the downstream environmental flow requirements are sustainable in the long term..

5.7 General Limitations and Recommendations

The numbers of monitoring surveys were limited by time constraints as well as the distance to the study area. An increased number of monitoring surveys over several years, with varying rainfall and hydrology, will create a more comprehensive picture of the current condition of the Tsitsa River.

Monitoring was carried out over a season with below average rainfall and flood peaks. In order to create a complete baseline of the current condition of the Tsitsa River, monitoring should ideally be carried out over seasons with average rainfall and flows as well as seasons with above average rainfall and flows. The period of reduced rainfall during this study was useful to monitor the impacts of sediment on macroinvertebrates because fine sediment drape was not as easily entrained and carried away by the prolonged high baseflows that are present in seasons with higher rainfall. Low flow conditions were also representative of post-dam conditions.

Very little of the variability in the ASPT is explained by the water quality variables. The lack of statistical significance between the independent variables and the ASPT is likely due to the ASPT being representative of the condition of the river prior to each field survey. The macroinvertebrates may not yet have been affected by the condition of the river when measurements were taken. Therefore it was important to look at the river conditions prior to each field survey. This was achieved through the logger data which gathered continuous data on water depth and temperature.

Sampling in summer months unintentionally corresponded to short periods of high flow (floods) in the Tsitsa River. This made it hard to access the middle of the river. Areas sampled included the banks of the river and submerged marginal vegetation. Recently submerged banks are not seen as being representative of the current state of the river. However, marginal vegetation and areas of reduced flow on the edge of the bank were found to have a range of macroinvertebrates present implying that high and turbid flows drive macroinvertebrates from the middle of the channel to marginal vegetation and shallower waters. Species very sensitive to fine sediment accumulation were not present or found in very low abundance under these habitat conditions.

Different methods can be used to calculate sediment concentration and each method uses specific units (e.g. mg/l, g/l, g/m^2). In order to compare this study to other studies it is important to note the method used to calculate sediment concentration. In this case sediment concentration was calculated using methods taken from Gordon *et al.* (2004) and then extrapolated to area of streambed sampled (Duerdoth *et al.*, 2015). The units for concentration are given as g/m^2 for surface and subsurface bed sediments and g/l for suspended sediment. For this study, the tolerance of macroinvertebrates to sediment concentrations were classed into low, medium and high using the calculated concentrations and given an appropriate sensitivity score.

Quinn and Hickey (1990) found that the presence of different substrates and their diversity played a crucial role in the abundance and presence of different macroinvertebrates. The study of biological and ecological traits of macroinvertebrates, such as body size and shape, life history and behavioural traits can shed further light on the history of sedimentation within a river system (Allan, 2004). The coating of gills and respiratory surfaces by sediment affects various macroinvertebrate families and can lead to reduced growth or mortality. An in depth study of macroinvertebrate families was not included in the scope of this research. More comprehensive research into the effects of sediment concentrations on macroinvertebrate physiology and morphology at a species level should be conducted, in particular for South African rivers. It is important that studies do not only focus on macroinvertebrates but also take into account the processes at work behind sediment accumulation.

During this study data for the ASPTsed scores was derived at the quadrat scale. This was in order to collect a more comprehensive data set on the occurrences of different macroinvertebrate families under varying fine sediment concentrations. However, as a future monitoring tool for rapid assessments the ASPTsed scores can be carried out on a site basis and can be calculated from macroinvertebrates found during a SASS assessment.

Variables within a catchment and river channel shape the channel morphology and habitats within different reaches of a river. Anthropogenic impacts in the catchment and alterations to the river channel disrupt the current processes at work in the river. The construction of the Ntabelanga Dam will alter the current flow and sediment regime downstream of the dam wall. This baseline study provides a set of data about the current geomorphic condition, variations in flow hydraulics and impacts of sediment on ecosystem health at selected sites in the Tsitsa River against which post-impoundment impacts can be assessed.

Five fixed sites, with varying gradients, channel morphologies and substrate types were monitored seasonally. Cross-sectional surveys were conducted to establish the current condition of the river and resurveyed after a single wet and dry season to pick up any seasonal changes to channel morphology. Substrate types were classified in each site and identified as the most important habitat variable affecting macroinvertebrates. Sites with lower gradients were dominated by the deposition of fine substrate resulting in low substrate diversity and a reduction in available habitat, whereas sites with higher gradients had diverse substrates and a range of channel features, resulting in more abundant habitats for aquatic biota. This has bearing on conditions downstream of the proposed Ntabelanga Dam, particularly downstream of the confluence between the Tsitsa River and Inxu River, where a reduction in gradient and increased sedimentation is expected.

Flow in the Tsitsa River is highly variable in the summer months. Discharge increases or decreases depending on rainfall in the catchment. Winter months have a more constant baseflow. During rising stages of a flood, the river was found to be highly turbid as the river was carrying sediment sourced from the eroded catchment and had sufficient energy to entrain sediments from the stream bed. With lowered stages in a flood, turbidity dropped as sediment was no longer sourced from the catchment and the reduced flow resulted in sediment deposition on the bed. During periods of high baseflow sediment was continuously flushed out of the system, particularly in reaches with high gradients. This resulted in a reduction of fine sediment drape on the bed and higher substrate diversity. During winter months low baseflows lacked the energy to entrain fine sediment drape on the bed of the river particularly in channel features with a low gradients such as pools.

There are no taxa related physical habitat scores for South African rivers. By looking at the processes creating habitat in the Tsitsa River under current conditions, a taxa related physical habitat score for the Tsitsa River was created in which taxa were scored (ASPTsed) in terms of their sensitivity to bed conditions with an emphasis on fine sediment accumulation. This provided a rapid assessment which can be used as a tool for managers to monitor the amount of fine sediment drape affecting habitats, whilst simultaneously monitoring water quality using SASS 5 methodology. The ASPT derived from SASS 5 can be used as a rapid assessment of water quality. However, in many rivers physical habitat conditions, in terms of fine sediment accumulation, play an important role in shaping the macroinvertebrate community structure. In this case the ASPTsed will give an indication of channel condition. Macroinvertebrates sensitive to water quality are not necessarily sensitive to sediment and vice versa. Low ASPT scores can be used to pick up a significant change in a rivers water quality due to the influx of a pollutant whereas the ASPTsed scores indicate habitats that are negatively impacted by fine sediment drape.

The ASPTsed scoring sheet derived in this study can be further researched so that it can be applied to a range of South African river types. The relationship between macroinvertebrates and the amount of fine sediment accumulation that constitutes optimal habitat conditions needs to be further developed. Work conducted by Ellis (2016) in the contrasting landscape of the Karoo can be linked to this study, improving the understanding of the current conditions of rivers and their catchments as well as the impact of deposited fine sediment on macroinvertebrates in South Africa.

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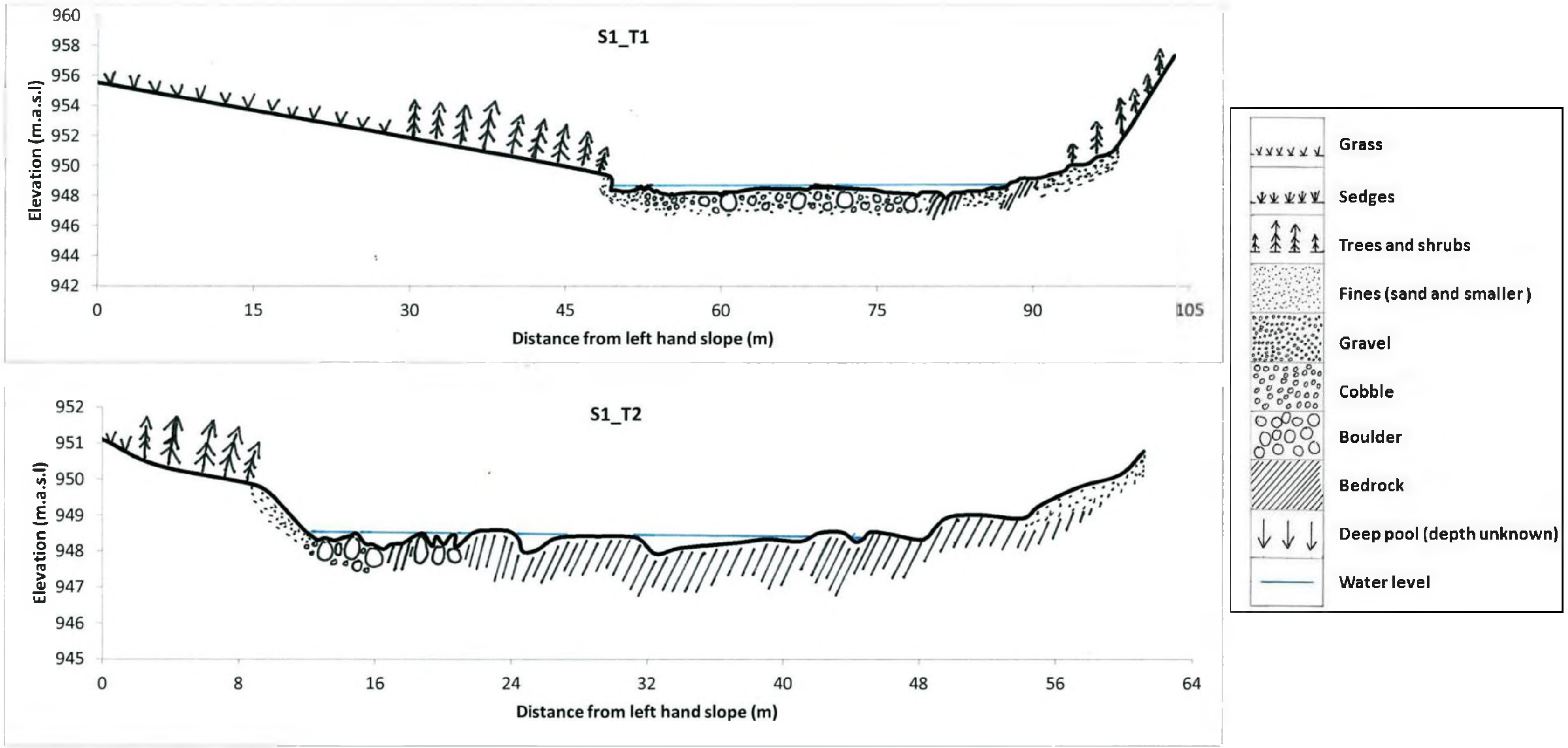
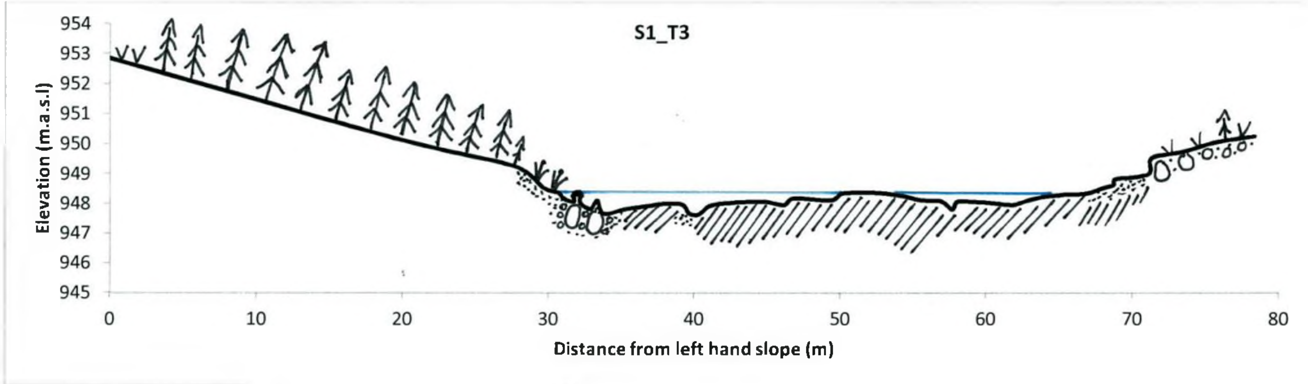
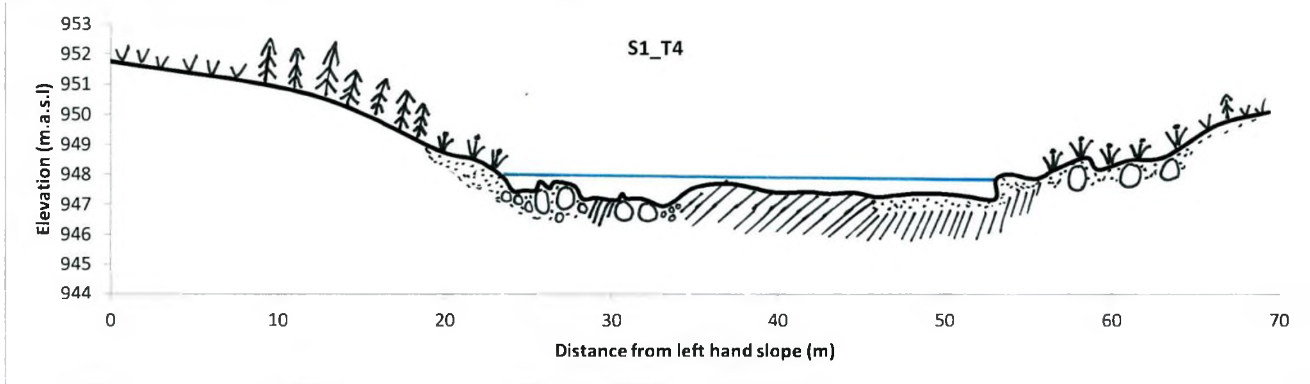
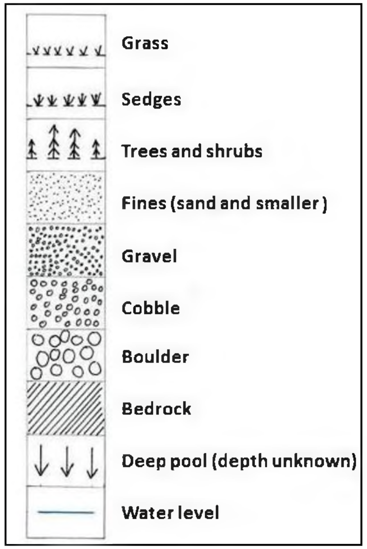
APPENDICES

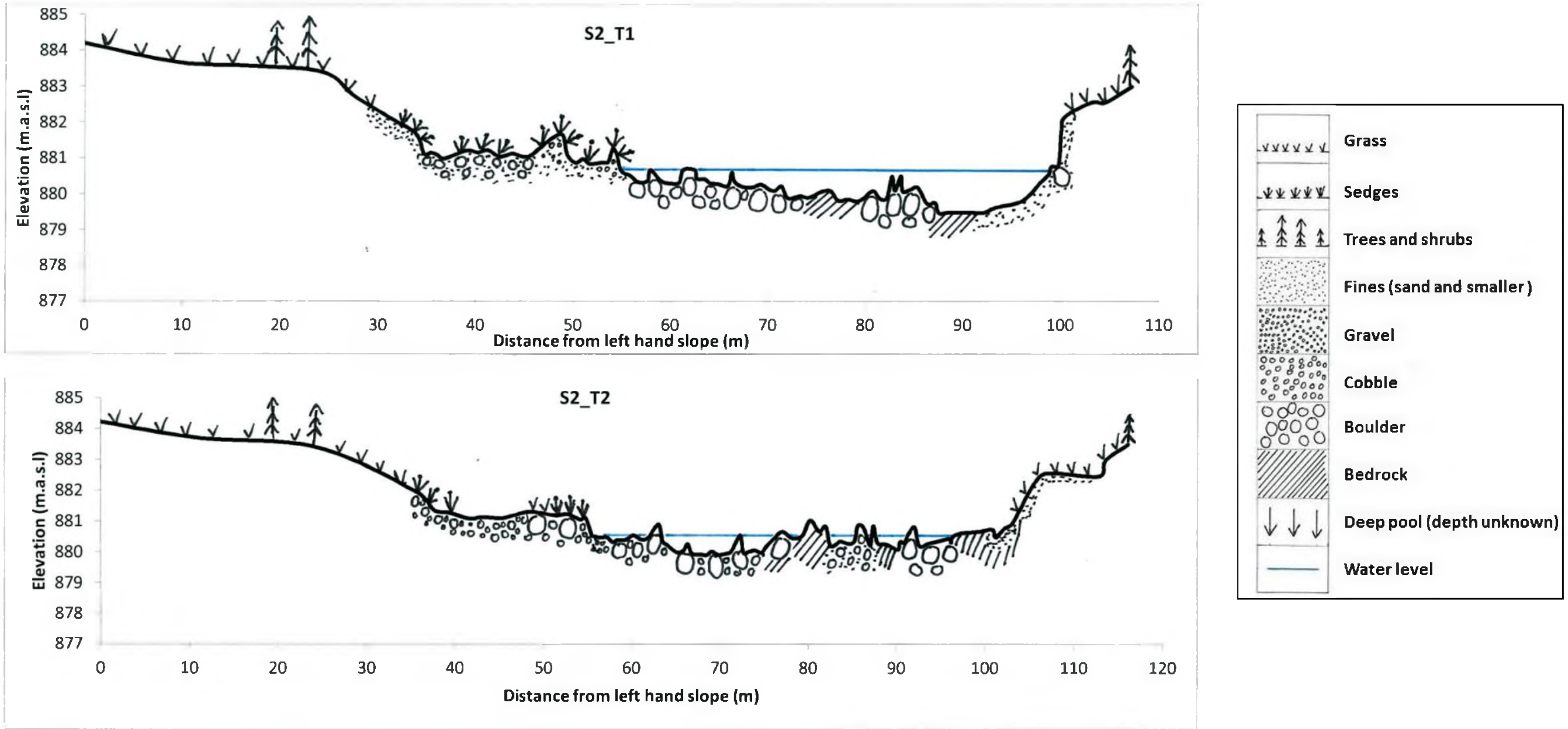
Appendix 1: Cross-sectional transects, including distribution of substrates, geo-habitats and July 2015 water levels, for each site in the Tsitsa River

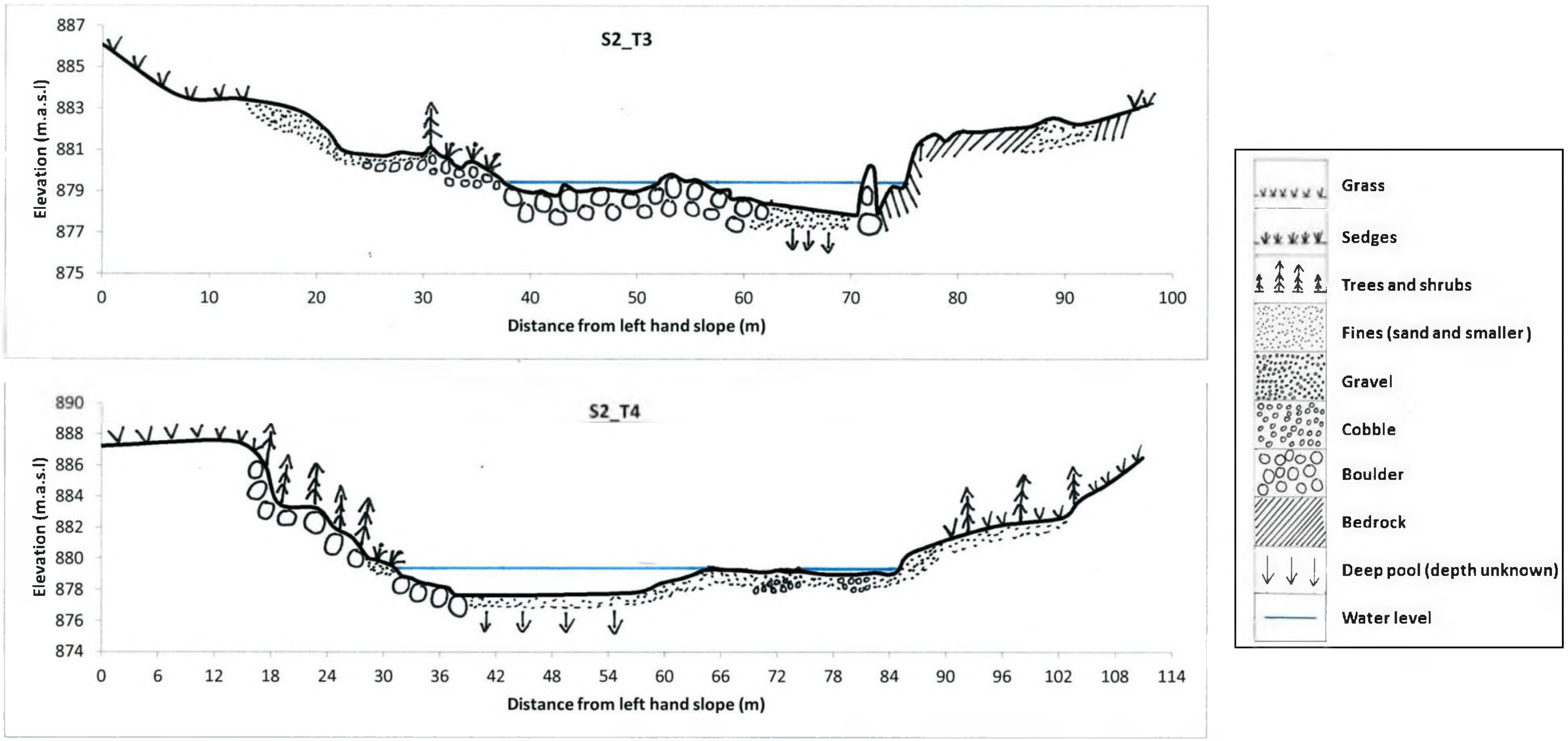

S1_T1
Elevation (m.a.s.l)
960
958
956
954
952
950
948
946
944
942
0
15
30
45
60
75
90
105
Distance from left hand slope (m)
S1_T2
Elevation (m.a.s.l)
952
951
950
949
948
947
946
945
0
8
16
24
32
40
48
56
64
Distance from left hand slope (m)
Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

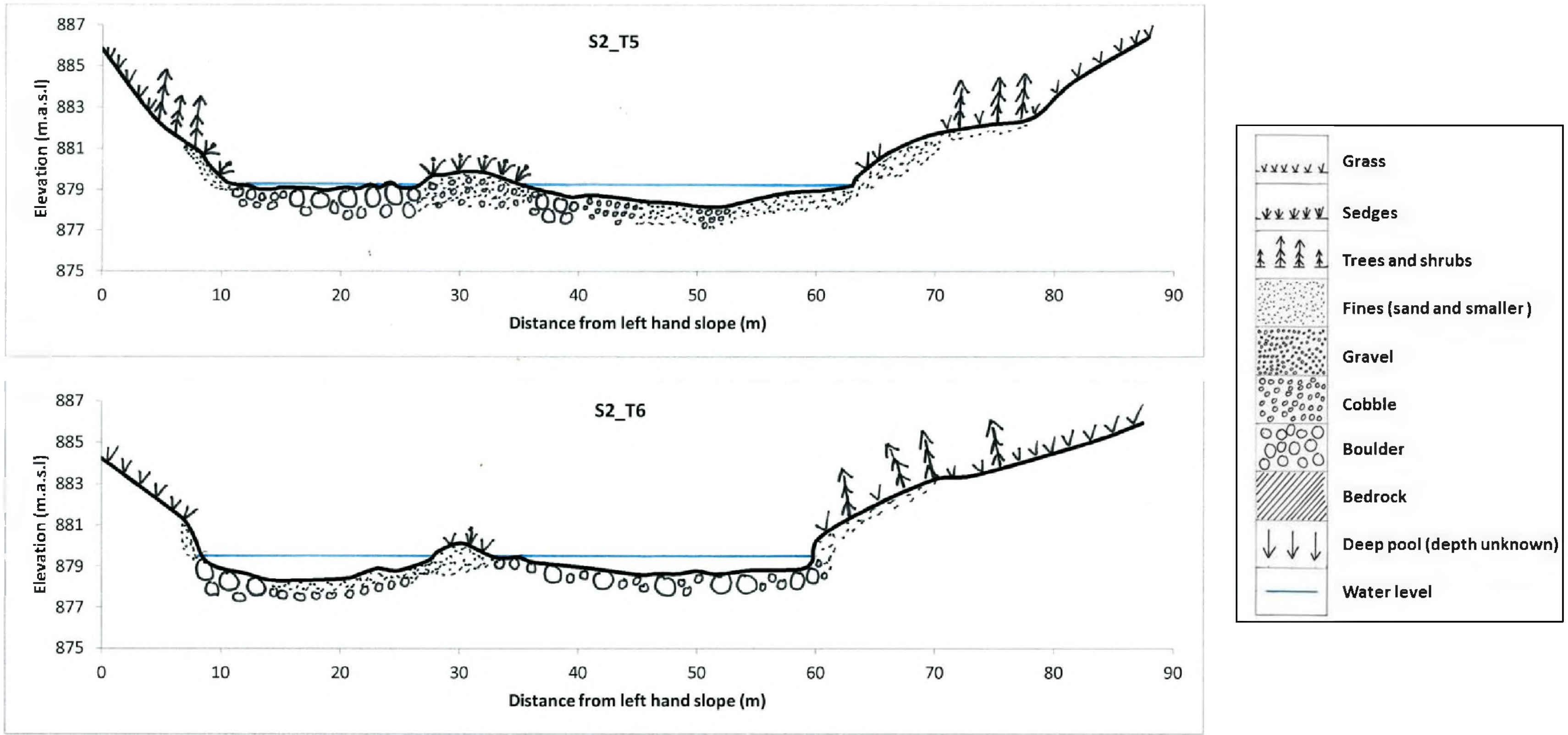

S1_T3
Elevation (m.a.s.l)
954
953
952
951
950
949
948
947
946
945
0
10
20
30
40
50
60
70
80
Distance from left hand slope (m)

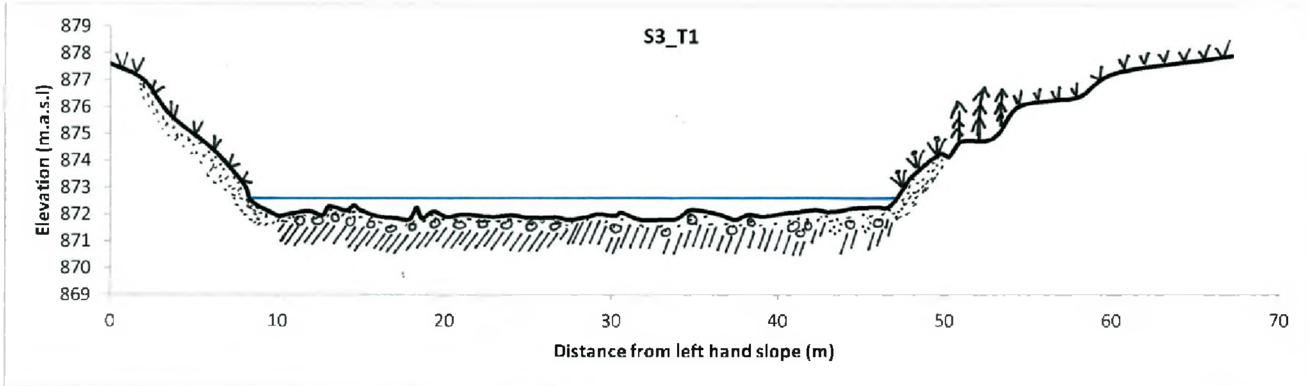

S1_T4
Elevation (m.a.s.l)
953
952
951
950
949
948
947
946
945
944
0
10
20
30
40
50
60
70
Distance from left hand slope (m)

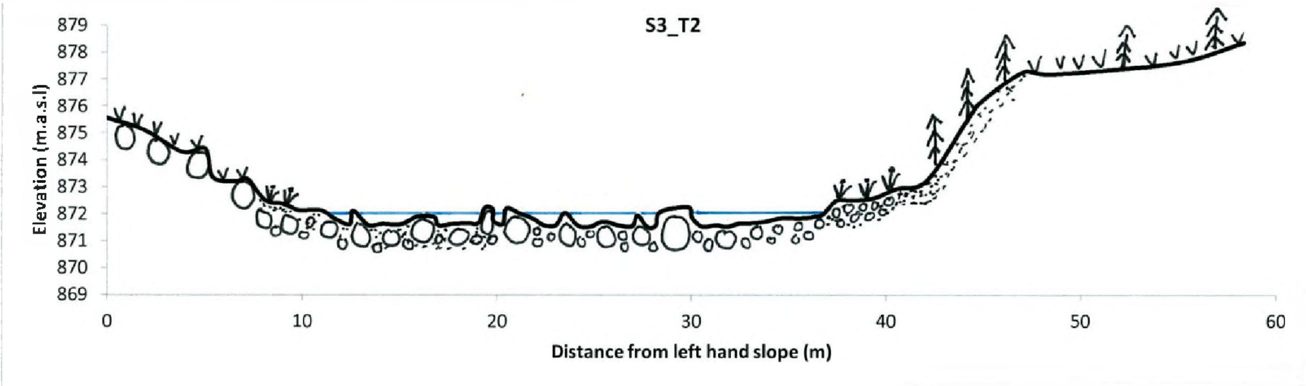

Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

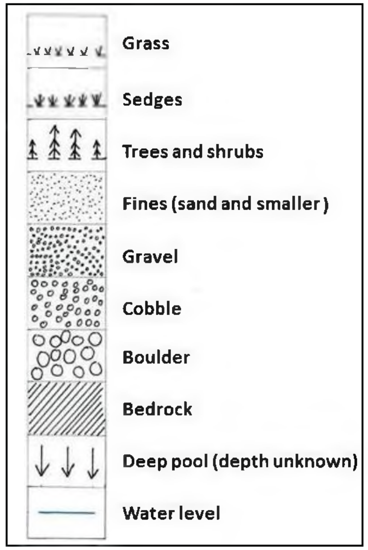

S2_T1
Elevation (m.a.s.l)
885
884
883
882
881
880
879
878
877
0
10
20
30
40
50
60
70
80
90
100
110
Distance from left hand slope (m)
S2_T2
Elevation (m.a.s.l)
885
884
883
882
881
880
879
878
877
0
10
20
30
40
50
60
70
80
90
100
110
120
Distance from left hand slope (m)
Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

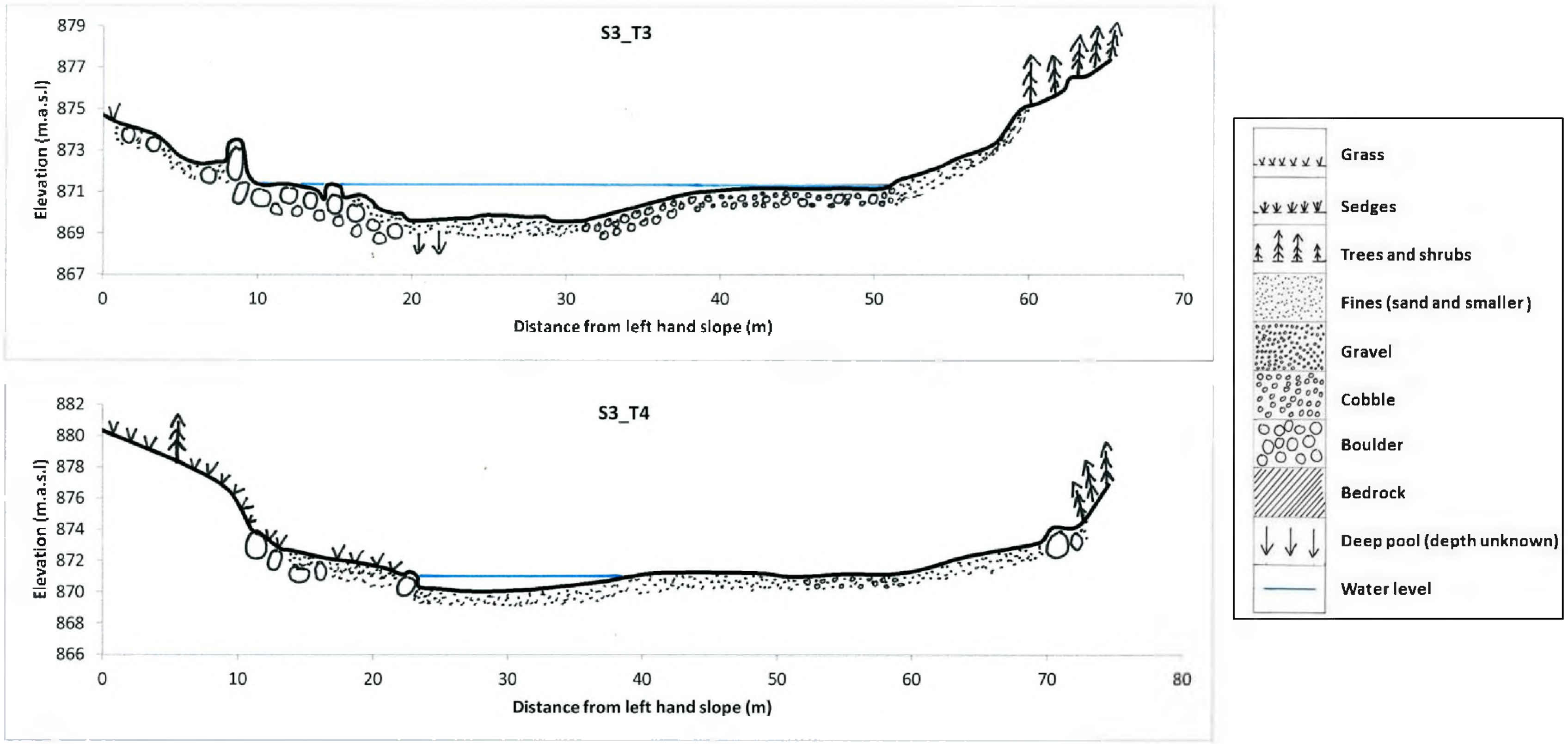

S2_T3
Elevation (m.a.s.l)
887
885
883
881
879
877
875
0
10
20
30
40
50
60
70
80
90
100
Distance from left hand slope (m)
S2_T4
Elevation (m.a.s.l)
890
888
886
884
882
880
878
876
874
0
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
Distance from left hand slope (m)
Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

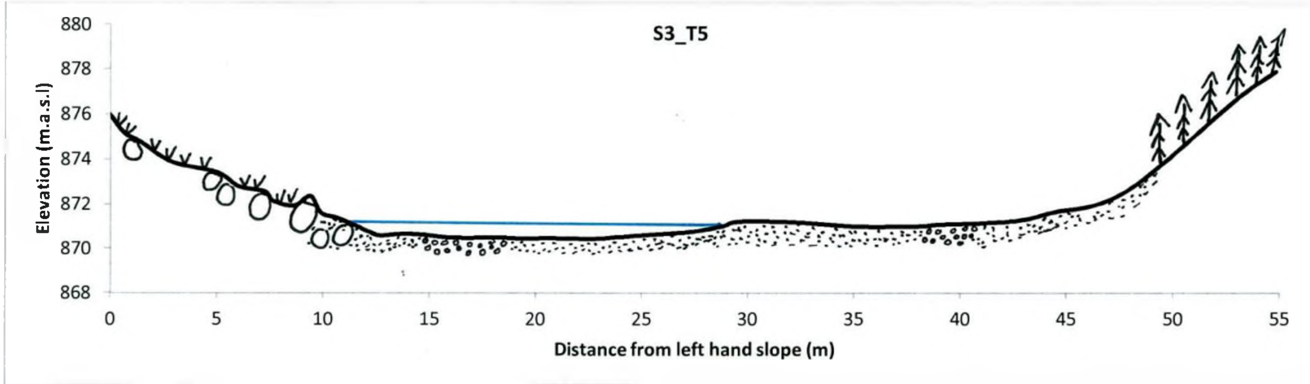

S2_T5
S2_T6
Elevation (m.a.s.l)
887
885
883
881
879
877
875
0
10
20
30
40
50
60
70
80
90
Distance from left hand slope (m)
Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

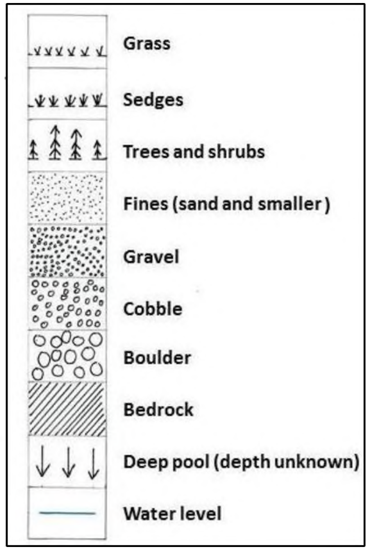

S3_T1
Elevation (m.a.s.l)
879
878
877
876
875
874
873
872
871
870
869
0
10
20
30
40
50
60
70
Distance from left hand slope (m)

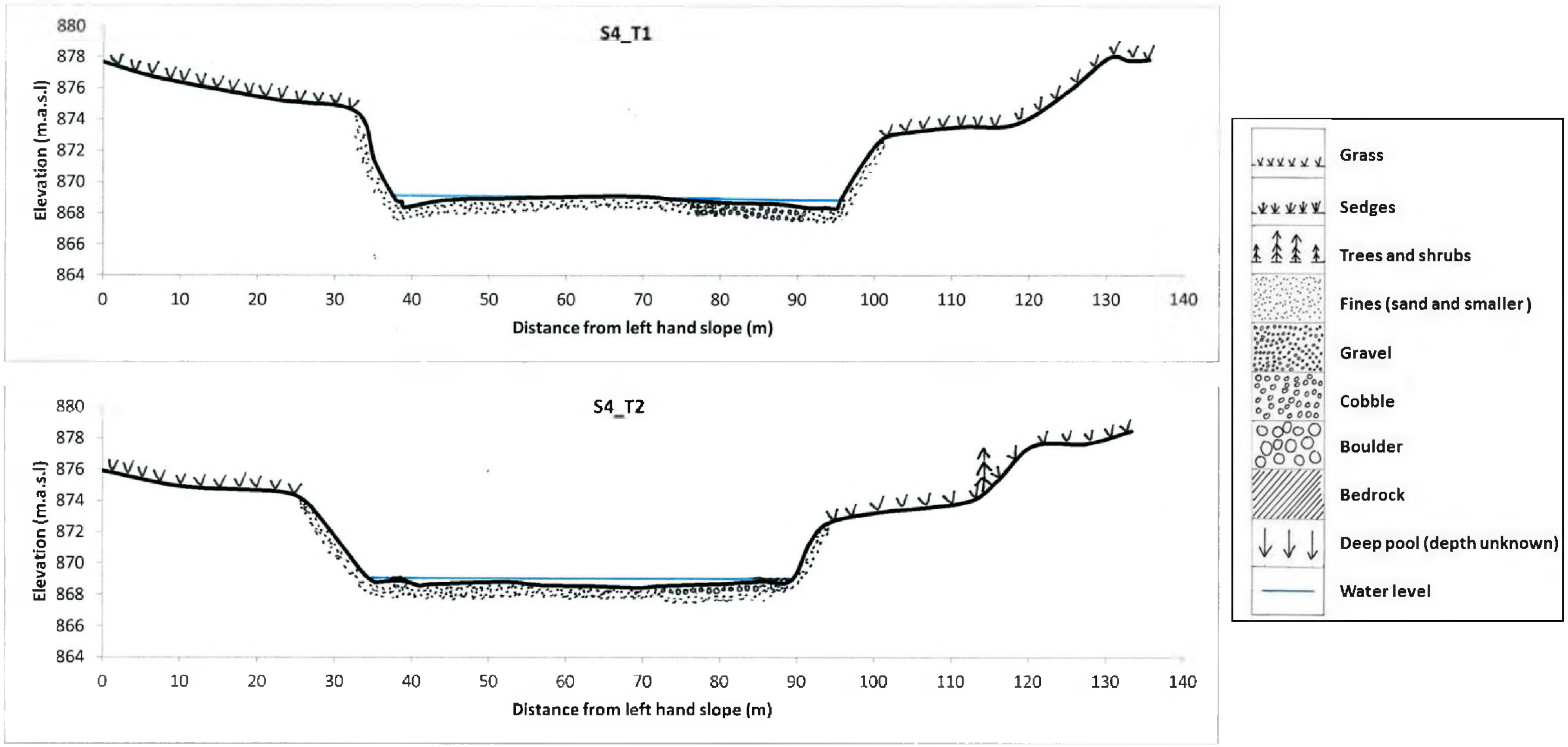

S3_T2
Elevation (m.a.s.l)
879
878
877
876
875
874
873
872
871
870
869
0
10
20
30
40
50
60
Distance from left hand slope (m)

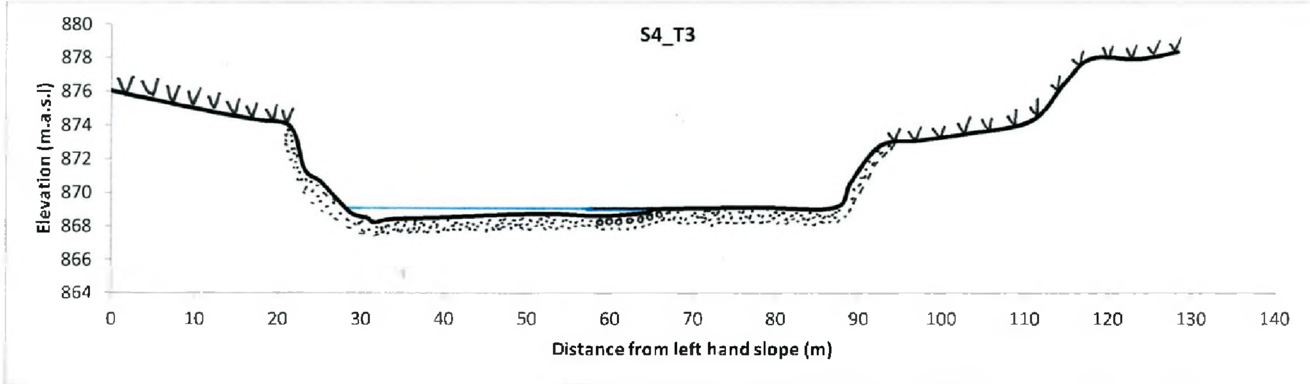

Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

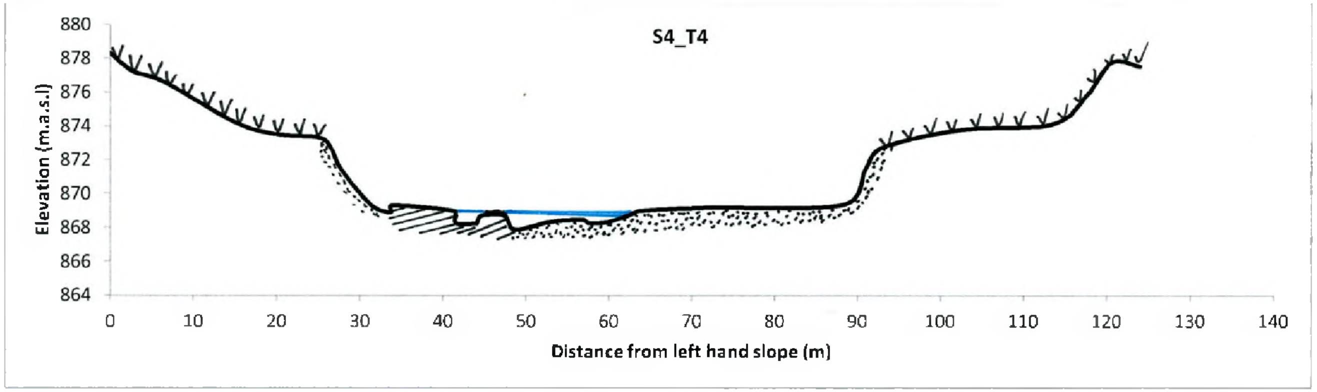

S3_T3
Elevation (m.a.s.l)
879
877
875
873
871
869
867
0
10
20
30
40
50
60
70
Distance from left hand slope (m)
S3_T4
Elevation (m.a.s.l)
882
880
878
876
874
872
870
868
866
0
10
20
30
40
50
60
70
80
Distance from left hand slope (m)
Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

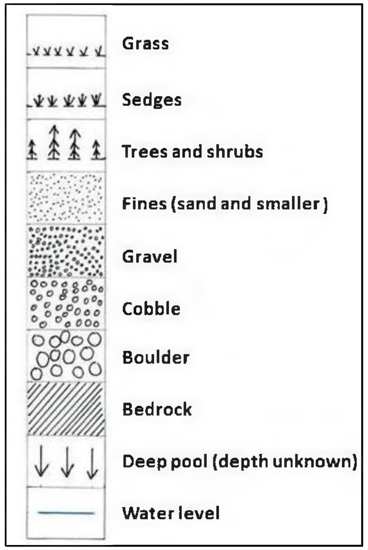

S3_T5
880
878
876
874
872
870
868
Elevation (m.a.s.l)
0
5
10
15
20
25
30
35
40
45
50
55
Distance from left hand slope (m)

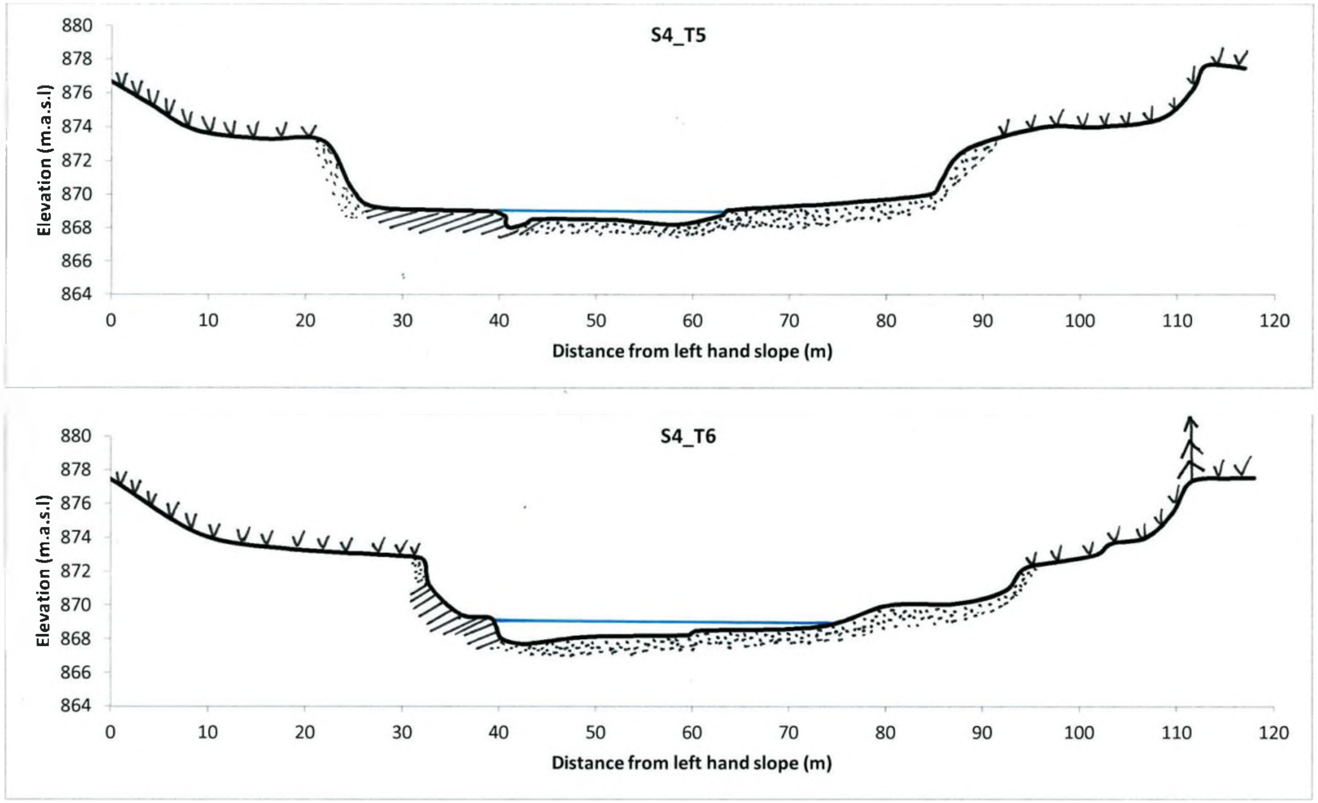

Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

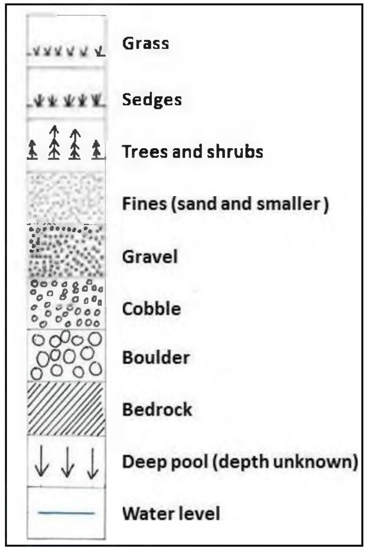

S4_T1
Elevation (m.a.s.l)
880
878
876
874
872
870
868
866
864
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
Distance from left hand slope (m)
S4_T2
Elevation (m.a.s.l)
880
878
876
874
872
870
868
866
864
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
Distance from left hand slope (m)
Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

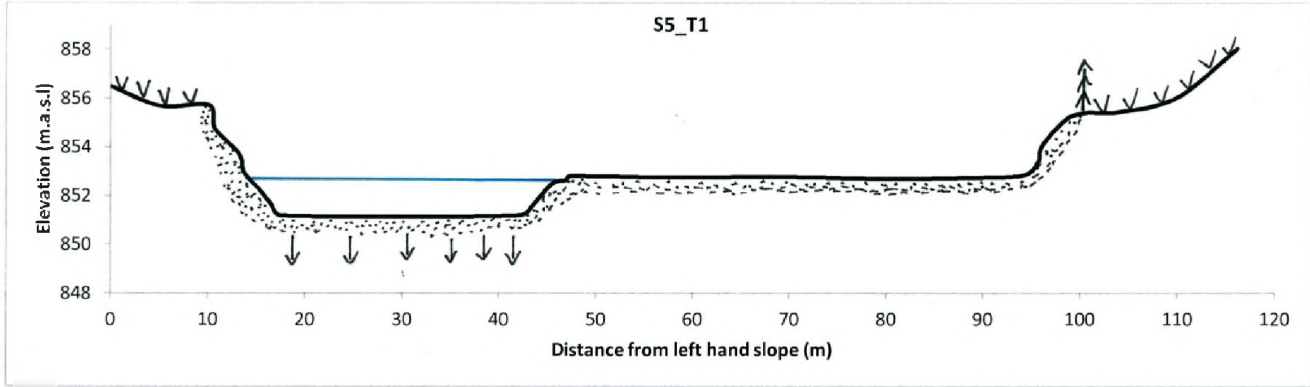

S4_T3
Elevation (m.a.s.l)
Distance from left hand slope (m)

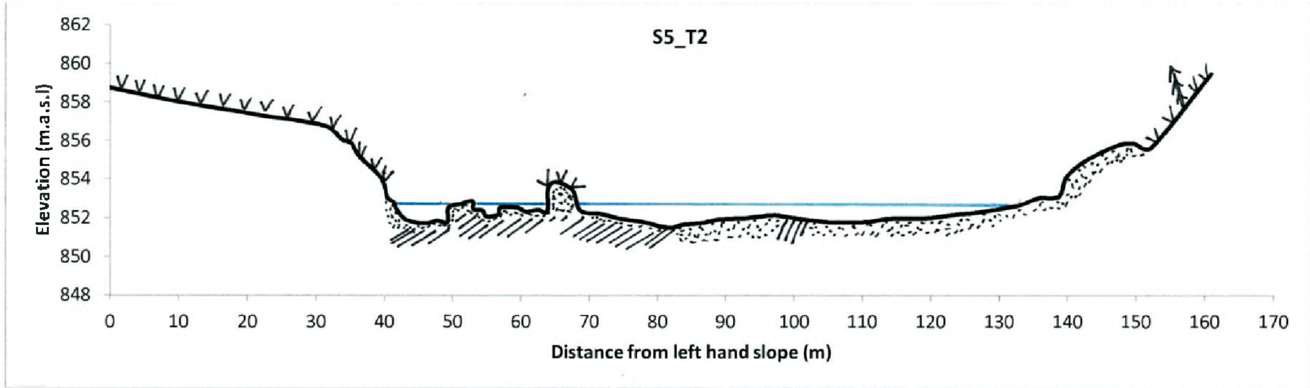

S4_T4
Elevation (m.a.s.l)
Distance from left hand slope (m)

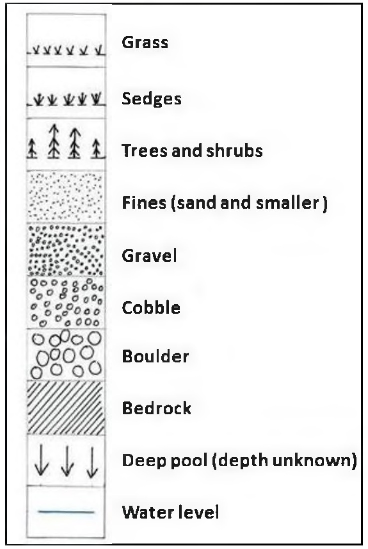

Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

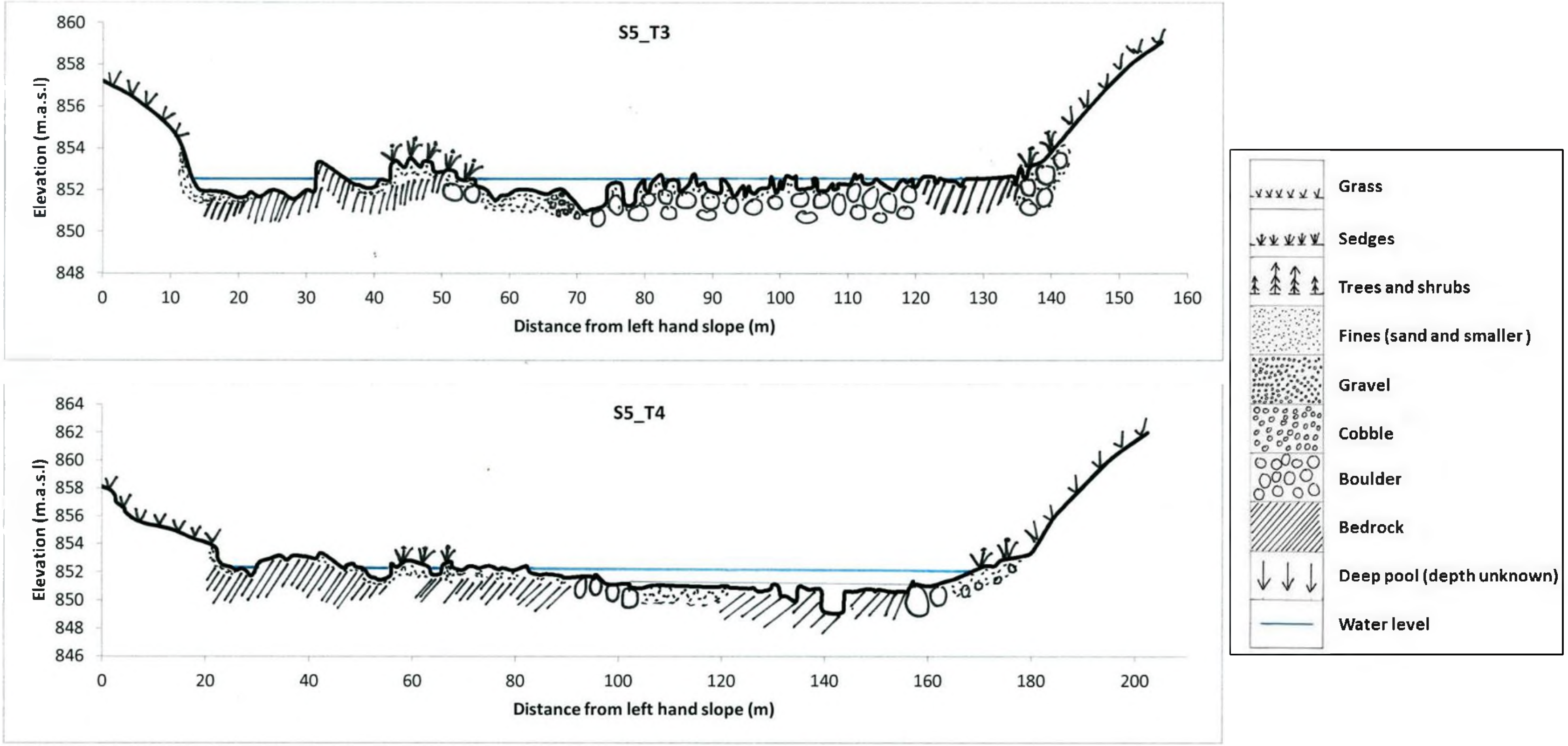

S4_T5
880
878
876
874
872
870
868
866
864
Elevation (m.a.s.l)
0
10
20
30
40
50
60
70
80
90
100
110
120
Distance from left hand slope (m)
S4_T6
880
878
876
874
872
870
868
866
864
Elevation (m.a.s.l)
0
10
20
30
40
50
60
70
80
90
100
110
120
Distance from left hand slope (m)

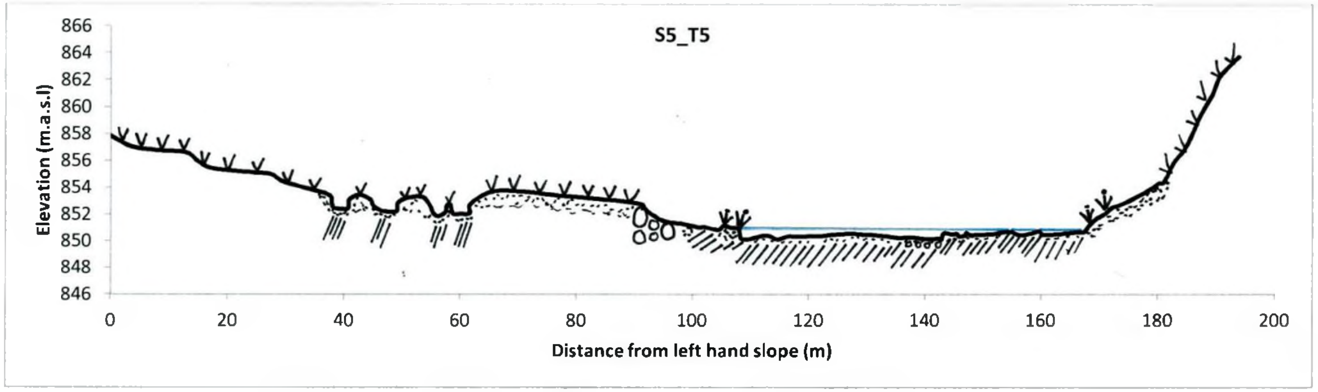

Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

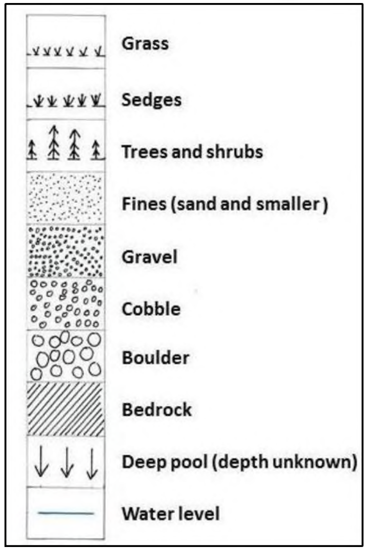

S5_T1
Elevation (m.a.s.l)
858
856
854
852
850
848
0
10
20
30
40
50
60
70
80
90
100
110
120
Distance from left hand slope (m)

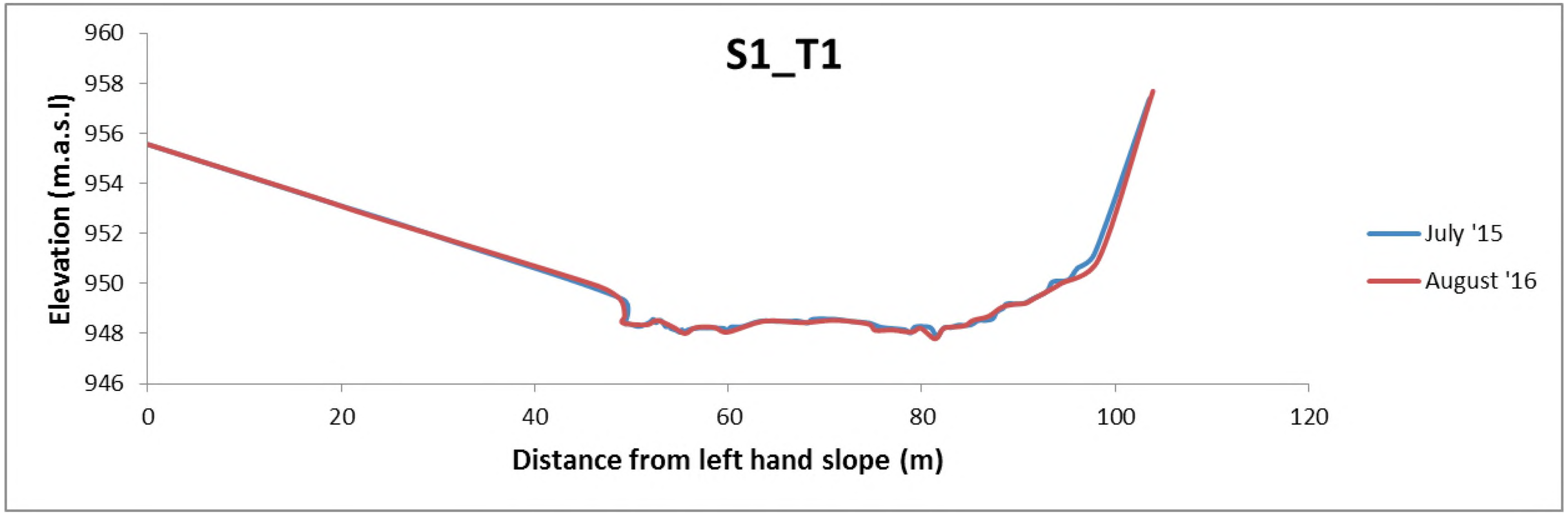

S5_T2
Elevation (m.a.s.l)
862
860
858
856
854
852
850
848
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
Distance from left hand slope (m)

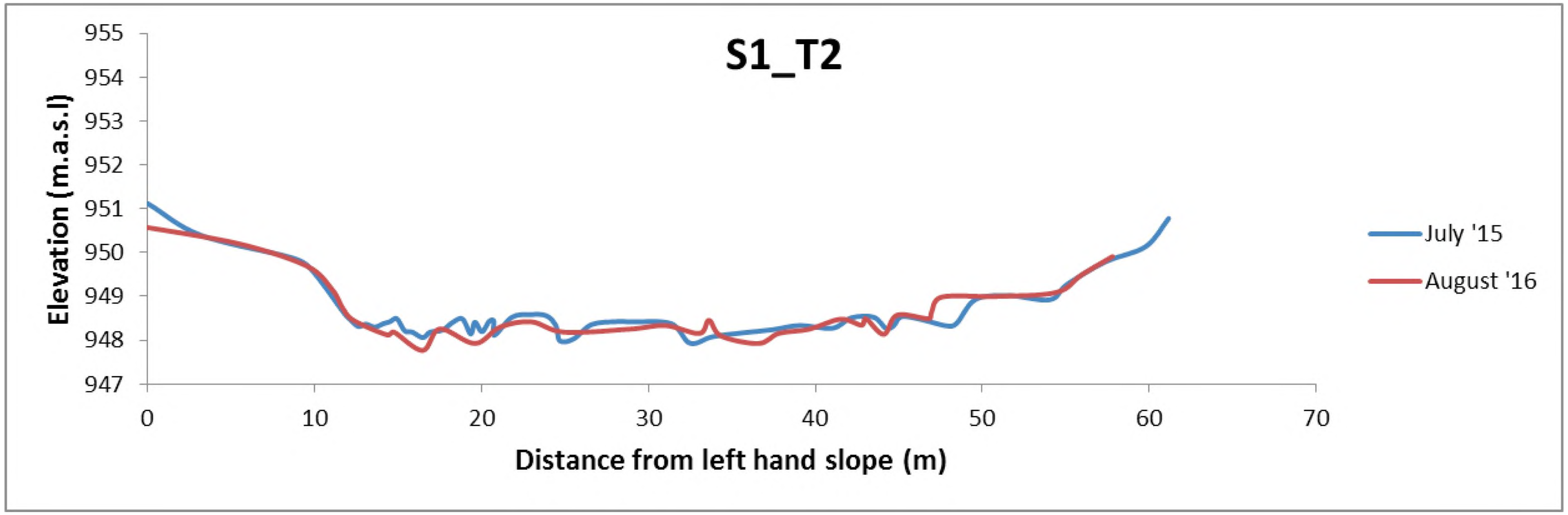

Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

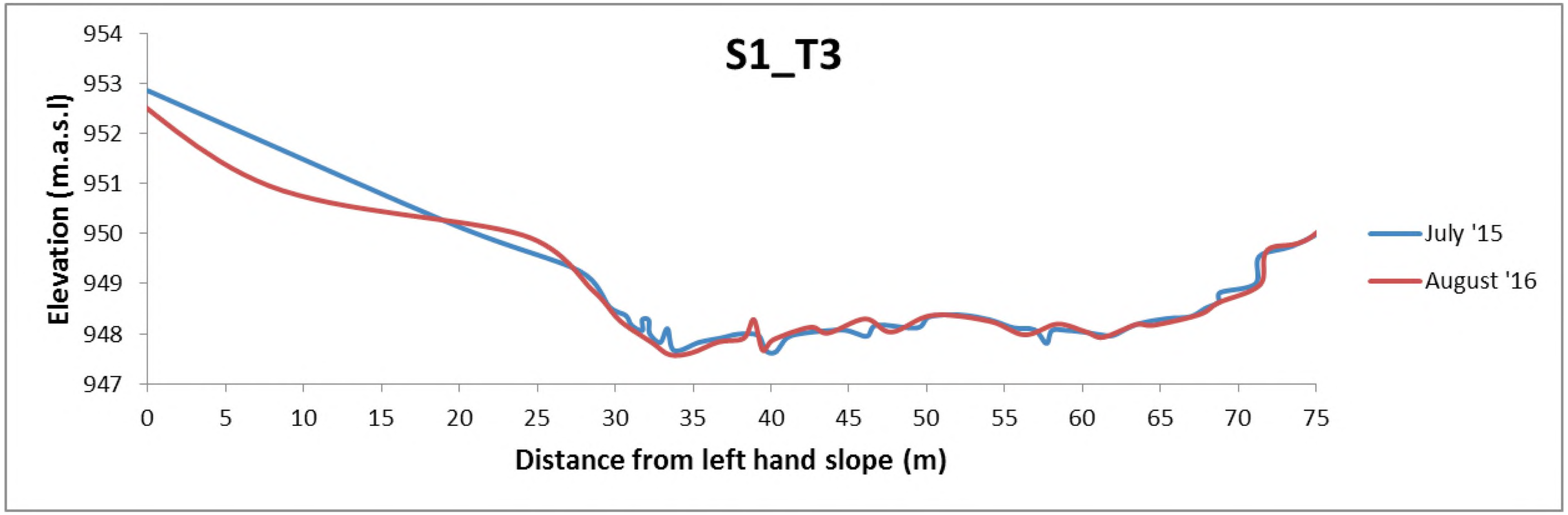

S5_T3
Elevation (m.a.s.l)
860
858
856
854
852
850
848
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
Distance from left hand slope (m)
S5_T4
Elevation (m.a.s.l)
864
862
860
858
856
854
852
850
848
846
0
20
40
60
80
100
120
140
160
180
200
Distance from left hand slope (m)
Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

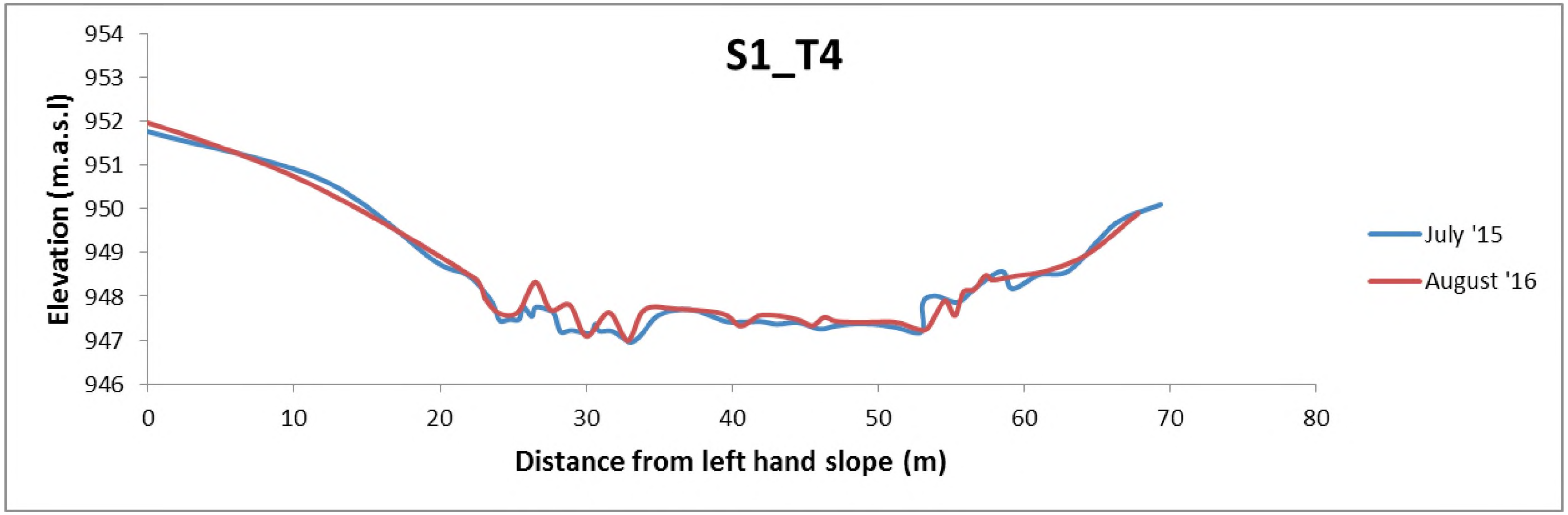

S5_T5
Elevation (m.a.s.l)
866
864
862
860
858
856
854
852
850
848
846
0
20
40
60
80
100
120
140
160
180
200
Distance from left hand slope (m)

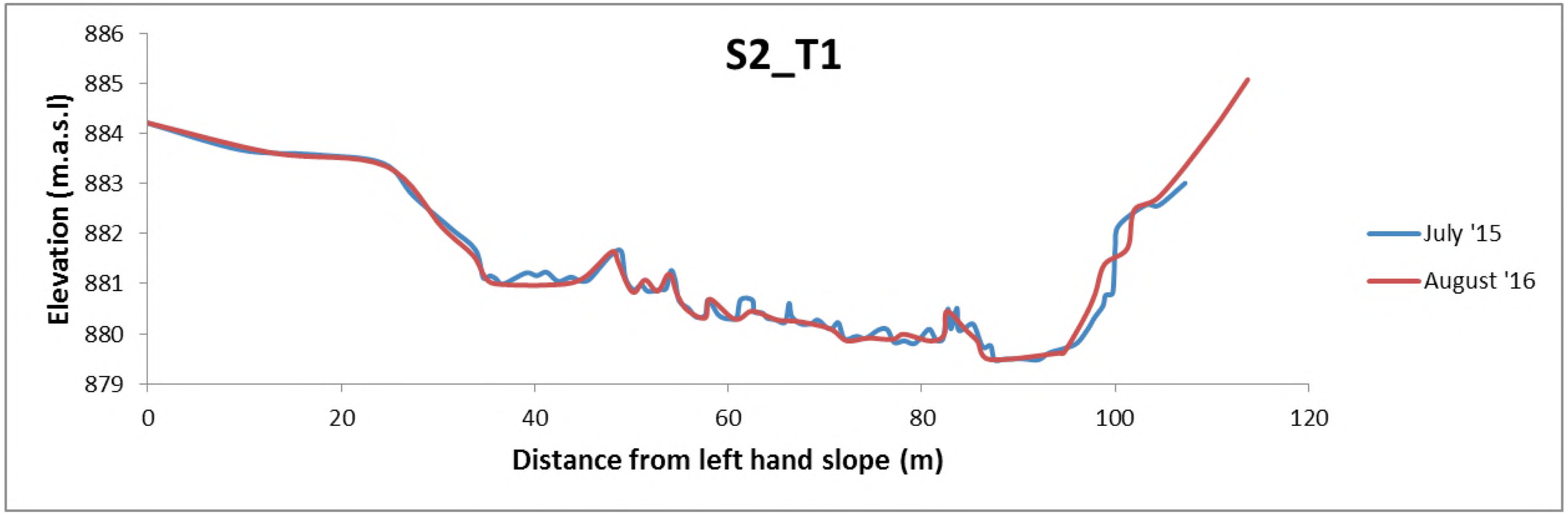

Grass
Sedges
Trees and shrubs
Fines (sand and smaller)
Gravel
Cobble
Boulder
Bedrock
Deep pool (depth unknown)
Water level

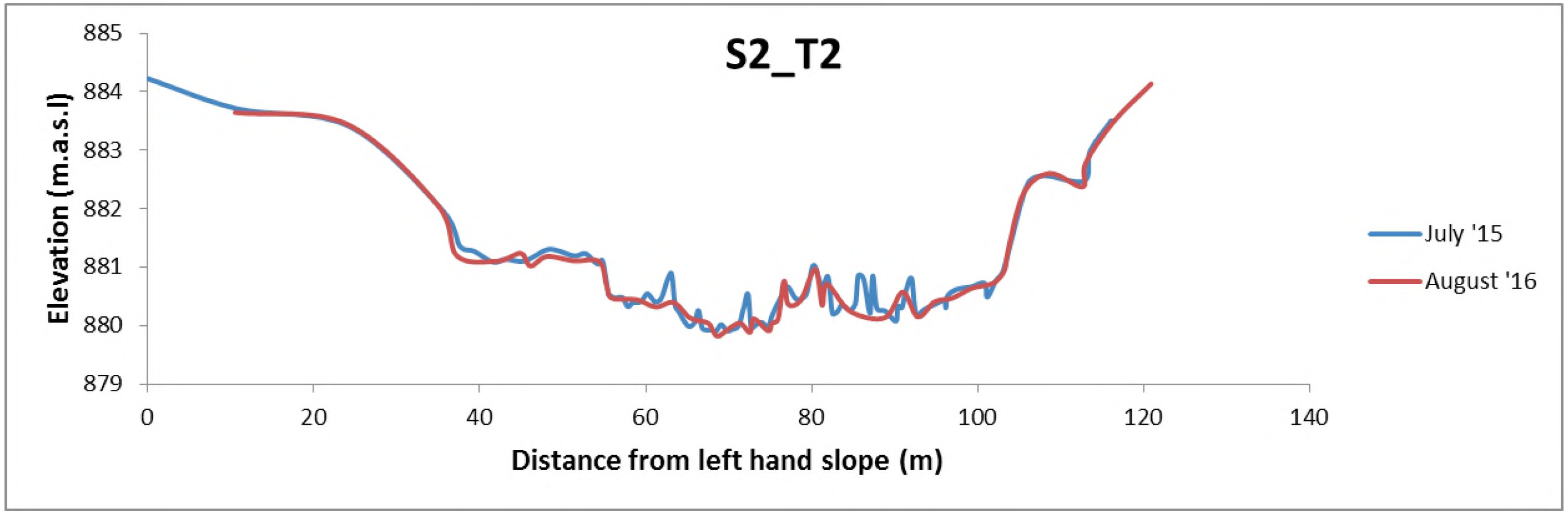

S1_T1
Elevation (m.a.s.l)
960
958
956
954
952
950
948
946
0
20
40
60
80
100
120
Distance from left hand slope (m)
July '15
August '16

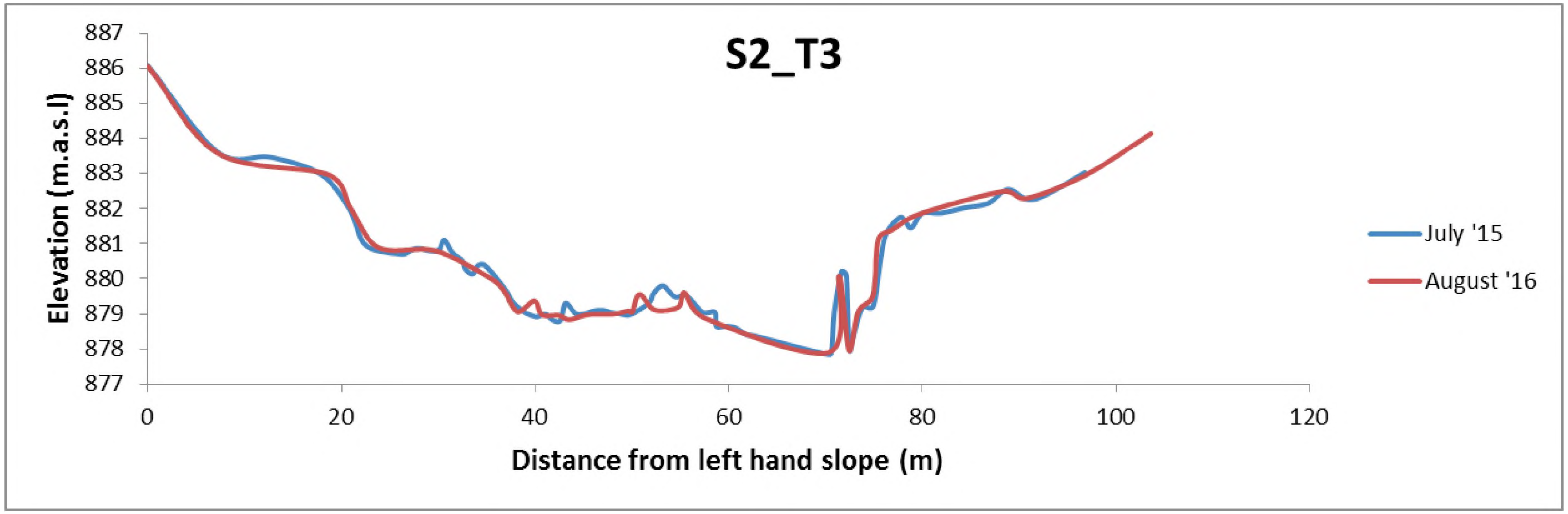

S1_T2
Elevation (m.a.s.l)
955
954
953
952
951
950
949
948
947
0
10
20
30
40
50
60
70
Distance from left hand slope (m)
July '15
August '16

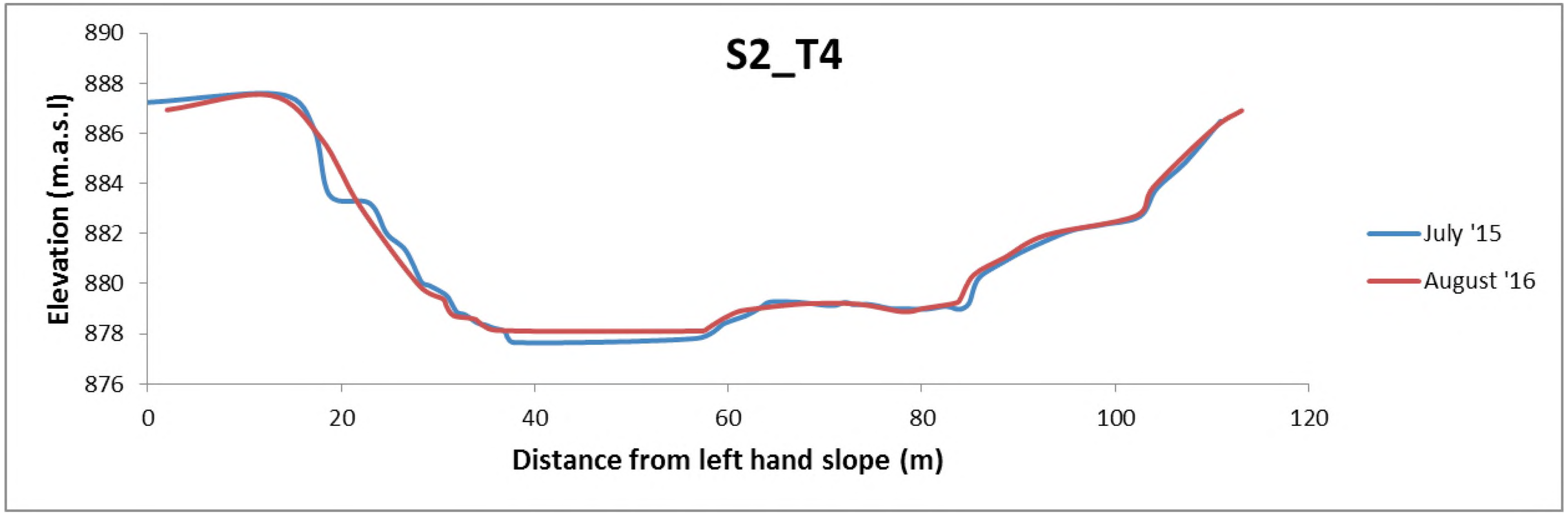

S1_T3
Elevation (m.a.s.l)
954
953
952
951
950
949
948
947
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
Distance from left hand slope (m)
July '15
August '16

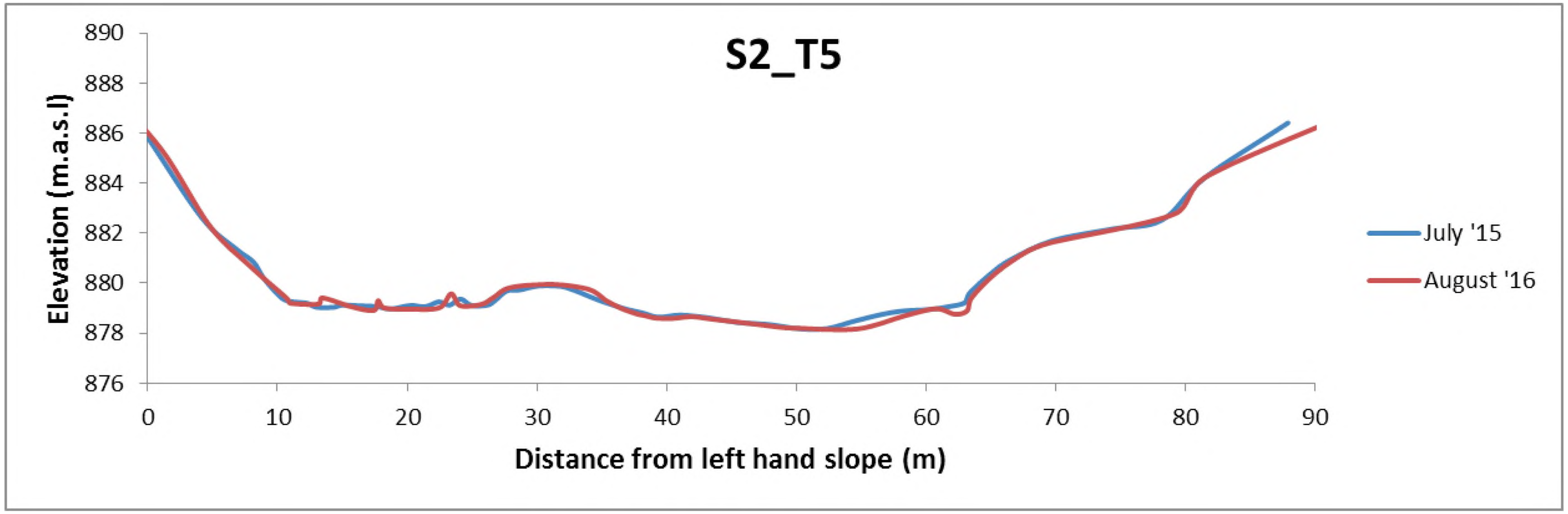

S1_T4
Elevation (m.a.s.l)
954
953
952
951
950
949
948
947
946
0
10
20
30
40
50
60
70
80
Distance from left hand slope (m)
July '15
August '16

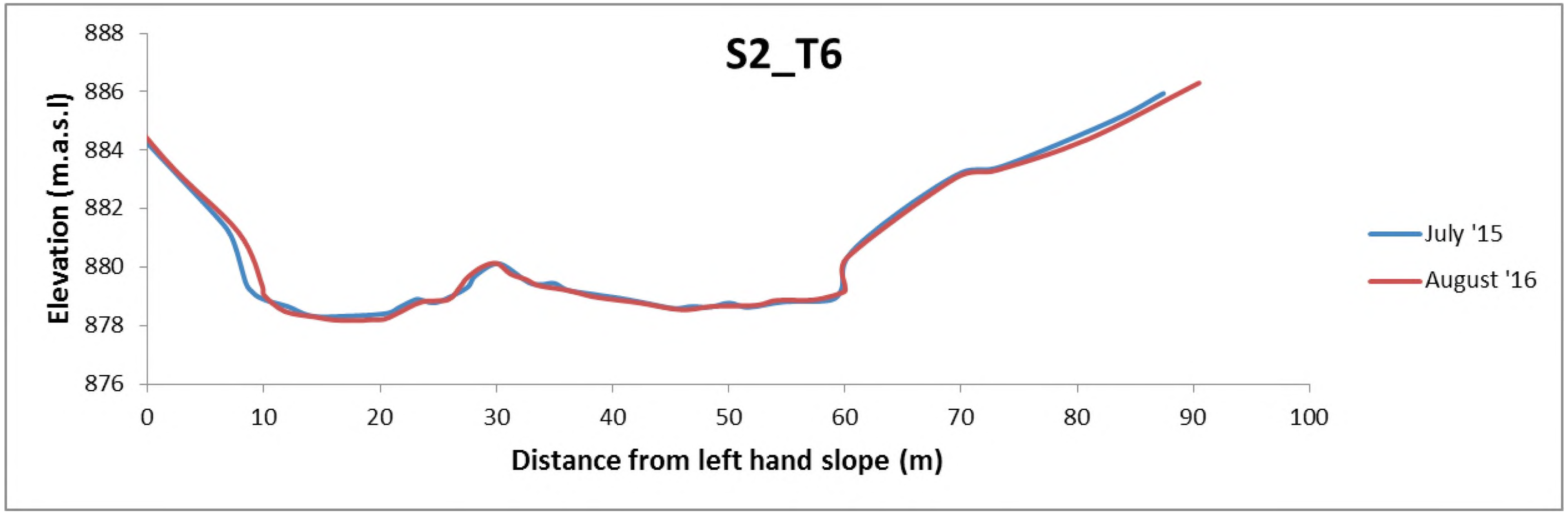

S2_T1
Elevation (m.a.s.l)
886
885
884
883
882
881
880
879
0
20
40
60
80
100
120
Distance from left hand slope (m)
July '15
August '16

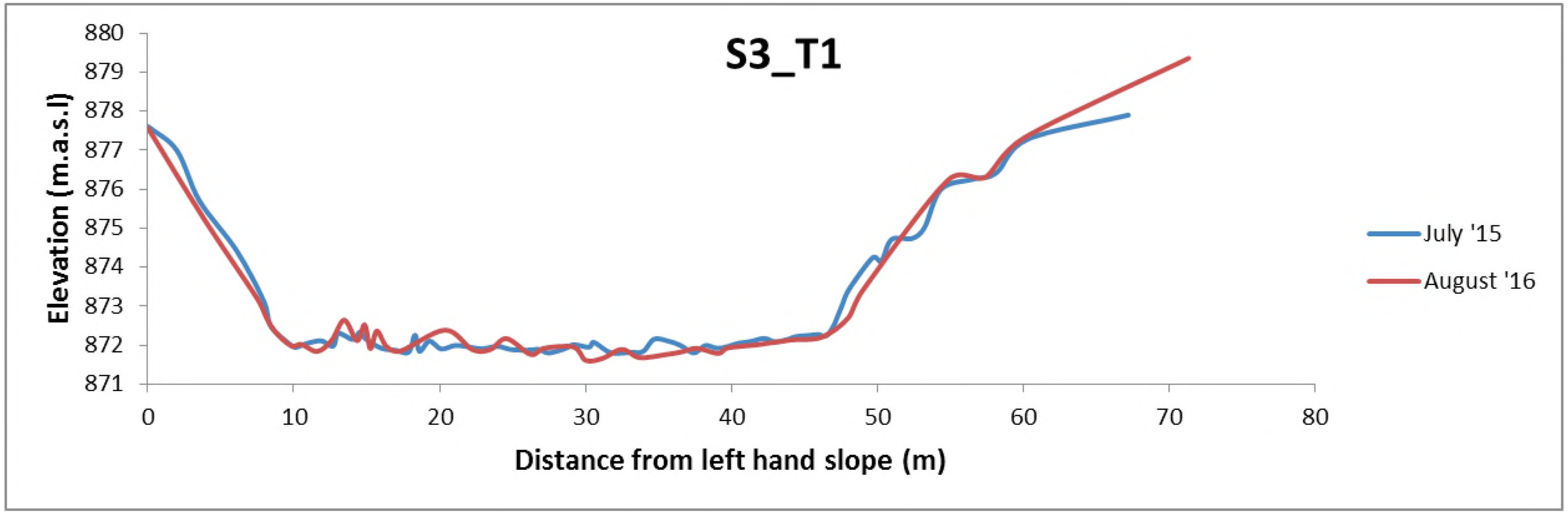

S2_T2
Elevation (m.a.s.l)
885
884
883
882
881
880
879
0
20
40
60
80
100
120
140
Distance from left hand slope (m)
July '15
August '16

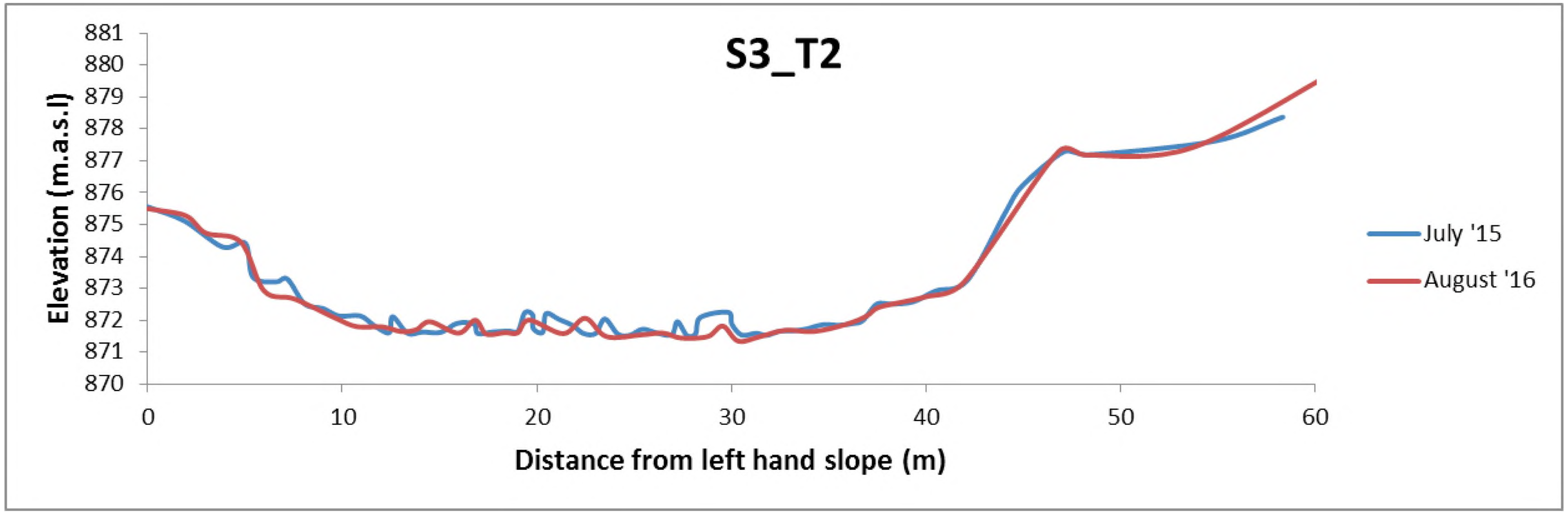

S2_T3
887
886
885
884
883
882
881
880
879
878
877
Elevation (m.a.s.l)
0
20
40
60
80
100
120
Distance from left hand slope (m)
July '15
August '16

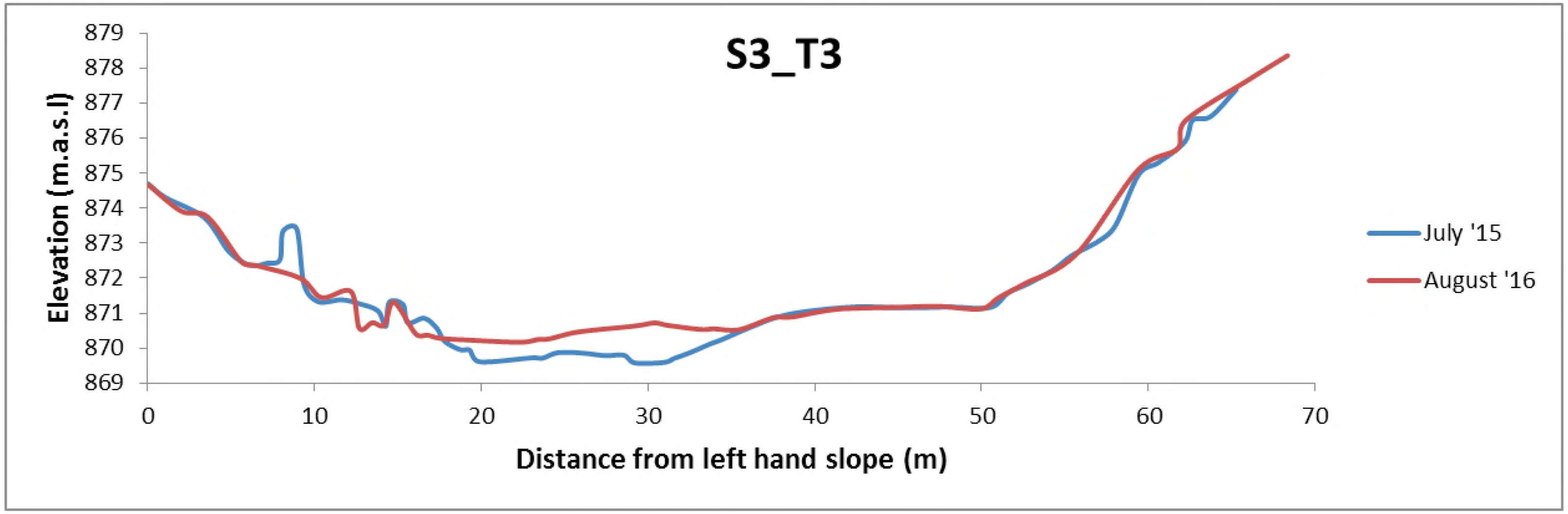

S2_T4
890
888
886
884
882
880
878
876
Elevation (m.a.s.l)
0
20
40
60
80
100
120
Distance from left hand slope (m)
July '15
August '16

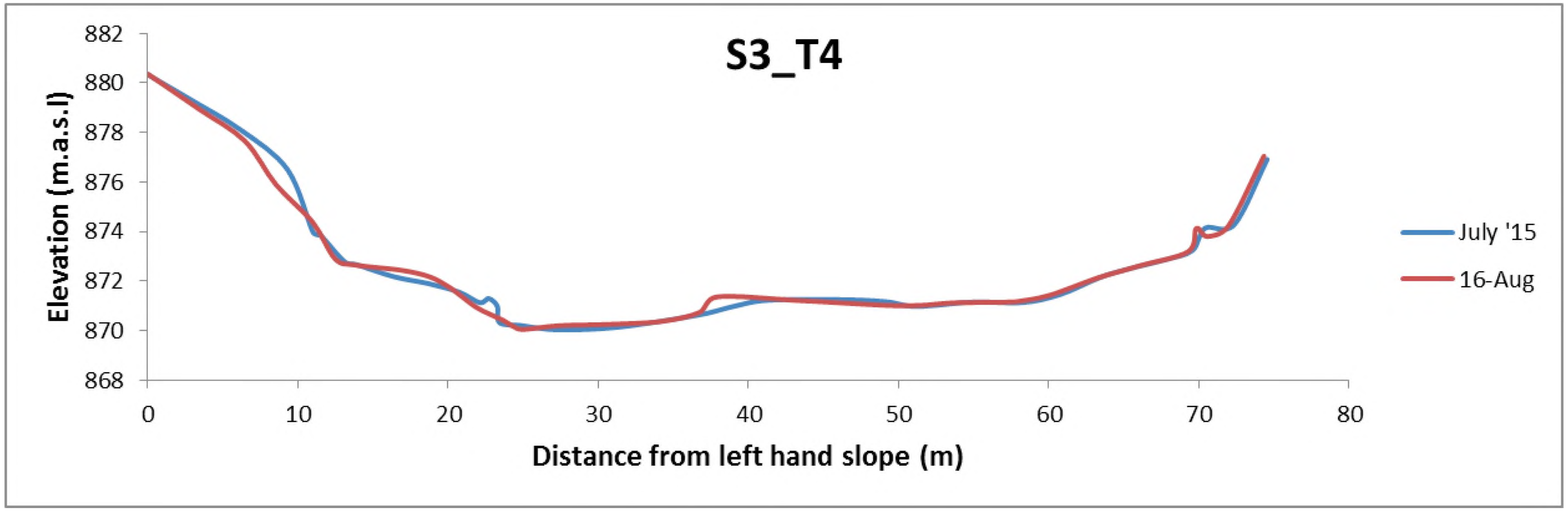

S2_T5
Elevation (m.a.s.l)
890
888
886
884
882
880
878
876
0
10
20
30
40
50
60
70
80
90
Distance from left hand slope (m)
July '15
August '16

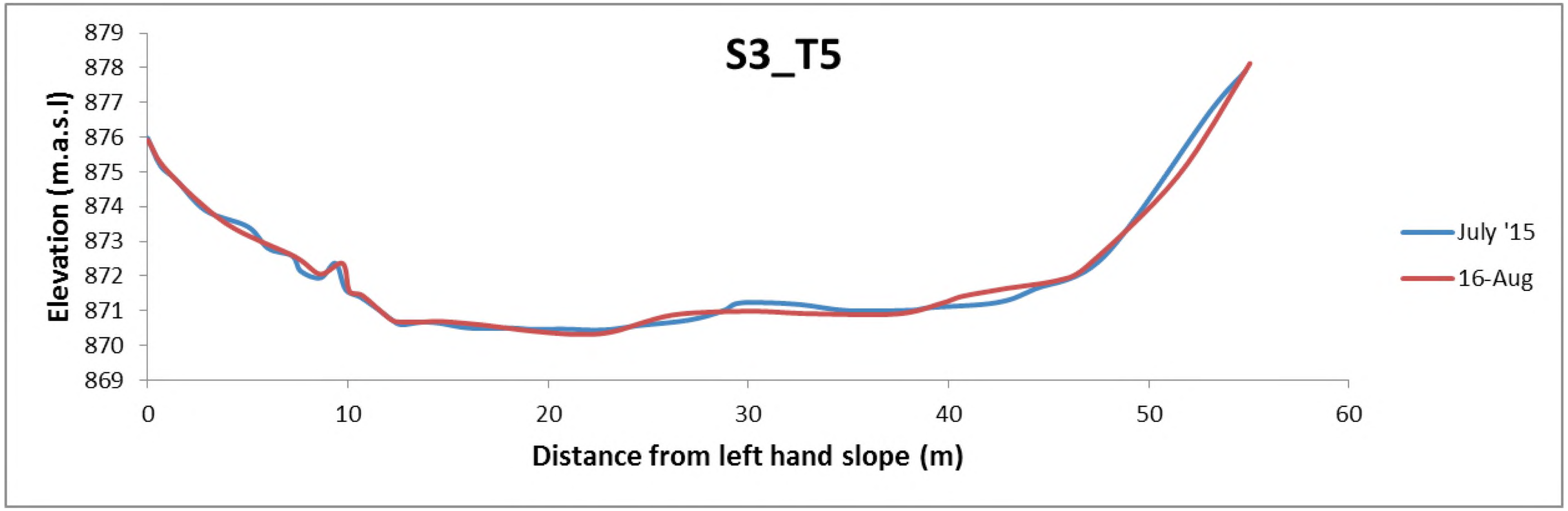

S2_T6
Elevation (m.a.s.l)
888
886
884
882
880
878
876
0
10
20
30
40
50
60
70
80
90
100
Distance from left hand slope (m)
July '15
August '16

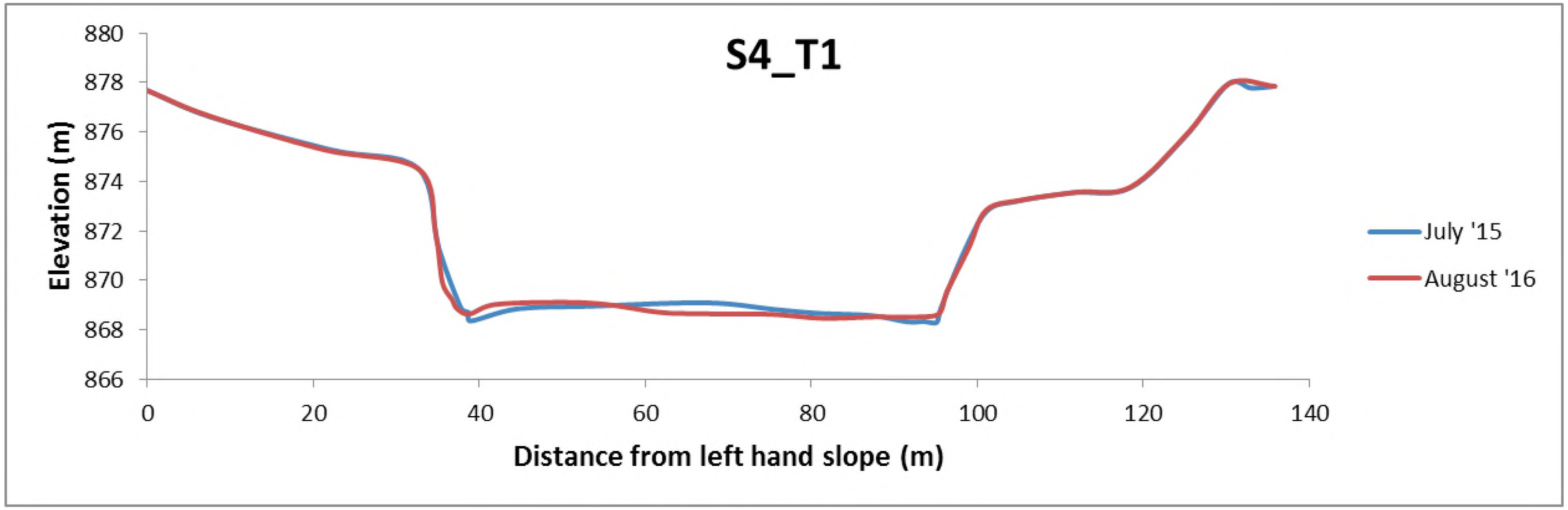

S3_T1
Elevation (m.a.s.l)
Distance from left hand slope (m)
July '15
August '16
880
879
878
877
876
875
874
873
872
871
0
10
20
30
40
50
60
70
80

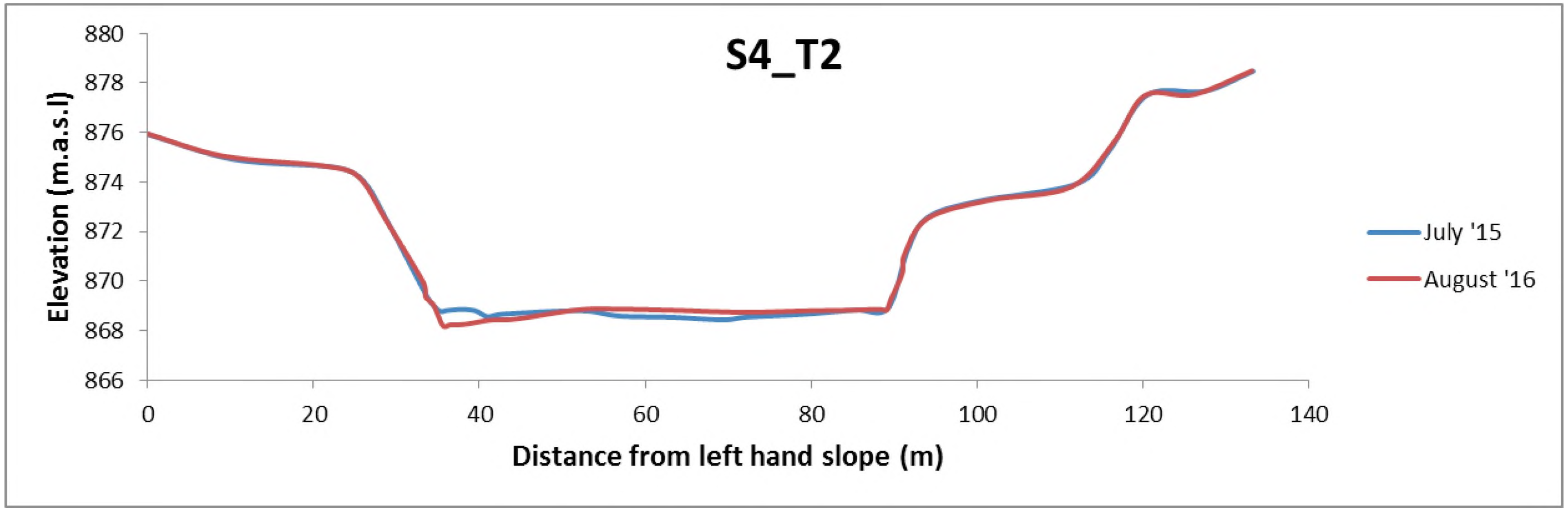

S3_T2
Elevation (m.a.s.l)
Distance from left hand slope (m)
July '15
August '16
881
880
879
878
877
876
875
874
873
872
871
870
0
10
20
30
40
50
60

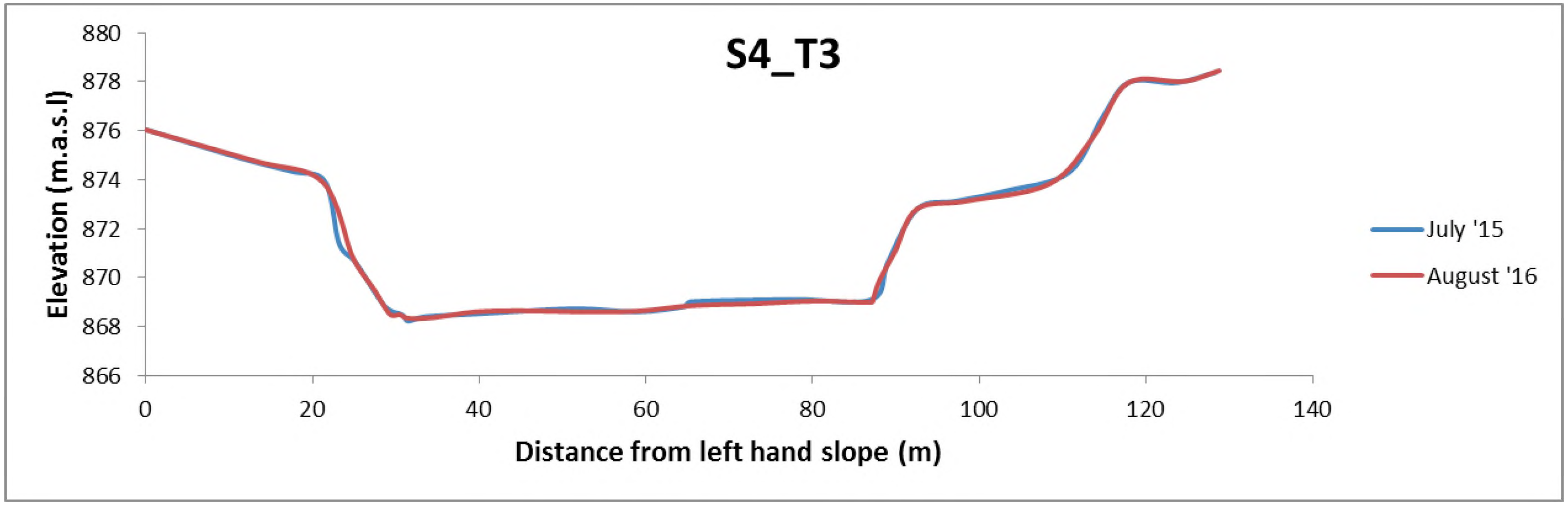

S3_T3
Elevation (m.a.s.l)
879
878
877
876
875
874
873
872
871
870
869
0
10
20
30
40
50
60
70
Distance from left hand slope (m)
July '15
August '16

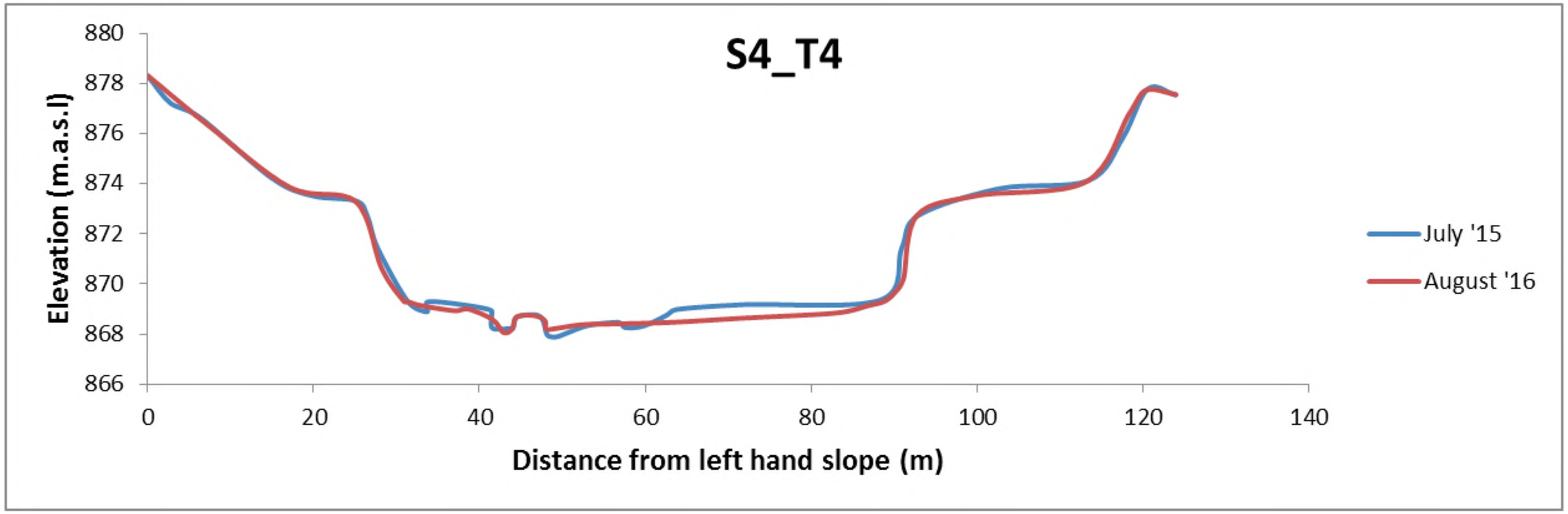

S3_T4
Elevation (m.a.s.l)
882
880
878
876
874
872
870
868
0
10
20
30
40
50
60
70
80
Distance from left hand slope (m)
July '15
16-Aug

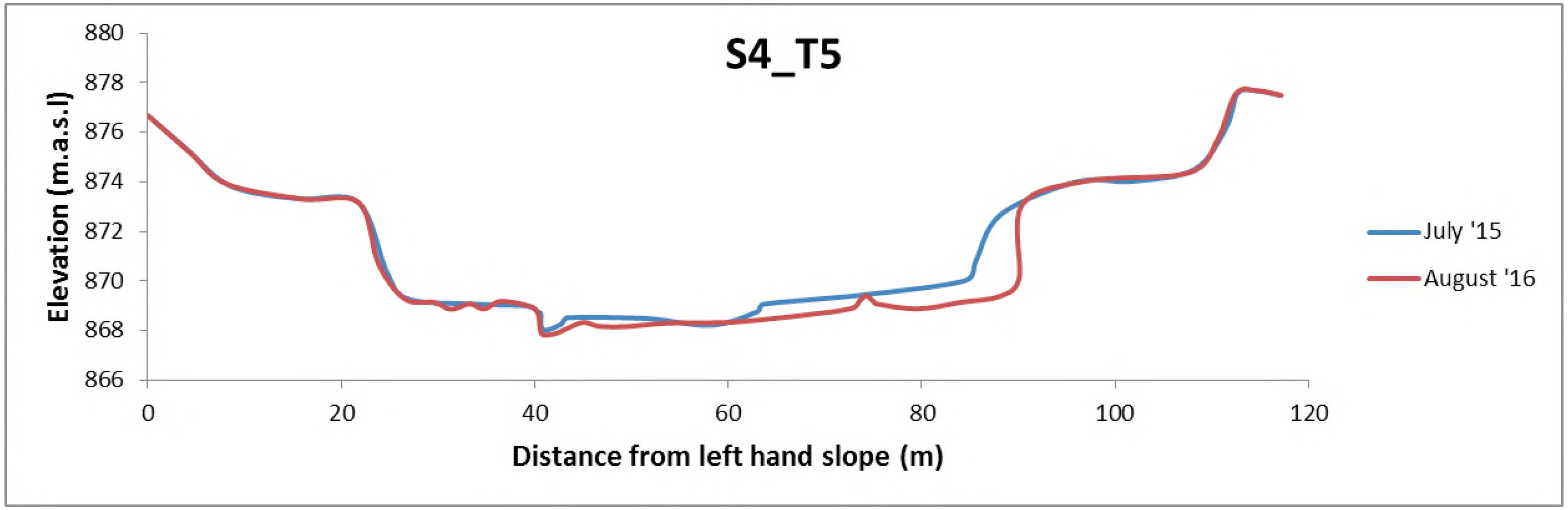

S3_T5
Elevation (m.a.s.l)
879
878
877
876
875
874
873
872
871
870
869
0
10
20
30
40
50
60
Distance from left hand slope (m)
July '15
16-Aug

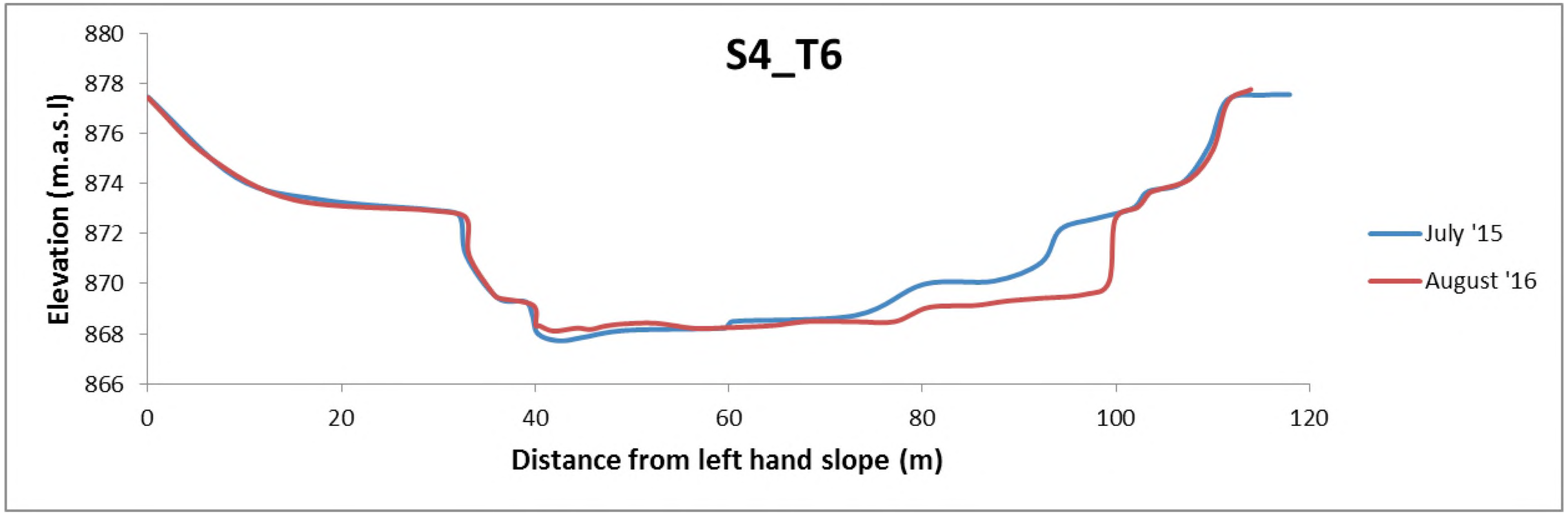

S4_T1
880
878
876
874
872
870
868
866
Elevation (m)
0
20
40
60
80
100
120
140
Distance from left hand slope (m)
July '15
August '16

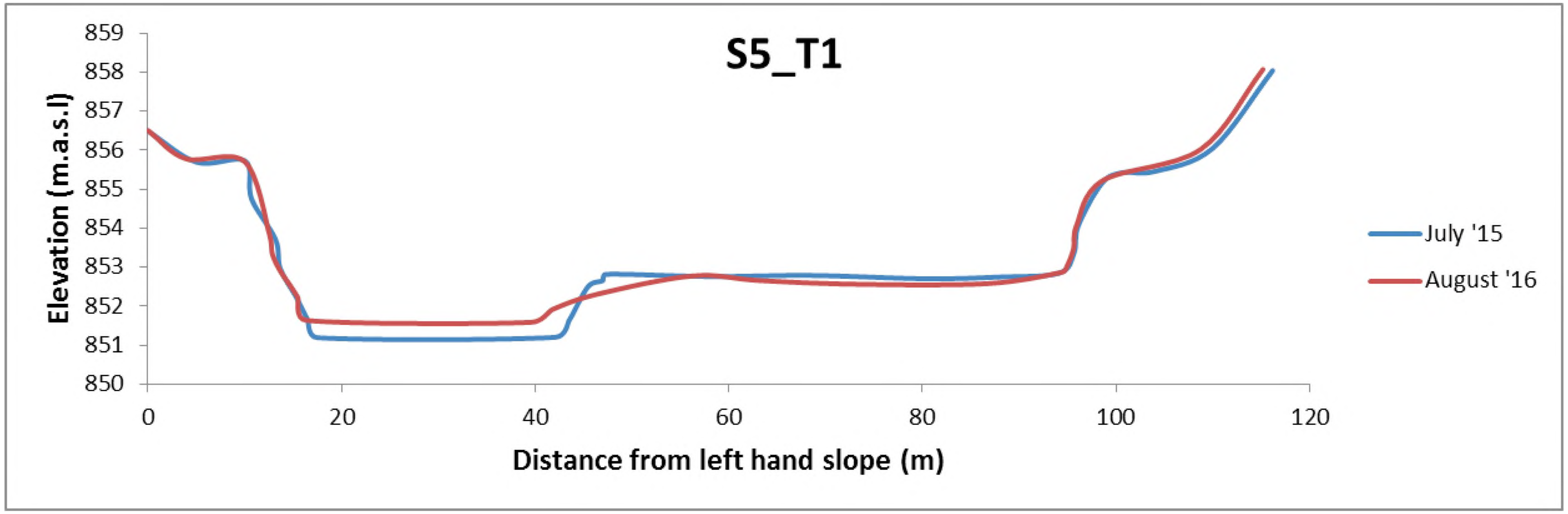

S4_T2
880
878
876
874
872
870
868
866
Elevation (m.a.s.l)
0
20
40
60
80
100
120
140
Distance from left hand slope (m)
July '15
August '16

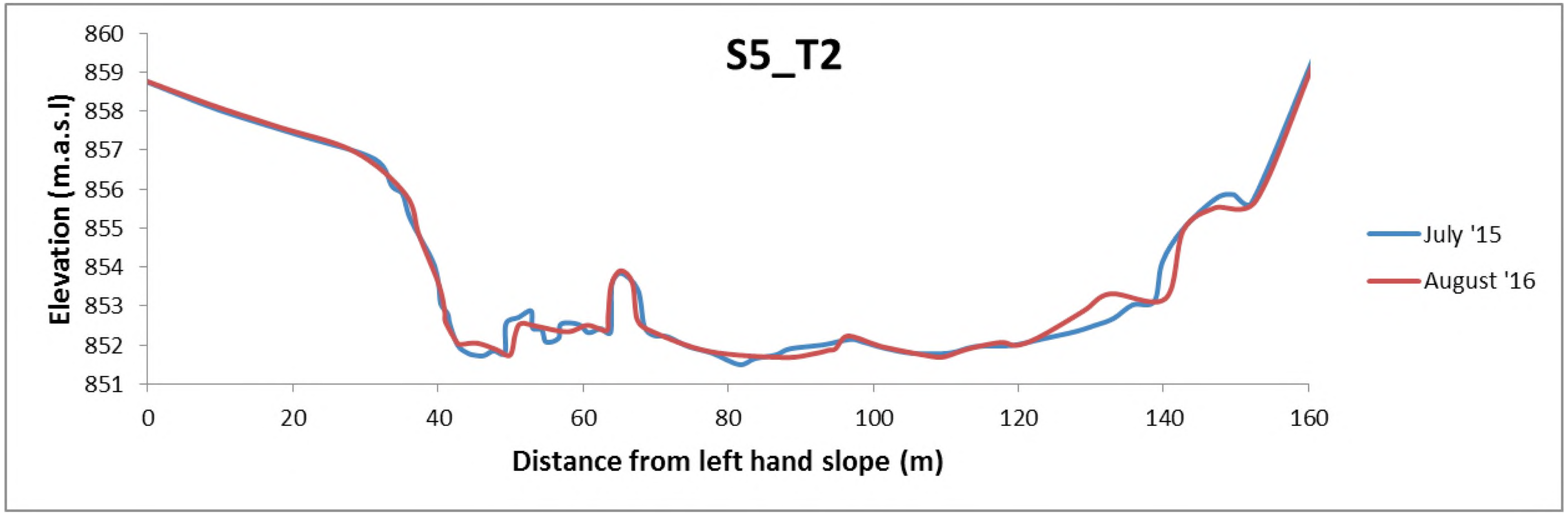

S4_T3
880
878
876
874
872
870
868
866
Elevation (m.a.s.l)
0
20
40
60
80
100
120
140
Distance from left hand slope (m)
July '15
August '16

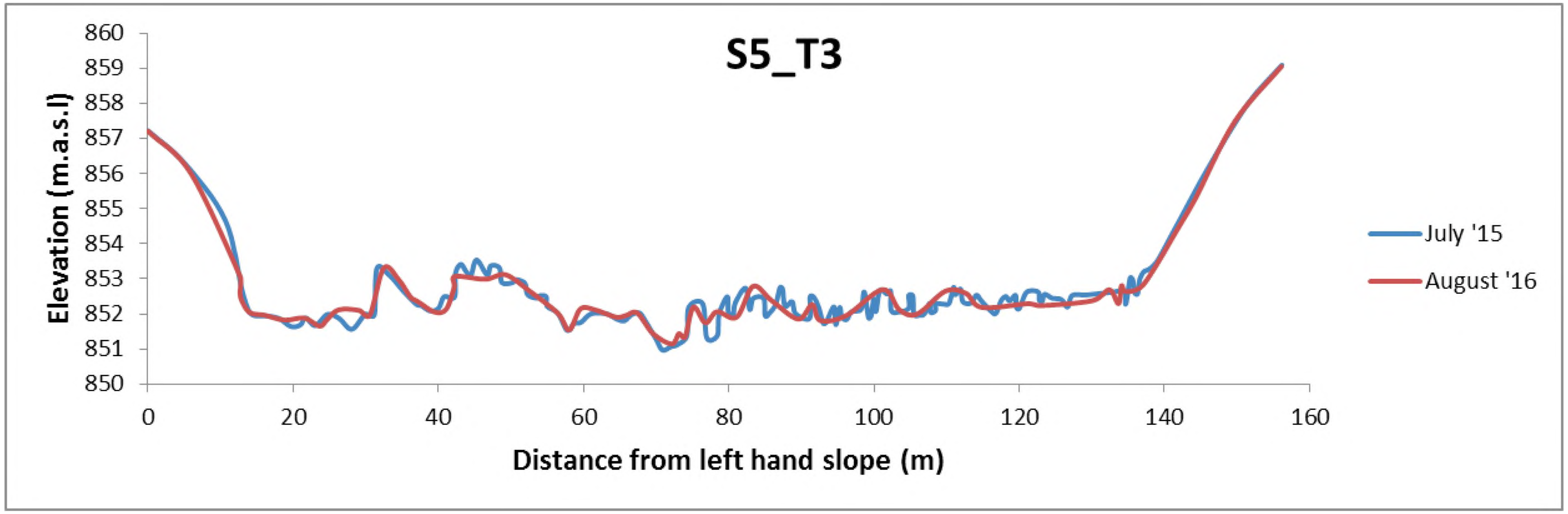

S4_T4
880
878
876
874
872
870
868
866
Elevation (m.a.s.l)
0
20
40
60
80
100
120
140
Distance from left hand slope (m)
July '15
August '16

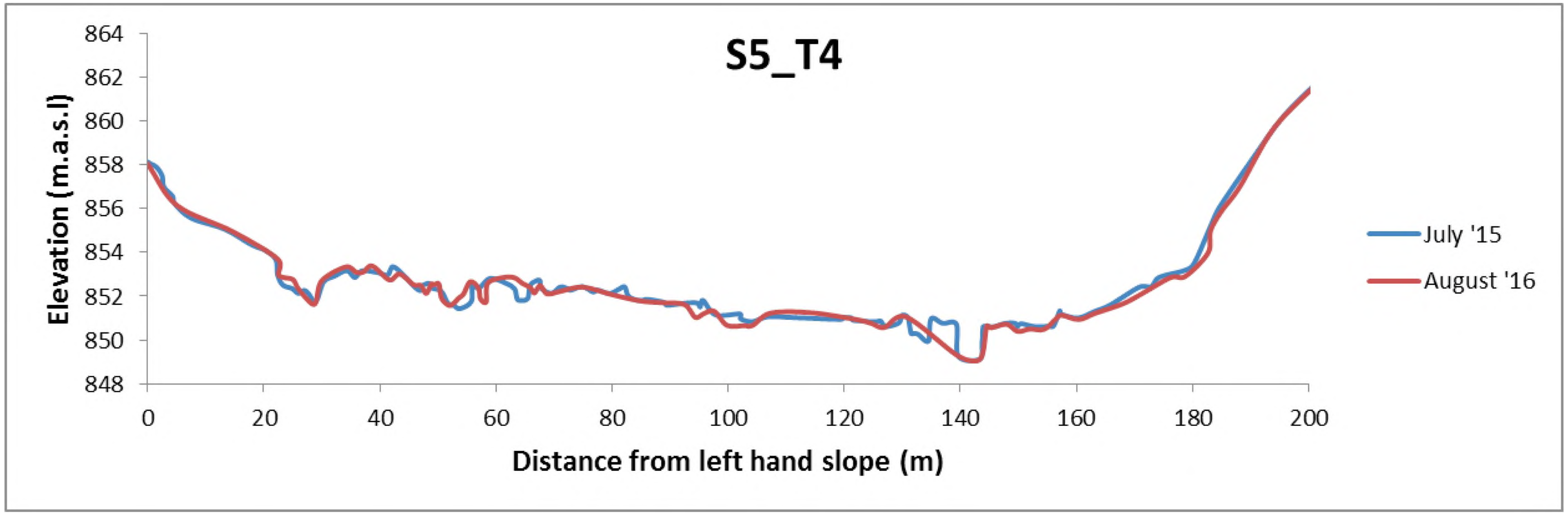

S4_T5
Elevation (m.a.s.l)
880
878
876
874
872
870
868
866
0
20
40
60
80
100
120
Distance from left hand slope (m)
July '15
August '16

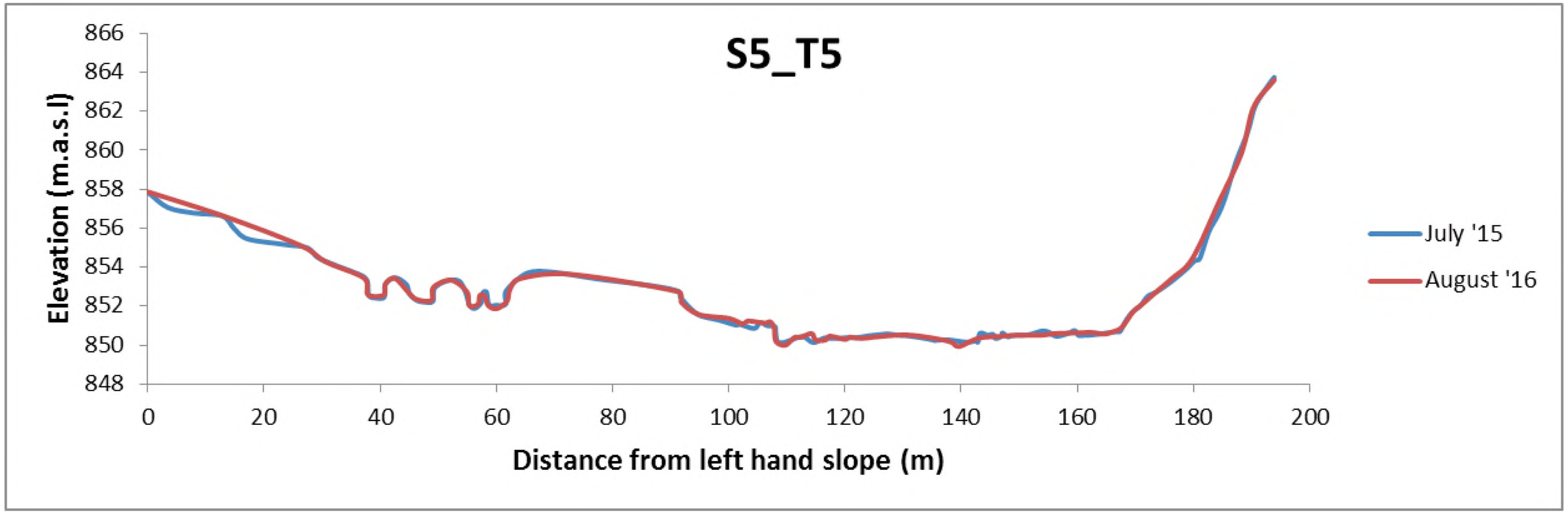

S4_T6
Elevation (m.a.s.l)
880
878
876
874
872
870
868
866
0
20
40
60
80
100
120
Distance from left hand slope (m)
July '15
August '16

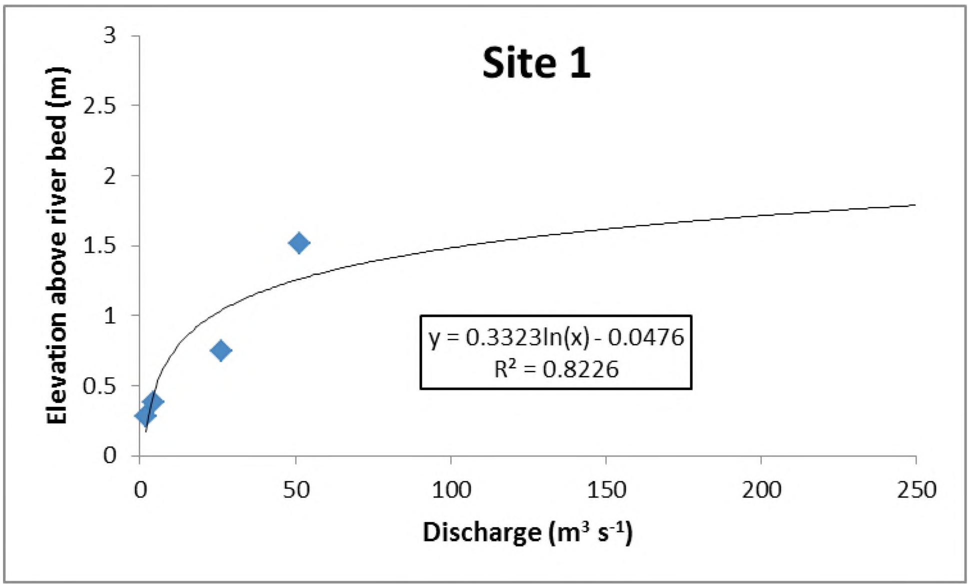

S5_T1
Elevation (m.a.s.l)
859
858
857
856
855
854
853
852
851
850
0
20
40
60
80
100
120
Distance from left hand slope (m)
July '15
August '16

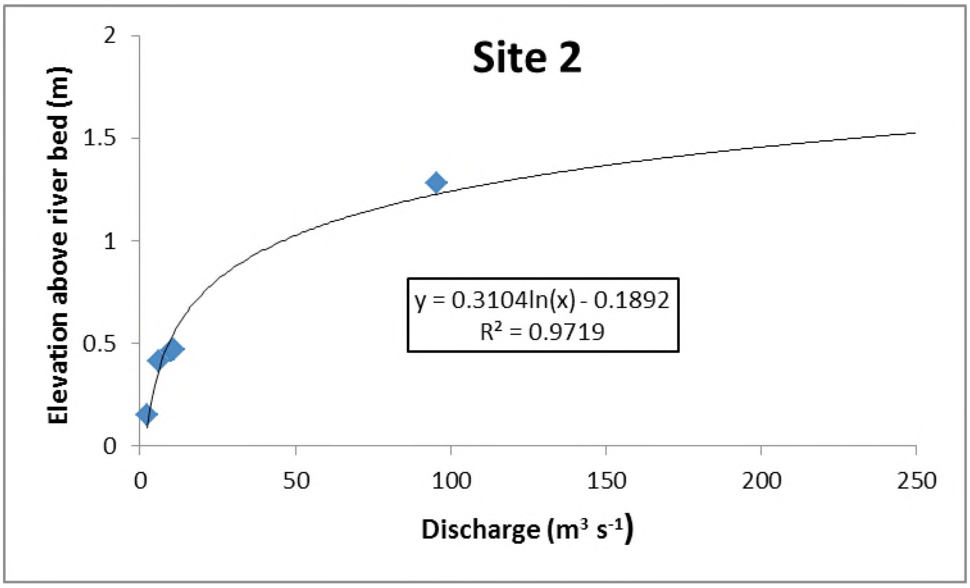

S5_T2
Elevation (m.a.s.l)
860
859
858
857
856
855
854
853
852
851
0
20
40
60
80
100
120
140
160
Distance from left hand slope (m)
July '15
August '16

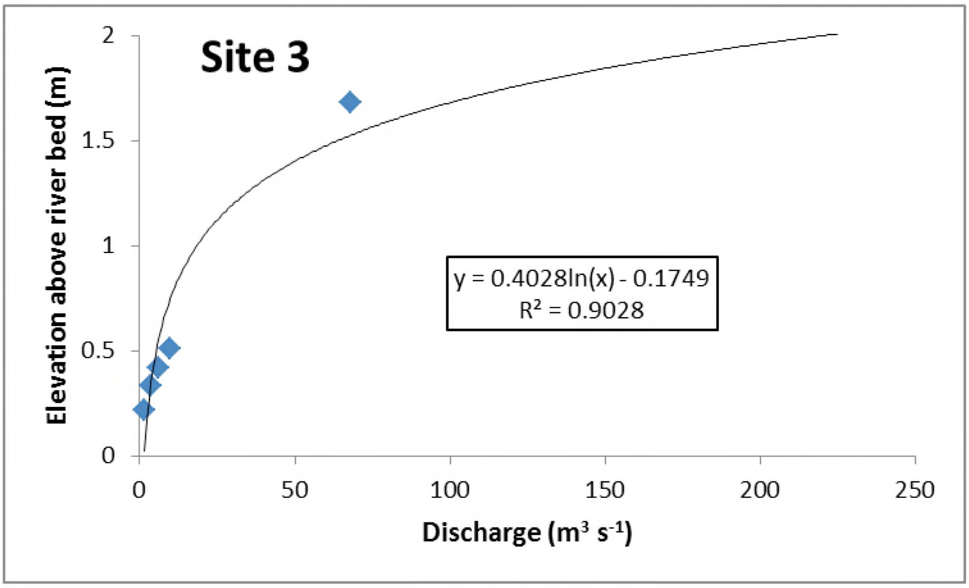

S5_T3
Elevation (m.a.s.l)
860
859
858
857
856
855
854
853
852
851
850
0
20
40
60
80
100
120
140
160
Distance from left hand slope (m)
July '15
August '16

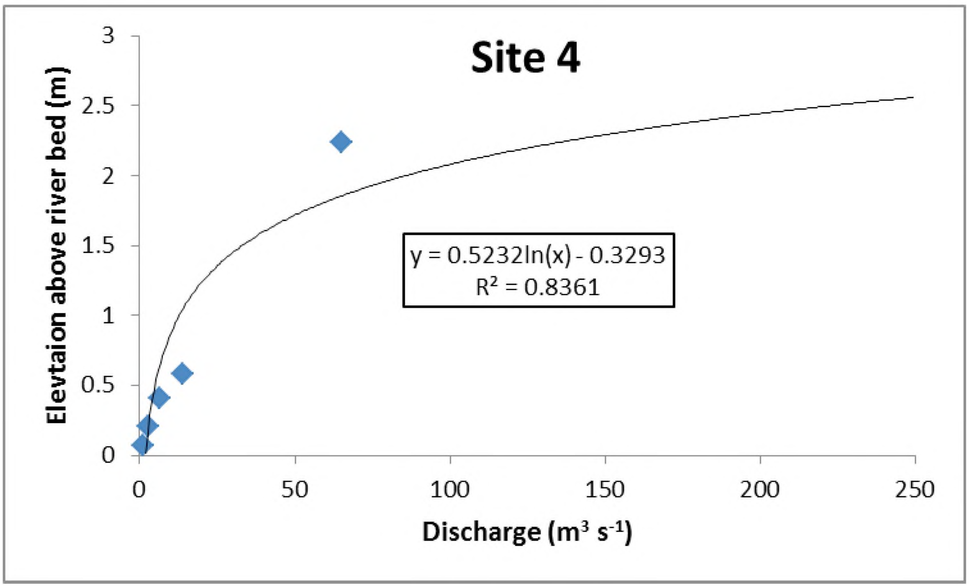

S5_T4
Elevation (m.a.s.l)
864
862
860
858
856
854
852
850
848
0
20
40
60
80
100
120
140
160
180
200
Distance from left hand slope (m)
July '15
August '16

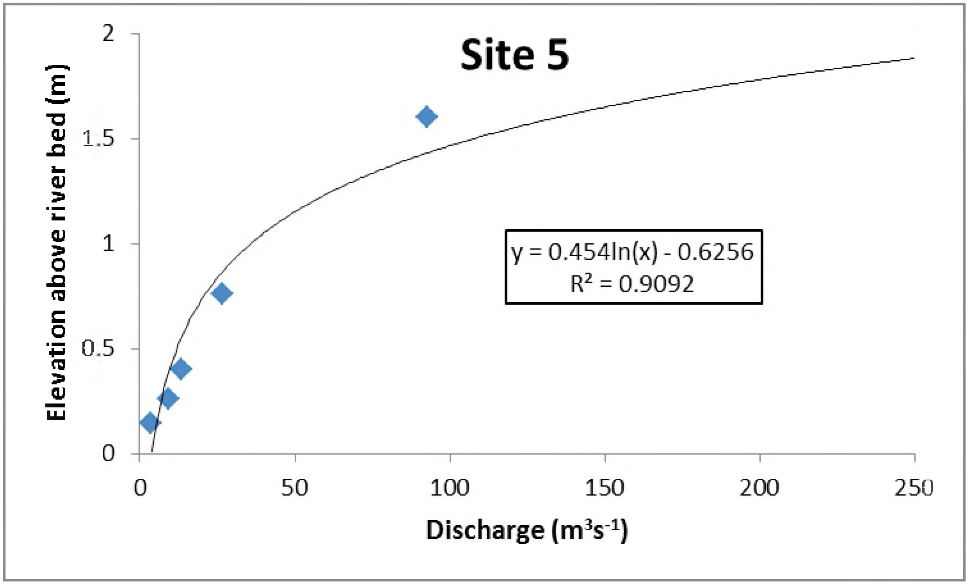

S5_T5
Elevation (m.a.s.l)
866
864
862
860
858
856
854
852
850
848
0
20
40
60
80
100
120
140
160
180
200
Distance from left hand slope (m)
July '15
August '16


Site 1
y = 0.3323ln(x) - 0.0476
R² = 0.8226
Elevation above river bed (m)
Discharge (m³ s⁻¹)
0
0.5
1
1.5
2
2.5
3
0
50
100
150
200
250

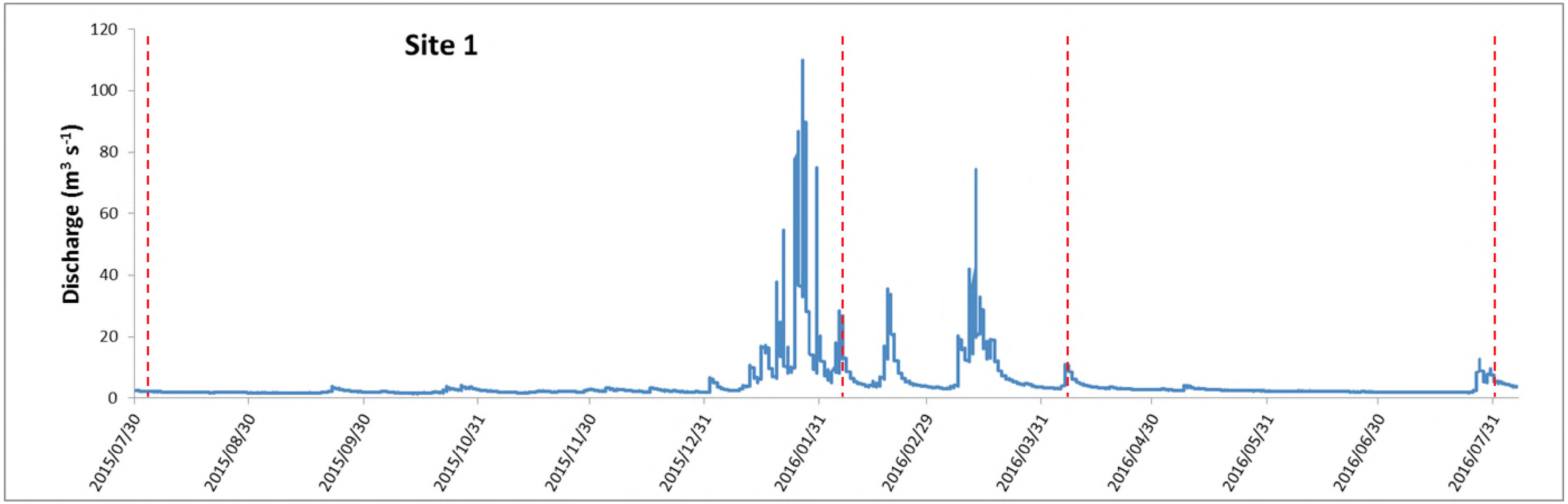

Site 2
y = 0.3104ln(x) - 0.1892
R² = 0.9719
Elevation above river bed (m)
Discharge (m³ s⁻¹)
0
0.5
1
1.5
2
0
50
100
150
200
250

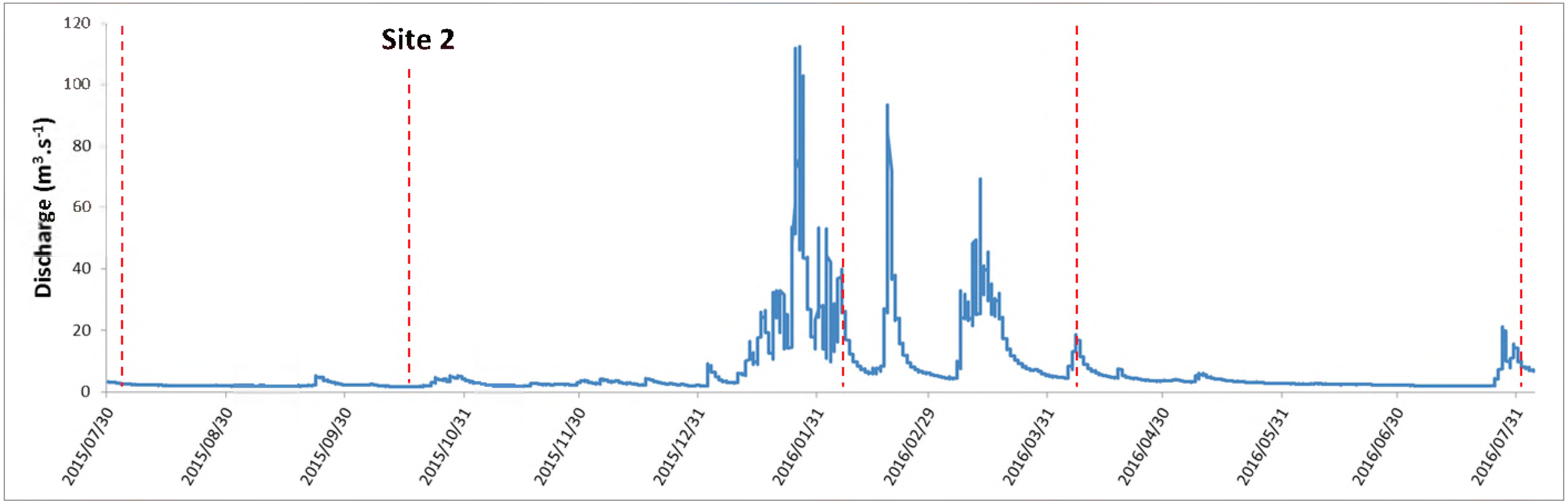

Site 3
Elevation above river bed (m)
Discharge (m³ s⁻¹)
y = 0.4028ln(x) - 0.1749
R² = 0.9028
0
0.5
1
1.5
2
0
50
100
150
200
250

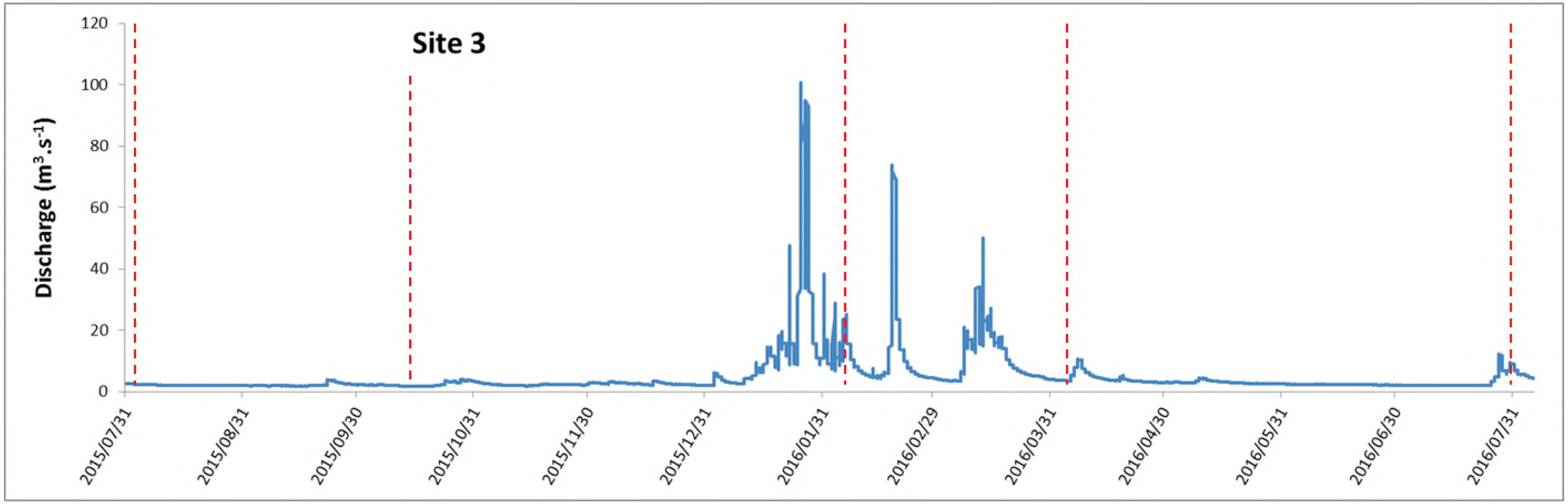

Site 4
Elevtaion above river bed (m)
Discharge (m³ s⁻¹)
y = 0.5232ln(x) - 0.3293
R² = 0.8361
0
0.5
1
1.5
2
2.5
3
0
50
100
150
200
250

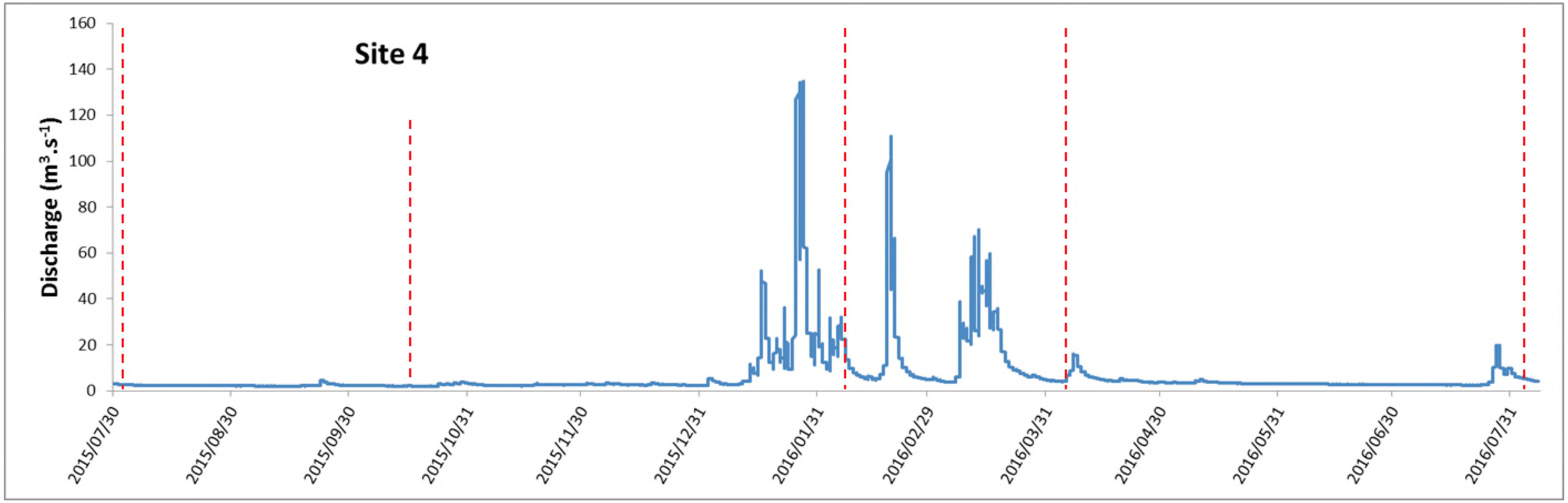

Site 5
Elevation above river bed (m)
0
0.5
1
1.5
2
Discharge (m³s⁻¹)
0
50
100
150
200
250
y = 0.454ln(x) - 0.6256
R² = 0.9092

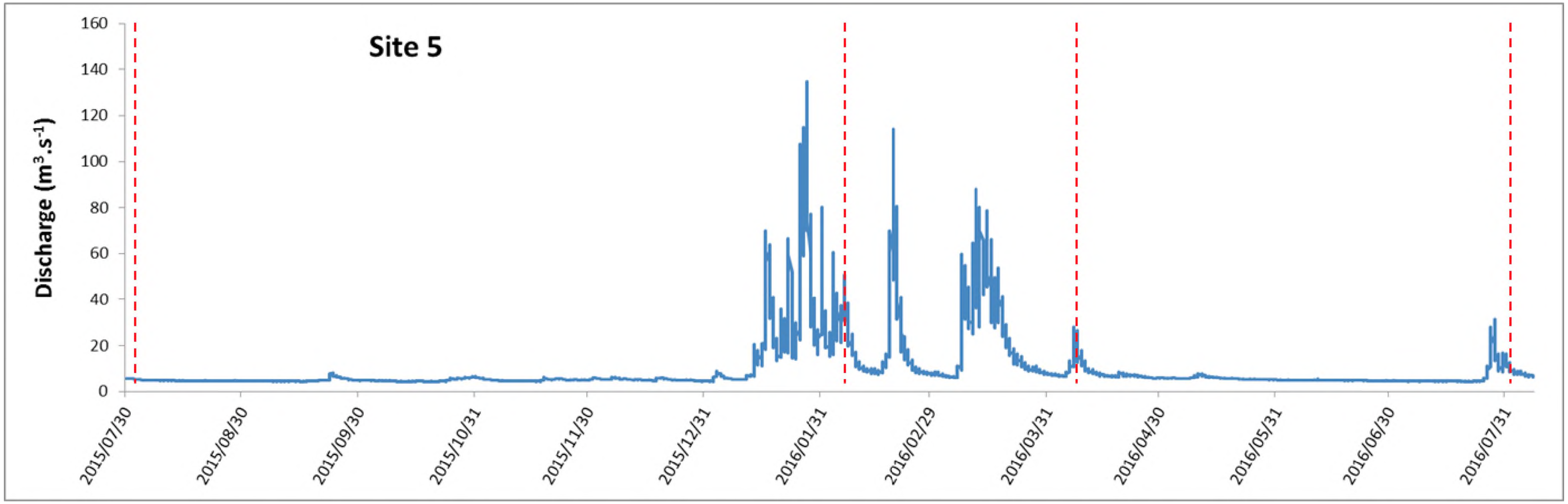
Appendix 4: Instream logger data showing twenty minute discharges for each site over the monitoring period showing approximate field sampling times



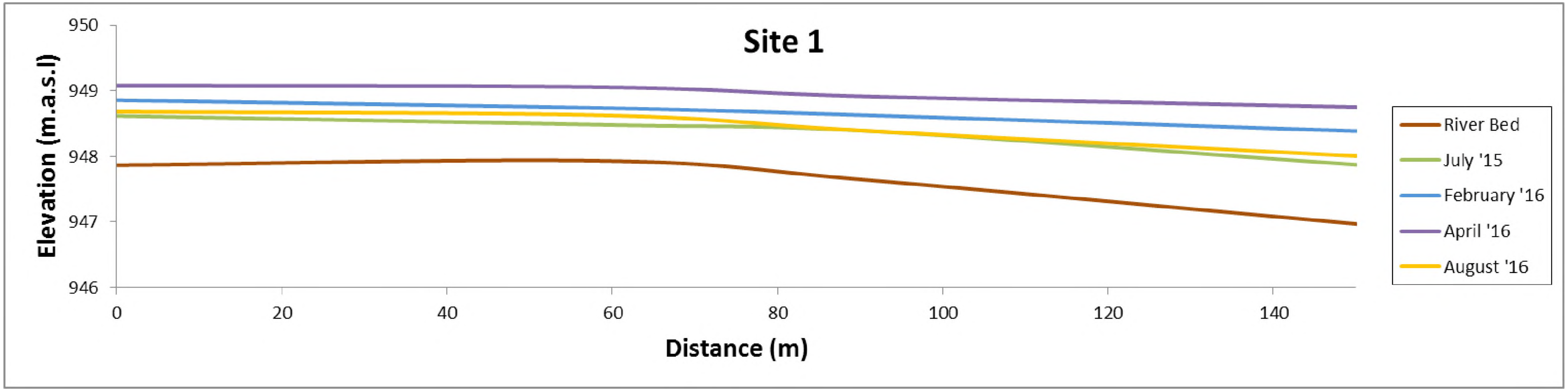

Site 2
Discharge (m^3.s^{-1})
120
100
80
60
40
20
0
2015/07/30
2015/08/30
2015/09/30
2015/10/31
2015/11/30
2015/12/31
2016/01/31
2016/02/29
2016/03/31
2016/04/30
2016/05/31
2016/06/30
2016/07/31

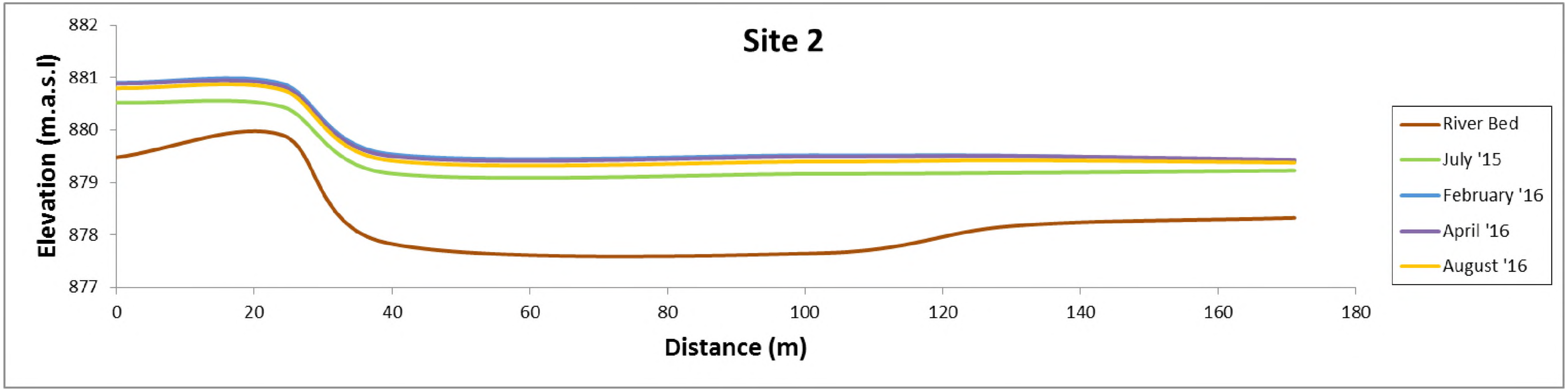

Site 3
Discharge (m^3.s^{-1})
120
100
80
60
40
20
0
2015/07/31
2015/08/31
2015/09/30
2015/10/31
2015/11/30
2015/12/31
2016/01/31
2016/02/29
2016/03/31
2016/04/30
2016/05/31
2016/06/30
2016/07/31

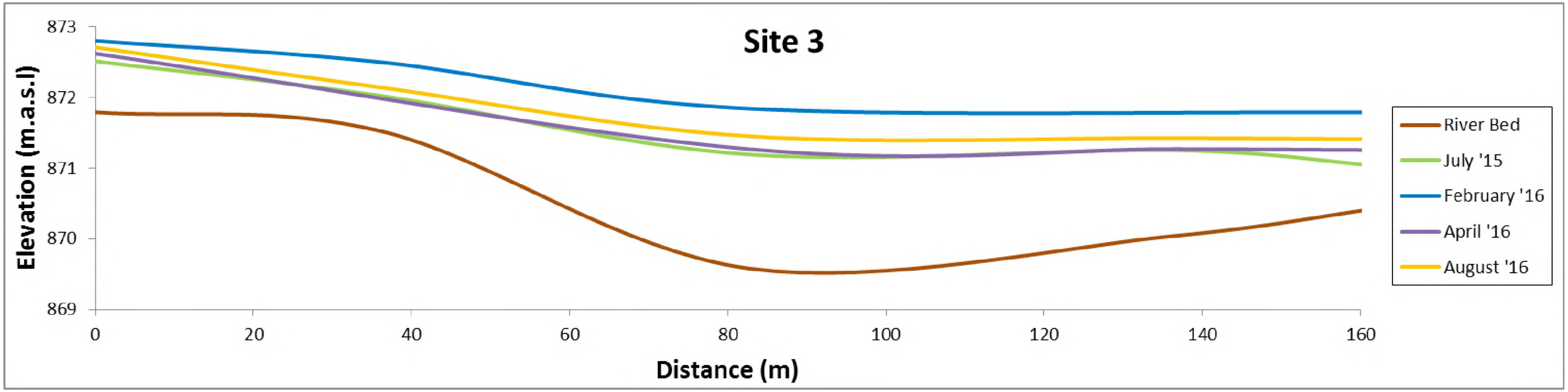

Site 4
Discharge (m3.s-1)
160
140
120
100
80
60
40
20
0
2015/07/30
2015/08/30
2015/09/30
2015/10/31
2015/11/30
2015/12/31
2016/01/31
2016/02/29
2016/03/31
2016/04/30
2016/05/31
2016/06/30
2016/07/31

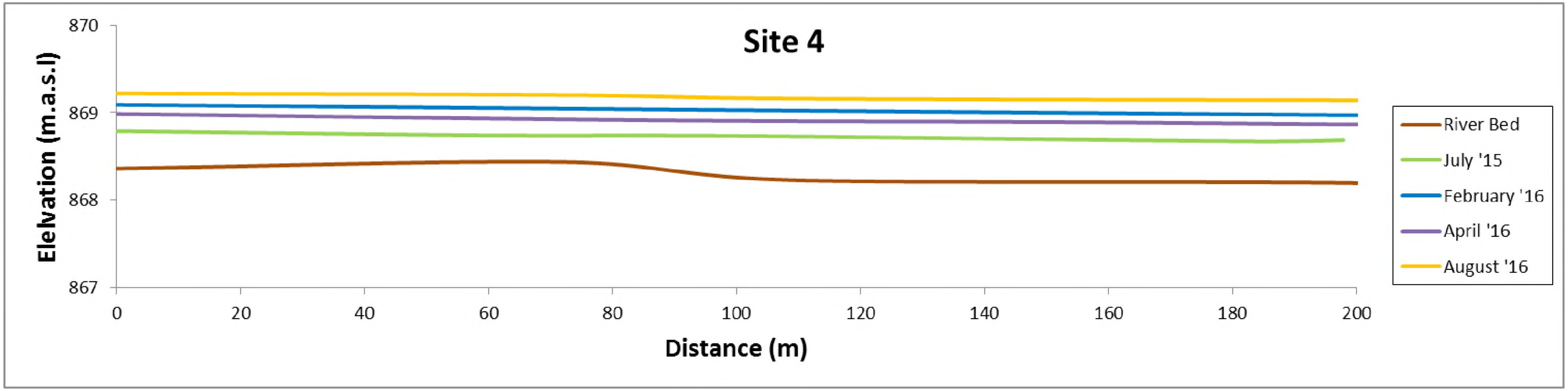

Site 5
Discharge (m3.s-1)
160
140
120
100
80
60
40
20
0
2015/07/30
2015/08/30
2015/09/30
2015/10/31
2015/11/30
2015/12/31
2016/01/31
2016/02/29
2016/03/31
2016/04/30
2016/05/31
2016/06/30
2016/07/31

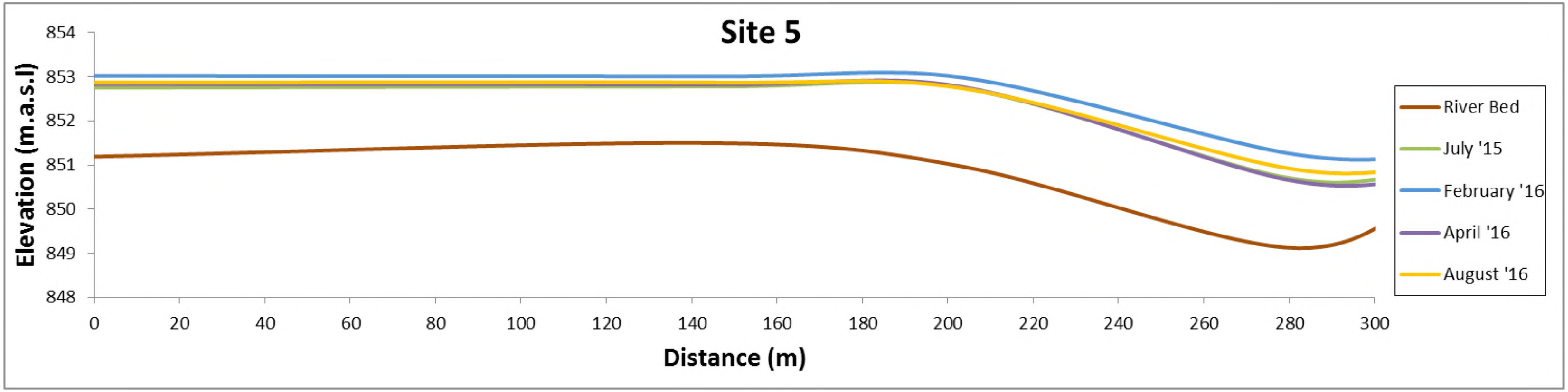
Appendix 5: Longitudinal profiles for each sampling site in the Tsitsa River showing a change in energy slope at different inundation levels



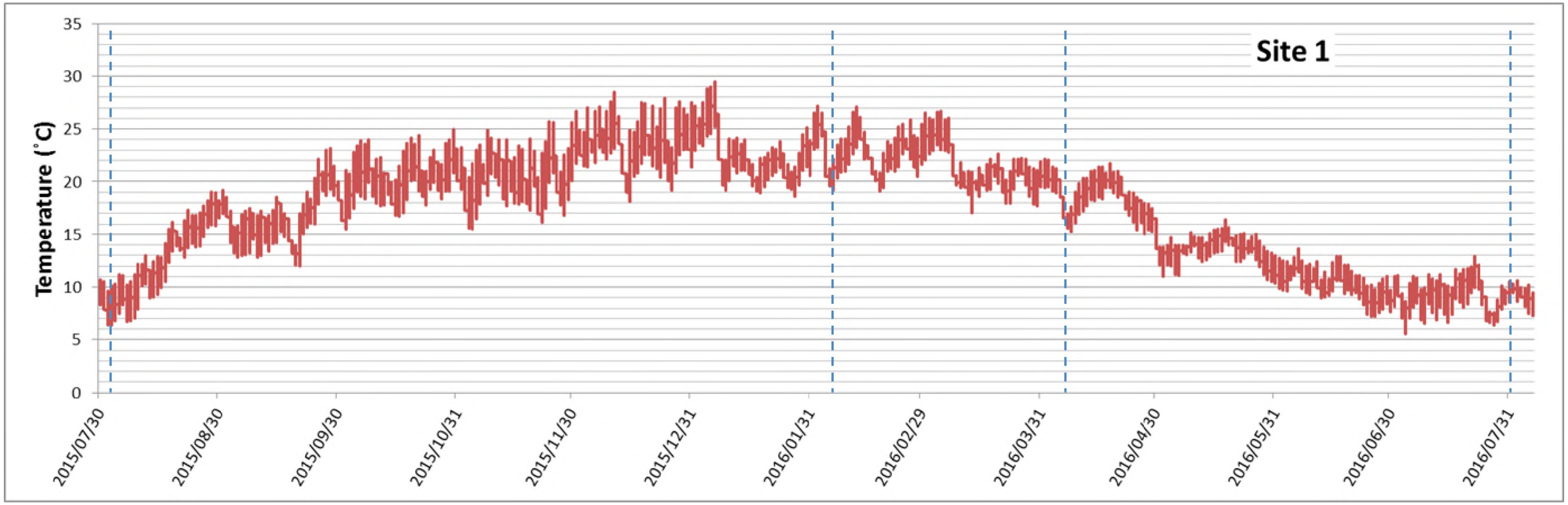

Site 2
Elevation (m.a.s.l)
882
881
880
879
878
877
0
20
40
60
80
100
120
140
160
180
Distance (m)
River Bed
July '15
February '16
April '16
August '16

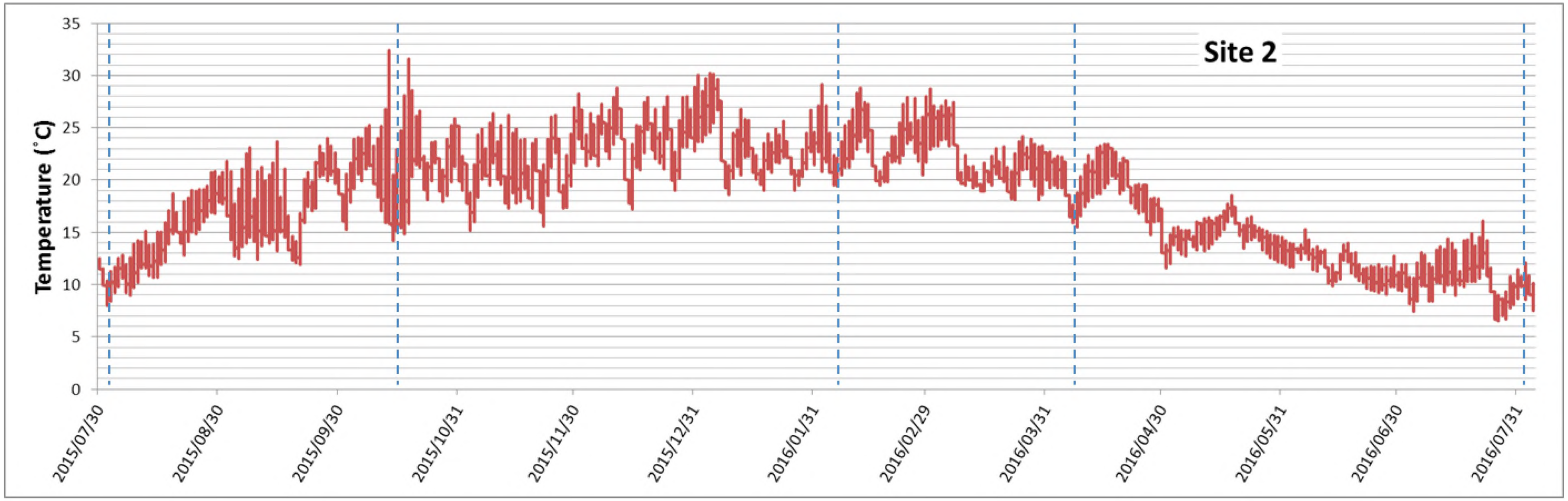

Site 3
Elevation (m.a.s.l)
873
872
871
870
869
0
20
40
60
80
100
120
140
160
Distance (m)
River Bed
July '15
February '16
April '16
August '16

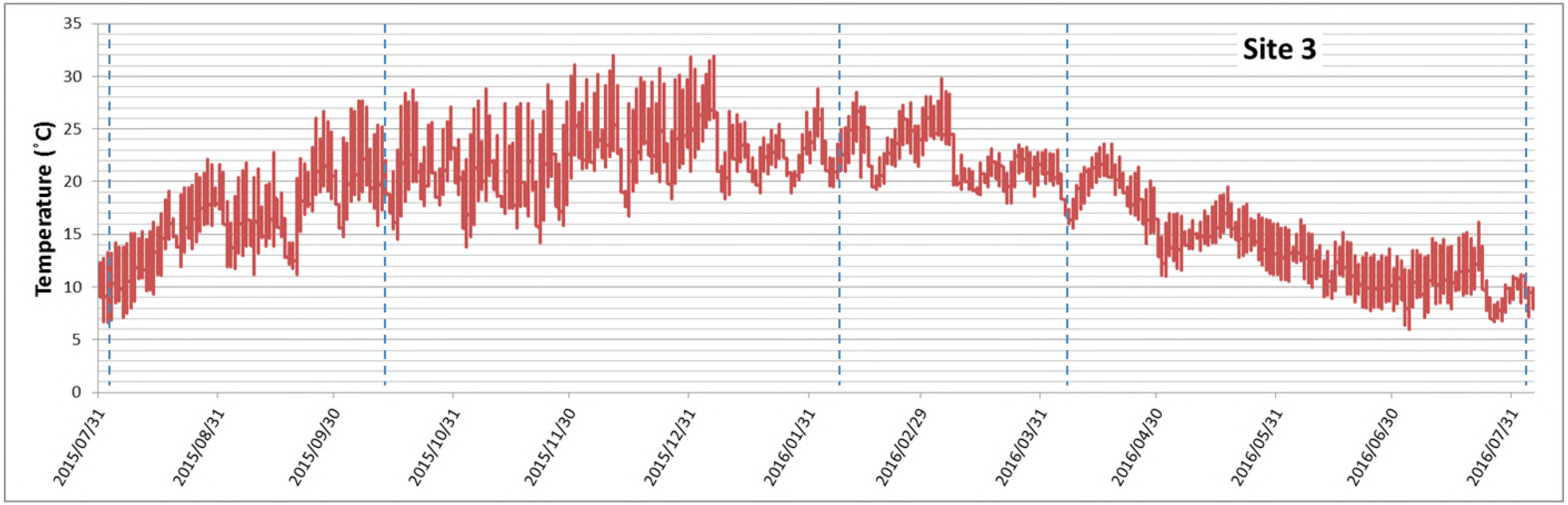

Site 4
Elevation (m.a.s.l)
870
869
868
867
0
20
40
60
80
100
120
140
160
180
200
Distance (m)
River Bed
July '15
February '16
April '16
August '16

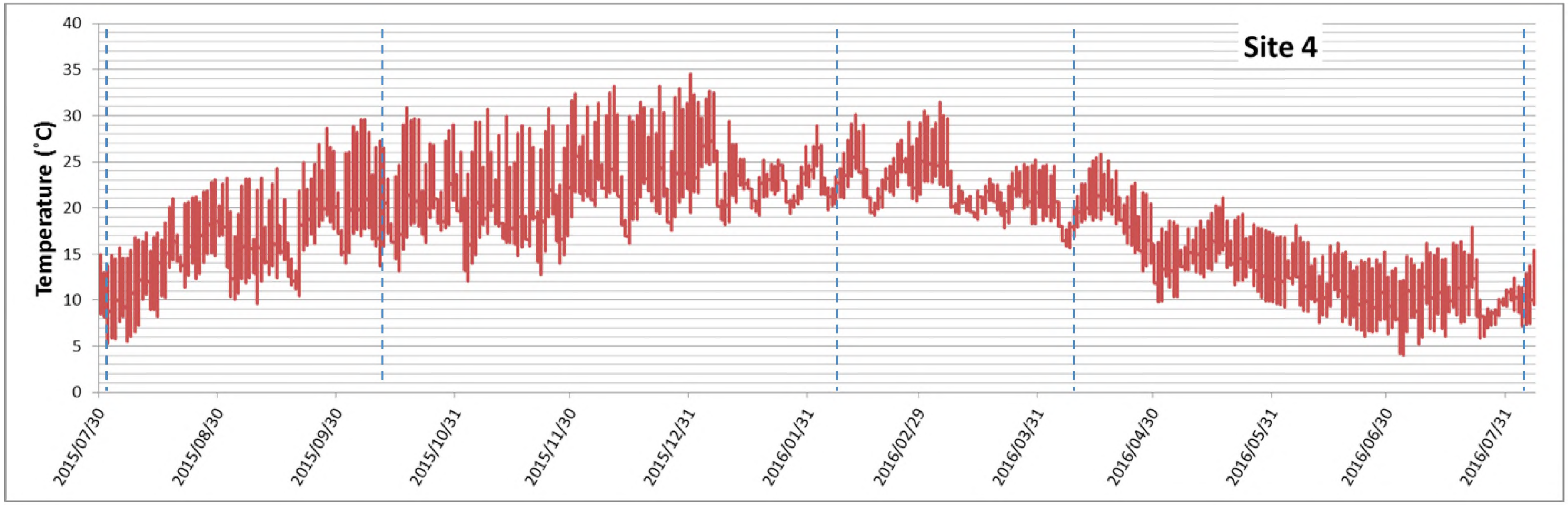

Site 5
Elevation (m.a.s.l)
854
853
852
851
850
849
848
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Distance (m)
River Bed
July '15
February '16
April '16
August '16

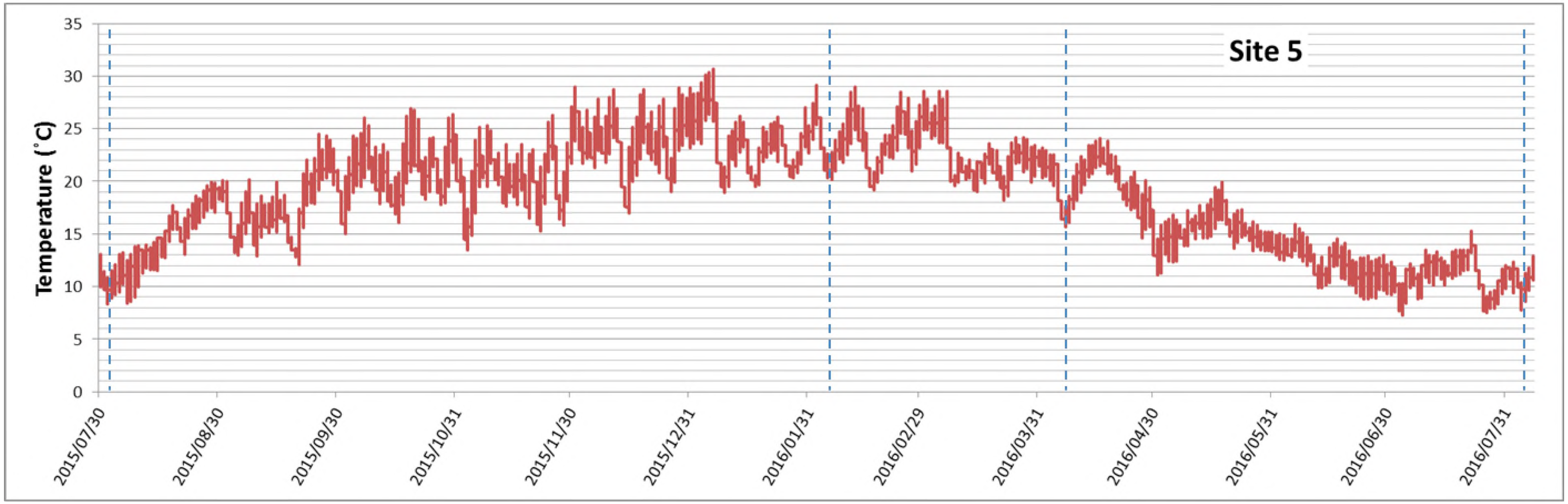
Appendix 6: Fluctuations in water temperatures over the monitoring period at each site in the Tsitsa River showing approximate field sampling times




Site 2
Temperature (˚C)
35
30
25
20
15
10
5
0
2015/07/30
2015/08/30
2015/09/30
2015/10/31
2015/11/30
2015/12/31
2016/01/31
2016/02/29
2016/03/31
2016/04/30
2016/05/31
2016/06/30
2016/07/31


Site 3
Temperature (˚C)
35
30
25
20
15
10
5
0
2015/07/31
2015/08/31
2015/09/30
2015/10/31
2015/11/30
2015/12/31
2016/01/31
2016/02/29
2016/03/31
2016/04/30
2016/05/31
2016/06/30
2016/07/31


Site 4
Temperature (˚C)
0
5
10
15
20
25
30
35
40
2015/07/30
2015/08/30
2015/09/30
2015/10/31
2015/11/30
2015/12/31
2016/01/31
2016/02/29
2016/03/31
2016/04/30
2016/05/31
2016/06/30
2016/07/31


Site 5
Temperature (˚C)
0
5
10
15
20
25
30
35
2015/07/30
2015/08/30
2015/09/30
2015/10/31
2015/11/30
2015/12/31
2016/01/31
2016/02/29
2016/03/31
2016/04/30
2016/05/31
2016/06/30
2016/07/31

APPENDIX 7: SASS5 DATA SHEETS FOR EACH MONITORING SITE, IN THE TSITSA RIVER, FOR FEBRUARY, APRIL AND AUGUST 2016

Site 1 _ Feb. '16

SASS Version 5 Score Sheet

Version date: Sept 2005

Date (dd:mm:yr):	09/02/2016
RHP Site Code:	
Collector/Sampler:	N. Huchzermeyer
River:	Tsitsa
Level 1 Ecoregion:	
Quaternary Catchment:	
Site Description:	Site 1 (Gorge)
Temp (°C):	21.3
pH:	8.06
DO (mg/L):	
Cond (mS/m):	
Riparian Disturbance:	
Instream Disturbance:	

Grid reference (dd mm ss.s) Lat:	S	
Long:	E	
Datum (WGS84/Cape):		
Altitude (m):		
Zonation:		
Routine or Project? (circle one)		
Project Name:	NH_MSc.	
Flow:	12.13 m^3/s	
Clarity (cm):	17	
Turbidity:	74 FTU	
Colour:	Brown	

(dd.ddddd)

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	5	n/a
Stones Out Of Current (SOOC)	2	n/a
Bedrock	4	n/a
Aquatic Veg	0	
MargVeg In Current	5	
MargVeg Out Of Current	3	
Gravel	4	
Sand	4	
Mud	4	
Hand picking/Visual observation	4	

THE RIVER HEALTH PROGRAMME

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blepharoceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5	A	A		B
Chironomidae (Midges)	2		A	A	B
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5		A		A
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ancylidae (Limpets)	6	B			B
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvles)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					178
No. of Taxa					24
ASPT					7.4

Other biota:

Comments/Observations:

- Different biotopes sample under varying flow + depths (see MSc Methods).
- SASS time constraints not followed.

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

SASS Version 5 Score Sheet   Site 2 – Feb.'16

Version date: Sept 2005

Date (dd:mm:yr):	07/02/2016				(dd.ddddd)
RHP Site Code:		Grid reference (dd mm ss.s) Lat:	S		
Collector/Sampler:	N. Huchzermeyer	Long:	E		
River:	Tsitsa	Datum (WGS84/Cape):			
Level 1 Ecoregion:		Altitude (m):			
Quaternary Catchment:		Zonation:			
	Temp (°C): 20.8	Routine or Project? (circle one)	Flow:	40.46 m³/s	
Site Description:	pH: 8.17	Project Name:	Clarity (cm):	7	
Site 2	DO (mg/L):	NH_MSc	Turbidity:	150 FTU	
	Cond (mS/m):		Colour:	Brown	
	Riparian Disturbance:				
	Instream Disturbance:				

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	3	n/a
Stones Out Of Current (SOOC)	0	n/a
Bedrock	3	n/a
Aquatic Veg	0	
MargVeg In Current	5	
MargVeg Out Of Current	3	
Gravel	3	
Sand	4	
Mud	3	
Hand picking/Visual observation	3	

THE RIVER HEALTH PROGRAMME

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blepharoceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5				
Chironomidae (Midges)	(2)			1	1
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	(5)		A		A
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ancylidae (Limpets)	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvles)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					75
No. of Taxa					13
ASPT					5.8

Other biota:

Comments/Observations:

- Very high flow. Mid-river inaccessable.
- Different biotopes sampled under varying flow + depth (see MSc Methods).
- SASS time constraints not followed.

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

SASS Version 5 Score Sheet

Site 3_Feb. '16

Version date: Sept 2005

Date (dd:mm:yr):	08/02/2016	Grid reference (dd mm ss.s) Lat: S	(dd.ddddd)
RHP Site Code:		Long: E	
Collector/Sampler:	N. Huchzermeyer	Datum (WGS84/Cape):	
River:	Tsitsa	Altitude (m):	
Level 1 Ecoregion:		Zonation:	
Quaternary Catchment:		Routine or Project? (circle one)	
Site Description: Site-3	Temp (°C): 25.4	Project Name: NH-MSc	Flow: 22.41 m^3/s
	pH: 7.95		Clarity (cm): 9.5
	DO (mg/L):		Turbidity: 120 FTU
	Cond (mS/m):		Colour: Brown
	Riparian Disturbance:		
	Instream Disturbance:		

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	5	n/a
Stones Out Of Current (SOOC)	0	n/a
Bedrock	0	n/a
Aquatic Veg	0	
MargVeg In Current	5	
MargVeg Out Of Current	2	
Gravel	5	
Sand	5	
Mud	2	
Hand picking/Visual observation	30	

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5				
Chironomidae (Midges)	(2)		A	A	B
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	(5)	A	A		B
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ancylidae (Limpets)	(6)	A			A
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvles)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					102
No. of Taxa					15
ASPT					6.8

Other biota:

Comments/Observations:

- Very high flow
- Different biotopes sampled under varying flows + depths (see MSc Methods)
- SASS time constraints not followed

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

SASS Version 5 Score Sheet

Site 4 – Feb.'16

Version date: Sept 2005

Date (dd:mm:yr):	07/02/2016		(dd.ddddd)	Biotopes Sampled (tick & rate)	Rating (1 - 5) / Time (min)
RHP Site Code:		Grid reference (dd mm ss.s) Lat: S		Stones In Current (SIC)	0 / n/a
Collector/Sampler:	N. Huchzermeyer	Long: E		Stones Out Of Current (SOOC)	0 / n/a
River:	Tsitsa	Datum (WGS84/Cape):		Bedrock	0 / n/a
Level 1 Ecoregion:		Altitude (m):		Aquatic Veg	0
Quaternary Catchment:		Zonation:		MargVeg In Current	5
	Temp (°C): 25.7	Routine or Project? (circle one)	Flow: 45.5 m³/s	MargVeg Out Of Current	3
Site Description:	pH: 7.88	Project Name:	Clarity (cm): 6	Gravel	5
Site-4 (sand dominated)	DO (mg/L):	NH - MSc	Turbidity: 230 FTU	Sand	5
	Cond (mS/m):		Colour: Brown	Mud	5
	Riparian Disturbance:			Hand picking/Visual observation	0
	Instream Disturbance:				

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5				
Chironomidae (Midges)	2				
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5				
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ancylidae (Limpets)	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvies)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					40
No. of Taxa					8
ASPT					5

Other biota:

Comments/Observations:

- Very high flow. Turbid.
- Different biotopes sampled under varying flows + depths (see MSc methods)
- SASS time constraints not followed.

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

SASS Version 5 Score Sheet — Site 5 - Feb. '16

Version date: Sept 2005

Date (dd:mm:yr):	08/02/2016
RHP Site Code:	
Collector/Sampler:	N. Huchzermeyer
River:	Tsitsa
Level 1 Ecoregion:	
Quaternary Catchment:	
Site Description:	

Grid reference (dd mm ss.s) Lat: S	(dd.ddddd)
Long: E	
Datum (WGS84/Cape):	
Altitude (m):	
Zonation:	
Routine or Project? (circle one)	
Project Name:	NH - MSc.

Temp (°C):	22.7
pH:	8.09
DO (mg/L):	
Cond (mS/m):	
Flow:	26.58 m³/s
Clarity (cm):	6
Turbidity:	216 FTU
Colour:	Brown
Riparian Disturbance:	
Instream Disturbance:	

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	5	n/a
Stones Out Of Current (SOOC)	3	n/a
Bedrock	2	n/a
Aquatic Veg	0	
MargVeg In Current	5	
MargVeg Out Of Current	3	
Gravel	5	
Sand	5	
Mud	3	
Hand picking/Visual observation		

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5	1			1
Chironomidae (Midges)	2	A			A
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5	C	A		C
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ancylidae (Limpets)	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvies)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					107
No. of Taxa					16
ASPT					6.7

Other biota:

Comments/Observations:

- High flow
- Different biotopes sampled under varying flows + depths (see MSc methods).
- SASS time constraints not followed.

Procedure: Kick SIC & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock for 1 min. Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg $1m^2$. Stir & sweep gravel, sand, mud for 1 min total. * = airbreathers

Hand picking & visual observation for 1 min - record in biotope where found (by circling estimated abundance on score sheet). Score for 15 mins/biotope but stop if no new taxa seen after 5 mins.

Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000 S = Stone, rock & solid objects; Veg = All vegetation; GSM = Gravel, sand, mud SWC = South Western Cape, T = Tropical, ST = Sub-tropical

Rate each biotope sampled: 1=very poor (i.e. limited diversity), 5=highly suitable (i.e. wide diversity) Rate turbidity: V low, Low, Medium, High, Very High

SASS Version 5 Score Sheet

Site 1 – April '16

Version date: Sept 2005

Date (dd:mm:yr):	07/04/2016	Grid reference (dd mm ss.s) Lat: S	(dd.ddddd)
RHP Site Code:		Long: E	
Collector/Sampler:	N. Huchzermeyer	Datum (WGS84/Cape):	
River:	Tsitsa	Altitude (m):	
Level 1 Ecoregion:		Zonation:	
Quaternary Catchment:			
Temp (°C):	14.7	Routine or Project? (circle one)	Flow: 26.19 m³/s
pH:	7.6	Project Name: NH. MSc.	Clarity (cm): 7
DO (mg/L):			Turbidity: 128 FTU
Cond (mS/m):			Colour: Brown
Riparian Disturbance:			
Instream Disturbance:			

Site Description: Site 1 (Gorge)

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	4	n/a
Stones Out Of Current (SOOC)	3	n/a
Bedrock	2	n/a
Aquatic Veg	0	
MargVeg In Current	4	
MargVeg Out Of Current	3	
Gravel	4	
Sand	4	
Mud	4	
Hand picking/Visual observation	4	

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	(5)	A			A
Chironomidae (Midges)	(2)	A	A	A	B
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	(1)			B	B
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5				
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	(5)	A			A
GASTROPODA (Snails)					
Ancylidae (Limpets)	(6)	A			A
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvles)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					161
No. of Taxa					25
ASPT					6.4

Other biota:

Comments/Observations:
- High Flow.
- Different biotopes sampled under varying flow + depths (see MSc Methods)
- SASS time constraints not followed.

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

SASS Version 5 Score Sheet Site 2 – April '16

Version date: Sept 2005

Date (dd:mm:yr):	06/04/2016
RHP Site Code:	
Collector/Sampler:	N. Huchzermeyer
River:	Tsitsa
Level 1 Ecoregion:	
Quaternary Catchment:	
Site Description:	Site - 2
Temp (°C):	16.9 °C
pH:	7.5
DO (mg/L):	
Cond (mS/m):	
Riparian Disturbance:	
Instream Disturbance:	

Grid reference (dd mm ss.s)			(dd.ddddd)
Lat:	S		
Long:	E		
Datum (WGS84/Cape):			
Altitude (m):			
Zonation:			

Routine or Project? (circle one)	
Project Name:	NH_MSc
Flow:	10.75 m³/s
Clarity (cm):	≤ 1
Turbidity:	> 2000 FTU
Colour:	Very brown

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	5	n/a
Stones Out Of Current (SOOC)	3	n/a
Bedrock	0	n/a
Aquatic Veg	0	
MargVeg In Current	5	
MargVeg Out Of Current	3	
Gravel	4	
Sand	5	
Mud	4	
Hand picking/Visual observation	4	

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5		1	1	A
Chironomidae (Midges)	2	B	B	B	B
Culicidae* (Mosquitoes)	1			A	A
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5		A		A
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5	1			1
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ancylidae (Limpets)	6	B			B
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvies)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					175
No. of Taxa					29
ASPT					6
Other biota:					

Comments/Observations:

- Very high flow. Very Turbid.
- Different biotopes sampled under varying flows + depths (see MSc methods)
- SASS time constraints not followed.

Procedure: Kick SIC & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock for 1 min. Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg 1m². Stir & sweep gravel, sand, mud for 1 min total. * = airbreathers

Hand picking & visual observation for 1 min - record in biotope where found (by circling estimated abundance on score sheet). Score for 15 mins/biotope but stop if no new taxa seen after 5 mins.

Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000 S = Stone, rock & solid objects; Veg = All vegetation; GSM = Gravel, sand, mud SWC = South Western Cape, T = Tropical, ST = Sub-tropical

Rate each biotope sampled: 1=very poor (i.e. limited diversity), 5=highly suitable (i.e. wide diversity) Rate turbidity: V low, Low, Medium, High, Very High

SASS Version 5 Score Sheet Site 3 _ April '16

Version date: Sept 2005

Date (dd:mm:yr):	04/04/2016		(dd.ddddd)	Biotopes Sampled (tick & rate)	Rating (1 - 5) / Time (min)
RHP Site Code:		Grid reference (dd mm ss.s) Lat: S		Stones In Current (SIC)	5 / n/a
Collector/Sampler:	N. Hochzermeyer	Long: E		Stones Out Of Current (SOOC)	5 / n/a
River:	Tsitsa	Datum (WGS84/Cape):		Bedrock	3 / n/a
Level 1 Ecoregion:		Altitude (m):		Aquatic Veg	0
Quaternary Catchment:		Zonation:		MargVeg In Current	4
	Temp (°C): 19.5	Routine or Project? (circle one)	Flow: 3.33 m³/s	MargVeg Out Of Current	4
Site Description:	pH: 8.3	Project Name:	Clarity (cm): 53	Gravel	4
Site-3	DO (mg/L):	NH_MSc	Turbidity: 54 FTU	Sand	4
	Cond (mS/m):		Colour: Clear	Mud	4
	Riparian Disturbance:			Hand picking/Visual observation	
	Instream Disturbance:				

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blepharoceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5				
Chironomidae (Midges)	2	A		1	A
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5	C			C
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ancylidae (Limpets)	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvles)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					156
No. of Taxa					23
ASPT					6.8

Other biota:

Barb

Comments/Observations:

- Different biotopes sampled under varying flows + depths (see MSc Methods)
- SASS time constraints not followed.

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

SASS Version 5 Score Sheet Site 4 - April '16

Version date: Sept 2005

Date (dd:mm:yr):	04/04/2016	Grid reference (dd mm ss.s) Lat: S	(dd.ddddd)
RHP Site Code:		Long: E	
Collector/Sampler:	N. Huchzermeyer	Datum (WGS84/Cape):	
River:	Tsitsa	Altitude (m):	
Level 1 Ecoregion:		Zonation:	
Quaternary Catchment:			
Site Description: Site - 4	Temp (°C): 25.5	Routine or Project? (circle one)	Flow: 6.5 m^3/s
	pH: 7.4	Project Name: NH - MSc	Clarity (cm): 41
	DO (mg/L): 77.8 %		Turbidity: 50 FTU
	Cond (mS/m):		Colour: Clear
	Riparian Disturbance:		
	Instream Disturbance:		

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	30	n/a
Stones Out Of Current (SOOC)	0	n/a
Bedrock	5	n/a
Aquatic Veg	0	
MargVeg In Current	3	
MargVeg Out Of Current	3	
Gravel	4	
Sand	5	
Mud	5	
Hand picking/Visual observation	4	

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	(5)			A	A
Chironomidae (Midges)	(2)			A	A
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5				
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ancylidae (Limpets)	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvies)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					105
No. of Taxa					17
ASPT					6.2

Other biota:

Comments/Observations:

- Different biotopes sampled under varying flows + depths (see MSc methods).
- SASS time constraints not followed.

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

SASS Version 5 Score Sheet   Site 5 - April '16

Version date: Sept 2005

Date (dd:mm:yr):	05/04/2016
RHP Site Code:	
Collector/Sampler:	N. Huchzermeyer
River:	Tsitsa
Level 1 Ecoregion:	
Quaternary Catchment:	
Site Description:	Site - 5
Temp (°C):	19.9
pH:	7.45
DO (mg/L):	
Cond (mS/m):	
Riparian Disturbance:	
Instream Disturbance:	

		(dd.ddddd)
Grid reference (dd mm ss.s) Lat:	S	
Long:	E	
Datum (WGS84/Cape):		
Altitude (m):		
Zonation:		

Routine or Project? (circle one)

Project Name: NH_MSc

Flow:	9.19 m³/s
Clarity (cm):	38
Turbidity:	58NTU
Colour:	Murky

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	5	n/a
Stones Out Of Current (SOOC)	5	n/a
Bedrock	3	n/a
Aquatic Veg	0	
MargVeg In Current	5	
MargVeg Out Of Current	5	
Gravel	4	
Sand	4	
Mud	4	
Hand picking/Visual observation	3	

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blepharoceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5			A	A
Chironomidae (Midges)	2			A	A
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5				
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5	1			1
GASTROPODA (Snails)					
Ancylidae (Limpets)	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalves)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3	1			1
Unionidae (Perly mussels)	6				
SASS Score					146
No. of Taxa					23
ASPT					6.4

Other biota:

Comments/Observations:

- Different biotopes sampled under varying flows & depths (see MSc method)
- SASS time constraints not followed.
- Sampled over a rising stage due to rain storm in catchment.

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

SASS Version 5 Score Sheet

Site 1 – August '66

Version date: Sept 2005

Date (dd:mm:yr):	06/08/2016
RHP Site Code:	
Collector/Sampler:	N. Huchzermeyer
River:	Tsitsa
Level 1 Ecoregion:	
Quaternary Catchment:	
Site Description:	Site 1
Temp (°C):	6.9
pH:	7.7
DO (mg/L):	
Cond (mS/m):	
Riparian Disturbance:	
Instream Disturbance:	

		(dd.ddddd)
Grid reference (dd mm ss.s) Lat:	S	
Long:	E	
Datum (WGS84/Cape):		
Altitude (m):		
Zonation:		

Routine or Project? (circle one)	
Project Name:	NH - MSc
Flow:	4.5 m³/s
Clarity (cm):	63
Turbidity:	74 FTU
Colour:	Nearly-Clear

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	5	n/a
Stones Out Of Current (SOOC)	5	n/a
Bedrock	5	n/a
Aquatic Veg	0	
MargVeg In Current	5	
MargVeg Out Of Current	5	
Gravel	4	
Sand	4	
Mud	2	
Hand picking/Visual observation	3	

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blepharoceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	(5)			A	A
Chironomidae (Midges)	(2)	B		A	B
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	(10)	1			1
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	(1)	1			1
Simuliidae (Blackflies)	(5)	B			B
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ancylidae (Limpets)	(6)	B	1		B
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvles)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					184
No. of Taxa					29
ASPT					6.3

Other biota:

Comments/Observations:

- Different biotopes sampled under varying conditions - flows + depths (see MSc methods).
- SASS time constraints not followed.

Procedure: Kick SIC & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock for 1 min. Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg 1m². Stir & sweep gravel, sand, mud for 1 min total. * = airbreathers

Hand picking & visual observation for 1 min - record in biotope where found (by circling estimated abundance on score sheet). Score for 15 mins/biotope but stop if no new taxa seen after 5 mins.

Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000 S = Stone, rock & solid objects; Veg = All vegetation; GSM = Gravel, sand, mud SWC = South Western Cape, T = Tropical, ST = Sub-tropical

Rate each biotope sampled: 1=very poor (i.e. limited diversity), 5=highly suitable (i.e. wide diversity) Rate turbidity: V low, Low, Medium, High, Very High

SASS Version 5 Score Sheet

Site 2 - August '16

Version date: Sept 2005

Date (dd:mm:yr):	04/08/2016	Grid reference (dd mm ss.s) Lat:	S		(dd.ddddd)
RHP Site Code:		Long:	E		
Collector/Sampler:	N. Huchzermeyer	Datum (WGS84/Cape):			
River:	Tsitsa	Altitude (m):			
Level 1 Ecoregion:		Zonation:			
Quaternary Catchment:					
Site Description: Site-2	Temp (°C): 7.5	Routine or Project? (circle one)	Flow:	6 m^3/s	
	pH: 7.5	Project Name:	Clarity (cm):	26 cm	
	DO (mg/L):	NH - MSc	Turbidity:	88 FTU	
	Cond (mS/m):		Colour:	Milky	
	Riparian Disturbance:				
	Instream Disturbance:				

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	5	n/a
Stones Out Of Current (SOOC)	5	n/a
Bedrock	4	n/a
Aquatic Veg	0	
MargVeg In Current	6	
MargVeg Out Of Current	5	
Gravel	4	
Sand	5	
Mud	4	
Hand picking/Visual observation	4	

Taxon	QV	S	Veg	GSM	TOT
PORIFERA (Sponge)	5				
COELENTERATA (Cnidaria)	1				
TURBELLARIA (Flatworms)	3				
ANNELIDA					
Oligochaeta (Earthworms)	1	A	1	B	A
Hirudinea (Leeches)	3				
CRUSTACEA					
Amphipoda (Scuds)	13				
Potamonautidae* (Crabs)	3				
Atyidae (Freshwater Shrimps)	8				
Palaemonidae (Freshwater Prawns)	10				
HYDRACARINA (Mites)	8				
PLECOPTERA (Stoneflies)					
Notonemouridae	14				
Perlidae	12	A			A
EPHEMEROPTERA (Mayflies)					
Baetidae 1sp	4				
Baetidae 2 sp	6	B		B	
Baetidae > 2 sp	12		B		C
Caenidae (Squaregills/Cainfles)	6	B			B
Ephemeridae	15				
Heptageniidae (Flatheaded mayflies)	13	A			A
Leptophlebiidae (Prongills)	9	B	1		B
Oligoneuridae (Brushlegged mayflies)	15				
Polymitarcyidae (Pale Burrowers)	10				
Prosopistomatidae (Water specs)	15	1			1
Teloganodidae SWC (Spiny Crawlers)	12				
Tricorythidae (Stout Crawlers)	9	A			A
ODONATA (Dragonflies & Damselflies)					
Calopterygidae ST,T (Demoiselles)	10				
Chlorocyphidae (Jewels)	10				
Synlestidae (Chlorolestidae)(Sylphs)	8				
Coenagrionidae (Sprites and blues)	4		A		A
Lestidae (Emerald Damselflies/Spreadwing	8				
Platycnemidae (Stream Damselflies)	10				
Protoneuridae (Threadwings)	8				
Aeshnidae (Hawkers & Emperors)	8				
Corduliidae (Cruisers)	8				
Gomphidae (Clubtails)	6	A		A	B
Libellulidae (Darters/Skimmers)	4	1			1
LEPIDOPTERA (Aquatic Caterpillars/Moths)					
Crambidae (Pyralidae)	12				
HEMIPTERA (Bugs)					
Belostomatidae* (Giant water bugs)	3				
Corixidae* (Water boatmen)	3	A	A	B	B
Gerridae* (Pond skaters/Water striders)	5				
Hydrometridae* (Water measurers)	6				
Naucoridae* (Creeping water bugs)	7		1		1
Nepidae* (Water scorpions)	3				
Notonectidae* (Backswimmers)	3		A		A
Pleidae* (Pygmy backswimmers)	4				
Veliidae/M...veliidae* (Ripple bugs)	5		A		A
MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)					
Corydalidae (Fishflies & Dobsonflies)	8				
Sialidae (Alderflies)	6				
TRICHOPTERA (Caddisflies)					
Dipseudopsidae	10				
Ecnomidae	8				
Hydropsychidae 1 sp	4	1			1
Hydropsychidae 2 sp	6				
Hydropsychidae > 2 sp	12				
Philopotamidae	10				
Polycentropodidae	12				
Psychomyiidae/Xiphocentronidae	8				
Cased caddis:					
Barbarochthonidae SWC	13				
Calamoceratidae ST	11				
Glossosomatidae SWC	11				
Hydroptilidae	6				
Hydrosalpingidae SWC	15				
Lepidostomatidae	10				
Leptoceridae	6				
Petrothrincidae SWC	11				
Pisuliidae	10				
Sericostomatidae SWC	13				
COLEOPTERA (Beetles)					
Dytiscidae/Noteridae* (Diving beetles)	5	1		A	A
Elmidae/Dryopidae* (Riffle beetles)	8				
Gyrinidae* (Whirligig beetles)	5	A	B	A	B
Haliplidae* (Crawling water beetles)	5				
Helodidae (Marsh beetles)	12				
Hydraenidae* (Minute moss beetles)	8				
Hydrophilidae* (Water scavenger beetles)	5		A	1	A
Limnichidae (Marsh-Loving Beetles)	10				
Psephenidae (Water Pennies)	10	1			1
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5	B		A	B
Chironomidae (Midges)	2	B	B	B	C
Culicidae* (Mosquitoes)	1	A		1	A
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5	B	A		B
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5			A	A
GASTROPODA (Snails)					
Ancylidae (Limpets)	6	1			1
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvles)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					162
No. of Taxa					26
ASPT					6.2

Other biota:

Comments/Observations:
- Different biotopes sampled under varying flows + depths (see MSc methods)
- SASS time constraints not followed.

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

SASS Version 5 Score Sheet Site 3 - August '16

Version date: Sept 2005

Date (dd:mm:yr):	05/08/2016	Grid reference (dd mm ss.s) Lat:	S		(dd.ddddd)
RHP Site Code:		Long:	E		
Collector/Sampler:	N. Huchzermeyer	Datum (WGS84/Cape):			
River:	Tsitsa	Altitude (m):			
Level 1 Ecoregion:		Zonation:			
Quaternary Catchment:					
Site Description:	Temp (°C): 7.4	Routine or Project? (circle one)	Flow:	6.2 m³/s	
Site 3	pH: 7.5	Project Name: NH - MSc	Clarity (cm):	30	
	DO (mg/L):		Turbidity:	90 FTU	
	Cond (mS/m):		Colour:	Milky	
	Riparian Disturbance:				
	Instream Disturbance:				

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	5	1/4
Stones Out Of Current (SOOC)	5	1/4
Bedrock	2	1/4
Aquatic Veg	2	
MargVeg In Current	5	
MargVeg Out Of Current	5	
Gravel	5	
Sand	5	
Mud	4	
Hand picking/Visual observation	3	

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10			1	1
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5		B	B	B
Chironomidae (Midges)	2	B	B	B	C
Culicidae* (Mosquitoes)	1		A		A
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1	1			1
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5	A	B	B	B
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5	1			1
GASTROPODA (Snails)					
Ancylidae (Limpets)	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvies)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					167
No. of Taxa					27
ASPT					6.2
Other biota:					

Comments/Observations:

- Different biotopes sampled under varying flows + depths (see MSc methods)
- SASS time constraints not followed.

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

SASS Version 5 Score Sheet

Site4 – August '16

Version date: Sept 2005

Date (dd:mm:yr):	02/06/2016	Grid reference (dd mm ss.s) Lat: S	
RHP Site Code:		Long: E	
Collector/Sampler:	N. Huchzermeyer	Datum (WGS84/Cape):	
River:	Tsitsa	Altitude (m):	
Level 1 Ecoregion:		Zonation:	
Quaternary Catchment:			
Site Description:	Temp (°C): 8.2	Routine or Project? (circle one)	Flow: 13.8 m³/s
	pH: 7.8	Project Name:	Clarity (cm): 18
	DO (mg/L):	NH - MSc	Turbidity: 104 FTU
	Cond (mS/m):		Colour: Milky Brown
	Riparian Disturbance:		
	Instream Disturbance:		

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	0	n/a
Stones Out Of Current (SOOC)	0	n/a
Bedrock	4	n/a
Aquatic Veg	0	
MargVeg In Current	5	
MargVeg Out Of Current	5	
Gravel	0	
Sand	5	
Mud	5	
Hand picking/Visual observation	3	

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5			A	A
Chironomidae (Midges)	(2)	A	B	B	B
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	(1)		A		A
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	(5)		B	B	B
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	(5)			A	A
GASTROPODA (Snails)					
Ancylidae (Limpets)	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvles)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					73
No. of Taxa					15
ASPT					4.9

Other biota:
- Tadpoles

Comments/Observations:
- Different biotopes sampled under different flows/depths (see MSc methods)
- SASS time constraints not followed.

Procedure:

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

SASS Version 5 Score Sheet Site 5 - August '16

Version date: Sept 2005

Date (dd:mm:yr):	03/06/2016	Grid reference (dd mm ss.s) Lat:	S		(dd.ddddd)
RHP Site Code:		Long:	E		
Collector/Sampler:	N. Huchzermeyer	Datum (WGS84/Cape):			
River:	Tsitsa	Altitude (m):			
Level 1 Ecoregion:		Zonation:			
Quaternary Catchment:					
Site Description:	Temp (°C): 9.5	Routine or Project? (circle one)	Flow:	13.6 m³/s	
Site - 5	pH: 7.8	Project Name: NH_MSc	Clarity (cm):	23	
	DO (mg/L):		Turbidity:	102 FTU	
	Cond (mS/m):		Colour:	Milky	
	Riparian Disturbance:				
	Instream Disturbance:				

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	5	n/a
Stones Out Of Current (SOOC)	4	n/a
Bedrock	4	n/a
Aquatic Veg	2	
MargVeg In Current	5	
MargVeg Out Of Current	5	
Gravel	5	
Sand	4	
Mud	4	
Hand picking/Visual observation	3	

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blepharoceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	(5)		A	B	B
Chironomidae (Midges)	(2)	B	B	B	C
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	(5)	A	A	B	B
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	(5)			A	A
GASTROPODA (Snails)					
Ancylidae (Limpets)	(6)	B	A		B
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalves)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	(3)			A	A
Unionidae (Perly mussels)	6				
SASS Score					173
No. of Taxa					27
ASPT					6.4

Other biota:

Tadpoles

Comments/Observations:

- Different biotopes sampled under varying depths + flows (see MSc methods)
- SASS time constraints not followed.

Procedure: Kick SIC & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock for 1 min. Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg 1m². Stir & sweep gravel, sand, mud for 1 min total. * = airbreathers

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