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Infection risk for riparian users of water from a catchment drain receiving treated wastewater and polluted urban discharges.

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Abstract

A large proportion of the rural population in the developing world uses water from natural sources directly for domestic as well as other non-domestic purposes such as agriculture and recreation. Human and animal excreta as well as domestic sewage inevitably carry a variety of human pathogens into surface and groundwater. These microbiological agents include pathogenic bacteria, viruses and protozoa that can cause gastro-intestinal diseases. Communities use a variety of waters for potable as well as non-potable purposes such as agriculture and recreation. Systems for water decontamination and clarification / disinfection for such a variety of human requirements are heavily relied upon to safeguard user-populations against contaminated water. In South Africa, urban authorities are compelled to promote sanitation and protect water resources by installing a variety of wastewater treatment facilities in urban areas to reduce the contaminant overload associated with untreated wastewater. Barriers such as chlorination are usually included in the design to remove pathogenic microorganisms. However, urban settlements at various levels of development are continually reported to contribute to pollution of aquatic environments. This is generally due to various factors such as treatment facilities either under-designed or improperly managed, faecally polluted surface run-off from underdeveloped areas with inadequate sanitation as well as poorly maintained sewage collection systems in developed areas. Results indicated that the treatment facilities intermittently released mean levels of microbiological indicator organisms that exceeded infection risk limits proposed by various water quality guidelines. Other diffuse urban discharges generally released similar levels of these indicators into receiving waters but higher levels during and directly after rainfall events. The results further indicated that faecally polluted urban run-off, in combination with the discharged treated effluents, overcame the assimilation capacity of the receiving waters, therefore creating a risk of infection to exposed riparian users for considerable distances downstream from the urban development.

INTRODUCTION

Despite modern technology and advanced knowledge regarding water quality management, the incidence of infectious diseases associated with water and related environments tends to increase (Grabow, 1996). Continued careless handling of human excreta maintains disease. In well-developed urban settlements, sewer overflows are recognised as primary point sources of faecal pollution indicator organisms and pathogens to urban receiving waters (Ellis and Wang, 1995; Jagals, 1997). In lesser-developed areas with inadequate sanitation, land deposited faecal material contributes substantially to faecal pollution of receiving waters (Jagals, 1994; 2000). According to Ferguson et al. (1996), significant increases in the concentrations of faecal coliforms, faecal enterococci, *Clostridium perfringens* spores, F-RNA bacteriophages as well as *Giardia* and *Cryptosporidium spp* in events of sewage overflows seriously affects receiving water quality. Jagals et al. (1995) also found that faecal pollution of surface water sources could be expected to increase substantially after rainfall events when stormwater run-off washes faecal material into receiving waters.

Wastewater treatment facilities are widely used and relied upon to safeguard riparian users against contaminated water by treating domestic sewage and other organic wastewaters, which are subject to considerable variation in microbiological quality. In South Africa, faecal pollution of public water resources is officially prohibited (Republic of South Africa, 1998) and urban authorities are expected to protect receiving water resources by the design and installation of a variety of wastewater treatment facilities in urban areas. These systems are generally designed to reduce the biochemical contaminant-overload associated with untreated wastewater and include barriers such as chlorination and maturation pond systems to reduce numbers of pathogenic microorganisms in the final effluent.

Despite treatment, reclaimed water may still contain potentially harmful microbiological contaminants with which riparian users must be familiar in order to minimise detrimental environmental or human health effects. In a water-scarce country like South Africa (Republic of South Africa, 1996), there are increasing demands to use various sources of surface waters for potable as well as non-potable purposes like agriculture and recreation. Faecal pollution in the vicinity of urban areas is a major health hazard in water used for these purposes (Jagals, 1997) and protection of riparian as well as recreational water users and the environment is enhanced by a set of South African Water Quality Guidelines (1996). However, hardly any standard/guideline exists for an acceptable quality for urban run-off such as storm water from urban and rural developments (Jagals, 1997).

A study is presently done on a public stream receiving a variety of discharges from the urban area of Bloemfontein in the Modder River catchment, in the Free State province of South Africa. These discharges include diffuse effluents from the urban areas as well as final effluent from two wastewater treatment facilities - of which one was very recently commissioned.

The potential release of pathogenic microorganisms from the new system and its impact on the microbiological water quality of the receiving waters were unknown. It was therefore not clear what the impact of the discharge from the new wastewater treatment facility would have on the health-related microbiological quality of the receiving stream, once the discharge was started and sustained.

It was also not clear to what effect the other urban discharges had on the health-related microbiological pollution of the receiving streams. This study investigated the potential release of microbiological indicator organisms from all these pollution sources into the aquatic systems of the target catchment. An assessment was also done of the compounded effects of the various discharges on the levels of health-related microbiological indicator organisms within the receiving waters. These effects were then used to describe the potential risk of infection to people using the receiving water for domestic purposes as well as agriculture and recreation.

Methodology

Study area: The study was conducted in the Renoster Spruit subcatchment southeast of Bloemfontein. The city has well-developed modern urban areas as well as economical and sub-economical residential developments, well functioning business sectors and well-developed industrial zones all serviced by full waterborne sewerage. There are also large areas of low cost residential settlements with limited sanitary facilities and additional areas of informal development with inadequate sanitary services.

Sampling sites (Fig.1): The Bloem Spruit is a perennial tributary of the Renoster Spruit. This stream flows through the city and drains an estimated 80% of the city's storm flow. The stream is impounded in a small dam, Loch Logan (B1) in the central part of Bloemfontein, where it concentrates the surface run-off from the well-developed western residential part of Bloemfontein. The Bloem Spruit continues to drain Bloemfontein through the eastern residential, industrial and lesser-developed zones. The Batho Spruit (S1) is a tributary which confluences with the Bloem Spruit southeast of Bloemfontein and drains surface run-off from the low-cost high-density residential sector of Mangaung and informal settlements in this area.

Sampling site B2 is situated downstream from the Bloem Spruit / Batho Spruit confluence and serves as the reference point in the Bloem Spruit for the city's total run-off before 20-Ml / day final effluent of treated and matured but unchlorinated sewage from an established fixed medium biological filter wastewater treatment facility discharges into the stream. B3 is downstream from the effluent discharge point and is the site representing the total urban surface water discharges from this part (80%) of Bloemfontein.

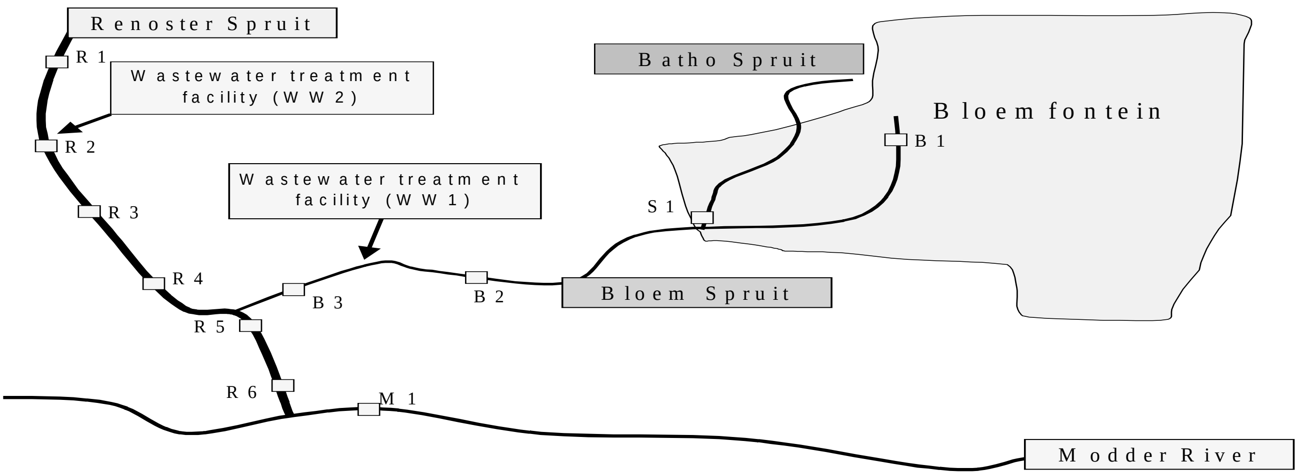

Figure 1: Modder River catchment indicating the target section of the Renoster Spruit and sampling sites.

The Renoster Spruit is a low-flow stream but could hardly be described as perennial up to the point where it receives the water of the newly commissioned treatment facility as well as the Bloem Spruit. Sampling included the region of the Renoster Spruit from the unpolluted reference point, Moedersgift (R1), an agricultural surrounding that is scarcely populated by human settlement, down to the point where the Renoster Spruit confluences with the Modder River (M1) northeast of Bloemfontein.

R2 is a site in the Renoster Spruit immediately downstream from the point of discharge from the newly commissioned wastewater treatment facility. The Renoster Spruit continues to flow and drain through rural areas down to R3, the site selected to monitor and assess the assimilation capacity of the Renoster Spruit for the discharged effluent. R4 was the site in the Renoster Spruit before confluence with the Bloem Spruit indicating the impact of the effluent discharged at R2 on the microbiological water quality of the Renoster Spruit before receiving other polluted urban discharges from the Bloem Spruit. R5 was the sampling site in the Renoster Spruit downstream from the confluence with the Bloem Spruit used to assess the impact on the microbiological water quality of the receiving waters of the final effluent and other urban discharges from Bloemfontein. R6 was the final sampling site in the Renoster Spruit selected to indicate the capacity of the Renoster Spruit to assimilate microbiological contaminants before draining into the Modder River (M1).

Sampling and analysis: Water samples were collected at least biweekly during all seasons for the last two years as well as during and directly after rain events. Water was collected in sterile Whirl packs®, transported at 4-10°C and analysed within 5-12h. Tests were carried out for *Escherichia coli* used as indicators for faecal pollution as well as microbiological pathogenic organisms, which may pollute water (Grabow, 1996; Standard methods, 1998). *E coli* were enumerated with the membrane filtration technique in triplicate on 90-mm petri dishes on Chromocult Coliformen Agar (Merck, 1996). The prepared plates were inverted and incubated at 35-37°C for 18-24h. Dark blue to violet colonies were counted as *E coli*.

Clostridium perfringens (CP) were used to indicate the possible presence of resistant pathogens such as cyst- and oocyst-forming protozoa of faecal origin (Payment and Franco, 1993). CP were enumerated on supplemented Perfringens (OPSP) Agar (OXOID, 1990) with the membrane filtration technique in triplicate on 90-mm petri dishes. The prepared plates were inverted and incubated anaerobically at 35-37°C for 18-24h. CP colonies were counted as typical black colonies. Colony identifications were confirmed on at least 10% of the colonies using API 20E for *E coli* and Rapid ID 32A for CP.

Somatic coliphages (SC) were enumerated by the Plaque Assay method for somatic coliphages with the Double Agar Layer technique (Grabow et al., 1997). This method is based on conventional plaque assays for SC (Grabow et al., 1993) in small volumes of water (generally 1ml) using 90-mm diameter petri dishes. The prepared plates were inverted and incubated overnight at 35-37°C and plaques of somatic coliphages counted.

Data were set up in Microsoft Excel® spreadsheets and were transformed to $\log_{10}$ values prior to doing descriptive statistical analysis such as sample size, range, geometric mean, median, and the 95% confidence intervals of the data. The statistical programme Sigma Stat Version 2.0 (1998) was used to test for significant differences in the data obtained in the Renoster Spruit before and after receiving treated wastewater discharges using the Mann-Whitney Rank Sum Test.

RESULTS AND DISCUSSION

Indicator organisms release potential of low socio economic urban developments

Numbers of microbiological indicator organism detected downstream in the Batho Spruit draining surface run-off from low-cost residential and informal settlements of Mangaung over the two-year sampling period are shown in Table 1.

The 95% confidence interval indicated that pollution levels were so high that even the calculated lower confidence limit (LL) of *E coli* and SC numbers in the Batho Spruit exceeded acceptable levels of infection risk in terms of the South African Water Quality Guidelines for domestic and recreational use (DWAF a, b, c, 1993 & 1996).

Significant health risks can be expected if the GM commonly exceed 400 organisms per 100ml for *E coli* and more than 100 organisms/100ml for SC when used for full- and intermediate contact recreation, taken into consideration the frequency and extent of water used (DWAF c, 1996).

Table 1: Numbers of microbiological indicator organisms detected in the Batho Spruit.

Sample Points	*Escherichia coli* Org / 100ml	*Clostridium perfringens* Org / 100ml	Somatic coliphages Org / 100ml
S1	n = 44 GM = 5.83E+04 **Log data** Median 4.96 95% Confidence interval (Ci) 0.42 Lower Limit (LL) = 4.54 Upper Limit (UL) = 5.38	n = 29 GM = 4.77E+02 **Log data** Median 2.79 95% Ci 0.36 LL = 2.43 UL = 3.15	n = 25 GM = 9.53E+03 **Log data** Median 4.26 95% Ci 0.32 LL = 3.94 UL = 4.58

The South African Water Quality Guidelines specifies no target guideline limits for CP and levels were compared with risk limits proposed by Water Quality Criteria in South Africa (Aucamp and Vivier, 1990) were they exceeded the drinking water maximum limit for low risk. Results also indicated that the GM levels of the microbiological indicator organisms detected in the Batho Spruit run-off were higher than the levels of the organisms detected in the final effluents of the two wastewater treatment facilities (Table 2).

Indicator release potential of final effluent quality from wastewater treatment facilities

Numbers of microbiological indicator organism detected in the final effluent from the two wastewater treatment facilities are shown in Table 2.

Table2: Microbiological indicator organisms numbers in the final effluent at the wastewater treatment facilities.

Sampling Points	*E. coli* Org / 100ml	*C. perfringens* Org / 100ml	Somatic coliphages Org / 100ml
Old facility	n = 30 GM = 2.16E+03 **Log data** Median 3.38 95% Ci 0.53 LL = 2.97 UL= 3.79	n = 26 GM = 1.22E+03 **Log data** Median 3.09 95% Ci 0.32 LL = 2.83 UL= 3.35	n = 17 GM = 7.30E+03 **Log data** Median 3.94 95% Ci 0.18 LL = 3.73 UL = 4.16
New facility	n = 20 GM = 1.91E+04 **Log data** Median 4.41 95% Ci 0.53 LL = 3.88 UL= 4.98	n = 9 GM = 1.84E+04 **Log data** Median 4.31 95% Ci 0.32 LL = 3.99 UL= 4.63	n = 4 GM = 1.31E+04 **Log data** Median 4.08 95% Ci 0.18 LL = 3.90 UL 4.26

Results in Table 2 showed that both the wastewater treatment facilities released GM levels of microbiological indicator organisms that exceeded the limits for final effluent according the requirements for the purification of wastewater or effluent in the Government Gazette 991 of 1984.

Impacts from various levels socio economic urban developments on water quality in the Bloem Spruit

Table 3 summarizes the numbers of indicator organisms detected in the Bloem Spruit. Numbers of microbiological indicator organisms detected in the surface run-off from the developed residential and business areas of the city were normally one order of magnitude lower than those detected in the runoff leaving the more informal and developing areas of Bloemfontein as summarised in Table 1.

Increases in the numbers of indicator organisms can be seen in the Bloem Spruit from B1 to B2 after confluence and receiving waters from the Batho Spruit. Run-off concentrated in the Bloem Spruit presented a real health threat to stream users although contact with water was generally restricted to intermediate-contact recreation (parks, golf course waterways and irrigation).

The 95% confidence interval indicated that the calculated lower confidence limits of the numbers of *E coli*, CP and those for SC at the point in the Bloem Spruit before receiving treated wastewater discharges were all higher than acceptable risk levels proposed by the South African Water Quality Guidelines (DWAF c, 1996) and Water Quality Criteria in South Africa (Aucamp and Vivier, 1990). Significant health risks can be expected if GM commonly exceed 400 organisms per 100ml for *E coli* and more than 100 organisms/100ml for SC when the water is used for full- and intermediate contact recreation. Microbiological indicator organisms concentrations detected in the surface run-off support previous findings by Jagals, 1997 that both developed and developing urban areas contribute to the microbiological pollution of rivers and streams but higher levels of faecal indicator organisms can be expected from developing areas.

Water of the Bloem Spruit received heavy loads of faecal pollution during and after rain events when stormwater run-off from the city drained into the stream. Inside the city, the GM of the dry weather data increased dramatically for all three the indicator organism groups. Similar increases in the Bloem Spruit's indicator organism concentrations could be seen after receiving stormflow from the Batho Spruit.

Results suggested that health risk associated with untreated water in the Bloem Spruit receiving run-off from a fully sanitised, developed residential area was lower than the risk associated with use of untreated surface waters draining from underdeveloped areas during dry weather periods, but that the risk of contracting gastrointestinal illnesses were similar during and directly after rainstorms.

GM levels of all the indicator organisms tended to decrease slightly in the Bloem Spruit after receiving final effluent from the fixed medium biological filter wastewater treatment facility but were still constantly exceeding acceptable risk limit as proposed by the South African Water Quality Guidelines for both domestic and recreational use of water (DWAF a, b + c, 1993 and 1996). The level of pollution presented a real environmental health threat to users of the receiving water in the direct vicinity of the city and the risk of contracting gastrointestinal effects increased during and directly after rainstorms.

Table3: Numbers of microbiological indicator organisms in the Bloem Spruit at the various sampling points.

		B1	**B2**	**B3**
E coli **Org / 100ml**	**Combined data**	n = 44 GM = 4.59E+03 **Log data** Median 3.98 95% Ci 0.39 LL = 3.59 UL = 4.37	n = 55 GM =1.03E+04 **Log data** Median 4.03 95% Ci 0.30 LL = 3.73 UL = 4.33	n = 73 GM = 3.49E+03 **Log data** Median 3.47 95% Ci 0.19 LL = 3.28 UL = 3.66
	Dry weather	n = 27 GM = 1.17E+03 **Log data** Median 2.95 95% Ci 0.50 LL = 2.45 UL = 3.45	n = 42 GM = 7.67E+03 **Log data** Median 3.62 95% Ci 0.55 LL = 3.28 UL = 3.96	n = 51 GM = 2.28E+03 **Log data** Median 3.24 95% Ci 0.71 LL = 3.04 UL = 3.44
	Wet weather	n = 17 GM = 4.01E+04 **Log data** Median 4.42 95% Ci 0.26 LL = 4.16 UL = 4.68	n = 13 GM =2.73E+04 **Log data** Median 4.64 95% Ci 0.69 LL = 4.01 UL = 5.27	n = 22 GM = 9.42E+03 **Log data** Median 4.17 95% Ci 0.46 LL = 3.80 UL = 4.54
C. perfringens **Org / 100ml**	**Combined data**	n = 28 GM = 3.30E+01 **Log data** Median 1.67 95% Ci 0.44 LL = 1.23 UL = 2.11	n = 49 GM = 4.01E+02 **Log data** Median 2.68 95% Ci 0.36 LL = 2.32 UL = 3.04	n = 56 GM = 4.62E+02 **Log data** Median 2.73 95% Ci 0.22 LL = 2.51 UL = 2.95
	Dry weather	n = 20 GM = 2.50E+01 **Log data** Median 1.14 95% Ci 0.34 LL = 0.59 UL = 1.69	n = 39 GM = 2.87E+02 **Log data** Median 2.68 95% Ci 0.38 LL = 2.30 UL = 3.06	n = 43 GM = 3.45E+02 **Log data** Median 2.62 95% Ci 0.17 LL = 2.37 UL = 2.87
	Wet weather	n = 8 GM = 6.50E+01 **Log data** Median 1.86 95% Ci 0.63 LL = 1.17 UL = 2.55	n = 10 GM = 1.48E+03 **Log data** Median 2.99 95% Ci 0.95 LL = 2.05 UL = 3.96	n = 13 GM = 1.21E+03 **Log data** Median 2.88 95% Ci 0.46 LL = 2.54 UL = 3.22
Somatic coliphages **Org / 100ml**	**Combined data**	n = 24 GM = 6.00E+02 **Log data** Median 2.70 95% Ci 0.52 LL = 2.18 UL = 3.22	n = 44 GM = 5.65E+03 **Log data** Median 3.64 95% Ci 0.16 LL = 3.49 UL = 3.80	n = 52 GM = 5.38E+03 **Log data** Median 3.71 95% Ci 0.13 LL = 3.58 UL = 3.84
	Dry weather	n = 16 GM = 3.10E+02 **Log data** Median 2.65 95% Ci 0.20 LL = 1.94 UL = 3.36	n = 35 GM = 5.86E+03 **Log data** Median 3.64 95% Ci 0.25 LL = 3.47 UL = 3.82	n = 41 GM = 5.57E+03 **Log data** Median 3.76 95% Ci 0.16 LL = 3.60 UL = 3.92
	Wet weather	n = 8 GM = 2.24E+03 **Log data** Median 3.54 95% Ci 0.37 LL = 3.08 UL = 4.00	n = 9 GM = 4.91E+03 **Log data** Median 3.40 95% Ci 0.34 LL = 3.04 UL = 3.76	n = 11 GM = 4.76E+03 **Log data** Median 3.63 95% Ci 0.16 LL = 3.47 UL = 3.79

Impacts from treated waste water discharge and the Bloem Spruit on the Renoster Spruit

Table 4 shows increases in the numbers of the indicator organisms at R2 after operation of the new wastewater treatment facility started.

GM levels for all the indicator organisms increased with two orders of magnitude after beginning to receive the final effluent. Statistically significant differences for *E coli* (P = <0.001), CP (P = <0.001) and SC (P = <0.001) in the water quality of the Renoster Spruit at R2 were detected since receiving the discharges compared to the water quality before discharging final effluent.

The numbers of microbiological indicator organisms in the Renoster Spruit declined downstream, but GM levels of *E coli* and SC still exceeded the acceptable risk levels for domestic and recreational water use (DWAF a, b + c, 1993 and 1996) at R4 before confluence with the Bloem Spruit. The GM levels for CP also exceeded the maximum limit for low risk proposed by Water Quality Criteria in South Africa (Aucamp and Vivier, 1990) but at lower levels than detected in the Bloem Spruit. Contact with the waters was mostly limited to intermediate contact recreation, but during long hot summer day's children were found playing in and next to the water. This implies that significant health risks exist and exposed water users can be expected to contract gastro-intestinal diseases.

Table 4: The impact of treated effluent discharge on the Renoster Spruit.

Sample Points	***Escherichia coli*** **Org / 100ml**		***Clostridium perfringens*** **Org / 100ml**		**Somatic coliphages Org / 100ml**	
	Before	**After**	**Before**	**After**	**Before**	**After**
R1	n = 15 GM = 8.00E+01 **Log data** Median 1.91 95% Ci: 0.34 LL = 1.57 UL= 2.25	n = 13 GM = 5.56E+01 **Log data** Median 1.71 95% Ci 0.42 LL = 1.29 UL= 2.13	n = 13 GM = 3.80E+01 **Log data** Median 1.68 95% Ci 0.33 LL = 1.35 UL= 2.01	n = 13 GM = 3.59E+01 **Log data** Median 1.48 95% Ci 0.49 LL = 0.99 UL= 1.97	n = 12 GM = 2.00E+00 **Log data** Median 0 95% Ci 0.38 LL = 0 UL= 0.38	n = 13 GM = 4.15E+01 **Log data** Median 2.30 95% Ci 0.97 LL = 1.33 UL=3.27
R2	n = 21 GM = 1.36E+02 **Log data** Median 2.36 95% Ci 0.46 LL = 1.90 UL= 2.82	n = 30 GM = 1.88E+04 **Log data** Median 4.31 95% Ci 0.39 LL = 3.92 UL= 4.70	n = 18 GM = 1.40E+01 **Log data** Median 1.05 95% Ci 0.44 LL = 0.61 UL= 1.49	n = 29 GM = 5.43E+03 **Log data** Median 3.68 95% Ci 0.29 LL = 3.39 UL= 3.97	n = 18 GM = 1.20E+01 **Log data** Median 0 95% Ci 0.57 LL = 0 UL= 0.57	n=27 GM = 1.20E+04 **Log data** Median 4.03 95% Ci 0.13 LL = 3.90 UL= 4.16
R3		n = 27 GM = 1.43E+03 **Log data** Median 3.20 95% Ci 0.34 LL = 2.86 UL= 3.54		n = 26 GM = 3.67E+03 **Log data** Median 3.65 95% Ci 0.28 LL = 3.37 UL= 3.93		n = 25 GM = 2.99E+03 **Log data** Median 3.68 95% Ci 0.35 LL = 3.33 UL= 4.03
R4	n = 29 GM = 8.30E+01 **Log data** Median 1.80 95% Ci 0.33 LL = 1.47 UL= 2.13	n = 34 GM = 3.44E+02 **Log data** Median 2.47 95% Ci 0.30 LL = 2.17 UL= 2.77	n = 24 GM = 1.90E+01 **Log data** Median 1.58 95% Ci 0.35 LL = 1.23 UL= 1.93	n = 31 GM = 1.00E+02 **Log data** Median 2.27 95% Ci 0.37 LL = 1.90 UL= 2.64	n = 23 GM = 1.30E+01 **Log data** Median 0 95% Ci 0.58 LL = 0 UL= 0.58	n = 28 GM = 4.41E+02 **Log data** Median 2.65 95% Ci 0.35 LL = 2.30 UL= 3.00

Table 5 shows the cumulative impact and increases in the numbers of the indicator organisms at R5 after confluence of the Renoster Spruit with the Batho Spruit.

Table 5: The cumulative impact of urban discharges and treated effluent discharge on the Renoster Spruit.

Sample Points	***Escherichia coli*** **Org / 100ml**		***Clostridium perfringens*** **Org / 100ml**		**Somatic coliphages Org / 100ml**	
	Before	**After**	**Before**	**After**	**Before**	**After**
R5	n = 29 GM = 1.81E+03 **Log data** Median 3.29 95% Ci 0.36 LL = 2.93 UL= 3.66	n = 34 GM = 2.25E+03 **Log data** Median 3.12 95% Ci 0.28 LL = 2.84 UL= 3.40	n = 25 GM = 1.32E+02 **Log data** Median 2.44 95% Ci 0.41 LL = 2.03 UL= 2.85	n = 32 GM = 5.38E+02 **Log data** Median 2.68 95% Ci 0.30 LL = 2.38 UL= 2.98	n = 22 GM = 6.77E+02 **Log data** Median 3.04 95% Ci 0.53 LL = 2.51 UL= 3.57	n = 29 GM = 7.42E+03 **Log data** Median 3.77 95% Ci 0.19 LL = 3.58 UL= 3.96
R6	n = 24 GM = 5.35E+02 **Log data** Median 2.58 95% Ci 0.41 LL = 2.17 UL= 3.00	n = 26 GM = 4.72E+02 **Log data** Median 2.63 95% Ci 0.31 LL = 2.32 UL= 2.94	n = 21 GM = 4.80E+01 **Log data** Median 2.33 95% Ci 0.55 LL = 1.78 UL= 2.88	n = 25 GM = 2.23E+02 **Log data** Median 2.41 95% Ci 0.37 LL = 2.04 UL= 2.78	n = 19 GM = 9.32E+02 **Log data** Median 3.08 95% Ci 0.41 LL = 2.67 UL= 3.49	n = 24 GM = 1.80E+03 **Log data** Median 3.53 95% Ci 0.34 LL = 3.19 UL= 3.88

The LL as calculated from the 95% confidence interval for all the microbiological indicator organisms in the Renoster Spruit exceeded the acceptable risk limit (DWAF a, b + c, 1993 and 1996; Aucamp and Vivier, 1990). The compounded effect of the urban and wastewater discharges on the receiving waters of the Renoster Spruit were to some extent lessened through dilution downstream.

The cumulative impact of urban discharges and treated effluent discharge on the microbiological water quality of the Renoster Spruit can be seen in Figure 1-3 illustrating the difference before and after receiving discharges from the new wastewater treatment facility. No statistically significant differences for E coli (P = 0.547), CP (P = 0.285) and SC (P = 0.167) could be seen at R6 before and after receiving the final effluent. Numbers of microbiological indicator organisms detected at R6 over the total sampling period exceeded the acceptable risk limit proposed by the various water quality guidelines (DWAF a, b +c, 1993 & 1996); Aucamp and Vivier, 1990) and the risk of infection increases as the numbers of microbiological indicator organisms increases.

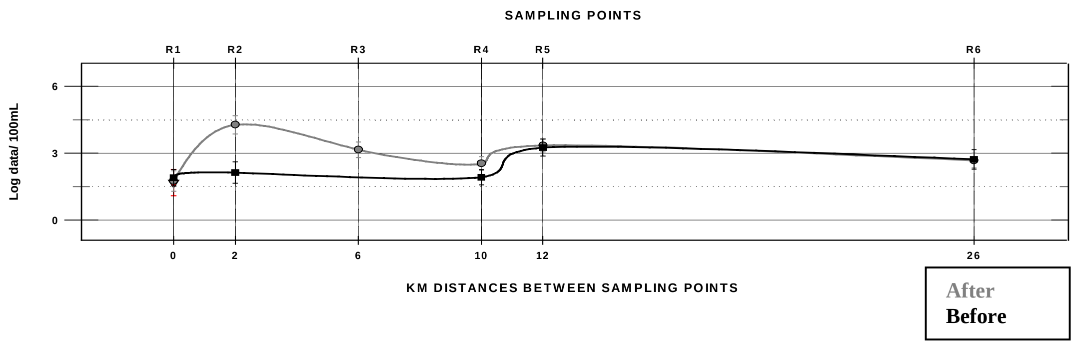

Figure 1: The impact of the various wastewater and other urban discharges on *E coli* numbers in the Renoster Spruit

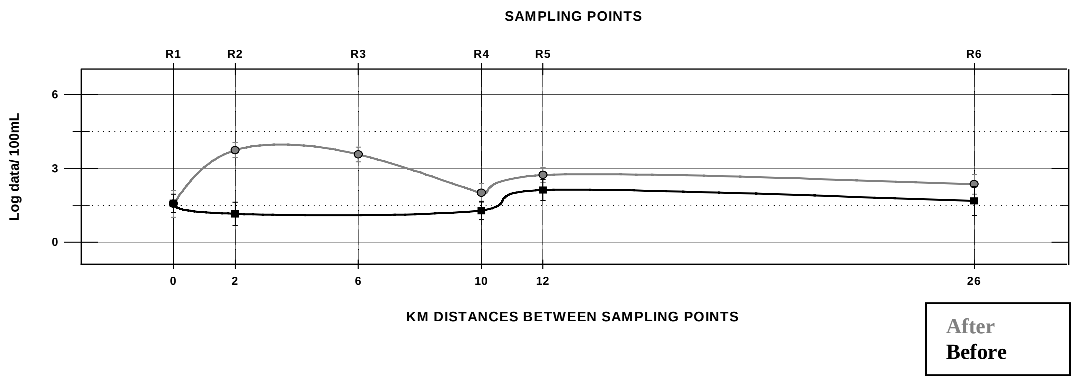

Figure 2: The impact of the various wastewater and other urban discharges on CP numbers in the Renoster Spruit

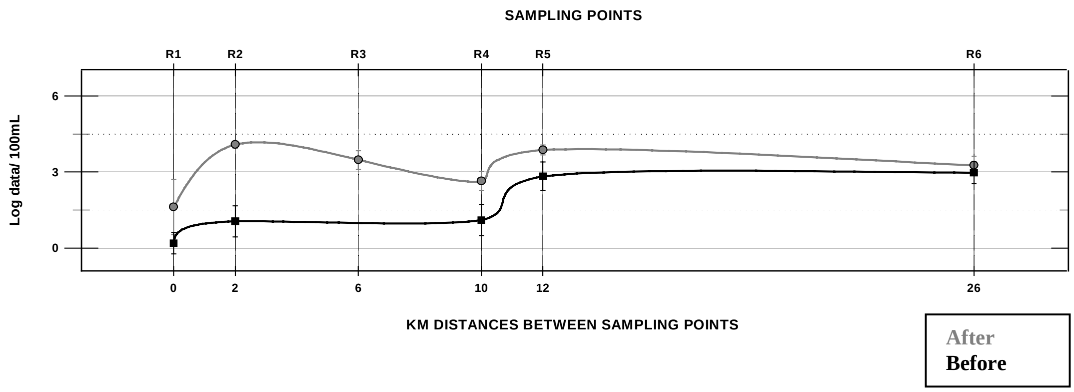

Figure 3: The impact of the various wastewater and other urban discharges on SC numbers in the Renoster Spruit

Impacts from the Renoster Spruit on the Modder River

The dilution effect of the Modder River (Table 5) lowered the levels of the indicator organisms to a level within the target water quality range for full-contact recreational water use (DWAF c, 1996). *E coli* numbers indicated a slight risk of gastrointestinal effects, and numbers of SC indicated some risk of virus infection. GM values of 1.80E+01 organisms/100ml for CP were also within drinking water quality range proposed by Water Quality Criteria in South Africa (Aucamp and Vivier, 1990) with the UL within the low limit for risk. The levels of microbiological indicator organisms detected were higher than detected before effluent from the new wastewater treatment facility started to discharge in the Renoster Spruit, but the risk of contracting gastrointestinal illnesses still remained low for riparian users irrespective the weather condition and time of year.

Table 6: Levels of microbiological indicator organisms in the Modder River.

Sampling Points	*Escherichia coli* Org / 100ml		*Clostridium perfringens* Org / 100ml		Somatic coliphages Org / 100ml	
	Before	**After**	**Before**	**After**	**Before**	**After**
M1	n = 12 GM = 1.40E+01 **Log data** Median 0.99 95% Ci 0.31 LL = 0.68 UL = 1.30	n = 21 GM = 5.00E+01 **Log data** Median 1.67 95% Ci 0.33 LL = 1.34 UL= 2.00	n = 10 GM = 3.80E+01 **Log data** Median 1.51 95% Ci 0.31 LL = 1.20 UL= 1.82	n = 23 GM = 1.80E+01 **Log data** Median 1.46 95% Ci 0.38 LL = 1.08 UL= 1.84	n = 10 GM = 1.00E+00 **Log data** Median 0	n = 21 GM = 4.40E+01 **Log data** Median 0 95% Ci 0.48 LL = 0 UL= 0.48

CONCLUSION

Results indicated that the treatment facilities intermittently released mean levels of indicator organisms that exceeded infection risk limits proposed by the South African Water Quality Guidelines (DWAF a, b + c, 1993 and 1996) and by Water Quality Criteria in South Africa (Aucamp and Vivier, 1990). Judged by these results, indications were that pathogen barriers within the treatment systems were intermittently breached. The other urban discharges generally released similar levels of these microbiological indicator organisms but higher levels during and directly after rainfall events. The results further indicated that faecally polluted urban run-off, in combination with the discharged treated effluents, overcame the assimilation capacity of the Renoster Spruit in the direct vicinity of the urban development and created risk of infection to exposed riparian users up to the point were the numbers of the microbiological indicator organisms were lowered by the dilution effect of the Modder River.

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