Inverstigation into the deleterious impact of urbanisation on the freshwater ecosystem of the Braamfontein Spruit

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ABSTRACT

This Study aimed to assess the impact of urbanisation and anthropic disturbance on freshwater aquatic ecosystems. This assessment was performed by tracking the differences observed, in selected physiochemical characteristics biological indicators of diversity and water quality, and indicators of habitat integrity, between the inner-city sample site, the Braamfontein Spruit, and a pristine rural reference site, the Magalies river. Significant differences were found in all biological and habitat indicators, as well as most physiochemical indicators, indication a significant impact of urbanisation on the water quality and ecological condition of the sample site, with the main causes of degradation potentially linked to heat pollution, eutrophication and erosion events.

KEYWORDS

Freshwater Ecosystems; Habitat Integrity; South Africa Scoring System; Urbanisation, Braamfontein Spruit

INTRODUCTION

Globally, urban freshwater ecosystems play a variety of very important social, economic and ecological roles. These systems function as: recreational areas (Swanwick et al, 2003); animal and plant habitats, an important source of fish stocks (Berkes, 1979), flood control systems (Levy et al, 2007), domestic or industrial water treatment and disposal systems; and even directly as a source of bathing or drinking water in some communities. However, urban, freshwater systems come under considerable stress due to human disturbance, predominately in the form of pollution, so much so that their natural functions may become entirely compromised. A detailed understanding of the nature and consequences of anthropic disturbance, may prove critical for effective protection and remediation of these vital systems.

Much research has already been done into the deleterious effects of pollution on aquatic ecosystems. Nitrate pollution, deriving from domestic sewerage, has been linked, at a global level, to eutrophication, and the resulting losses in biodiversity and system function, (Julio and Alvaro, 2006). Other nutrient pollution, such as phosphate pollution from agricultural fertilisers, or washing powders has also been shown to decreased species diversity, nutrient uptake, and productivity within aquatic systems, (Walsh et al, 2005). Finally industrial pollution such as, acid mine drainage, can lead to increased heavy metal toxicity (Ata and Soner, 2006), which is particularly difficult to remove from waste water (Fu and Wang, 2011), and can build up to highly toxic levels with aquatic organisms through the process of bioaccumulation and biomagnification, (Spehar et al, 1978). Human communities also suffer from heavy metal pollution due to increased toxicity in drinking water (Duruibe et al, 2007).

Significant physical sources of disturbance have also been identified, such as the effects of storm water run off, where a connection was established between water run off schemes and river ecological condition. (Walsh et al, 2012). Erosion from ground disturbance in building can also wash down into urban aquatic systems increasing the turbidity, and potentially even blocking up the water channel completely. (Collins et al, 2011).

Finally, Biological source of disturbance, such as the introduction of invasive alien species may also be anthropically introduced, and can have a serious negative impact on the water quality and biodiversity of a system. For example species large predator fish species introduced to add to local fish stocks, such as salmoides species in South Africa, can serious reduce the diversity of macroinvertebrate communities by vociferous predation (Weyl et al, 2010). . Furthermore this increased predation pressure can lead to a trophic cascade, as reduced numbers of primary consumers promote algae biomass further disturbing underlying nutrient cycling and ecological processes within an ecosystem (Simon et al, 2003). Biological impact can also come from the lowest trophic levels as with the invasive diatom species Didymosphenia geminata in Australian systems which forms thick sludge layers covering the channel substrate affecting the hydrology, and food web structure. This invader impacts negatively on fisheries, hydrological power stations and tourism, degrading the local water systems and decreasing their water quality. (Spaulding and Elwell, 2007).

Overall, many pertinent anthropic causes of pollution have been identified and categorised, and their effects investigated at a global level; however, the degree of disturbance, and well as the leading causes of anthropic disturbance still remain relatively unknown within many smaller localised systems. Investigations into the condition of such systems can provide important insight to local administrators, or other interested and affected parties such as recreational uses, and communities dependant for water and fishing resources, and assist in community and governmental remediation attempts.

The aim of this study was to assess the effects of urbanisation and anthropic disturbance on the ecological state on of the Braamfontein Spruit freshwater ecosystem. This aim was split into several objectives. Firstly, to assess the extent, and nature of physiochemical changes within the urban system, specifically, dissolved oxygen, pH, temperature and turbidity. Secondly to assess the differences in biological diversity, and by extension water quality in the urban versus the rural system, using the South African Scoring System Version 5 (SASS) methodology. SASS scores were also used to calculate the Present Ecological Status (PES) of each site. Thirdly, to assess any differences of the ecological integrity of the surrounding catchment between the urban and the rural system using the Index of Habitat Integrity (IHI) scoring methodology. The SASS methodology uses the diversity of macroinvertebrate species observed as an indicator of water quality, as many rarer macroinvertebrate species are dependant on high water quality for survival (Phipps et al, 1995). The IHI scoring methodology relies on visual clues of anthropic presence within the catchment to access the overall level of anthropic disturbance.

METHODS AND MATERIALS

Study area

Two separate sites were assessed in this study, a lowlands section of the Braamfontein Spruit (the main study site) lying within a highly urbanised area, and a pristine upland section of the Magalies River, used as a reference site.

Braamfontein Spruit study site

The Braamfontein Spruit study site (GPS coordinates, $26°07'35.3S28°00'59.1E$), shown in Figure 2 lies within, Delta Park, a public park located along Craighall Road within Victory Park, Johannesburg, a major city within the Provence of Central Gauteng. The Braamfontein Spruit falls within the upper Crocodile sub-region of the Crocodile (west) and Marico water management area water management area seen in Figure 1 below (Statistics South Africa, 2010), which falls under the jurisdiction of the department of Water and Sanitation. The area under study is within the Highveld ecoregion, a level 1 ecoregion (DWAF, 2005), under the jurisdiction of the Johannesburg Metropolitan Municipality.

The Spruit itself is fed by the Montgomery and Westdene Spruits and originates just above the Westdene dam flowing through several kilometers of highly developed city areas before the sample site is reached (Masetle, 2014). The parks lies within a highly populated urban district with many recreational users frequenting the park every day (Visser, 2008), as well as homeless individuals who inhabit the park, and may use the river waters for bathing or cooking (Bosaka, 2015). Furthermore the park was historically a sewerage treatment site (Maud, 2008) any although it has been re-purposed, it is still a hub of the Johannesburg sewerage transport network ((Johannesburg City Council,2008), with the possibility of multiple leaks of raw sewerage directly into the river, or by overflowing sewer nearby(Jonker, 2017) , see Figure 4. Many storm water drains also empty directly into the river as seen in Figure 4. The site is prone to frequent serious erosion due to flooding from storm water drains. (Masawi, 2018).

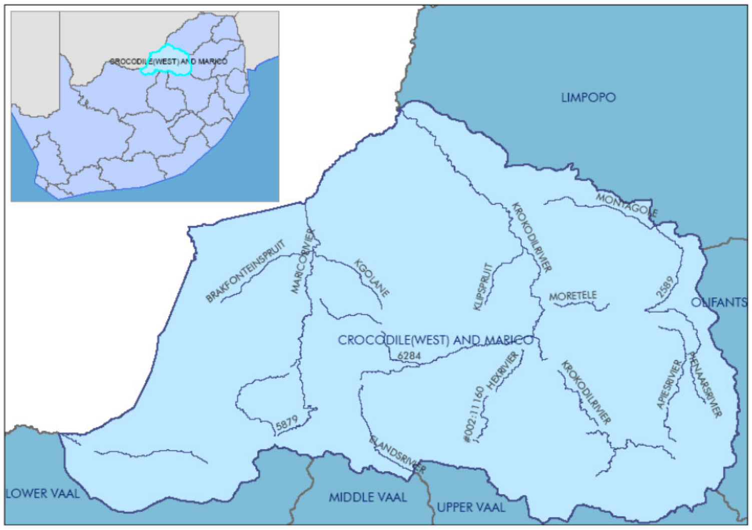

Figure 1: Crocadile West and Marico Water Managment Area, October 2010, Report number DO405.8 by Statistic South Africa,National Accounts, Environmental and economic accounts

The Magalies River study site (GPS Coordinates $26°0'59.7S, 27°33'51.5E$), shown in Figure 3, lies within the Magaliesburg mountains just to outside the city of Johannesburg, to the west. The Magalies river also falls within the upper Crocodile sub-region of the Crocodile (west) and Marico water management area, but the site itself is within the western Bankenveld ecoregion (a level 1 ecoregion (DWAF, 2005)), and falls under the jurisdiction of the Westrand district municipality.

The sampling site is within less than a kilometers of the river source, with only very limited housing developments, including the wedding venue and school seen in Figure 3 upstream, and only one major road, the R24, near by. The riparian zone is highly forested, predominately with alien invasives such as the Pyracantha angustifolia seen in figure 5, and these tree covered extends significantly over the stream itself, blocking out light and depositing leafy debris.

Figure 2: Left: Google Maps sataline image of Braamfontein spruit sampling site (2018), DigitalGlobe, AfriGIS, Google, accessed October 24th 2018.
Right: Upstream view from Braamfontein Spruit sampling site, image captured August 1st 2018

Figure 3: Left: Google Maps sataline image of Braamfontein spruit sampling site (2018), DigitalGlobe, AfriGIS, Google, accessed October 24th 2018.
Right: Downstream view from Magalies river sampling site, image captured July 25th 2018

Figure 4: Signs of anthropic disturbance at Braamfontein spruit sampling site.
Top Left: Storm water drain emptying dirrectly into river channel.
Top Right: Plastics debris in water channel: Bottom Left: Manhole of nearly sanitation sewer.
Botton Right: Power line gurder on river bank. Images captured August 1st. 2018

Figure 5: *Pyracantha angustifolia* , Invasive alien species present at Magalies river sampling site, image captured July 25th 2018

Experimental design and protocol

Physiochemical parameters

For each study site, measures of physiochemical parameters and biological/habitat indicators were assessed at four sample sites displaced $\approx$ 30m from each other along the stream channel. For each sample site an identical sampling procedure was employed.

Before any other sampling took place, a turbidity sample was taken by gently submerging a sampling bottle in the center of the channel, and allowing it to fill. The sampling bottle was then sealed tightly, for storage and taken back to the laboratory where absorbance was measured (in Nephelometric Turbidity Units) using a Hanna turbidity meter (model HI98703-02).

pH, Temperature, dissolved oxygen, and conductivity were all assessed using a handheld YSI Professional Plus multi-parameter meter; measurements were taken by placing the probe in the center of the water channel, and taking the measurement only once the reading stabilised. Only one reading was taken at each sample site.

A Transparent Velocity Head Rod (TVHR) (sourced from the company GroundTruth, operating in Pietermaritzburg, South Africa), along with a 50m tape measure were used to make the measurements required to calculated discharge[1]. The tape measure was used to measure the in channel width of a slow flowing section of the channel with a smooth, homogeneous benthos, i.e an area with no sudden variations in high or large stones on the river bed, or macrophytes blocking the river flow. The TVHR was then used to, measure the depth of the channel at 0.5m intervals along the horizontal line which was used in measuring channel width. The height difference due to water build up behind the TVHR was also measured and were also measured and used to calculate an estimate of water velocity at this point in the channel. The overall discharge estimated using the method set out in (Benson and Dalrympl, 1967).

[1]Due to anomalies which occurred in data collection only one measurement of discharge was taken for each study sites

Biological indices

The Standard Methodology described in the SASS Version 5 as described in Dickens and Graham, 2002, was used for the sampling of Aquatic invertebrates with some minor adaptions. In place of the standard SASS sampling nets, butterfly catching nets were used, the sampling period was also extended to 5 minutes, in cases where it appeared few macroinvertebrates had been collected the period was extended to five minutes. The macroinvertebrate samples, once collected where stored in $\approx 85\%$ ethanol solution, and stored for several weeks, before identification.

The overall SASS score as well as the ASPT where used to calculate the Present ecological status using the boundary level given in Dallas, 2007). A relatively pristine section of the Magalies river was also sampled as a control/stand for comparison.

Habitat integrity

Signs of human impact were observed and categorised in nature and extent by using the IHI scoring system as detailed in (Amis, 2007)

Data Analysis

The overall average of each physiochemical measure, as well as the habitat integrity score, and biological indicators were calculated from the data collected at each sample site. This averaging was used to reduce no-determinate errors, and local variations associated individual measures. The standard error for each parameter was also calculated to given an indication of the natural variation seen, and the precision of the measurements obtained.

Two sample, equal variance, two tailed, Student t tests were also performed to test for significant differences in each parameter between the two study site (Braamfontein Spruit and Magalies River), at a 5% significance level. Equal variance of the two study site was assumed with no explicit statistical test. Two tailed tests were used as the null hypothesis behind the assessment was simply that there was no significant difference between the sample site and the reference site.

RESULTS

Physiochemical data

Summary measures of the physiochemical data collected are shown in Table 1, while statistical analysis of the physiochemical differences between the two sampling sites is shown in Table 2, below.

In Table 1 it can be seen that measures of Conductivity, Dissolved oxygen, and Turbidity were all a good deal higher, on average at the Braamfontein Spruit sampling sight, at which there was a higher current, and more riffles/shallow rocky sections, and more macrophytes growing within the water channel itself. The discharge measured at that Braamfontein site was also a good deal higher than that of the Magalies reference site, however, due to the lack of repetitions the significance of this difference could not be assessed. Manholes for operational sewers were also located near to the banks of the stream at this site. Furthermore, it can be seen from channel two that the differences observed in Turbidity, dissolved oxygen concentration were all both highly significant well below the conventional 5% significance level set for the purpose of this study. Conversely, however, the difference observed in average conductivity had only a low associated significance level (Predominately due to the very large variance in the conductivity measures taken), and so was not considered significant for the purposes of this study.

It can also be seen from Table 1 that measures of pH and Temperature, were higher at the Magalies sampling site, however only the difference in temperature actually proved to be significant, as seen in Table 2.

Habitat assessment

As seen in Table 1 the Index of Habitat Integrity (IHI) score was far higher at the Braamfontein Spruit site, which as afore mentioned, in a densely populated urban area, and exhibited visible signs of human disturbance such as plastic waste floating within the channel itself, as well as large storm drain pipes draining directly into the channel and bridges and a large pedestrian bridge placed over the channel. This significant difference is further demonstrated by Figure 1, in which it can be seen that not only is the mean IHI score at the Braamfontein Spruit sampling site more than double that of IHI score for the Magalies River sampling site, there is is no overlap in the error bars for the two means, Theses error bars, which show the standard error in the means calculated support the observation of significant difference given in table 2, showing that the difference in means is highly unlikely to have arisen simply from random variation.

Biological indicators

All of the indicators of biological diversity measured i.e, South Africa Scoring System, version 5 (SASS) Score, taxa score, and Average Score per Taxon (ASPT), (Also calculated with the SASS method), were higher at the Magalies sampling site at which different biome types were more distinctly segregated, and evenly distributed along the river channel, as seen in Table 1. The differences observed in these parameters between the two sampling sites were without exception significant, as seen in Table 2. The significance of this difference is further reinforced by the PES categorisation, given by the SASS scores obtained, which identifies the disturbance seen at the Braamfontein site at a distinctly higher level/category than that seen at the Magalies reference site. The present ecological status calculated from the SASS scores obtained also shown a marked difference between the sample and reference sites, as seen in Figure 7.

Table 1: Summary measure of key physiochemical characteristics, biological indicators of water quality, and habitat integrity indicators for the Braamfontein Spruit study site, and Magalies river pristine reference site.

	Braamfontein Spruit		Magalies River	
	Mean	Standard.Error	Mean.	Standard.Error.
Discharge (m^3/min)	28.36	(-)	2.00	(-)
pH	8.21	(0.06)	8.32	(0.02)
Conductivity (μS)	269.20	(42.12)	224.50	(0.78)
Temperature($^\circ C$)	14.40	(0.25)	18.87	(0.1)
Dissolved Oxygen($mg \cdot L^{-1}$)	9.09	(0.43)	6.21	(0.17)
Turbidity(NTUs)	13.56	(1.78)	1.60	(0.26)
IHI	126.57	(17.05)	42.29	(20.8)
SASS	44.25	(3.41)	121.88	(19.94)
taxa	9.38	(0.62)	18.88	(2.58)
ASPT	4.72	0.2	6.33	0.23

Table 2: Student t test, for significant difference in physiochemical characteristics, biological indicators of water condition, and measures of habitat integrity between the Braamfontein Spruit sample site, and the pristine Magalies river reference site.

	T.statistic	Degrees.of.freedom	p.value
pH	-1.658	12	0.12
Conductivity (μS)	1.061	12	0.31
Temperature($^{\circ}C$)	-16.474	12	0.00
Dissolved Oxygen($mg \cdot L^{-1}$)	7.089	10	0.00
Turbidity(NTUs)	6.646	12	0.00
IHI	3.133	12	0.01
SASS	-3.837	14	0.00
taxa	-3.578	14	0.00
ASPT	-5.269	14	0.00

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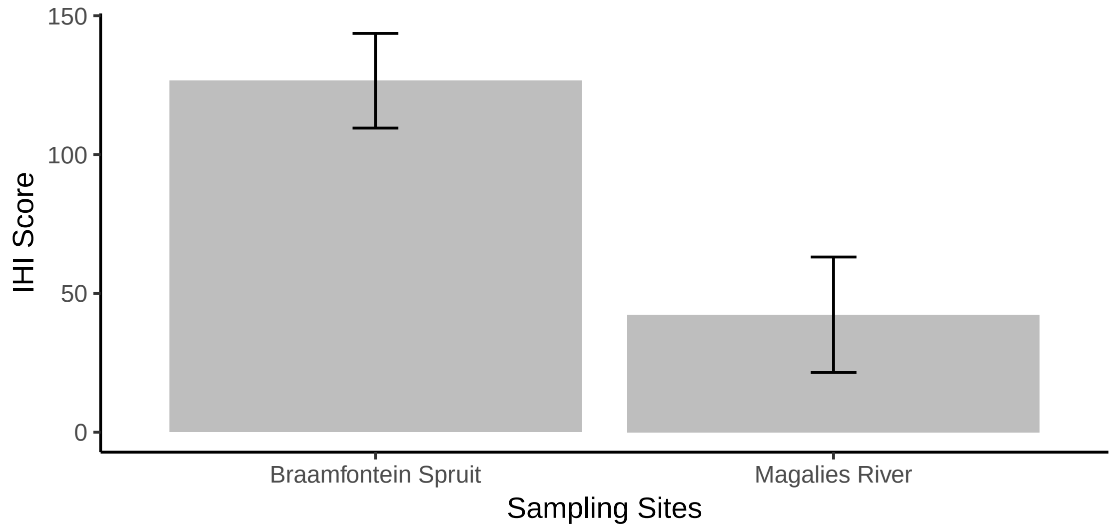

Figure 6: Index of Habitat Integrity (IHI) scores (Amis, 2007) for the Braamfontein Spruit study site catchment, and Magalies river pristine reference site catchment.Error bars are equivalent to standard error

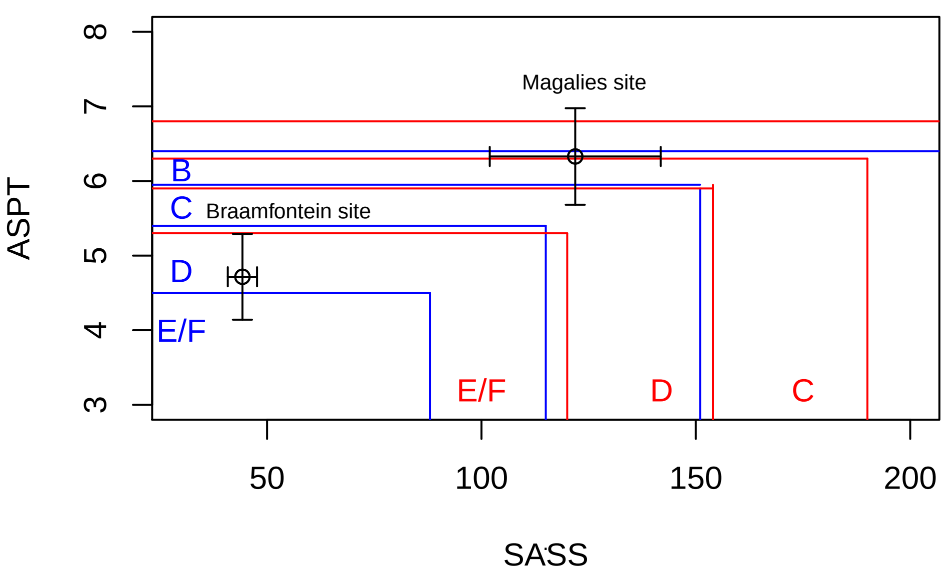

Figure 7: The average score per taxon (ASPT) vs the overall Ecosystem score, calculated using the South African Scoring system for rapid bioassessment (SASS), Version 5 (Dallas, 2007), using data collected from the Braamfontein Spruit study site, and Magalies River reference site. The zones donated by letters E to B indicate categories of Present ecological Status varying from A,Pristine to E: Highly disturbed. The zones marked in red refer to areas within the highveld ecoregion which includes the Braamfontein Spruit study site, and the zone boundaries marked in blue apply to the western Bankenveld ecoregion which contains the Magalies reference site.

DISCUSSION

The disruptive effects of urbanisation are clearly present across all aspects of the Braamfontein Spruit system, from the physiochemistry to the biology, to the integrity of the surrounding habitat. Theses changes are closely connected. Arguably the processed underlying the degradation observed may originate with changes in the physiochemical characteristic, and catchment conditions related to anthropic disturbance, which subsequently impact the biology of the system. This amalgamation of changes leads to a marked decreased in water quality, and links to the degradation of the system as a whole.

This first major sign of disturbance is evident in the significant difference in temperatures measured between the two sites. This nature of this difference was unexpected as mountainous headwater are conventionally much cooler than larger lowland streams, due to their higher altitude, lower exposure to sunlight, and proximity to the cold river source. (Allanson and Gieskes, 1961). The lower temperature in the Braamfontein Spruit may related to the increased turbidity, as even at very shallow depth below the surface the penetration of sunlight, and the resultant heating may be markedly decreased (Paaijmans et al, 2008). However given the vigorous current, the exposure to wind action (due to low tree cover) and the frequent riffles present in the Braamfontein Spruit physical/mechanical water mixing might be expected bring the sunlight heated surface waters into thermal equilibrium with the water just below minimizing the effects of this difference. Perhaps a more likely explanation is that in influx of cold storm water in flooding ((Masawi, 2018)), brings in water which enters the river directly from the underground storm sewers system (Hence not exposed to sunlight), resulting in thermal pollution lowering temperature of the Braamfontein Spruit site. Thermal pollution can be an issue for the local biota affecting the energy budget of aquatic animals which must expend additional energy in heating/ cooling, or triggering unseasonal spawning critically endangering reproductive cycles. (Olden and Naiman, 2010).

The significant difference in oxygen concentration observed may be direct related to this abnormal temperature difference, as oxygen solubility in water increases with decreased temperature. (Truesdale, and Downing, 1954). Additionally, the increase in oxygen levels may also come as a result of the afore mentioned mechanical mixing. Despite the anomaly of relative oxygen concentrations, its biological effect is likely to be less significant as higher oxygen concentrations are not directly associated with any form of toxicity. The increased oxygen concentration, in conjunction with the lower temperatures may favour a change in the macroinvertebrates, as well as fish and macrophytes populations within the system increasing the competitive advantage of highly oxygen dependant species. However, given that headwater species are usually highly sensitive to chemical pollution (Woodcock and Huryn, 2007), and are maladapted to high turbidity environments (Vuori and Joensuu, 1996), they are still unlikely to persist in a polluted urban system and hence little overall biological effect, aside perhaps from a slight increase in productivity could be expected. Conversely the significant increase in turbidity may have a more serious biological effect.

Increased turbidity may be linked to erosion caused by flooding from the afore mentioned storm drains, in addition to direct run off from the surrounding catchment. The increase in impervious surfaces within the surrounding surfaces which contributed in part to the high IHI score obtained, implies that water will not infiltrate as well within the catchment, leading to increased run off as a pose to subsurface flow. This run off is more likely to pick up loose surface sediments which will be washed down into the river itself. The disruption of the nearby land surface in human developments, such as mud or clay from road work excavations, or fine sand deposited for use in construction, will also be picked up by run off, adding to the sediment load. Increased turbidity can have a serious negative impact on the local biology such as diminishing the number of visual predators such as fish or even crabs (Utne-Palm,2002), diminishing biomass of phytoplankton due to decreased light penetration, and hence lower overall productivity, and finally diminishing numbers of benthic macroinvertebrates sensitive to mud accumulation within their integument or gills, or loss of interstitial habitats. (Kasangaki et al,2008). The decrease in benthic macroinvertebrates may be one of the major drives behind the lower SASS, and ecological status scores obtained.

The increased turbidity may also be due in part to an increase in dissolved and suspended biological material. Dog and horse feces (resulting from recreational uses of the park), brought down in runoff, in addition to potential sewerage overflows, could increase the concentration of dissolved biological molecules, and hence the nutrient,especially nitrogen and phosphorous, concentration within the river. Increased nutrient concentration runs the serious risk of inducing eutrophication, and the related decrease in biodiversity and water quality (Nyenje et al, 2010). In this case it appears that the system has not yet reached transformed into a eutrophic state due to the high dissolved oxygen content, in addition to the neutral/ slightly basic pH which are fairly atypical of a eutrophic system. None the less such pollution still places the system in significant danger of eutrophication especially as the decreased biodiversity and modified physiochemistry are already likely to have reduced resilience and resistance within the system.

The higher level of discharge seen in the Braamfontein site may also link directly to this increased run of and injection from storm drains. This comparison is unreliable both because of the lack of repetition in the discharge measurements taken and because the Braamfontein site which is further down stream would by default be expected to have a higher discharge (Vannote, 1980). However, an increase discharge related to flooding events could help to explain help to explain the lack of biological diversity captured in the SASS scores, leading to high levels of disturbance which are typically linked with decreased biodiversity (Townsend, 1997). Over time the system may be expected to shift to to contain only coloniser species adapted to common disturbance, or species specifically adapted to high flow such as larval caddisflies (Anabolia) (Statzner and Holm, 1989).

In Conclusion, The significant difference seen in biological indicators of water quality and ecological status, can be linked to both physiochemical changes within the river as well as degradation of the surrounding catchment resulting from urbanisation. Erosion and run off from increased flooding due to nearby roads and other impervious surface, and loose sand deposits for construction, increase the turbidity of the water and hence negatively impacting on fish macroinvertebrates and phytoplankton within the stream. Aside from the physical effects of turbidity there is also the related increase in nutrient concentration, exacerbated by potential sewerage leaks/ overflows which risk push the system towards a eutrophied state. Finally potential temperature pollution from storm drains, in combination with the increased flooding disturbance causes by these drain may also decrease the biological diversity, leading to further ecological degradation and decreases in water quality.

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Posible imporvements

1. break up and expand the introduction, i.e there can be a paragraph on eutrophication, one on metal toxicity etc.