The ecological state of the Braamfontein Spruit – an urban river

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A Dissertation submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science.

Johannesburg, 2019

Declaration

I declare that this dissertation is my own unaided work. It is being submitted for the degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.

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09/04/2019

Abstract

Urban environments are unique systems comprising many ecosystems. These ecosystems include urban rivers and green spaces (parks, green belts, gardens) which are important for the provision of ecosystem services and help increase city resilience to climate change. They have however come under pressure from development and have become severely degraded with many of the ecosystem services, being lost. The Braamfontein Spruit in Johannesburg, South Africa, is one such example of how developmental pressure impacts on river and riparian ecosystems. The aim of this study was to assess the current condition of the Braamfontein Spruit using the South African Scoring System 5 (SASS 5) and a River Health Assessment to determine if it was a viable system for restorative measures. The results showed that the river itself is seriously/ critically modified whilst the riparian and green spaces along its length are moderately modified. pH, conductivity and dissolved oxygen (DO) were found to be above limits considered to be natural while Average Score Per Taxon (ASPT) was below levels that indicate good water quality. Relationships between variables and taxa numbers were all negative with increases in pH, conductivity and DO resulting in fewer observed taxa. The main vegetation type found along the Spruit was grass, followed closely by bare ground. The observed patterns are due to issues such as land-use change, pollution (both point and non-point), urban development, surface runoff and poor maintenance. These aspects have impacted the tested variables resulting in a degraded ecosystem, however, the results suggest that the Braamfontein Spruit is a suitable option for restoration and proper environmental management if the necessary measures are taken. Measures recommended include clearing of litter and debris, improving river flow (creation of riffles and pools), reducing runoff and creating natural vegetation strips.

Keywords:

Urban rivers, ecosystem services, resilience, Braamfontein Spruit, restoration, environmental management

Acknowledgements

I would like to thank my supervisor, Dr Ute Schwaibold for your constant support, guidance, advice and motivation throughout this master's dissertation and for keeping my spirits up during times I felt the research was not working. Your attention to detail pushed me to pursue excellence and has made this dissertation better than I could have imagined.

I would like to give recognition to my fellow researchers Tyrone Mckendry, Courtney Gardiner, Robyn Dent and Kelly Grawez for their assistance in the field. Without your selfless help and support I would not have been as successful as I was in the field. Thank you for your constant support, encouragement and expertise and for making otherwise impossible fieldwork, possible. I am extremely grateful to you.

I would like to acknowledge my friends outside of my academic circle who provided support and encouragement during the last few years and who kept me going when times were difficult.

Finally, I would like to extend my appreciation to my parents, Colin and Felicity, sister Bianca and brother-in-law Keith. Thank you for your guidance, understanding and patience throughout my dissertation and for your love and belief in me, I could not have asked for a better support team. You got me to the end. Thank you!

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Glossary of Abbreviations

ΔH – Change in height

ASPT - Average Score Per Taxon

DO – Dissolved oxygen

DWAF - Department of Water Affairs

GCRO - Gauteng City-Region Observatory

GLM - General Linear Model

GSM - Gravel, sand and mud

IHI - Index of Habitat Integrity

JCPZ - Johannesburg City Parks and Zoos

MVegIC – Marginal Vegetation in current

MVegOOC - Marginal Vegetation out of current

RHA - River Health Assessment

SASS5 – South African Scoring System 5

SAWS – South African Weather Service

SIC - stones in current

SOOC - stones out of current

TEEB - The Economics of Ecosystems and Biodiversity

TVHR - Transparent Velocity Head Rod

WRC - Water Research Commission

Y.S.I. - Yellow Springs Instruments

Chapter 1: Introduction and Literature Review

Ecosystems comprise communities of organisms and the physical environments in which they interact. While ecosystems may be classified as being similar across regions, they all differ in certain ways. The grasslands of America differ from those of Africa as can be said for the Great Lakes of those same continents. However, while they may differ in appearance and composition, they all include abiotic and biotic features which make them unique (Wallace 2007). Abiotic or non-living factors are those that influence the structure, distribution, inter-relations and behaviours of organisms (Carpenter 2018), and include climatic (rain, temperature, wind etc.) and edaphic (soil, pH, topography etc.) components (Meier *et al.* 2010). Biotic or living factors include plants, animals and micro-organisms that can be grouped into three categories and are part of a complex web of interdependencies. Producers, or autotrophs, include all green plants that use photosynthesis to produce their own food. They form the base of the food web and are eaten by primary consumers (herbivores) which depend on producers as they cannot produce their own food. Carnivores making up secondary and tertiary consumers and rely on primary consumers for food. Finally there are decomposers (saprotrophs) which help to break down dead decaying material and waste from producers and consumers (Carpenter 2018). Each factor with its corresponding components is part of an interconnected system which provides a range of services to regulate and support the functioning of the ecosystem, as well as provide many benefits for society (Costanza *et al.* 2017).

Ecosystem services are the ecological functions and processes that either directly or indirectly contribute to human wellbeing, or the benefits that people derive from functioning ecosystems (Costanza *et al.* 2017). Ecosystem services consist of both ecosystem processes and ecosystem functions but differ in that ecosystem processes and ecosystem functions describe biophysical relationships that exist regardless of whether or not humans benefit from them (Costanza *et al.* 2017). Ecosystem services fall into one of four categories : provisioning (the energy outputs from the environment which include food, water, raw materials, and energy production, regulating (services provided by the ecosystem that help regulate and moderate natural processes such as carbon sequestration and climate regulation (Stürck, Schulp, and Verburg 2015), supporting (includes habitat provisions for species as well as maintenance of genetic diversity; TEEB, 2016) and cultural services (non-material benefits humans derive from ecosystems including tourism, aesthetic appeal, recreation, mental and physical health as well as sense of place; TEEB 2016).

Among the many features of ecosystems, their ability to support biodiversity and provide ecosystem services are two of their most important contributions (Oliver *et al.* 2015). Support for biodiversity does not only keep organism diversity and richness up but is a natural way of sustaining all life forms on Earth, humans included (Kotiaho 2017). The interdependent nature of ecosystems means that ecosystems support each other to provide habitats as well as natural functions across multiple levels for multiple organisms (Guerry *et al.* 2015).

1.1 Urban Ecosystems

The world's growing human population has resulted in the rapid development of urban areas at the expense of rural land (Song, Pijanowski, and Tayyebi 2015). While these urban areas may seem unnatural, they can be classified as ecosystems, with both living and non-living components. Cities are home to people, wildlife and plants all making up the living components, while the non-living components include those found in all other ecosystems with the addition of all buildings found within the city (Donihue and Lambert 2015). In a city like Johannesburg in South Africa, the ecosystem structure consists of built up artificial environments in town, to open green spaces and urban streams scattered amongst the many residential areas making up the majority of Johannesburg. It is these green spaces and streams that provide vital natural services for the city. The ecosystem services provided by these spaces encompass all four categories- provisioning, regulating, supporting and cultural (Gómez-Baggethun and Barton 2013). Cities with their multitude of ecosystems are important for providing residents with services and natural goods (Threlfall and Kendal 2018). The urban green spaces scattered throughout the city along with the numerous streams and rivers are particularly important for these regulating services.

Every ecosystem can provide a variety of habitats necessary for different species to survive and a city is no different. Birds will often roost atop buildings or in trees, while green spaces provide a habitat for small mammals and rivers for fish (Jokimäki *et al.* 2016; Gallo *et al.* 2017). Cultural services are especially evident across Johannesburg's parks, with many botanical gardens and nature reserves attracting residents to multiple recreational activities (running, cycling etc.). Not only do they promote active lifestyles, but the health benefits associated with cultural services provided by parks are well documented (Elwell Bostrom *et al.* 2017). The role of these urban green spaces as buffers from extreme weather and in combatting the heat island effect by cooling the surrounding environment has been the focus of many studies around the world (see Feyisa *et al.* 2014; Brown *et al.* 2015; Zhang *et al.* 2017). Their ability to absorb and store water decreases the chances of the rivers and streams flooding by decreasing the amount of water that reaches the river (Wolch, Byrne, and Newell 2014).

The effects of green spaces go beyond simply buffering daily fluctuations in temperature. They help build resilience to climate change, a growing global concern (Meerow and Newell 2017). Climate change causes abnormal temperature fluctuations, changes in rainfall patterns and more severe and frequent extreme events such as tropical storms, hurricanes and flooding (Jentsch and Beierkuhnlein 2008). Cities are particularly vulnerable to heat waves, heavy rainfall and long periods of drought (Albers *et al.* 2015). Many of these events can impact urban ecosystems. As such, having urban green spaces along with ecologically healthy river systems can help reduce the potential for damage and human health impacts and can lead to more stable green and blue infrastructure which in turn can have multiple benefits. Voskamp and van de Ven (2015) found the benefits of such infrastructure to include cooling from evapotranspiration, water storage after heavy rainfall events as well as seasonal water storage and groundwater recharge, all of which can help improve city resilience to climate change. Further evidence to suggest green spaces are important for city resilience to climate change comes from Zhang, Murray, and Turner (2017) who found that optimal green space placement can reduce local surface temperatures by approximately 1-2^{o}C and regional temperatures by approximately 0.5^{o}C. As shown, green spaces are important for a multitude of reasons, many of which will help improve city resilience to climate change.

Green spaces are not only important for combatting climate change, they are also important for the survival of wildlife. More importantly, their connectivity across a larger area creates support for biodiversity and ecosystem services. Rivers and streams often intersect, forming large networks that stretch for several kilometres. Their interconnected nature allows for easy movement for a number of species when not disturbed by humans (Braaker *et al.* 2014; Fuller, Doyle, and Strayer 2015). It is not just the aquatic species that benefit, but those species that rely on land to move can also benefit greatly from the riparian zones found on either side of the river. These zones follow the path of the river and as such create ecological corridors, often stretching the length of the river (Vollmer *et al.* 2015). Along the way, larger green spaces open up, offering a number of benefits to animals and humans alike.

In an urban setting, wildlife is often not adequately considered when it comes to development. As such, their habitats are often destroyed, reduced or fragmented (Dupras *et al.* 2016). Green corridors not only open up pathways for wildlife to move, with their resource provision they create suitable habitats for many organisms to live whilst also providing refuge for those migrating between areas, along with maintaining vegetation cover and composition, allowing for the continuous regeneration of key plant species vital for the functioning of the system (Hüse *et al.* 2016). Their importance for the maintenance of viable populations, of both plants and animals, is key, allowing for dispersal of seeds and groups of animals which then increase biodiversity in the city (Hüse *et al.* 2016). These ecological corridors provide benefits not only for wildlife but for the residents of cities as well.

Urban green corridors can be closely linked to ecosystem services, providing the natural capital necessary for many services that benefit humans (Green *et al.* 2016). Whilst these green spaces and corridors provide many benefits for humans, especially in an urban setting, they are under threat from development (Niemelä *et al.* 2010). High levels of pollution from industries, dumping and general carelessness are other significant pressures these ecosystems face (Hua, Shao, and Zhao 2017). Increased demand for goods and services increases energy demand, greenhouse gas emissions and waste, and whilst environmental legislation exists, industries are often environmentally unaware, making corporate environmental responsibility a necessary action to try prevent further damage to the city's ecosystems (Mårtensson and Westerberg 2016).

Developmental pressure is however not limited to urban areas and more and more rural areas are experiencing these pressures, often resulting in significant land-use changes (Deng *et al.* 2015). Cities however are more prone to further development as more and more people move to urban centres. With space already being limited, pressure to remove urban green spaces for development increases. A study conducted by Tajima (2003) found that proximity to urban green space affected property values, with those closer to green spaces fetching higher values than those close to major roads. Carrus *et al.* (2015) found that biodiversity in urban green spaces had a positive influence on individual well-being within urban and peri-urban settings and as such species richness in such environments should be protected. Knowing the benefits that we derive from the services these ecosystems offer it is crucial to protect them from further development.

1.2 River and riparian ecosystems

Rivers are considered vital for sustaining ecological integrity of an area (Petts 1996). They play a particularly important role within an urban setting. As with any other ecosystem, rivers are comprised of two factors. A river's biotic factors include all animals, plants and micro-organisms living within its waters or between its banks (Echolls 2017). A river's abiotic factors are the interactions between its physical (rocks, soil, water) and chemical (ion make up of water) components (Echolls 2017). Every river will be different in its chemical composition based on its tributaries, surrounding environment and physical makeup as well as introductions from human actions (such as fertilizers, oils and pollution), both direct and indirect (Chang *et al.* 2015).

Rivers in general are extremely sensitive to external factors and with their close proximity to the built environment, urban rivers are at high risk of being adversely affected. The shift in river quality between urban and rural areas is evident. However, more often than not, rural areas downstream of urban rivers are negatively affected by the actions of those upstream (Saul, Hudgens, and Mallin 2017). The problem comes when those downstream are more reliant on the river for resources, as found by Munia *et al.* (2016) who found that downstream areas underwent large changes in stresses from withdrawal and consumption upstream.

Some of the greatest threats to urban rivers come from pollution, land-use changes and poor land management (Paul and Meyer 2001). It is well known that changes in land-use cause impacts, from climate-related issues to infrastructural problems. Urban expansion requires large amounts of space for development and as such large areas of the natural environment that surround rivers have turned into large, artificial environments consisting mainly of concrete, stone and steel, all impermeable to water. One result of this is an increase in water runoff during rainfall events (Sajikumar and Remya 2015). This is problematic as the volume of water that reaches the river is often greater than the volume of water the river can hold and transfer. With such a large volume of water moving down the water course, flooding hazards, bank erosion and environmental instability become risks to those around the river (Walsh *et al.* 2016). A study by Du *et al.* (2015) on the Pearl River Delta in China found that over the past two decades, a transition from agricultural landscape to metropolitan areas with impervious surfaces has resulted in an increase in flooding events. They also state that failure to halt any further land-use change would see a further increase in surface runoff and ultimately flooding.

Pollution compounds matters by introducing foreign chemical and heavy metal compounds, changing the water composition, whilst debris from careless dumping can alter water flow. This can change the course of a river, making ground surrounding the banks unstable. The resulting effect of all these changes is a drastically altered and severely deteriorated ecosystem that does not function as it should. The implications of these changes range from ecosystem degradation to habitat fragmentation and biodiversity loss (Essl *et al.* 2015). Fuller, Doyle, and Strayer (2015) suggest that habitat fragmentation, particularly caused by anthropogenic agents, could be the most significant contributor to biodiversity loss from freshwater rivers. The reliance on river ecosystems for so many services makes them important features in urban environments. As such, restorative measures should be employed in an attempt to reconcile their functions for everyday life.

1.3 Current Johannesburg Situation

While ecosystems provide many services that are important in cities, their importance becomes particularly clear when placed in the current context of the larger environment and environmental issues. Global change has brought with it a myriad of issues, from overpopulation and overexploitation of resources to climate change, extreme weather events and biodiversity loss (Rosenzweig *et al.* 2008; Bellard *et al.* 2012). Johannesburg is no exception to this and over the past few years has experienced its own extreme events (Kruger and Shongwe 2004). With no guarantee that these are isolated events, the ecosystems with their multiple services will become more important (Lavorel *et al.* 2015). The natural environments found throughout the city act as buffers for multiple events.

With so many artificial and impermeable surfaces along with a lack of good infrastructure, the predicted increase in severe storm events in Johannesburg will inevitably result in an increased possibility of flooding, as has already been experienced (Ringwood and Govender 2017). Having green spaces and river ecosystems that are healthy and functional could reduce the impacts of these storms to some extent.

Johannesburg is a city with an extensive network of public parks (2000 +), green belts (ecological corridors), private gardens and fields that all make it the greenest metro in South Africa (Petterson 2017). These parks are often found along the city's rivers and play an important role in providing the neighbouring communities with multiple services. On any given day, the parks are used for recreational activities from running to cycling, from bird watching to picnicking and more. The rivers, ecological corridors and parks in Johannesburg are all interconnected and play important roles in maintaining a comfortable living environment. Unfortunately, they have been and continue to be neglected and left to decay. Due to their urban nature, these river and riparian ecosystems come under pressure from multiple drivers that are unlikely to slow down in the near future. Poverty, pollution, greenhouse gas emissions and urban expansion are just a few of the pressures all urban ecosystems experience (Stanley *et al.* 2015). South Africa, being a developing country, has a high level of poverty, increasing in urban areas since 1993 (Leibbrandt *et al.* 2010). Poverty is especially evident in cities where people flock in the hopes of finding work, often unsuccessfully. This leaves large numbers of people with no income, no shelter and no food to survive on (Awumbila, Owusu, and Teye 2014). As such, they rely on the natural environments within cities to try and survive, placing unsustainable strain on natural resources (Capps, Bentsen, and Ramírez 2016). This is the situation in Johannesburg with a large number of poverty affected individuals relying on the city's natural resources for survival. The demands placed on these ecosystems along with the deterioration of its services are evident along many of the city's rivers and green corridors as well as in the many parks (City of Johannesburg 2009).

1.4 Protection and maintenance of ecosystems

Protection and maintenance of the environment is often viewed as a national issue (Mostert 2015). As such, many believe that it should fall to National Government to implement, act on and pay for maintenance and upkeep of the environment. Unfortunately, South Africa is a developing country with more pressing issues on the agenda, such as unemployment, crime, service delivery and education, protection of the environment falls to the bottom of the list, if it makes the list (Cronje 2017). This task has thus been passed down to local and provincial government departments. In Johannesburg, Johannesburg City Parks and Zoos has been tasked with looking after these rivers and green spaces but they are understaffed and underfunded and as such cannot ensure the protection or maintenance of every park and river in Johannesburg (de Vries and Kotze 2016). Due to this, many rivers and parks have fallen into a state of deterioration, which needs to be addressed.

Restoration in general means to return something to its former state. Ecosystems, being very sensitive, can often be taken past their tipping point (point of no return), meaning that no level of intervention will completely restore it to its former state. Standish, Hobbs, and Miller (2013) discuss four options for restoration in cities, including, conserving and restoring natural areas at urban fringes, restoring remnant patches of urban nature (parks), management of novel ecosystems and gardening with native species. While these restoration options deal primarily with terrestrial environments, urban streams also need to be considered for restoration in order to halt urban stream syndrome, which describes the ecological degradation of streams draining terrestrial environments (Walsh *et al.* 2005).

Violin *et al.* (2011) conducted a study comparing the physical and biological structure of four degraded urban streams, four restored urban streams and four forested (natural) streams. They found that the restored urban streams were undistinguishable from the degraded urban streams and that the overall health and quality of both urban stream types was much worse than that of the forested streams. They went on to say that reach-scale restoration (restoration of portions of the stream) would not be successful in alleviating physical and biological degradation. Both Walsh *et al.* (2005) and Bernhardt and Palmer (2007) suggest that broader catchment management strategies need to be implemented to deal with aspects such as stormwater drainage, higher discharges and increased sediment loads. Walsh *et al.* (2005) found that the direct connection of impervious surfaces to streams causes large disturbances even during small rainfall events. As such it is important to consider not only the river ecosystem in urban environments, but the riparian ecosystems that make up part of the catchment.

The environment, the protection thereof and understanding of the services we obtain from the ecosystem are becoming more important as we experience global change impacts. As such, more and more environmental matters are making it onto many countries' strategic agendas, through a number of different avenues (Ralph and Stubbs 2014). While environmental matters are becoming more important in a number of areas, and people become more aware of what needs to be done, the issue still comes in the implementation of and funding for suitable solutions. With more pressing issues concerning government, only limited funds are allocated to the environmental management. This makes potential restoration of ecosystems challenging.

1.5 Aim and Objectives

In order to improve green infrastructure, river health and urban ecology, one would first need to study the current conditions of the affected areas and investigate if restorative measures can be applied. With this knowledge one can start to develop ideas around how to successfully restore the areas and offer solutions for the practical challenges that will be faced. The aim of this study was thus to assess the current condition of the Braamfontein Spruit, with the objectives to (1) determine specific levels of certain variables, indicating current condition, (2) assess the impact the current condition is having on ecosystem services and (3) discuss recommendations for restoration

1.6 Layout of the Dissertation

This dissertation is comprised of four chapters. Chapter 1 provides and introduction, literature review and the aim and objectives of this research study. Chapter 2 provides the methodology and approach used to conduct this study. Chapter 3 presents the data collected and an analysis of these results in terms of the quality of the Braamfontein Spruit and surrounding riparian area. Chapter 4 provides an interpretation of the analysed data in comparison to the literature review undertaken and concludes with the implications of key findings, recommendations for restoration and limitations to the study along with recommendations for future studies. All references for the study are listed after chapter 4. Appendices that supplement this study can be found at the end of this research report. Figures and tables are numbered consecutively.

Chapter 2: Methodology

2.1 Study Site

The Braamfontein Spruit is a small perennial stream originating in Braamfontein, Johannesburg. It flows through Johannesburg, Randburg and Sandton and is considered to have one of the longest parks (32km) alongside it (Figure 1). Johannesburg's annual rainfall varies between 600–700mm per year, with the wettest months being between October and April. Temperatures range between 16-28^{o}C with highs reaching into the 30's (SAWS 2018b). The Braamfontein Spruit falls under the Egoli Granite Grassland classification which is under severe threat from urbanisation (Wolmarans 2017). There are many residential areas along its banks and within close proximity to the river. The abundant green spaces make the Braamfontein Spruit an attraction for many nature lovers and outdoor enthusiasts alike. Unfortunately, the stream and its surrounds have fallen victim to much decay through pollution, destruction and poor upkeep.

A 10-kilometre section along the Braamfontein Spruit was identified for data collection, stretching from Parkhurst to Sandton (Figure 1). A total of 10 sites approximately one-kilometre apart were sampled on four separate occasions. Two of the four sampling sessions were conducted in winter (July and August 2017) and two in spring (October and November 2017). Gauteng's rainy season is from October to April but 2017 was marked by early storms in October (SAWS 2018a). While these storms may flush out pollution, they do not improve macroinvertebrate assemblages that are used for assessing river health. At every site a simplified River Health Assessment, comprised of a physical habitat assessment (including water quality measurements (pH, conductivity, DO etc.) and riparian vegetation structure assessments) and aquatic macroinvertebrate assessment (SASS 5) were conducted. Sites were selected on the basis of access and safety, with some sites being overgrown or in areas of high safety concern.

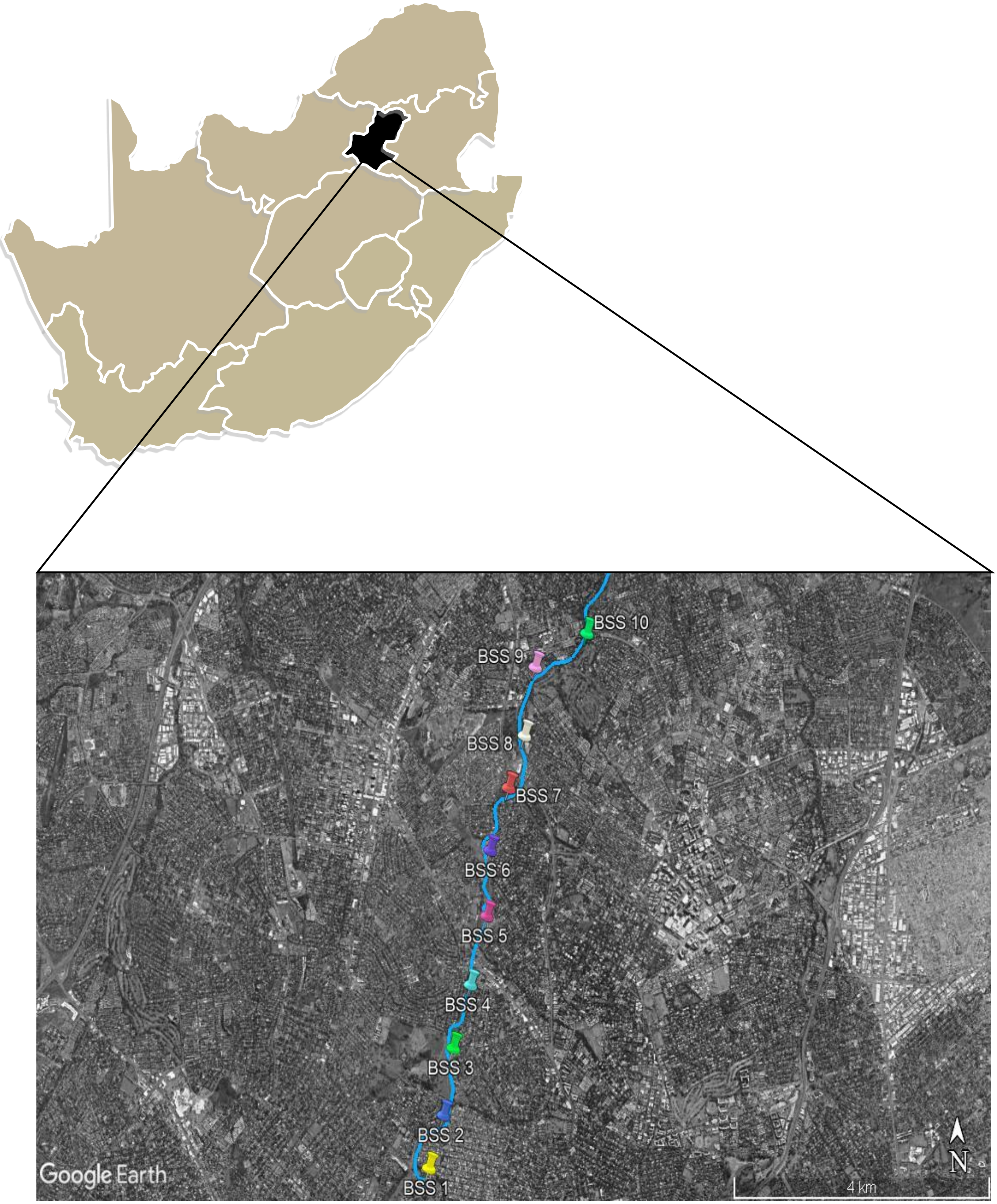

Figure 1: Braamfontein Spruit and the ten associated study sites (bottom) located in the Gauteng Province of South Africa (top) (Google Earth, 2017).

2.2 River Health Assessment

The ecological conditions of river ecosystems are reflected by the system drivers and biological responses, both instream and riparian. By determining a river's biotic diversity, habitat integrity and water quality, appropriate restoration and management goals can be set, improving ecosystem function (McDonald *et al.* 2016). To measure these attributes, a physical habitat assessment and aquatic macroinvertebrate assessment were carried out.

The River Health Assessment as described by the Department of Water Affairs (DWAF 2003) consists of several sections. Section A involves the collection of site information (site number/code, location details such as latitude and longitude), Section B is an assessment of catchment condition and land-use and Section C involves the collection of aquatic data (water chemistry, hydrological characteristics and aquatic biodiversity). A basic River Health Assessment was carried out at multiple sites along the Braamfontein Spruit, together with a SASS5 (South African Scoring System 5) assessment described in section 2.3 below. The information collected included aspects such as channel condition as well as information required to calculate an Index of Habitat Integrity (see below, and see Appendix 1 for full River Health Assessment).

<u>Catchment condition and land-use</u>

The condition of the site and upstream catchment was assessed by collecting information pertaining to land-use, channel conditions, habitat integrity and channel morphology. Conditions were assessed on each of the four visits.

Condition of local catchment indicates the extent of land-use(s) and type of disturbance within and beyond the riparian zone and was determined using a rating scale from 0 to 4 (Table 1). Google Earth (2017) and Gauteng City-Region Observatory (GCRO 2018) landcover maps and ground-truthing were used to accurately describe the types of land-use along the Braamfontein Spruit, which included residential, commercial, agricultural, recreational (playgrounds and parks) land uses and transport. Disturbances such as litter/debris and afforestation were rated on the same scale as above and were assessed on a site by site basis. A level of confidence was assigned to each rating (high, medium or low confidence). A high confidence level applies when an assessor has good knowledge and understanding of the site and the area for at least 5 kilometres upstream. Low confidence level would apply if the assessor has knowledge based only on the site visit and some supplementary information such as land-use from spatial mapping (DWAF 2003). Additional comments on distance upstream/downstream were also included if applicable.

Table 1: Rating Scale used for determining extent of land-use/ impact of disturbance adapted from the DWAF's River Health Programme site characterisation field-manual and field-data sheets (Dallas 2005).

Score	Description
0	None in vicinity of site; no discernible impact
1	Limited to a few localities; impact minimal
2	Land-use generally present; impact noticeable
3	Land-use widespread, small areas unaffected; impact significant
4	Land-use 100% in area; impact significant

Channel condition, including in-channel and bank modifications that could affect the site such as weirs, dam walls and bridges, were rated using the same rating scale as for condition of local catchment (Table 1). The extent of in-channel and bank modifications was indicated, estimating the distance upstream/downstream where appropriate. Distance was taken as zero if the modification occurred at the sampling site. Additional comments such as height of the dam/weir walls or any other noticeable aspects were recorded. This qualitative data was used to aid the assessment of the quality of the river by providing possible explanations as to why the tested variables were high or low.

The Index of Habitat Integrity (IHI), which aims to assess the severity and abundance of anthropogenic disturbances on the river and the potential damage that could be inflicted on the integrity of the system, was calculated (Kleynhans 1996). Disturbances, including anthropogenic factors (water abstraction, weirs, dams, pollution and dumping) and biotic factors (alien plant presence, aquatic animals which modify habitat), were identified at each sampling site. The features considered included instream and riparian disturbances and were considered as primary causes of degradation of the river ecosystem. The severity of each anthropogenic feature was scored based on its impact class (Table 2). A confidence level was assigned (high, good knowledge of area and surrounds; low, poor knowledge of area and surrounds). A brief overview of the list of criteria used is included in Table 3 while full descriptions can be found in Appendix 2.

Table 2: Impact value system to rate anthropogenic and biotic impacts (Kleynhans 1996).

Impact Class	Description	Score
None	No discernible impact or the modification is located in such a way that it has no impact on the habitat quality, diversity, size and variability.	0
Small	The modification is limited to very few localities and the impact on the habitat quality, diversity, size and variability is limited.	1 – 5
Moderate	The modifications are present at a small number of localities and the impact on habitat quality, diversity, size and variability are fairly limited.	6 – 10
Large	The modification is generally present with a clearly detrimental impact on habitat quality, diversity, size and variability. Large areas are, however, not affected.	11 – 15
Serious	The modification is frequently present and the habitat quality, diversity, size and variability in almost the whole of the defined area are affected. Only small areas are not influenced.	16 – 20
Critical	The modification is present overall with a high intensity. The habitat quality, diversity, size and variability in almost the whole of the defined section are influenced detrimentally.	21 - 25

Table 3: Definition of possible anthropogenic and biotic impacts (Kleynhans 1996)

Criterion	Description
Water abstraction	Direct abstraction from within the specified river
Extent of inundation	Destruction of instream habitat and riparian zone through submerging by water
Water quality	Based on direct measurement or indirectly via observation of activities
Flow modification	Consequence of abstraction or regulation by impoundments
Bed modification	Result of increased input of sediment from the catchment or a decrease in the ability of the river to transport sediment
Channel modification	Result of a change in flow which alters channel characteristics casing a change in instream and riparian habitat
Presence of exotic aquatic fauna	Disturbance of the stream bottom during exotic fish feeding may influence the water quality and lead to increased turbidity
Presence of exotic macrophytes	Exotic macrophytes may alter habitat by obstruction of flow and may influence water quality
Solid waste disposal	The amount and type of waste present in and on the banks of the river is indicator of external influences on stream and a general indication of the misuse and mismanagement of the river
Decrease of indigenous vegetation from the riparian zone	Refers to physical removal of indigenous vegetation for farming, firewood and overgrazing
Exotic vegetation encroachment	Excludes vigorous natural vegetation growth. Encroachment of exotic vegetation leads to changes in the quality and proportion of natural allochthonous organic matter input and diversity of the riparian zone habitat is reduced.
Bank Erosion	A decrease in bank stability will cause sedimentation and possible collapse of the river bank resulting in a loss or modification of both instream and riparian habitats.

Once anthropogenic disturbances were assigned an appropriate score (Table 2), a weighting system was used to moderate the scores and calculate both instream and riparian status. Weighting was based on the threat the impact would pose to the habitat integrity of the ecosystem (Table 4). Total scores were equal to the assigned scores multiplied by the weight of the impact. Impacts were then calculated using the equation below:

$$\text{score for criterion}/_{25} \text{ x weighting (percent).}$$

The scores of all the individual disturbances at each sample site were summed and subtracted from 100 (the total achievable score after all weightings are applied and calculations are done) to achieve a present status score (IHI score). The score was expressed as a percentage (%), for the instream and riparian components individually. The IHI scores (%) were then used to place the two components into specific habitat integrity classes, with care being taken to evaluate scores against photographic evidence to ensure scores were correct (Table 5: Kleynhans 1996).

Table 4: Weighting of instream and riparian disturbance criteria (Kleynhans 1996).

Instream Criteria	Wgt	Riparian Zone Criteria	Wgt
Water abstraction	14	Water abstraction	13
Extent of inundation	10	Extent of inundation	11
Water quality	14	Water quality	13
Flow modification	7	Flow modification	7
Bed modification	13	Channel modification	12
Channel modification	13	Decrease of indigenous vegetation from the riparian zone	13
Presence of exotic macrophytes	9	Exotic vegetation encroachment	12
Presence of exotic fauna	8	Bank erosion	14
Solid waste disposal	6		

Table 5: Habitat Integrity Classes (Kleynhans 1996)

Class	Description	Score (% Of Total)
A	Unmodified, natural.	90 – 100
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place, but the assumption is that the ecosystem functioning is essentially unchanged	80 – 89
C	Moderately modified. A loss or change in natural habitat and biota has occurred, but basic ecosystem functioning appears predominantly unchanged.	60 – 79
D	Largely modified. A loss of natural habitat and biota and a reduction in basic ecosystem functioning is assumed to have occurred.	40 – 59
E	Seriously modified. The loss of natural habitat, biota and ecosystem functioning is extensive.	20 – 39
F	Modifications have reached a critical level and there has been an almost complete loss of natural habitat and biota. In the worst cases, the basic ecosystem functioning has been destroyed.	0 – 19

Photographic records were taken for reference purposes and to note any changes that occurred over the course of the data collection period. Photographs were taken from the centre of the river (on a bridge or rocks), pointing the camera upstream, downstream, as well as at the left and right banks. Any distinguishing features such as large concrete slabs were also photographed as evidence of flow obstructions in the river, which affected the IHI scores in the analysis.

Aquatic measurements

In this section, general information relevant to the study about the river and its surrounds were noted. General Site Visit Information (site code, location, co-ordinates, sampling date etc.) was gathered during each sampling day. This information was used to give additional information about the state of the river on the day and support explanations for the scores calculated from the collected data.

Water velocity was measured using a Transparent Velocity Head Rod (TVHR). The TVHR was placed perpendicular to stream flow to establish a difference in height between water hitting the front of the rod and water behind the rod. The maximum height reached by the water over a 20 second period was recorded. The lower point, occurring behind the rod, was observed for 15 seconds. The difference between the maximum and minimum level was calculated as ΔH (delta H or change in height) and was measured in centimetres (cm). A table of ΔH values (Table 6) along with the corresponding velocities was used to assign average velocity at each site (the process was repeated three times and the velocity values averaged). These velocities were used as additional indicators for dissolved oxygen numbers at sites and showed gradient changes (greater velocity indicates steeper gradient) along the river, which is important during flooding events as steeper gradients can exacerbate flooding effects such as erosion and sediment transfer (Karimaee Tabarestani and Zarrati 2015).

Table 6: Table of change in height (∆H) and corresponding velocities for river water (taken from Capacity 4 Capture Citizen Science tools, a Department of Water and Sanitation initiative 2016)

Table of Velocities									
∆H (cm)	**Velocity (m/s)**	**∆H (cm)**	**Velocity (m/s)**	**∆H (cm)**	**Velocity (m/s)**	**∆H (cm)**	**Velocity (m/s)**	**∆H (cm)**	**Velocity (m/s)**
0,5	0.12	5,5	0.80	10,5	1.17	15,5	1.45	20,5	1.70
1	0.24	6	0.84	11	1.20	16	1.48	21	1.72
1,5	0.33	6,5	0.88	11,5	1.23	16,5	1.50	21,5	1.74
2	0.41	7	0.92	12	1.26	17	1.53	22	1.76
2,5	0.48	7,5	0.96	12,5	1.29	17,5	1.55	22,5	1.79
3	0.54	8	1.00	13	1.32	18	1.58	23	1.81
3,5	0.60	8,5	1.03	13,5	1.34	18,5	1.60	23,5	1.83
4	0.65	9	1.07	14	1.37	19	1.63	24	1.85
4,5	0.70	9,5	1.10	14,5	1.40	19,5	1.65	24,5	1.87
5	0.75	10	1.13	15	1.43	20	1.67	25	1.89

Any significant rainfall in the area in the week leading up to sampling session was noted. This information was used to assess the likelihood of raised water levels, increased velocity or debris build up not previously noted. An estimate of the extent of riparian vegetation cover over the river, including trees, was noted as canopy cover and was either open, partially open or closed. This was used as an estimation of the amount of sunlight the site received. Any organic debris that could impede water flow or alter stream habitat was noted as impact on channel flow and scored on a scale of 0 to 3 (0-no impact; 1-limited impact, partially blocked channel; 2-extensive impact, extensively blocked channel; 3-channel blocked completely) (DWAF 2003).

A Yellow Springs Instruments (Y.S.I.) handheld multiparameter instrument was used to measure pH, conductivity (mS/m), temperature (°C) and dissolved oxygen (%) and methods, described below, were followed as suggested by YSI Incorporated (2018). Prior to the first measurement being taken on each sample day, the probe was calibrated, after which it was held suspended approximately mid-way (distance between river bed and top of water flow) in the flowing water for upwards of 30 seconds. Leaving it suspended for this amount of time allowed measurements to stabilise, after which they were recorded.

Aquatic Macroinvertebrate Assessment

The macroinvertebrate assessment was carried out following the South African Scoring System (SASS) version 5 Rapid Bioassessment method outlined by Dickens and Graham (2002). The procedure was followed at each sample site and all necessary information was recorded on a SASS 5 scoring sheet (Appendix 3).

Sample collection

Samples were collected over a wide area to ensure that the full diversity of the biotope was sampled. Pools or backwaters adjacent to the river were not sampled as they were not connected to the river itself. Where possible, three biotopes were sampled and visual observations were included. These methods followed those outlined by Dickens and Graham (2002) for SASS5 assessments.

A stones (S) biotope is comprised of both ‘stones in current’ (SIC) and ‘stones out of current’ (SOOC). ‘Stones in current’ are loose stones of between 2-25cm situated where the movement of the water prevents them from settling out of fine silt. Bedrock, boulders larger than 25cm, large sheets of rock, waterfalls and chutes are included. Stones were kicked, turned over against each other and rubbed for two minutes to dislodge biota. A sweep net of approximately 40cm in diameter was placed downstream of these stones to catch any dislodged invertebrates. Where stones were embedded or difficult to move, sampling continued for five minutes. ‘Stones out of current’ are moveable stones out of the perceived current that allow sediments to settle on their upper surfaces. Stones and bedrock were kicked, scraped and turned for one minute whilst continuously sweeping the net through the disturbed area. Samples from both in current and out of current sampling were combined into a single Stones biotope sample.

Vegetation (Veg) biotopes are comprised of marginal vegetation and aquatic vegetation. Marginal vegetation is any hanging vegetation or vegetation that grows at the edge of the river, both in current (MVegIC) and out of current (MVegOOC). A total of two metres of vegetation was sampled, spread over one or more locations where possible, sampling different types of marginal vegetation. A sweep net of approximately 40cm in diameter was pushed vigorously into the vegetation, moving back and forth through the same area. The net was kept below the surface of the water to avoid collecting samples from the water surface.

Aquatic vegetation consists of vegetation unrestricted to the river banks and is mostly submerged, including filamentous algae and the roots of floating aquatic plants such as water hyacinth. The net was pushed through the vegetation repeatedly over one square meter. Samples from both in current and out of current sampling were combined into a single vegetation biotope sample.

Gravel, sand and mud (GSM) biotopes were sampled, where available, for approximately one-minute. Gravel, made up of small stones <2cm in size were stirred up by shuffling feet while sweeping the net over the disturbed area. Sand grains <2mm in diameter were sampled by shuffling feet, waiting a few seconds for larger particles to settle and then sweeping the net over the disturbed area. Mud, silt and clay particles <0.06mm in diameter were stirred by shuffling feet while the net was continuously swept over the disturbed area. Samples from both in current and out of current sampling were combined into a single gravel, sand and mud biotope sample.

Visual assessments of all biotopes were conducted for approximately one minute per site to note any organisms that should not be collected, such as crab or fish, as well as fast moving pond skaters.

Sample preparation and analysis

Once the above collection had been completed, the samples were washed to the bottom of the net. The samples were then tipped into a white sorting tray by inverting the net. The net was then flushed out, ensuring all specimens were washed into the tray. The net was checked and any remaining specimens were removed. Enough clean water to immerse the specimens was added to the tray. Any large obstructions such as leaves, twigs or stones were rinsed thoroughly before being removed from the tray.

Organisms listed on the SASS 5 scoring sheet (Appendix 3) were identified to family level. Each taxon has been assigned a quality score based on its vulnerability or resistance to pollution and disturbances. Lower scores are assigned to resistant taxa while high scores are assigned to taxa susceptible to pollution. Identification was done for a maximum of 15 minutes per biotope sampled. If no new taxon was seen for approximately five minutes, the identification process was stopped. Any taxa that were identified were marked off under the appropriate biotope heading. The columns were then combined into a single total column.

The abundance of organisms from each taxon was estimated and noted (single organism -1; 2 to 10 organisms – A; 10 to 100 – B; 100 to 1000 – C; >1000 – D). Upon completion of the identification, samples were returned to the river Any organisms that could not be identified on site were collected in vials with water and ethanol for laboratory identification.

Three principle indices were calculated for SASS: SASS score, Number of Taxa and Average Score Per Taxon (ASPT). Calculations were done by noting any families seen in any of the biotopes sampled, irrespective of abundance. Quality scores for each taxon were noted in the total column of taxa and were summed to give the SASS score. The total number of taxa found was the Number of Taxa. ASPT was calculated by dividing the SASS score by the number of Taxa. The ASPT score was then used to determine the river's ecological category/ condition (Table 7). Should a taxon have been present in multiple biotopes, only the total column represented the SASS5 result and the scores were not added as per (Dickens and Graham 2002).

Table 7: Interpretation of SASS score (Ouse and Adur River Trust 2017).

Ecological category (Condition)	ASPT	Water Quality
Unmodified (NATURAL condition)	> 7	Very Good (Natural)
Largely natural/ few modifications (GOOD condition)	6.0 to 6.9	Good
Moderately modified (FAIR condition)	5.0 to 5.9	Fair
Largely modified (POOR condition)	4.0 to 4.9	Poor
Seriously/ critically modified (VERY POOR condition)	< 3.9	Very Poor

2.3 Vegetation Structure

The structure of vegetation found along the Braamfontein Spruit was sampled using methods modified from Braun-Blanquet (1932). The method used a scoring system (Table 8) which relates to abundance and cover combined. While the Braun-Blanquet method focused on species composition, the study of the Braamfontein Spruit was focused on the structure of vegetation and the amount of ground each type covered and as such, a percentage value was used rather than a numbering system (Baxter 2018). All sites were sampled apart from sites 7 and 9 which lacked the necessary width on either side of the bank to do a transect. At each site, a starting point was selected as close to the bank of the river as possible. From there, a 50m transect was measured perpendicular to the river, moving away from the river. At every 5-metre interval, a 1x1m quadrat was thrown left or right of the transect, in a consecutive manner. The vegetation structure (grass, shrub and bare ground) and percentage ground cover within the quadrat were determined. The mean percentage cover for each vegetation type was then calculated per site. Whilst a number of large trees can be found along the Braamfontein Spruit, they are often sparsely located. As such, trees were not found within the sampled area at most of the sample sites.

Table 8: Braun-Blanquet (1932) method of estimating vegetation abundance and cover.

Score	Definition
0	Sparsely or very sparsely present; cover very small
1	Plentiful but of small cover value
2	Very numerous, or covering at least ½ of the area
3	Any number of individuals covering ¼ to ½ of the area
4	Any number of individuals covering ½ to ¾ of the area
5	Covering more than ¾ of the area

2.4 Data Analysis

The collected data were analysed in Statistica Version 13.2 (© Statsoft 2017). Data were tested and found to be normally distributed. A General Linear Model (GLM) with a Fishers Exact post-hoc test was used to determine whether sample days or sites were predictors for SASS 5 scores, Number of Taxa, ASPT, pH, Conductivity, Dissolved Oxygen and velocity and whether the physical variables (pH, Conductivity and DO) were affecting the number of taxa present. For variables where significant differences ($p < 0,05$) were found, multiple regression analyses were run to understand the nature of relationships between those variables (pH, Conductivity and DO) and the number of taxa found, a direct relationship to ASPT and thus river health. Vegetation data were analysed using a t-test to determine if there was any significant difference between sites for grasses, shrubs and bare ground.

Chapter 3: Results

3.1 Assessment of catchment condition, land-use and Index of Habitat Integrity

The assessment of the local catchment which used Google Earth, GCRO maps and ground-truthing at each site gave a good indication of land-uses which could possibly have an effect on the river ecosystem. Table 9 shows the most frequently occurring land use types as well as the most common forms of disturbance.

Table 9: Local catchment land-use categories and disturbances found at sample sites along the Braamfontein Spruit.

	Site									
Land-use	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Agriculture – crops										
Agriculture – livestock			X							
Agriculture – irrigation										
Aquaculture										
Construction	X	X	X							
Roads	X	X		X	X	X				
Impoundment (weir/ dam)						X				
Industrial Development										
Urban Development	X	X	X	X	X	X	X	X	X	X
Rural Development										
Informal settlement								X		
Recreational	X	X	X	X	X			X	X	X
Sewage Treatment Works										
Nature conservation										
Wilderness Area*										
Disturbances										
Afforestation- general										
Afforestation – felled area										
Alien vegetation infestation	X	X	X	X	X	X	X	X	X	X
Litter/ Debris	X	X	X	X	X	X	X	X	X	X

*A wilderness area is one with limited anthropogenic modifications but is not officially a nature conservation area.

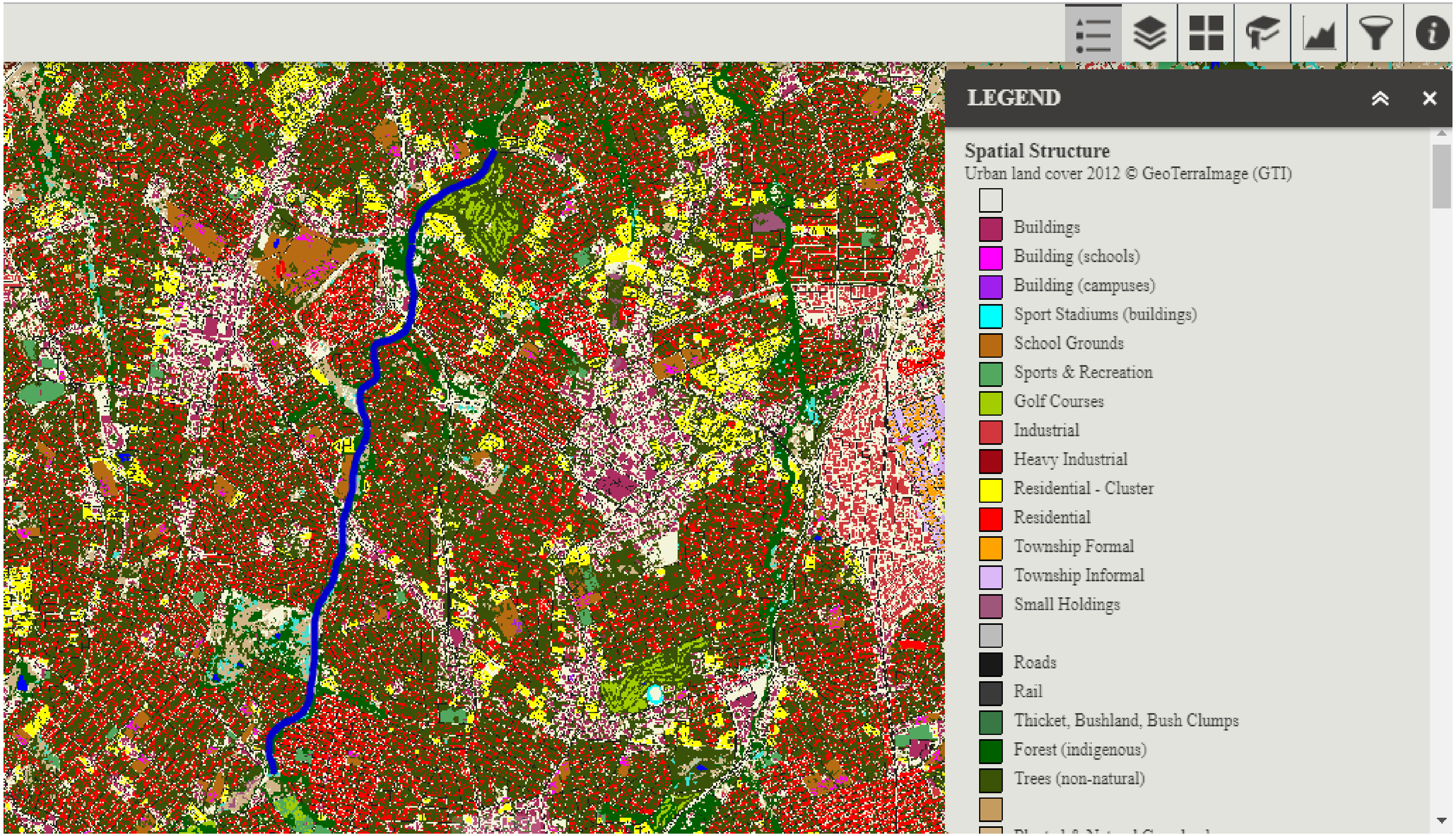

Figure 2: GCRO map showing the Urban Land Cover (2012) along the sampled portion of the Braamfontein Spruit (blue line)

A number of modifications within the river channel and to its banks were also noted (Table 10). Bridges within channel supports and gabions/ reinforced banks were the most noted modifications. A number of other modifications were noted at various sites with site 3 having the highest number of modifications occurring.

Table 10: Modifications to the channel or banks of the Braamfontein Spruit that affect channel conditions.

	Site									
In-channel and bank modifications	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Bridge – elevated; in channel supports	X				X					X
Bridge – elevated; side channel supports										
Causeways/ low-flow bridges							X			
Bulldozing			X							
Canalisation – concrete/ gabion										
Canalisation – earth/ natural	X								X	
Gabions/ reinforced bank		X	X		X	X				
Fences – in channel										
Gravel, cobble and/ or sand extraction	X		X							
Roads in riparian zone – tar										
Roads in riparian zone – gravel										
Dams (large)										
Dams (small)/ weir						X			X	
Other:			X							

The Index of Habitat Integrity (IHI) reflects the number and severity of anthropogenic perturbations at each site. The main land use types found along the river included residential and recreational areas. While the majority of residential areas are built a fair distance (20+ metres) from the edge of the river, a number of houses occurred very close to its banks. Many of these banks have not been reinforced to support these properties and with the large threat of erosion, are in danger. Along the spruit there a number of weirs, low lying bridges and other large obstructions that can cause issues with flow. These flow modifications have had a substantial impact on the banks of the river with large amounts of erosion occurring along the length of the sampled river. Much of the banks have been undercut, leaving an unstable area at the top of the bank. Some banks close to one or two of the sampling sites looked to have been strengthened by cinderblock walls in order to stop further erosion and damage to properties lying atop the bank. Every sampled site was affected by litter from plastic bottles, to discarded bags to empty gas bottles. As such the highest scoring anthropogenic perturbations (i.e. those considered to be most harmful) for instream IHI were water quality (considering smell, clarity etc.), exotic macrophytes and solid waste (debris, litter etc.), whilst the highest scoring anthropogenic perturbations for riparian IHI were water quality, decrease in indigenous vegetation from riparian zone, exotic vegetation encroachment and bank erosion (Table 11). The IHI scores ranged from 52,16 to 86,64 giving classes of B (largely natural with few modifications), C (moderately modified) and D (largely modified) (comprehensive descriptions are included in Table 5) with the average class along the river for both instream and riparian zones being C or moderately modified (Figure 3).

Table 11: Scores assigned to the anthropogenic perturbations at each site contributing to the IHI score. Scale: 0 – none, 1 to 5 – limited, 6 to 10 – moderate, 11 to 15 – extensive, 16 to 20 – extreme, 21 to 25 – critical.

	Site									
Criterion	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
INSTREAM										
Water abstraction	0	0	0	0	0	0	0	0	0	0
Extent of inundation	3	2	1	2	1	2	2	13	2	2
Water quality	20	21	15	16	16	20	16	16	6	20
Flow modifications	0	0	0	0	0	20	0	0	0	0
Bed modifications	0	0	11	0	0	0	0	0	0	0
Channel Modification	0	0	0	0	0	0	0	0	0	0
Presence of exotic macrophytes	20	20	15	10	13	18	18	20	6	16
Presence of exotic fish	0	0	0	0	0	0	0	0	0	0
Presence of solid waste	13	16	11	2	6	21	21	15	6	21
RIPARIAN ZONE										
Water abstraction	0	0	0	0	0	0	0	0	0	0
Extent of inundation	3	1	1	2	1	2	2	13	2	2
Water quality	20	21	15	16	16	20	16	16	16	20
Flow modifications	0	0	0	0	0	0	0	0	0	0
Channel modifications	0	0	0	0	0	0	0	0	0	0
Decrease of indigenous vegetation from the riparian zone	15	18	16	20	16	20	16	25	11	16
Exotic vegetation encroachment	20	20	13	10	20	21	20	20	16	23
Bank erosion	15	16	20	16	10	10	16	20	6	6

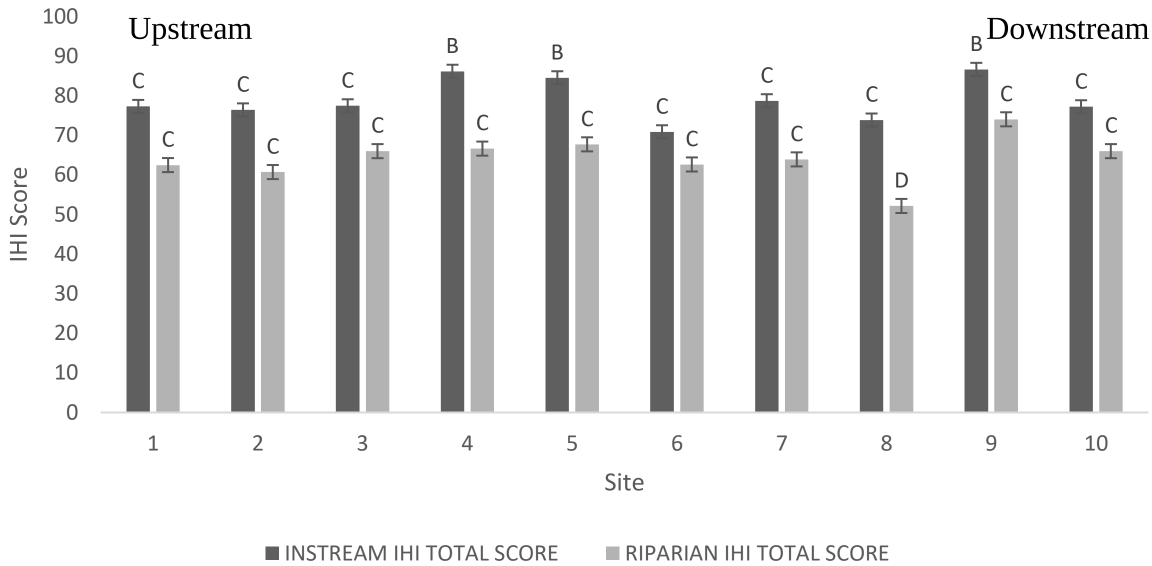

Figure 3: Total IHI scores for both Instream and Riparian zones at each site along the Braamfontein Spruit. Letters (B, C, D) indicate the IHI class corresponding to the calculated score. Error bars denote standard error between means.

3.2 Aquatic measurements

Stream velocity was found to be highly variable between sites with sites 4 (flowing slower), 6 and 8 (flowing faster) showing the greatest variability to most other sites ($p < 0.01$). Average stream velocity during the sampling period never exceeded 0.5 m/s (±1.8 km/h) with the lowest average velocity being 0.075m/s (±0.27 km/h) (Figure 4). Stream width was measured where water flowed (i.e. not bank to bank) and ranged between 3 and 5.5 meters (Figure 5).

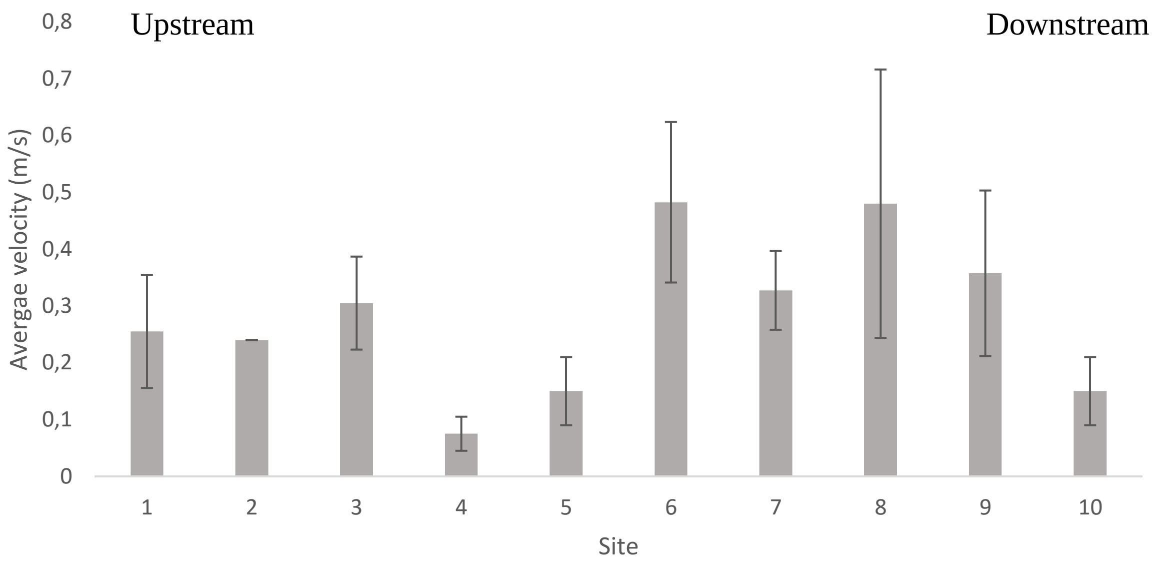

Figure 4: Average stream velocity across the 10 sample sites of the Braamfontein Spruit. Error bars denote standard deviation from the mean.

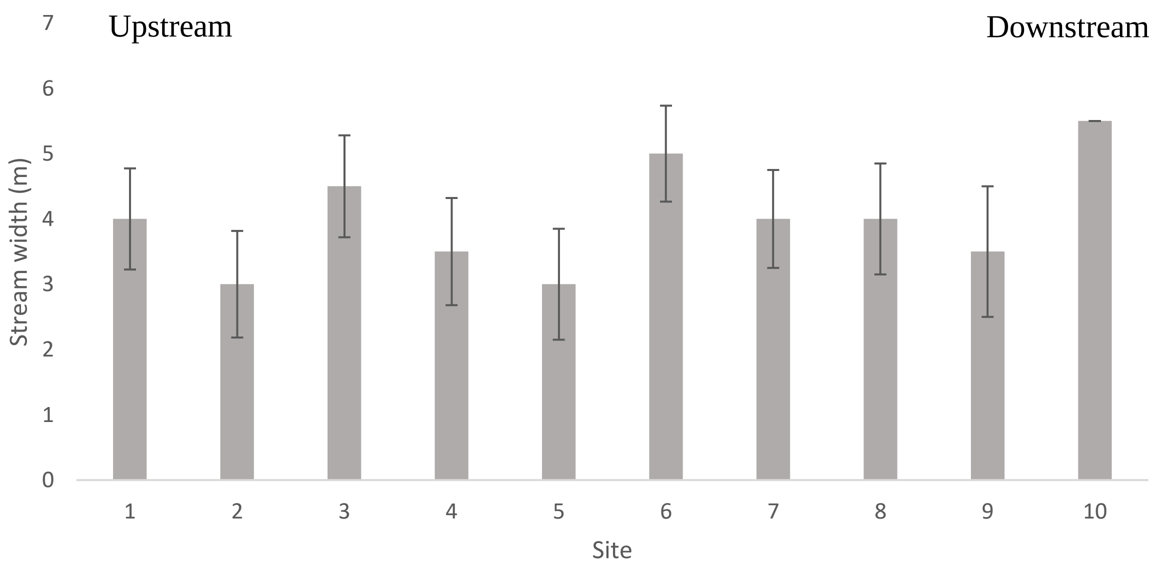

Figure 5: Stream width at 10 sampling sites along the Braamfontein Spruit. Error bars denote standard deviation from the mean.

The results obtained from the sampling yielded interesting patterns across the individual variables tested. Average Score Per Taxon (ASPT), pH, and Dissolved Oxygen (DO) scores increased between site 1 and site 10 across all four sampling days ($F_{3,30} = 5.13$; $p < 0.01$), whilst all four days differed from each other ($F_{3,30} = 20.19$; $p < 0.01$) (Figures 6, 9 and 10). Conductivity was observed to either stay constant or decrease from site 1 to site 10 (Figure 7).

pH was significantly lower at sites 1 compared to sites 7,8,10 ($p < 0.01$), site 2 compared to sites 7,8,10 ($p < 0.01$) and site 3 compared to sites 7,8,10 ($p < 0.01$). pH was significantly different between days 1 and 2 ($p < 0.001$), 1 and 3 ($p < 0.001$), 2 and 4 ($p < 0.001$) and 3 and 4 ($p < 0.001$). pH was consistently higher than the acceptable value (7) given by Rand Water (2018).

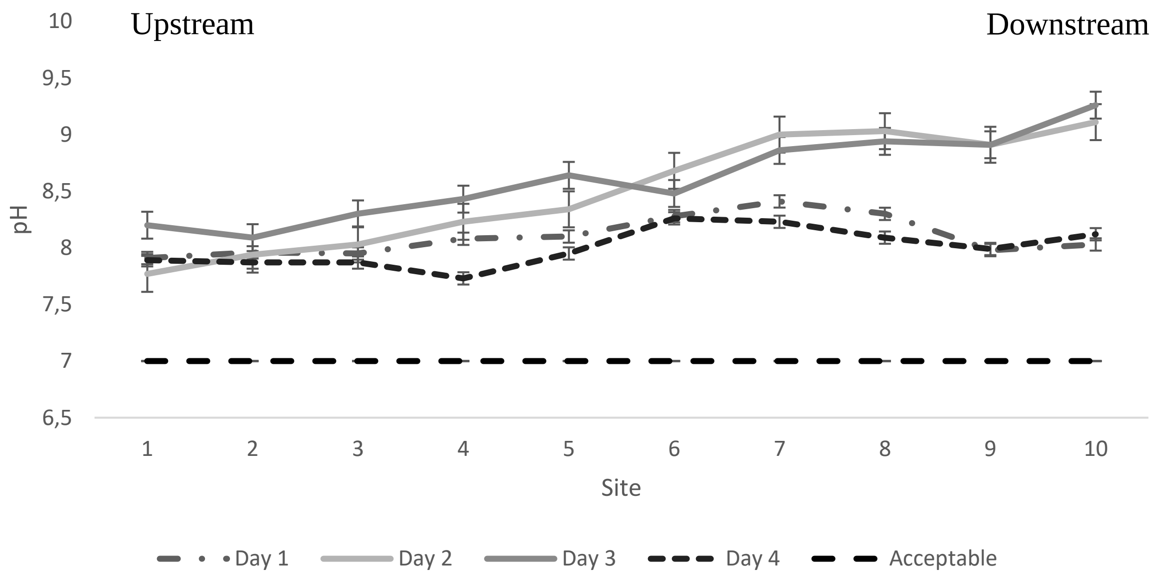

Figure 6: pH along the Braamfontein Spruit. Horizontal line indicates pH score considered acceptable (Rand Water 2018). Error bars denote standard error between means.

Conductivity did not differ significantly between days ($p = 0.18$) but was significantly higher between site 1 and sites 4, 5, 6, 7, 8, 9 and 10 ($p < 0.01$). Conductivity was consistently well above the acceptable value (150mS/m) given by Rand Water (2018).

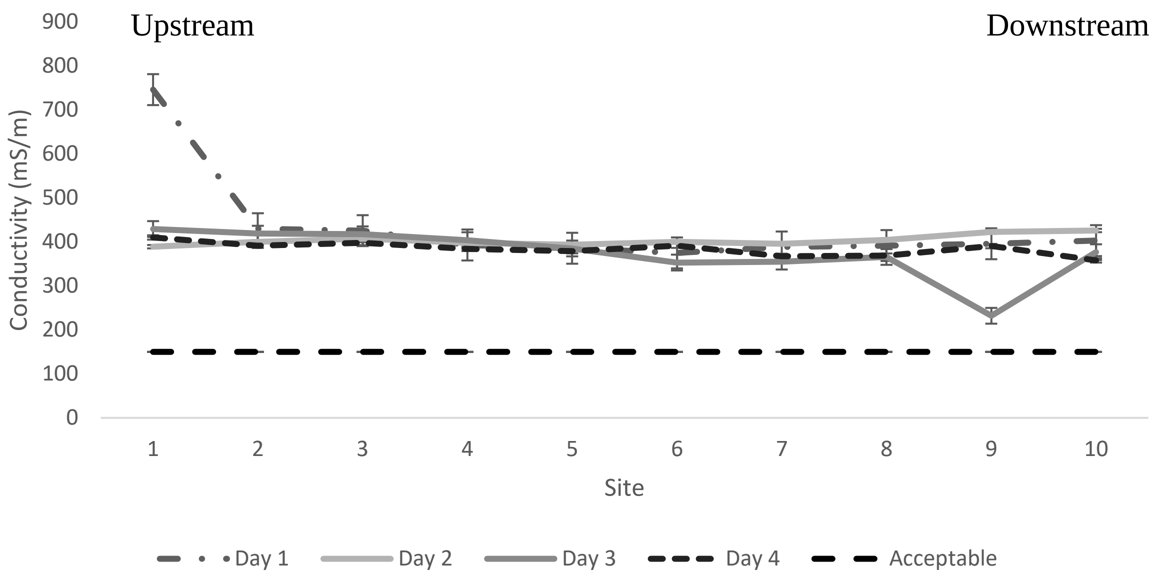

Figure 7: Conductivity along the Braamfontein Spruit. Horizontal line indicates conductivity considered acceptable (Rand Water 2018). Error bars denote standard error between means.

Water temperatures along the Spruit show an increasing trend from site 1 to 10 (Figure 8). The lowest recorded temperature was recorded at the first sample site of the first sample session and was 8.9^{o}C whilst the highest recorded temperature occurred at the final site during the third sample session and was 24 ^{o} C.

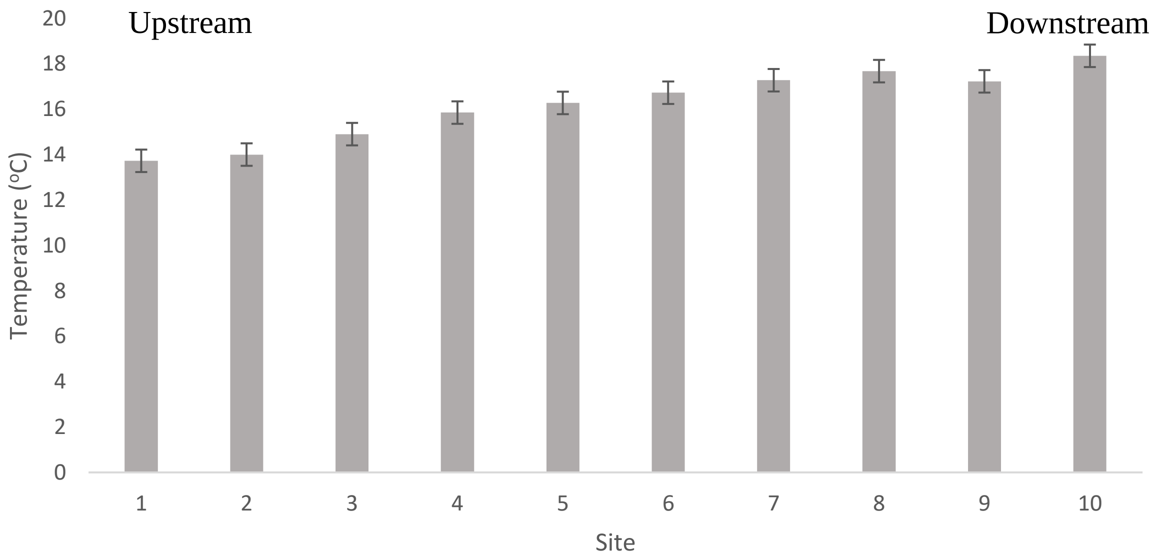

Figure 8: Average water temperature of the Braamfontein Spruit at each sample site. Error bars denote standard error between means.

Dissolved oxygen was found to differ significantly between days ($p < 0.05$) and only between site 2 and 3 ($p = 0.04$). It fluctuated with three of the four days being above, and one below, the acceptable value (90%) given by Rand Water (2018).

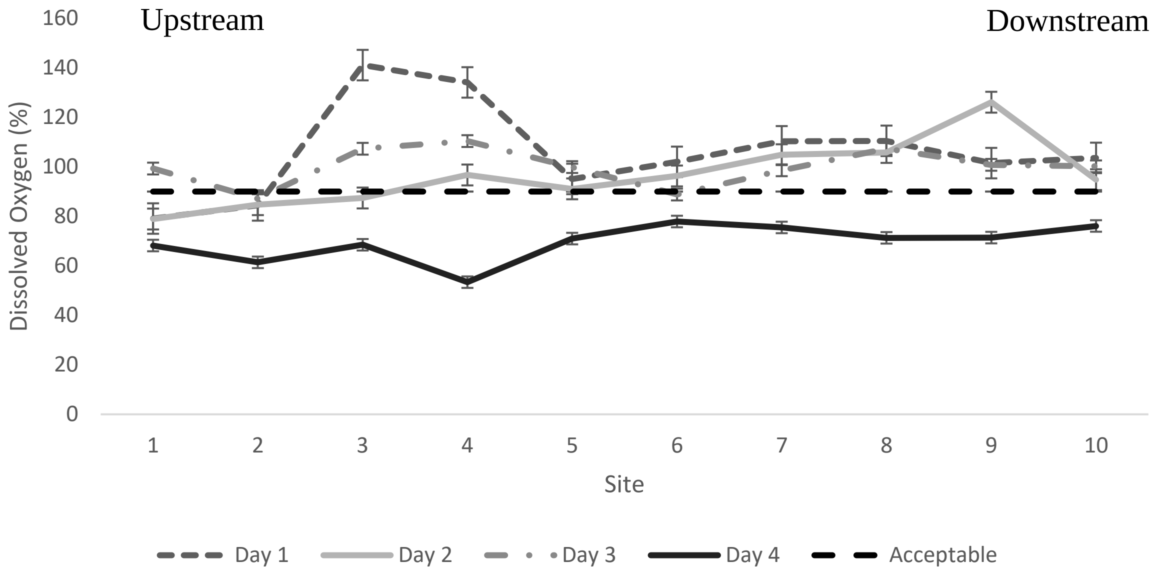

Figure 9: Dissolved Oxygen along the Braamfontein Spruit. Horizontal line indicates dissolved oxygen score considered acceptable (Rand Water 2018). Error bars denote standard error between means.

ASPT was found to be significantly higher at site 8 compared to sites 1,2,3,4,5 and 7 ($p < 0.01$) while the ASPT at site 3 was significantly lower than at sites 6 and 9 ($p < 0.01$), however ASPT did not differ significantly between days ($p = 0.13$). ASPT was also found to consistently be below the acceptable value (7) given by Rand Water (2018).

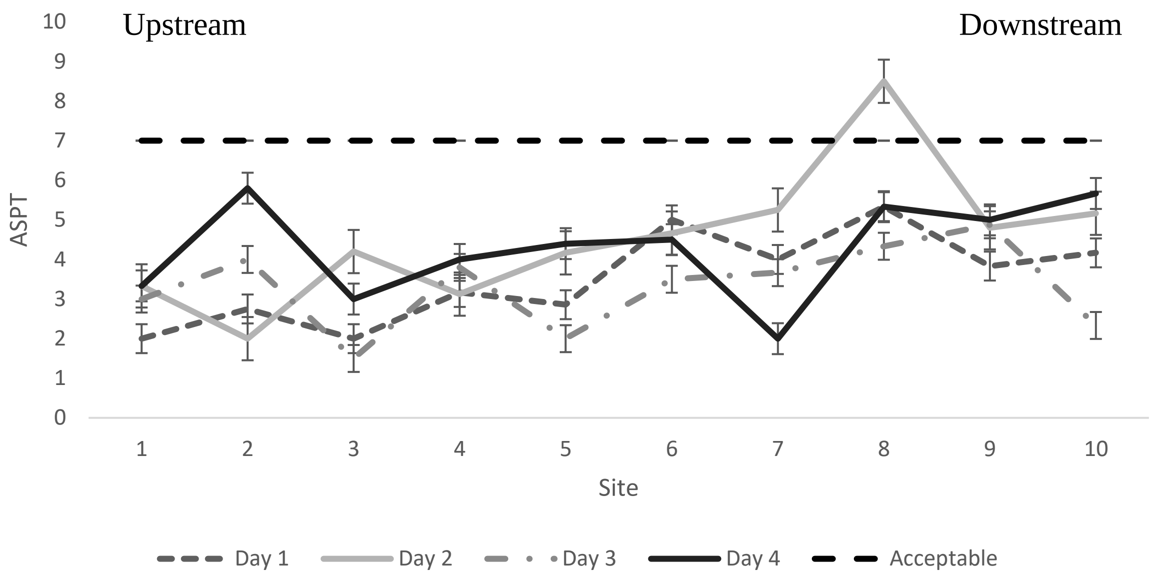

Figure 10: ASPT along the Braamfontein Spruit. Horizontal line indicates ASPT score considered to be Natural/ Good quality (Rand Water 2018). Error bars denote standard error between means.

3.3 SASS5 data

The composition (biotypes) of the river is shown in table 12. While every effort was made to sample each biotype at every site it was not possible at certain sites where one or more biotypes could not be found.

Table 12: Biotypes sampled at 10 sample sites along the Braamfontein Spruit. X denotes the presence of, and ability to, sample the biotype at the sample site.

Site	Biotypes		
	Stones	Vegetation	Gravel, Sand, Mud
1			X
2	X	X	X
3			X
4	X	X	X
5	X	X	X
6	X	X	X
7		X	X
8	X	X	X
9	X	X	X
10		X	X

Average SASS scores across the ten sample sites ranged from 9.5 to 29 (Figure 11) over the four sample days, while the average number of taxa found ranged from 3 to 6.25 (Figure 12) over the same period and sites. The most common taxa found included *Oligochaeta* (earth worms) and *Chironomidae* (midges) which were found on every visit at nearly every site, as well as *Baetidae* (mayflies) which were frequent but not present at every site (Table 13). Average Score Per Taxon (ASPT) was calculated per site per sampling day and was found to range from a minimum of 2 (multiple days and sites) to a maximum of 8.5 (sample day 2, site 8).

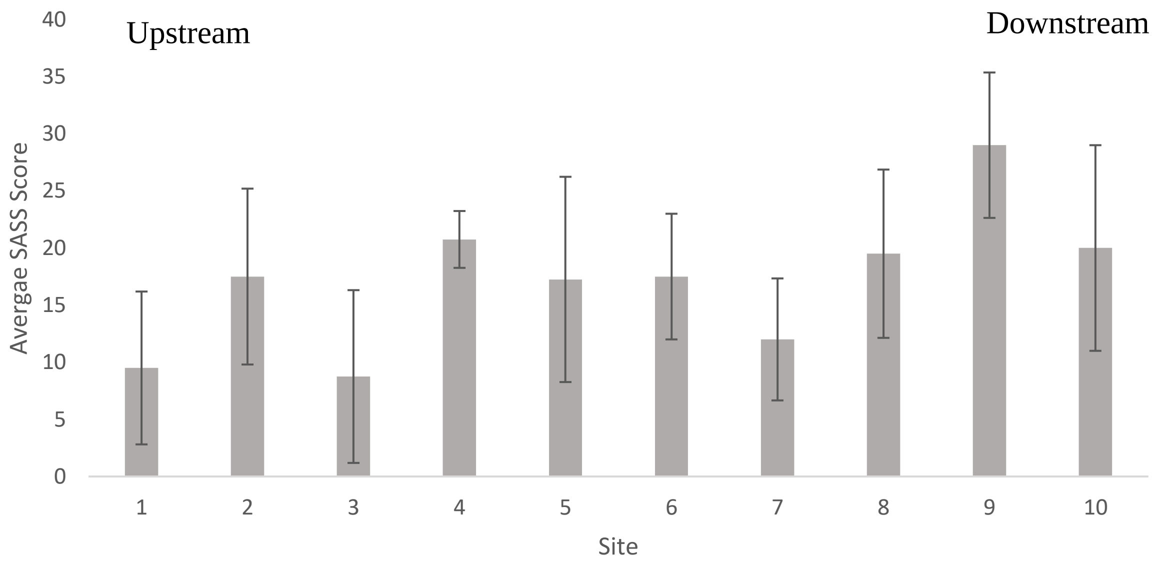

Figure 11: The Average SASS score found at 10 sites along the Braamfontein Spruit. Error bars denote standard deviation from the mean.

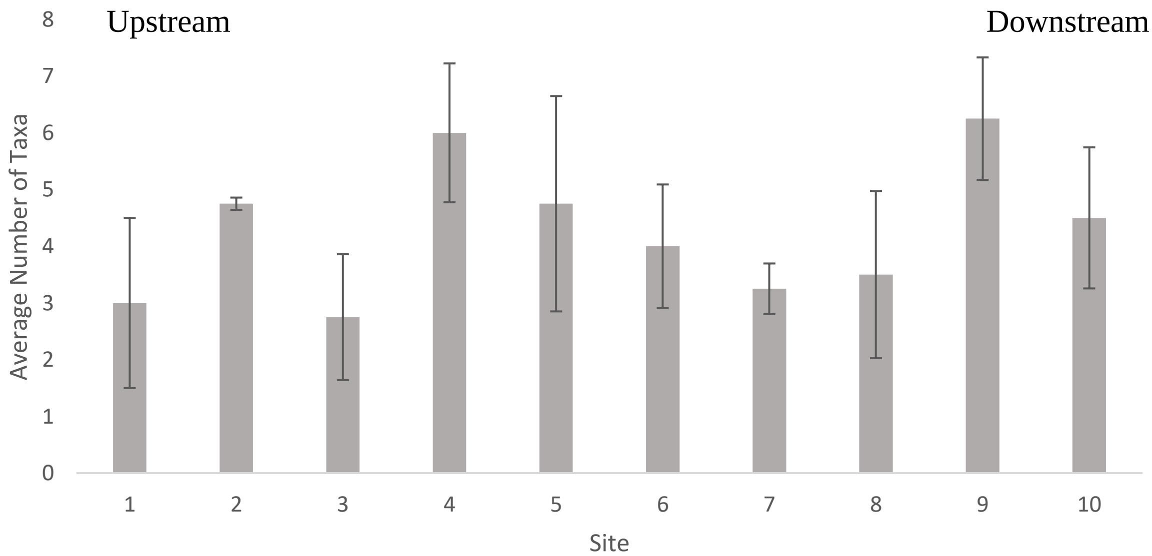

Figure 12: The average number of Taxa found at 10 sites along the Braamfontein Spruit. Error bars denote standard deviation from the mean.

Table 13: Taxa found at the sample sites. Numbers indicate frequency of taxa at the various sites (1 = found only on one day; 4 = found on all four days).

Site	1	2	3	4	5	6	7	8	9	10	Total/ Taxon
Taxa											
Chironimidae (Midges)	4	4	4	4	4	4	4	3	3	3	37
Oligochaeta (Earthworms)	1	2	1	2	2	1	2	2	3	1	17
Baetidae (Mayflies)	3	3	2	3	3	4	4	4	4	4	34
Coenagrionidae (Sprites and Blues)	0	2	0	2	2	1	0	0	3	0	10
Corixadae (Water boatmen)	0	1	0	2	2	0	0	0	0	1	6
Notonectidae (Backswimmers)	0	0	1	3	1	0	0	0	1	1	7
Pleidae (Pygmy backswimmers)	1	0	0	2	1	0	0	0	0	2	6
Hirudinae (Leeches)	1	1	2	0	1	0	1	1	1	2	10
Culicidae (Mosquitoes)	0	1	0	0	0	0	0	0	0	0	1
Tabanidae (Horse flies)	1	1	1	1	1	1	1	1	1	0	9
Lymnaeidae (Pond snails)	0	0	0	0	0	0	0	0	0	1	1
Dytiscidae/Noteridae (Diving beetles)	0	0	1	0	0	0	0	0	0	0	1
Gerridae (Pond skaters)	0	0	0	1	1	0	0	0	1	0	3
Simuliidae (Blackflies)	0	1	0	0	0	1	1	1	1	0	5
Gyrinidae (Whirligig beetles)	0	0	0	2	0	0	0	0	1	0	3
Velildae/M...Velildae (Ripple bugs)	0	0	0	0	0	1	0	0	0	0	1
Muscidae (House flies)	0	0	0	0	0	0	1	1	0	0	2
Philopotamidae (Caddisflies)	0	0	0	0	0	0	0	1	0	0	1
Potamonautidae (Crabs)	0	0	0	2	0	0	0	0	0	1	3
Cyprinus carpio (Common Carp) *	0	0	0	0	0	0	1	0	0	0	1
Total/ site	11	16	12	24	18	13	14	14	19	16	

***** while fish do not affect the SASS 5 score, they are a good indicator of water quality and as such were noted.

3.4 Relationships between variables

A General Linear Model showed that temperature, pH and velocity were not found to be significant predictors of number of taxa present, but the GLM did reveal a significant association between number of taxa found and conductivity ($F_{1,38}$=8.491; p=0.007), suggesting that conductivity may play a part in determining taxon numbers.

All variables exhibited negative relationships with regards to taxon numbers, where taxon numbers decreased as the tested variables increased (Figures 13, 14 and 15), however none of these relationships were significant (pH: r_{40} = -.13, p = 0.436 conductivity: r_{38} = -.02, p = 0.282), DO: r_{40} = -.19, p = 0.251). Velocity was positively correlated with stream width, where velocity increased with increasing width, however it was not significant (r_{40} = .20, p = 0.211). Velocity was negatively correlated with taxa numbers, showing taxa decreasing as velocity increased, although not significantly (r_{38} = -.18, p = 0.25) (Figure 16 and 17).

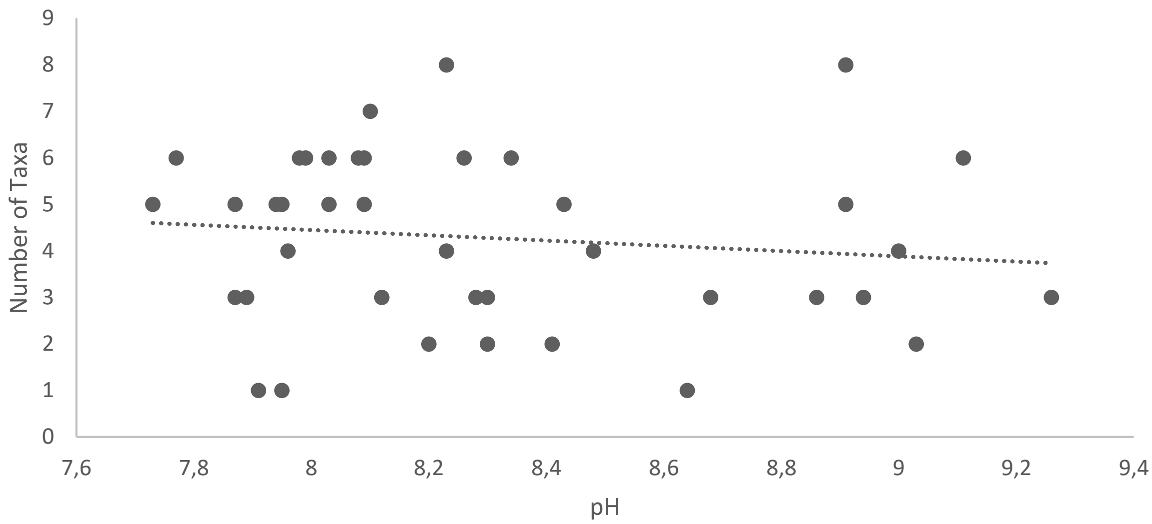

Figure 13: The relationship between pH levels and the number of taxa found. Linear regression line indicates the linear relationship between Taxa numbers and pH.

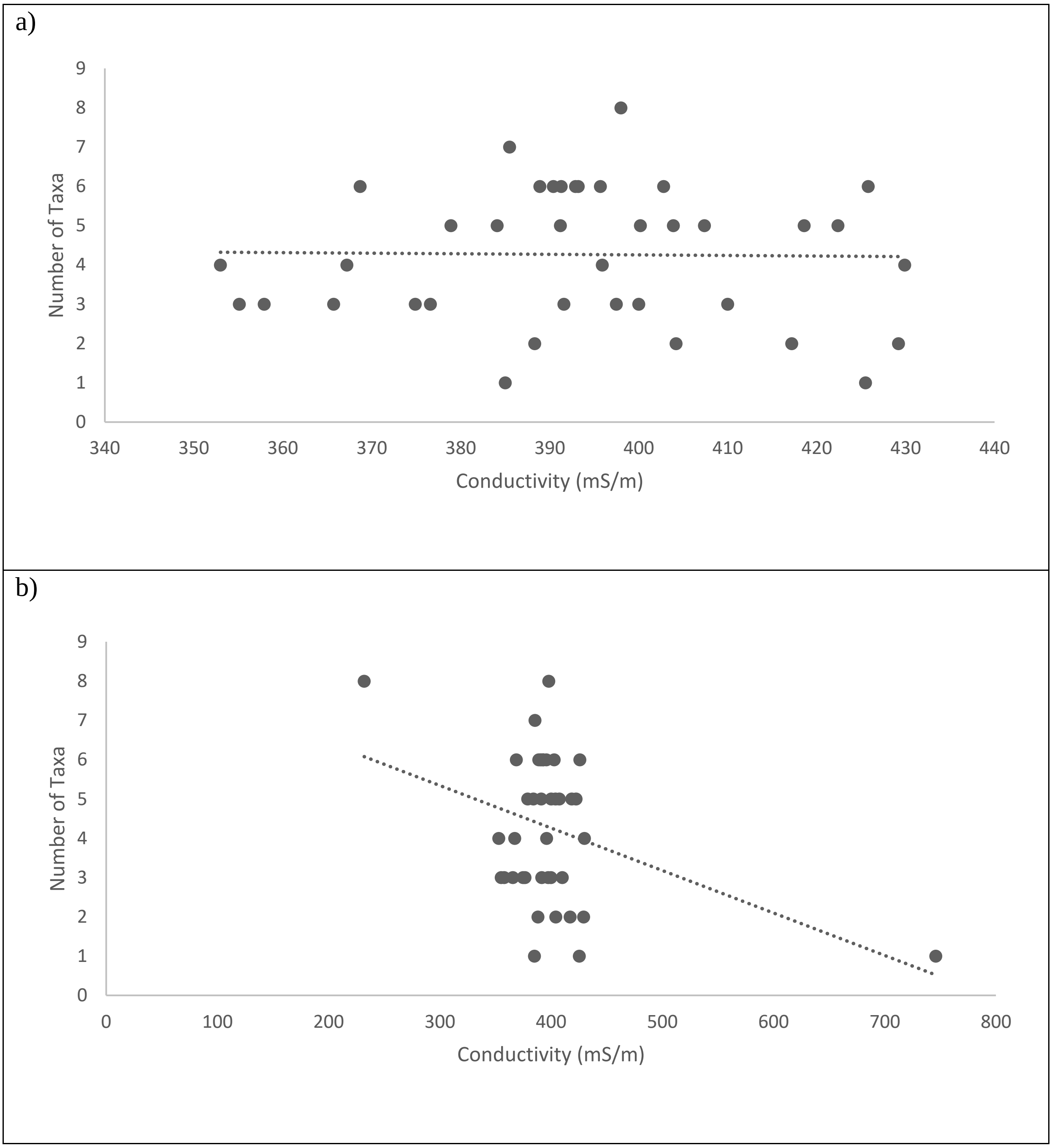

Figure 14: The relationship between conductivity and the number of taxa found. Figure 14a shows the relationship that exists when outliers are removed, whilst Figure 14b shows the significant relationship when outliers are included. Linear regression line indicates the linear relationship between Taxa numbers and conductivity.

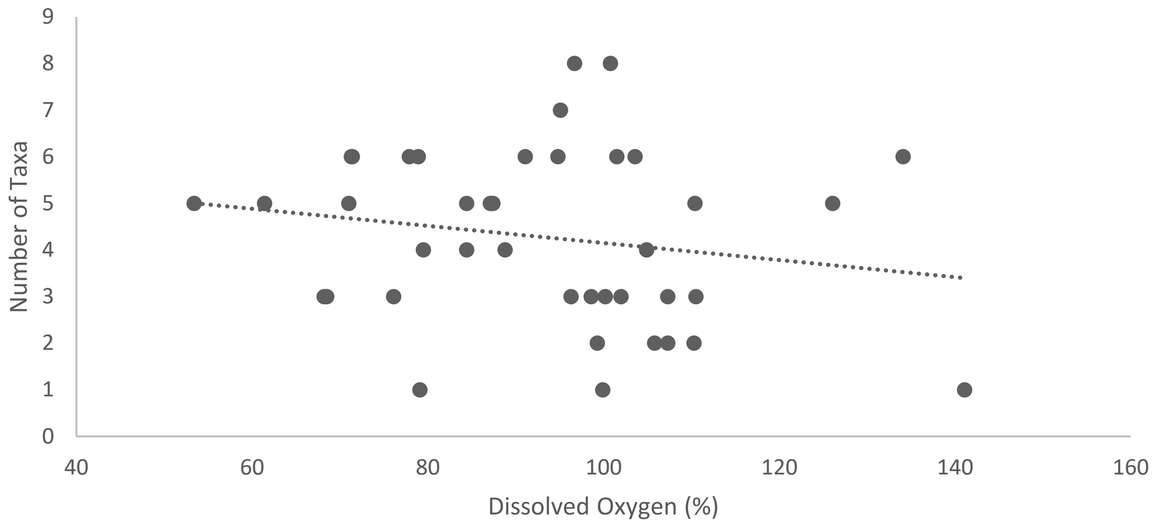

Figure 15: The relationship between dissolved oxygen and the number of taxa found. Linear regression line indicates the linear relationship between taxa numbers and dissolved oxygen.

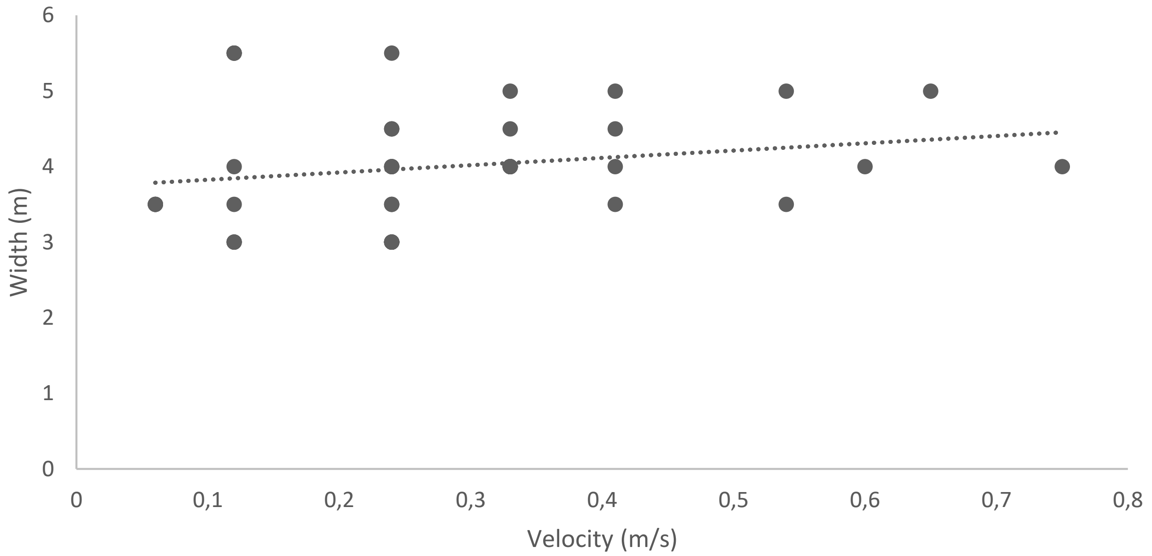

Figure 16: The relationship between velocity and stream width. Linear regression line indicates the linear relationship between velocity and stream width.

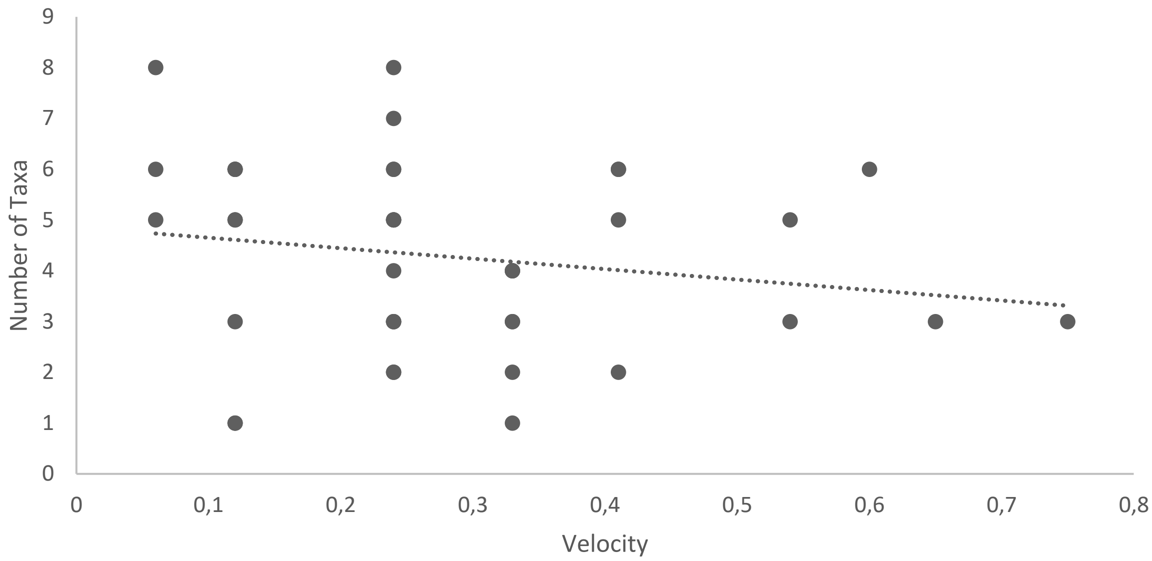

Figure 17: The relationship between velocity and number of taxa. Linear regression line indicates the linear relationship between velocity and number of taxa.

3.5 Vegetation Structure

Vegetation structure was found to consist predominantly of grass and significant differences in the amounts of grass ($p < 0.01$) and bare ground ($p < 0.01$) between sites were found (Figure 18) with grass dominating all sites and bare ground covering only small proportions of the area. All sites contained bare ground where cycling/ running paths occurred. Only three of the eight sites sampled contained shrubs within the sampled area.

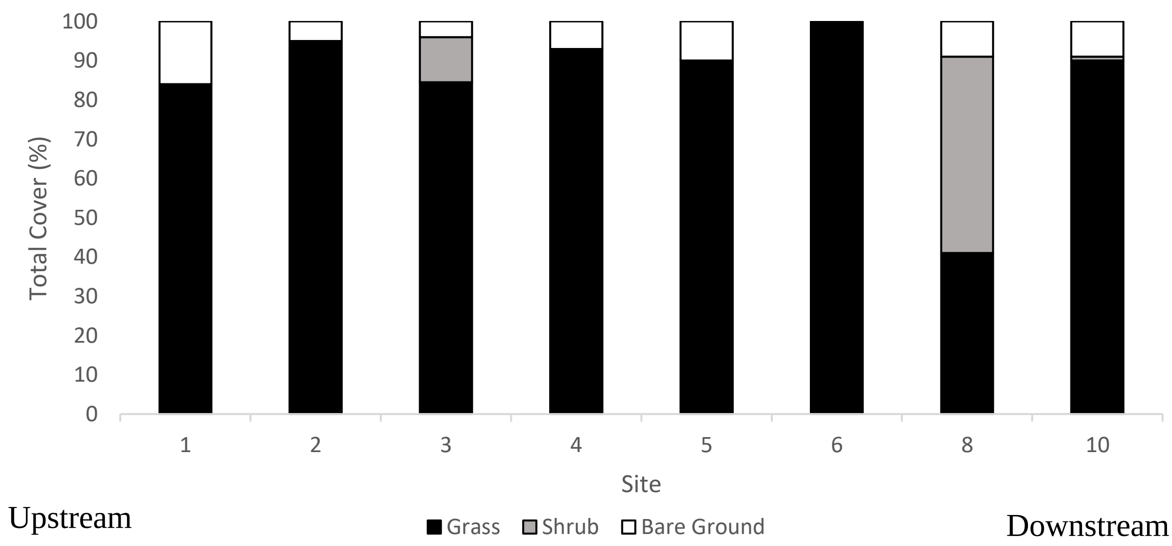

Figure 18: Vegetation structure at eight of the ten sample sites. Bars show the makeup of sampled vegetation being either grass, shrub or bare ground. Only ground cover was measured.

Chapter 4: Discussion

In this study I set out with the aim to assess the current condition of the Braamfontein Spruit, an urban river. The objectives were to (1) determine specific levels of certain variables, indicating current condition, (2) assess the impact the current condition is having on ecosystem services and (3) discuss recommendations for restoration. This chapter will provide a brief assessment of the results obtained as well as a discussion on the implications of these findings on key ecosystem services as well as potential restoration options and associated benefits.

4.1 Current condition of the Braamfontein Spruit

The Braamfontein Spruit is in poor condition. The urban to peri-urban pattern that the river follows is evident in the gradient of marginal improvement seen between sites 1 (urban) and 10 (peri-urban). The Braamfontein Spruit's source is located close to Johannesburg's city centre and the river flows towards more open residential areas (Stone 2009). Despite this evident gradient, there is also variation along the river as seen in the results. Furthermore, the assessment of the current ecological state of the Braamfontein Spruit and surrounding riparian area was successfully carried out and revealed the Braamfontein Spruit to be moderately to seriously/critically modified (ASPT between 3.9 and 4.9 as well as average IHI scores being within class C – moderately modified). Whilst the conditions are currently poor, the river holds great potential for improvement and with restorative measures could see great benefits, particularly from restored ecosystem services.

The Braamfontein Spruit is located in an urban setting, as such much of the surrounding land has been turned into residential and business zones. Every site was in close proximity to urban development, made up of either free-standing homes or estate developments, while some sites were impacted by other land-uses including golf-courses (upstream of site 1 and at site 9 and 10), a shopping centre (site 8), informal settlement (site 8) and business parks (site 9). Many sites are found in close proximity to main roads (roads receiving heavy traffic) including site 1 (Rustenburg Rd), site 5 (Jan Smuts Ave), site 8 (William Nicol Rd) and site 10 (Ballyclare Dr) while other sites occur close to roads that are frequently used by local residents only. Hoban and Tsunokawa (1997) noted that roads can degrade water quality through modifications to drainage, chemical and oil spills and chronic pollution, resulting in sedimentation and changes in biological activity both instream and along the banks of a river.

Among the many land-uses, parks and open green spaces are found at many points along the Spruit's bank. Whilst these parkland areas are useful for rainwater filtration, purification and slowing down the rate at which water reaches the river, they have come under pressure due to poor management (Harnik and Martin 2016). Additionally, the Spruit Trail, a foot path running the entire stretch of the river is, used frequently by cyclists, trail runners and other residents. The frequency with which the path is used has created exposed areas that increase sedimentation of the river through erosive action. Construction along rivers is known to be one of the leading causes of sedimentation (Houser and Pruess 2009) often caused due to land clearance (removal of vegetation). Clearance of vegetation can expose the water to more sun, increasing temperatures and reducing dissolved oxygen (Mesner and Geiger 2010). Exposed land also allows increased runoff to occur increasing the nutrient load in the river, which can cause excess algal growth which in turn affects pH and conductivity (Mathieu 2009). The Spruit was observed to have multiple construction zones (sites 1 -3) where vegetation has been cleared which affected water quality (low DO, high pH and conductivity). The marginal improvement in water quality from site 1 to 10 could be due to the pattern of land-uses seen along the river (construction zones – heavy residential- business) along with the many main roads crossing the river at different locations.

The Spruit has a number of channel modifications occurring at many of the sampled sites. These modifications include in-channel bridge supports, weirs, miscellaneous concrete slabs and reinforced banks/gabions that can alter water levels, flow/ velocity and clarity (Hooke 2015). With issues such as erosion and increased surface runoff (due to lack of vegetation) occurring more frequently (Ochoa *et al.* 2016), increasing sedimentation and water volume, the need for natural channels without modifications become more important. The river is already fairly narrow with the widest section sampled being 5.5 metres. Channel modifications and sedimentation further decrease channel width leaving narrow channels for large volumes of water to flow during storm events. Additionally, issues such as litter/ debris that clog sections of the river, exacerbate flooding during extreme rainfall events. This was seen in September of 2017 and again in March 2018 (Lindeque 2018).

While little information is available on how often the Spruit floods, periods of heavy rainfall cause the river to rise rapidly (impeded flow causing water to build up), break the banks along certain sections and carry objects (trees, litter, debris) from one area to another. These heavy rainfall and flood events drive erosion, not only of the bare ground surrounding the Spruit, but also of its banks. The impacts of this erosion include undercutting of banks, encroachment of the river on residential property and unstable ground which can result in risks to human lives (Chatterjee and Mistri 2013), displacement of populations (Rabbi *et al.* 2017) and economic losses (Baki 2014). A report by Bremner and Jonker (2017) on the Spruit found that impacts from erosion and sedimentation amongst other factors were cause for concern (as above) and should be addressed in order to improve the integrity of the system.

In the aftermath of the flood events, the impacts of pollution were clearly seen. Artificial and natural debris as well as vast amounts of litter were observed in the river course. The majority of the litter comes from illegal dumping that happens across the city (McCormick and Hoellein 2016). Pedestrians using the paths will also drop litter and other debris whilst walking along the river's edges. The pollution of the river is not just due to litter and debris with many informal settlements along rivers, home to large numbers of people, adding to the pollution problem (Vollmer *et al.* 2015). The Braamfontein Spruit is no exception. These informal settlements are frequented by individuals who are severely affected by poverty. As a result, they rely on the river for basic needs such as water, but also often use the river for washing, both of themselves and their clothes (Ward and Shackleton 2016). The substances (soaps etc.) they use cause pollution of the river system and introduce additional nutrients to the water that can have devastating effects (Dube *et al.* 2017). Along with these substances, sewage, both from informal settlements but also from poorly maintained infrastructure, seeps into the river. This not only causes water quality to deteriorate but poses a significant risk to human health.

The impact on water quality these land uses and channel modifications have had have also influenced the Braamfontein Spruit's IHI. Both the instream and riparian Index of Habitat Integrity scores (between 52,16 and 86,64) show the river course and its immediate surrounds to be moderately modified. There appears to be no marked improvement in IHI scores as the river moves from urban to peri-urban environments, suggesting impacted water running the length of the Braamfontein Spruit. The scores indicate that a loss of, or change in, natural habitat and biota has occurred, but basic ecosystem functioning appears predominantly unchanged. The highest scoring anthropogenic perturbations (i.e. those considered to be most harmful) for instream IHI were water quality, exotic macrophytes and solid waste (debris, litter etc.), whilst the highest scoring anthropogenic perturbations for riparian IHI were water quality, decrease in indigenous vegetation of the riparian zone, exotic vegetation encroachment and bank erosion (see Table 11). All of these factors affect the ability of the Spruit to provide ecosystem services and can impact other characteristics such as pH, conductivity and DO. The reason many of the perturbations exist may be due to the urban area the river is found in. Everard and Moggridge (2012), in their paper on rediscovering the value of urban rivers explain how urbanisation has degraded rivers to the point that they no longer provide the very services that caused the settlements to develop in the first place. Dyson and Yocom (2015) meanwhile explain that, although urban rivers and waterfronts are not usually designed to support biodiversity or ecosystem services, their potential for provision and support is great.

The Spruit's pH levels ranged from 7.89 to 9.26, which falls above the (Rand Water 2018b) target of 7 for streams and rivers. pH is logarithmic and as such any number above or below 7 is ten times more or less acidic than the previous value (Ophardt 2003). This places the Braamfontein Spruit in the basic range of the pH scale. pH fluctuates with precipitation, wastewater, harmful discharges (point source pollution) as well as carbon dioxide and can have a significant negative impact on the organisms within the river ecosystem. The observed pattern of the Spruit shows pH increasing from 7,9 at sites 1,2 and 3, and from site 4 to site 10 it increases from 8,1 to 8,6. The path the river follows moves from city (high impact from traffic and pollution) to residential (moderate impact from traffic and pollution) with interspersed green spaces (low impact from traffic and pollution). The lowest scores occurring at sites 1 through 3 seem to indicate that large green spaces (found at all three sites) may help reduce the harmful effects on pH, while the highest values at site 8 suggest that large shopping centres (8) could potentially increase pH through harmful stormwater runoff. The impacts of stormwater runoff from urban landscapes, including shopping centres, are covered in a handbook on stormwater management by the Massachusetts Department of Environmental Protection (1997) and a study by Botha (2005). Both agree that urban development causes increased sediment and pollution discharge that affects water quality, causing algal growth that can increase pH and lower dissolved oxygen.

The high pH values measured at site 10 may be due to algal growth which increases photosynthesis (pollution results in higher algal and plant growth (e.g. from increased temperature or excess nutrients), which in turn increases pH (Michaud 1991). Rand Water

(2018a) explains this process, saying that as river pollution increases, so do nutrient levels, increasing the growth of blue-green algae. With increasing algal blooms, pH increases, affecting water quality. Kawamura *et al.* (2015) found that pH below the natural state (taken to be 7.5) negatively impacted survival, growth, size distribution and carapace quality of the freshwater prawn *Macrobrachium rosenbergii*.

The river's dissolved oxygen levels ranged between 68.2 and 141.1% (dissolved oxygen readings can be greater than 100% as air saturation can occur in environmental water due the production of pure oxygen by photosynthetically-active organisms and/or due to non-ideal equilibration of dissolved oxygen between the water and the air above it; Environmental Protection Agency 1986). Rand Water (2018) considers 90% dissolved oxygen to be good with fluctuations occurring due to surface area, rapids (aeration of water) and groundwater seepage. Dissolved oxygen averaged close to or above 100% on sampling days one (106%), two (96%) and three (99%) while day four dropped to 69%, with all sites having below normal (90%) readings. Seven of the ten sample sites had readings over 100% on one or more sample days (site 6 = 1, sites 3,4,7 and 10 = 2, site 8 and 9 = 3) but only site 3 averaged over 100% for all four sampling days. The readings above 100% at sites 8 and 9 are likely due to the rapids located upstream of the sampling site that aerate the water (Mack 2003), while the other high readings are likely due to the shallow nature of the Spruit which keeps the water in constant atmospheric contact and allows constant diffusion or due to photosynthetic plants and algae that produce oxygen as a by-product (Schulz 2006). Dissolved oxygen that is too high or low can affect water quality and harm aquatic life (Wetzel 2001). Increased debris can lead to increased decomposition which in turn lowers the amount of dissolved oxygen as it is used up by microbes. Connolly, Crossland, and Pearson (2004) found that, while many macroinvertebrate assemblages can withstand hypoxic conditions (lack of sufficient oxygen) for short periods of time, most will die if subjected to such conditions for long periods of time. The United States Environmental Protection Agency (1986) explained that fish can undergo a process known as gas bubble disease, with significant mortality rates, if DO remains in a high state of between 115 -120% for too long. While many sites had values over 100%, only one site on one day (site 3, day 1) was above 115% making it unlikely that fish, while few, would undergo such a process.

Conductivity was determined to be between 232 and 746ms/m, which is well outside what Rand Water consider safe at 150ms/m (Rand Water 2018b). The higher conductivity of the river may be due to a higher number of ions in the water, caused by the underlying geology, groundwater inflow, runoff (increase in chloride, phosphate and nitrate ions entering the river; Botha 2005) or pollution from waste water/sewage (Daniel *et al.* 2002). Azrina *et al.* (2006) showed that elevated conductivity levels can cause a decrease in macroinvertebrate species richness and diversity. The conductivity of the river was high but fairly constant between sites and across days which could be attributed to low flow and water levels experienced during the time of year the river was sampled. Conductivity is considered to be an early indicator of change in a river ecosystem that can be detrimental to water quality (Environmental Protection Agency 2012). It can often be used as an indicator that pollution from activities such as dumping, mining and construction are harming freshwater ecosystems (Das *et al.* 2005). In the case of the Braamfontein Spruit, irresponsible dumping, waste water pollution and urban development are the likely causes of increased conductivity. While often localised to certain points along the river, flowing water carries these contaminants along the length of the river, which may explain the fairly uniform conductivity profile.

A report generated for the Water Research Commission (WRC) by Dube *et al.* (2017) found that the river ecosystems in South Africa, Gauteng in particular, are degraded past their natural thresholds and that the most significant cause of degradation was human settlements along the urban to peri-urban gradient. Walsh and Wepener (2009) noted high nutrient levels from point source introductions as well as urban impacts on the Crocodile River and this, as with the Braamfontein Spruit, can lead to altered variables that harm the river's ecosystem. Gauteng's rivers are under continued threat from wastewater pollution and contaminants and with no treatment plans in place this poses great risks to the river quality and human health (Showers 2002; Wang *et al.* 2014).

Fourie, Thirion, and Weldon (2014) and Dallas (1995) explain that variables such as pH, conductivity, dissolved oxygen and temperature can impact water quality, which in turn can affect SASS5 scores, and ultimately ASPT scores used for assessing the ecological state of rivers. These variables impact the growth, survival rate and breeding success of organisms and factors such as shade, habitat availability and food resources are also said to be driving factors determining macroinvertebrate assemblages (Lenat and Crawford 1994; Quinn *et al.* 1997). Flores and Zafaralla (2012), in their study on the Mananga River in the Philippines confirmed that variables such as pH, conductivity and dissolved oxygen influence the species composition of rivers, and given the variables along the Spruit, may explain the poor composition found here. The Spruit's ASPT ranged between 2 and 8.5 which reflects the poor quality of the water as rivers are considered to be in good condition if ASPT scores are above

7 (Rand Water 2018b). Whilst there was one score above this (day 2, site 8- Figure 2), all other measurements were below the level considered to be of good quality.

ASPT relates to the kind of invertebrate taxa that occur in the river which relates back to environmental quality. An environment that is in poor condition (bad water quality) will only be able to support the hardiest of organisms, which have low quality scores. These low-quality scores (1-6) in turn yield poor ASPT scores as no sensitive (high quality scores of 8 onwards) invertebrate taxa can survive. The Spruit had many low scoring, hardy macroinvertebrates such as *Oligochaeta* (Earthworms), *Chironomidae* (Midges) and *Notonelidae* (Backswimmers) to name a few, which produced low ASPT scores. In a study on the Hartebeespruit, Mulders (2015) found that of the nineteen families sampled, *Oligochaeta*, *Chironomidae* and *Hirudinae* (leeches) accounted for 80% of the total macroinvertebrates sampled. The study also found that chemical and physical surface water parameters influenced macroinvertebrate assemblages, much like in this study, where similar results were found, including the trend of increasing macroinvertebrate values (ASPT) from upstream to downstream sample sites. A similar pattern of improvement along a water course was found by Steeves (2016) when studying the Santa Maria River, in California, USA. It was observed that, as the river flows through areas of differing land-uses, the macroinvertebrate assemblages changed, decreasing through urban and agricultural areas compared to the more natural areas. This study showed that within urban areas, macroinvertebrate assemblages remain constant, fluctuating slightly but never enough to show improvement. Compared to natural streams, urban streams are severely degraded and of poor quality. Species composition, being the identity of living organisms in a given environment, is important for ecological and management processes at sites and can help indicate the state of river biotopes.

4.2 Vegetation structure along the Braamfontein Spruit

The Braamfontein Spruit is lined on either side by a number of open parks, small holdings, golf courses and areas of transition (areas that connect the various parks together but are not necessarily accessible by people). The vegetation composition along the Spruit is fairly uniform with the largest portion of vegetation being grass. Few shrubs and trees are found along the length of the river with trees being sparsely distributed along the Spruit (often in the form of sections with clumps of large trees) and are found close to the banks of the river. While many of these trees have anchored roots that hold soil together, flooding of the river, along with the aforementioned modifications and impacts have resulted in severe impacts. Many of the river's banks have been undercut or severely washed away, leaving what remains of the banks unstable and prone to further erosion (Gurnell 2014). Maintenance of the many green spaces along the Spruit is limited, often only occurring at large parks or on a limited maintenance schedule (Johannesburg City Parks and Zoo 2018). This allows many areas along the Spruit to become overgrown, creating hazards and safety concerns for the public. Golf courses are known to be a concern for rivers in general, often being built alongside in an effort to improve the setting in which the game is played. With so much emphasis being placed on perfect fairways and manicured greens, strong fertilisers and large volumes of water are often used to keep fields of play looking flawless (Bramble, Jones, and Govus 2009). Fertilisers can cause eutrophication (addition of nutrients to aquatic ecosystems) which can lead to excess algal growth issues, affecting variables such as dissolved oxygen (Das *et al.* 2005). This was seen at sites 9 and 10 which were found along The River Club golf course in Sandton. The vegetation along the Braamfontein Spruit plays an important role in maintaining water quality, but with both point and nonpoint pollution occurring this appears to be ineffective.

4.3 Impact of conditions on ecosystems and their services

The Braamfontein Spruit is an important ecosystem for Gauteng. The ecosystem services the Spruit provides, and has the potential to provide, make it an invaluable asset to the city. Failure to protect our river ecosystems means failure to protect our ecosystem services, which in an urban environment are vitally important (Gómez-Baggethun and Barton 2013). If urban river systems become so degraded that they no longer serve any function or provide services, we will need to provide the same services/ functions at additional costs (Grimm *et al.* 2008). It is for this reason that the Spruit needs to be protected from further deterioration and destruction.

The Spruit is a river that provides multiple ecosystem services that the public derive benefit from. It is important for a number of provisioning services, particularly water for domestic use and food. Many poverty affected individuals rely on the river for daily water and individuals were observed fishing whilst sampling occurred. The poor water quality puts these provisioning services under pressure and increases the risk of disease proliferation and spread, reduces the number of species that are able to live in it and increases the likelihood of water-borne pathogens being spread to those who rely on the water for daily living (Han *et al.* 2016). Urban rivers are under increasing pressure from urban expansion and already they are unable to cope due to their degraded state.

The Spruit's regulating services are some of the most important services for the surrounding urban areas. The river and its surrounding riparian areas, along with the multiple green spaces, are important climate control mechanisms that can assist in mitigating the impacts of extreme weather events. Reduction in the heat island effect through evaporative cooling and transpiration of plants help maintain a comfortable climate for urban dwellers. Rivers and green spaces provide increased flood attenuation through reduced surface runoff and infiltration (Kim *et al.* 2016; Zhang *et al.* 2015). However, the collapse of river banks during floods can change the shape of a river which can lead to flow issues, affecting the river's capacity for flood attenuation. A study by Muis *et al.* (2015) in Indonesia found that between 2000 and 2030, river flooding in urban areas could increase by as much as 76%, making adaptation measures vital for urban areas. Furthermore, erosion and collapse of river banks can increase the width of a river, creating shallower storage areas for water. This can lead to problems as climate change increases the risk of drought conditions in many cities (Mukheibir and Ziervogel 2007). With less water being stored, less evaporative cooling can take place and the effects of extreme heat events will be noticeable in the city (Hathway and Sharples 2012).

Supporting services are also provided by the Spruit and although important, are impacted and a cause for concern. The river itself provides habitat for macroinvertebrates, fish and other mammal species but due to its current condition is not able to support good biodiversity. This affects species composition and makes maintaining genetic diversity difficult. Species composition and diversity are required to maintain ecosystem services that support society (Duffy 2009). Losing the ability to support biodiversity results in diminished ecosystem services provided by rivers. Culturally, the Spruit is used as a place of recreation and learning and provides an area for spiritual experience and sense of place for many people. Unfortunately, this also puts these individuals at risk as they come into contact with the water that is of poor quality. Those who use the Spruit for recreational purposes (running, cycling, dog walking etc.) are also at risk.

Overall, the degradation of the Spruit's ecosystem services is linked to aspects such as land-use change, pollution (both point and non-point), urban development, surface runoff and poor maintenance. This has resulted in poor water quality, indicated by the collected variables (pH, DO, conductivity) and macroinvertebrate assemblages (ASPT), resulting in decreased biodiversity (Bremner and Jonker 2017), pest proliferation and spread, as well as increased risk of diseases (cholera and bilharzia)(du Plessis 2017). Finally, the ability of the Spruit to minimise the damage from and effects of extreme weather events (heavy rainfall, flooding and severe heat) is diminishing, which could lead to damaged infrastructure and threat to human health. The possibility that the Spruit has lost its ability to provide resilience to climate change could lead to economic losses as alternative adaptations become necessary.

4.4 Recommendations for restoration of the Braamfontein Spruit

Based on the assessment of the Braamfontein Spruit and its surrounding riparian zone, a number of actions can and should be taken in an attempt to restore the river system and thereby improve the provision of ecosystem services and increase resilience to change. It does however mean that both the degraded ecosystem and the degrading actions need to be addressed simultaneously, a challenge Dube *et al.* (2017) reported, explaining that through restoring the riparian zones and improving the state of the river itself, a more functional state may be reached, one that is acceptable and sustainable.

In order to ensure good service provision and resilience to climate change, measures need to be taken that will ensure habitat diversity, good means of velocity control and bank stabilisation to help create stable and functional systems. Both the river and riparian zones need to be sufficiently cleared of litter and debris (natural and artificial) such as fallen trees and chunks of concrete. Clearing this debris and litter should promote plant growth which will help stabilise the river banks (Bertoldi *et al.* 2015) as well as decrease the volume of water that runs off the surface into the river during heavy rainfall events, decreasing the risk of flooding. Erosion control is essential for river flow and bank stabilisation. A bank that is unstable can cause shifts in flow patterns that can affect flood attenuation abilities of the river. In areas where erosion is too severe or happens often regardless of mitigation methods, barriers such as retaining walls can be built (Matthews 2016). This has already been done in some areas along the Braamfontein Spruit. While unnatural, these walls can be built in such a way that they mimic the river's natural flow and can include hardy vegetation that will grow to cover them, making them look more natural (Rossi 1990).

The flow of a river can affect a number of things such as habitat characteristics, acquisition of resources, dispersal of organisms, competition and predation of and by organisms (Hart and Finelli 1999). Fast flowing rivers with little to no slow flowing areas can cause organisms to be swept away, failing to establish along the river. To prevent this from happening, natural riffles or pools can be created by strategically placing rocks and stones in the water current (Palmer and Hondula 2014). This will create environments in which invertebrates and vertebrates alike can survive. The creation of 'rest spots' should promote the expansion of fish, frog and even otter populations, which are known to have occurred along the Braamfontein Spruit (Fourie 2015).

Artificial surfaces surrounding the river make it easier for these pollutants to enter the river and with no wetlands along the river it means the substances are able to travel the full length of the river. Reducing runoff through creation of natural vegetation strips along key zones as well as promotion of native plant species (this will also improve IHI scores of the river) will help slow down and filter these harmful substances that get washed into the river during heavy storm events. Implementing restorative measures should create a stable and functional river and a riparian ecosystem that will slow, aerate and filter water, improving flood attenuation, provide much needed habitat for invertebrates and vertebrate species alike, improving biodiversity and help ensure a functioning food web that will sustain these organisms.

A study conducted in Finland by Polizzi *et al.* (2015) found that when river systems were regenerated, they increased recreational ecosystem service values by between €40 and €144 per person per year. They also noted that this value would extend to include all other ecosystem services as the restoration should not deteriorate any other services (provisioning, regulating and maintenance services). River restoration whilst aesthetically appealing can also have a large financial benefit attached for those involved and the residents alike (Weber and Stewart 2009). The argument that urban rivers need to be restored is thus great and the Braamfontein Spruit is an ideal candidate in Gauteng.

4.5 Limitations to study

While the study yielded good results there were limitation. In this study, only invertebrate taxa were analysed for indicating water quality. The sampling for the study was time sensitive as it needed to be conducted before the rainy season (it is advised not to measure after rain has occurred and Johannesburg frequently has storms), thus only four sampling days occurred. More sample days could have allowed for monthly and seasonal variation analyses. Access to sites was another limiting factor and while the Braamfontein Spruit is a public river and access to it is not restricted, getting to sample sites and into the river was difficult at a number of potential sites. Coupled with access was that of safety concerns. Parts of the Braamfontein Spruit have become informal settlements and a number of incidents have occurred along it in the past. As such, sampling could only take place when a large group of volunteers were available. Lastly, in order to obtain more measurements would require further exposure to water that is a high risk for Bilharzia. In order to minimize the risk only the necessary samples were taken.

4.6 Recommendations and future studies

While the study gave an idea of the overall health of the Braamfontein Spruit using key indicators a number of future studies could be conducted to complement this study.

Past studies have noted that a number of vertebrate species, including otters have been known to frequent the Braamfontein Spruit. The populations of such vertebrate and fish species should be assessed further to gauge the impact that the river quality has on them. Not only would this be a good complimentary study on the habitat quality that is provided but would also provide a set of indicators for vertebrate and fish species that could be used at later stages to determine if habitat quality is improving, thus supporting more or larger populations.

The hope is that through development of an effective plan, rivers and green spaces in urban environments that have been degraded to large degrees can be restored or regenerated to improve the natural environments that we as residents interact with on a daily basis without even realizing it.

4.7 Conclusions

I investigated the quality of urban rivers and green spaces along one of Johannesburg’s most well-known green belts, the Braamfontein Spruit. I showed that firstly, the river and its surrounding riparian zone were of poor quality and that actions need to be taken to improve them. While this is not a novel finding it is of importance to a city such as Johannesburg. Secondly, the ecosystem services that we derive from the Braamfontein Spruit, are under immense pressure and have been severely degraded. Lastly, the study showed that the Braamfontein Spruit is a candidate for regeneration and that the right actions could restore some of its natural functions. This is however not possible if the actions causing the degradation do not cease. As such it would not simply be a case of cleaning the river and riparian zones but would include actions to mitigate harmful human actions.

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Appendices

Appendix 1 – Recreated from original

River Health Programme: FILED-DATA SHEETS

Assessor Name(s)			
Organisation		Date	/ /

NB: An explanation of the terminology used in the field-data sheets in the associated River Health Programme – Site Characterisation field-manual.

SECTION A: SITE INFORMATION (to be filled in before or during initial visit to site)

1. GENERAL SITE INFORMATION

<table>
<tr><td colspan="8">Site information -Assessed at the site</td></tr>
<tr><td>RHP Site Code</td><td colspan="2"></td><td colspan="2">Project Site Number</td><td colspan="3"></td></tr>
<tr><td>River</td><td colspan="2"></td><td colspan="2">Tributary of</td><td colspan="3"></td></tr>
<tr><td>Latitude and Longitude co ordinates</td><td colspan="7"></td></tr>
<tr><td>Site Description</td><td colspan="7"></td></tr>
<tr><td>Map Reference (1: 50 000)</td><td colspan="2"></td><td>Site length (m)</td><td></td><td>Altitude (m)</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Longitudinal Zone</td><td>Source zone</td><td>Mountain headwater stream</td><td>Mountain stream</td><td>Transitional</td><td>Upper foothill</td><td>Lower foothill</td><td>Lowland river</td></tr>
<tr><td>Rejuvenated cascades (gorge)</td><td>Rejuvenated foothill</td><td>Upland floodplain</td><td colspan="2">Other:</td><td colspan="2"></td></tr>
<tr><td>Hydrological Type: “natural”</td><td>Perennial</td><td>Seasonal</td><td>Ephemeral</td><td colspan="4"></td></tr>
<tr><td>Hydrological Type: “present-day”</td><td>Perennial</td><td>Seasonal</td><td>Ephemeral</td><td colspan="4"></td></tr>
<tr><td>Associated Systems:</td><td>Wetland</td><td>Estuary</td><td>Other:</td><td colspan="4">Distance:</td></tr>
<tr><td>Additional comments:</td><td colspan="7"></td></tr>
</table>

Desktop/ spatial information – data used for classifying a site and subsequent querying of data			
Political region		Water Management Area	
Ecoregion I		Ecoregion II	
Secondary Catchment		Quaternary Catchment	
Water chemistry Management Region			
Vegetation Type		Geological Type	
Contour Range (m): From:		to:	
Source distance (km)		Stream order	

Rainfall Region	Summer	Winter	Aseasonal	Other:

DWAF Gauging Station	Yes	No	Code:		Distance Upstream		Or Downstream	

2. LOCATION DETAILS

Sketch a map of the site showing the following details: scale, north, access to site, roads, bridges/crossings, gauges/ instream barriers, buildings, flow direction. Record the following:

Location and Landowner Detail:	Contact No:		
	Notify Owner?	yes	no
Permit Required?	yes	no	Details:
Key Needed?	yes	no	Details:
Farm Name:	Farm Reg. Code:		
Comments:			

SECTION B. CATCHMENT CONDITION AND LAND USE (to be checked on each visit to site)

Assessor Name(s)			
Organisation			
Date	/ /	Time	

1. PHOTOGRAPHIC RECORD

		Photograph Number	Comments
Photographs	Upstream		
	Downstream		
	Bank to bank		
	Specific features		

2. CONDITION OF LOCAL CATCHMENT – Rate extent (land-use) or impact on a scale of 0 to 4: 0 – none; 1 – limited; 2 – moderate; 3 – extensive; 4 – entire. Indicate level of confidence: High (H); Medium (M) or Low (L).

Land-use	**Within riparian zone**	**Beyond riparian zone**	**Potential impact on River Health**	**Level of confidence (H, M, L)**	**Comments (e.g. distance upstream/downstream, time since disturbance, etc.)**
Afforestation-general					
Afforestation – felled area					
Agriculture – crops					
Agriculture – livestock					
Agriculture – irrigation					
Alien vegetation					
Aquaculture					
Construction					
Roads					
Impoundment (weir/ dam)					

Industrial Development					
Urban Development					
Rural Development					
Informal settlement					
Recreational					
Sewage Treatment Works					
Nature conservation				N/A	
Wilderness Area				N/A	
Litter/ Debris					
Disturbance by wildfire					
Other:					

3. CHANNEL CONDITION (In-channel and bank modifications) – Rate impacts on a scale of 0 to 4: 0 – none; 1 – limited; 2 – moderate; 3 – extensive; 4 – entire

In-channel and bank modifications	**Upstream**		**Downstream**		**Comments**
	Impact score	**Distance**	**Impact score**	**Distance**	
Bridge – elevated; in channel supports					
Bridge – elevated; side channel supports					
Causeways/ low-flow bridges					
Bulldozing					
Canalisation – concrete/ gabion					
Canalisation – earth/ natural					
Gabions/ reinforced bank					
Fences – in channel					
Gravel, cobble and/ or sand extraction					
Roads in riparian zone – tar					
Roads in riparian zone – gravel					
Dams (large)					
Dams (small)/ weir					

Other:			

4. INDEX OF HABITAT INTEGRITY – Rate impacts on a scale of 0 to 25: 0 – none, 1 to 5 – limited, 6 to 10 – moderate, 11 to 15 – extensive, 16 to 20 – extreme, 21 to 25 – critical (see manual for explanation). Indicate level of confidence: High (H); Medium (M) or Low (L).

CRITERION	**Score**	**Level of confidence (H, M, L)**	**Comment**
INSTREAM			
Water abstraction (presence of pumps, irrigation etc.)			
Extent of inundation			
Water quality (clarity, odour, presence of macrophytes etc.)			
Flow modifications			
Bed modification (bulldozing of bed)			
Channel modification			
Presence of exotic macrophytes			
Presence of exotic fauna (e.g. fish)			
Presence of solid waste			
RIPARIAN ZONE			
Water abstraction (presence of pumps, irrigation etc.)			
Extent of inundation			
Water quality (clarity, odour, presence of macrophytes etc.)			
Flow modifications			
Channel modifications			
Decrease of indigenous vegetation from the riparian zone			
Exotic vegetation encroachment			
Bank erosion			

SECTION C: FIELD-BASED DATA FOR EACH SITE VISIT

1. GENERAL SITE VISIT INFORMATION

Assessor Name(s)			
Organisation			
Date	/ /	Time	

Water level at time of sampling – tick appropriate category

Dry	Isolated pools	Low flow	Moderate flow	High flow	Flood

Velocity and discharge estimates – optional

Horizontal distance (m)					
Velocity (ms^{-1})					
Depth (m)					
Water Surface Width (m):		Discharge (m^3s^{-1}):			

Significant rainfall in the last week? – i.e. likely to have raised the water level

Yes	No	Comment:

Canopy Cover – tick appropriate category

Open	Partially Open	Closed	Comment:

Impact on stream habitat – Rate impacts on a scale of 0 to 3: 0 – no impact; 1 – limited impact; 2 – extensive impact; 3 – channel blocked

	Score	**Source: local/upstream**
Coarse woody debris		
Other:		

Water chemistry data – Recording of the *in-situ* measurements is also included in the SASS5 data-sheet – please complete here if doing the full RHP assessment. Instruments should be positioned in the clearly-flowing points on the river where possible.

Instruments in fast flow?	Yes	No	If no, where:	
Samples collected?	Yes	No	Date sent for analysis?	
Water filtered?	Yes	No	Volume filtered (mL):	
Samples frozen?	Yes	No	Other preservation?	
Name of institution to which samples were sent:				

Variable	**Value**	**Units**
pH		
Conductivity		
Temperature		
Dissolved Oxygen ($mgLl^{-1}$)		
Percentage O_2 Saturation		

Water Turbidity – tick appropriate category

Clear	Discoloured	Opaque	Silty	Comment:
Turbidity (if measured (NTUs))				
Secchi Depth (m)				

2. STREAM DIMENSIONS – estimate widths and heights by ticking the appropriate categories; estimate average depth of dominant deep and shallow water biotopes.

(m)	< 1	1-2	2-5	5-10	10-20	20-50	50-100	>100
Macro-channel width								
Active-channel width								
Water surface width								

Bank height – Active channel			
(m)	**< 1**	**1-3**	**>3**
Left Bank			
Right Bank			

Dominant physical biotope	Average Depth (m)	Specify physical biotope type
Deep-water (>0.5m) physical biotope (e.g. pool)		
Shallow-water (<0.5m) physical biotope (e.g. riffle)		

3. SUBSTRATUM COMPOSITION – Estimate abundance of each material using the scale: 0- absent; 1- rare; 2- sparse; 3- common; 4-abundant; 5-entire

Material	Size class (mm)	Bed	Bank
Bedrock			
Boulder	>256		
Coble	100 – 256		
Pebble	16 – 100		
Gravel	2 – 16		
Sand	0.06 – 2		
Silt/mud/clay	<0.06		

Degree of embeddedness of substratum (%)
0-25
26-50
51-75
76-100

4. INERTEBRATE BIOTOPES (present at a site compared to those actually sampled)

Summarised river make up: ('pool'=pool only; 'run' only; 'riffle/rapid' only; '2mix'=2 types, '3mix'=3 types)				
pool	run	Riffle/rapid	2 mix	3 mix

Rate abundance of each SASS and specific biotope present at a site using the scale: 0- absent; 1- rare; 2- sparse; 3- common; 4- abundant; 5- entire. Add additional biotopes if necessary.

		Specific Biotope					
SASS Biotope	Rating		Rating		Rating		Rating
Stones in current		Riffle		Run		Boulder rapid	
		Chute		Cascade		Bedrock	
Stones out of current		Backwater		Slackwater		Pool	
		Bedrock					

Marginal vegetation in current		Grasses		Reeds		Shrubs	
		Sedges					
Marginal vegetation out of current		Grasses		Reeds		Shrubs	
		Sedges					
Aquatic vegetation		Sedges		Moss		Filamentous Algae	
Gravel		Backwater		Slackwater		In channel	
Sand		Backwater		Slackwater		In channel	
Silt/mud/clay		Backwater		Slackwater		In channel	

Appendix 2 – recreated from original

Table 3: Descriptions of criteria used in the IHI assessment (Kleynhans 1996).

Criterion	Description
Water Abstraction	Direct abstraction from within the specified river/ river reach as well as upstream (including tributaries) must be considered (excludes indirect abstraction by for example exotic vegetation). The presence of any of the following can be used as indication of abstraction: cultivated lands, water pumps, canals, pipelines, cities, towns, settlements, mines, impoundments, weirs, industries. Water abstraction has a direct impact on habitat type, abundance and size; is implicated in flow, bed, channel and water quality characteristics; and riparian vegetation may be influenced by a decrease in water quantity.
Extent of inundation	Destruction of instream habitat (e.g. riffle, rapid) and riparian zone habitat through submerging with water by, for example, construction of an in-channel impoundment such as a dam or weir. Leads to a reduction in habitat available to aquatic fauna and may obstruct movement of aquatic fauna; influences water quality and sediment transport.
Water quality	The following aspects should be considered; untreated sewage, urban and industrial runoff, agricultural runoff, mining effluent, effects of impoundments. Ranking may be based on direct measurements or indirectly via observation of agricultural activities, human settlements and industrial activities in the area. Water quality is aggravated by a decrease in the volume of water during low or no flow conditions.
Flow modification	This relates to the consequences of abstraction or regulation by impoundments. Changes in temporal and spatial characteristics of flow such as an increase in duration of low flow season can have an impact on habitat attributes, resulting in low availability of certain habitat types or water at the start of the breeding, flowering or growing season.
Bed modification	This is regarded as the result of increase input of sediment from the catchment or a decrease in the ability of the river to transport sediment. The effect is a reduction in the quality of habitat for biota. Indirect indications of sedimentation are stream bank ad catchment erosion. Purposeful alteration of the stream bed, e.g. the removal of rapids for navigation is also included. Extensive algal growth is also considered to be bed medication.
Channel Modification	This may be the result of a change in flow which alters channel characteristics causing a change in instream and riparian habitat.

	Purposeful channel modification to improve drainage is also included.
Presence of exotic aquatic fauna	The disturbance of the stream bottom during exotic fish feeding may influence, for example, the water quality and lead to increase turbidity. This leads to a change in habitat quality.
Presence of exotic macrophytes	Exotic macrophytes may alter habitat by obstruction of flow and may influence water quality. Consider the extent of infestation over instream area by exotic macrophytes, the species involved and its invasive capabilities.
Solid waste disposal	The amount and type of waste present in and on the banks of a river (e.g. litter, building rubble) is an obvious indicator of external influences on stream and a general indication of the misuse and mismanagement of the river.
Decrease of indigenous vegetation from the riparian zone	This refers to physical removal of indigenous vegetation for farming, firewood and overgrazing. Impairment of the riparian buffer zone may lead to movement of sediment and other catchment runoff products (e.g. nutrients) into the river.
Exotic vegetation encroachment	This excluded natural vegetation due to vigorous growth, causing bank instability and decreasing the buffering function of the riparian zone. Encroachment of exotic vegetation leads to changes in the quality and proportion of natural allochthonous organic matter input and diversity of the riparian zone habitat is reduced.
Bank erosion	A decrease in bank stability will cause sedimentation and possible collapse of the river bank resulting in a loss or modification of both instream and riparian habitats. Increased erosion can be the result of natural vegetation removal, overgrazing or encroachment of exotic vegetation.

Appendix 3 – Recreated from original

5. SASS Version 5 Score Sheet – Note: do not complete details (shaded area) on SASS sheet if doing a full RHP assessment

Date: RHP Site Code:	/ /			(dd.ddddd)	**Biotopes Sampled**	Rating (1 – 5)	Time (min)
Collector/ Sampler:		Grid ref (dd mm ss.s):			Stones in Current (SIC)		
River:		Lat: S			Stones out of Current (SOOC)		
Level 1 Ecoregion:					Bedrock		
Quaternary		Long: E		m	Aquatic Veg		
Catchment: Site Description:		Datum (WGS84/Cape): Altitude (m): Zonation:			MargVeg in current		
	Temp	Cond (mS/m):			MargVeg out of Current		
	pH	Clarity (cm):			Gravel		
	DO	Turbidity:			Sand		
	Flow	Colour:			Mud		
	Riparian Disturbance				Hand picking/ Visual observation		
	Instream Disturbance						

Taxon		**S**	**Veg**	**GSM**	**TOT**	**Taxon**		**S**	**Veg**	**GSM**	**TOT**	**Taxon**		**S**	**Veg**	**GSM**	**TOT**
PORIFERA (Sponges)	5					HEMPITERA (Bugs) Belostomatidae*(Giant water bugs)	3					DIPTERA (Flies) Athericidae					
COELENTERATA (Cnideria)	1					Corixidae*(Water boatmen)	3					Blephariceridae (Mountain midges)					

TURBELLARIA (Flatworms)	3					Gerridae*(Pond skaters/Water striders)	5					Ceratopogomidae (Biting midges)					
ANNELIDA Oligochaeta (Earthworms)	1					Hydrometridae*(Water measurers)	6					Chironomidae (Midges)					
Hirudinea (Leeches)	3					Naucoridae*(Creeping water bugs)	7					Culicidae*(Mosquitoes)					
CRUSTACEA Amphipoda	13					Nepidae*(Water scorpions)	3					Dixidae*(Dixid midge)					
Potamonautidae*(Crabs)	3					Notoneclidae*(Backswimmers)	3					Empididae (Dance flies)					
Atyidae (Shrimps)	8					Pleidae*(Pygmy backswimmers)	4					Ephydridae (Shore flies)					
Palaemonidae (Prawns)	10					Velildae/M…velildae*(Ripple bugs)	5					Muscidae (House flies, Stable flies)					
HYDRACARINA (Water mites)	8					MEGALOPTERA (Fishflies, Bobsonflies & alderflies) Corydalidae (Fishflies & dobsonflies)	8					Psychodidae (Moth flies)					
PLECOPTERA (Stoneflies) Notonemouridae	14					Sialidae (Alderflies)	6					Simuliidae (Blackflies)					
Perilidae	12					TRICHOPTERA (Caddisflies) Dipseudopsidae	10					Syrphidae*(Rat tailed maggots)					
EPHEMEROPTERA (Mayflies) Baetidae 1 sp	4					Ecnomidae	8					Tabanidae (Horse flies)					
Baetidae 2 sp	6					Hydropsychidae 1 sp	4					Tipulidae (crane flies)					
Baetidae > 2 sp	12					Hydropsychidae 2 sp	6					GASTROPODA (Snails) Ancylidae (Limpets)					
Caenidae (Squaregills/ cainflies)	6					Hydropsychidae >2 sp	12					Bulininae*					
Ephemeridae	15					Philopotamidae	10					Hydrobiidae*					
Heptaganiidae (Flathead mayflies)	13					Polycentropodidae	12					Lymnaeidae*(Pond snails)					

Leptophlebiidae (Prongills)	9					Psychomyiidae/ Xiphocentronidae	8					Physidae*(Pouch snails)					
Oligoneuridae (Brushlegged mayflies)	15					Cased caddis: Barbarochthonidae SWC	13					Planorbinae*(Orb snails)					
Polymitarcyidae (Pale Burrowers)	10					Calamoceratidae ST	11					Thiaridae*(=Melanidae)					
Prosopistomatidae (Water specs)	15					Glossosomatidae SWC	11					Viviparidae*ST					
Teloganodidae SWC	12					Hydroptilidae	6					PELECYPODA (Bivalves)					
Tricorythidae (Stout crawlers)	9					Hydrosalpinigidae SWC	15					Corbiculidae					
ODONATA (Dragonflies & Damselflies) Calopterygidae ST, T	10					Lepidostomatidae	10					Sphaerlidae (Pills clams)					
Chlorocyphidae	10					Leptoceridae	6					Unionidae (Perly mussels)					
Synlestidae (Chlorostidae)(Sylphs)	8					Pelrothrinicidae SWC	11					**SASS Score**					
Coenagrionidae (Sprites and blues)	4					Pisuliidae	10					**No. of Taxa**					
Lestidae (Emerald Damselflies)	8					Sericostomatidae SWC	13					**ASPT**					
Platycnemidae (Brook Damselflies)	10					COLEOPTERA (Beetles) Dytiscidae/Noteridae*(Diving beetles)	5					Other biota:					
Protoneuridae	8					Elmidae/Druopidae*(Riffle beetles)	8										
Aeshnidae (Hawkers & Emperors)	8					Gyrinidae*(Whilygig beetles)	5										
Corduliidae (Cruisers)	8					Haliplidae*(Crawling water beetles)	5										
Gomphidae (Clubtails)	6					Helodidae (Marsh beetles)	12										

Libellulidae (Darters)	4					Hydraenidae*(Minute moss beetles)	8					Comments/ Observations:
LEPIDOPTERA (Aquatic Caterpillars/ Moths) Crambidae (=Pyralidae)	12					Hydrophilidae*(Water scavenger beetels)	5					
						Limnichidae	10					
						Psephenidae (Water pennies)	10					

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. Stir and sweep gravel, sand, mud for 1 min total. Hand picking and visual observation for 1 min – record in biotope where found (by circling estimated abundance on score sheet). Score for 15 mins/bitope 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 biodiversity), 5 = highly suitable (i.e. wide diversity).