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Parallel drainages – the urban hydrology of the Moreletaspruit

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Abstract

The flow gauging and chemical monitoring data for the Roodeplaat Dam catchment east of Pretoria were combined to calculate inflow and nutrient loads with and without the contribution of treated sewage effluent from wastewater treatment works. The combined Moreleta-Hartbees subcatchment contributes about 27% of the surface inflow to the dam, the adjacent Pienaars River about 43% and the Edendale Spruit 8%. The remainder, nearly a quarter of the annual volume, enters the dam directly via the Zeekoegat sewage works. Treated effluent makes up a large proportion of the water entering Roodeplaat Dam, especially during dry periods. The effluent contributes several tons of phosphorus per year, with the consequence that the dam is highly eutrophic, causing water supply problems from the dam and downstream. Understanding the source and destination of water and pollutants may contribute to better management practices in the catchment, and encourage more realistic expectations for conservation efforts.

Keywords: *urban hydrology, phosphorus load, sewage*

1. Introduction

The Moreleta Spruit and Hartbees Spruit drain headwater catchments of the Limpopo system, in the east of the City of Tshwane, and are part of the catchment area of Roodeplaat Dam, a 43 $10^6 m^3$ storage dam (Figure 1). A forum named “Adopt Moreletaspruit” helps coordinate the activities of members of the public and government agencies in the management of the Moreleta Spruit, Hartbees Spruit and their tributaries (Golder, 2012). One matter of concern to residents and managers is the development and management of sewage pipelines and treatment systems. Population growth since the 1960s has required extensive infrastructure development. Much of the sewage network is a gravity system, and thus runs alongside the natural drainage lines of the catchment. Constructing sewer lines along the river course avoids costly disruption of other infrastructure such as roadways. However, with the Moreleta and Hartbees riverine corridors being valuable recreational and biodiversity assets, the digging of trenches for pipelines can be quite disruptive. Like most South African sewage systems, the system does not cater for stormwater and must not have connections to surface water drainage (Bester *et al*. 2010). During storms, incorrect connections between surface drainage and the sewage network result in overflow and contamination of rivers with potentially pathogenic microbes.

Enrichment of Roodeplaat Dam water by the nutrients in sewage effluent, especially phosphorus and nitrogen, has been noted since the 1970s (Walmsley *et al*., 1978). Two main sewage treatment works serve the residents of the Roodeplaat catchment. The Baviaanspoort works (BV in Figure 1) have been in operation since 1965, treating waste from the Pienaars River catchment and discharging into the Pienaars River seven kilometres upstream of where it enters Roodeplaat Dam. Zeekoegat works is within 700 metres of the banks of Roodeplaat Dam (Figure 1: ZK), and discharges treated waste directly into the dam. The phosphorus in the waste, mainly orthophosphate, contributes to the growth of cyanobacteria, algae and aquatic macrophytes. Macrophytes such as *Eichhornia* obstruct water flow and hinder recreational use of the dam. Cyanobacteria ("blue-green algae") produce toxins under certain conditions. The City of Tshwane abstracts water directly from Roodeplaat Dam via selective-depth offtakes at the wall, and the presence of cyanobacterial toxins complicates the potable water treatment process (van Ginkel and Silberbauer, 2007; Harding *et al*., 2009; van Ginkel, 2011).

This study presents a preliminary study of the current hydrology of the Roodeplaat Dam catchment and sums up the movement of phosphorus through the system. It also highlights areas where our understanding of the system is incomplete.

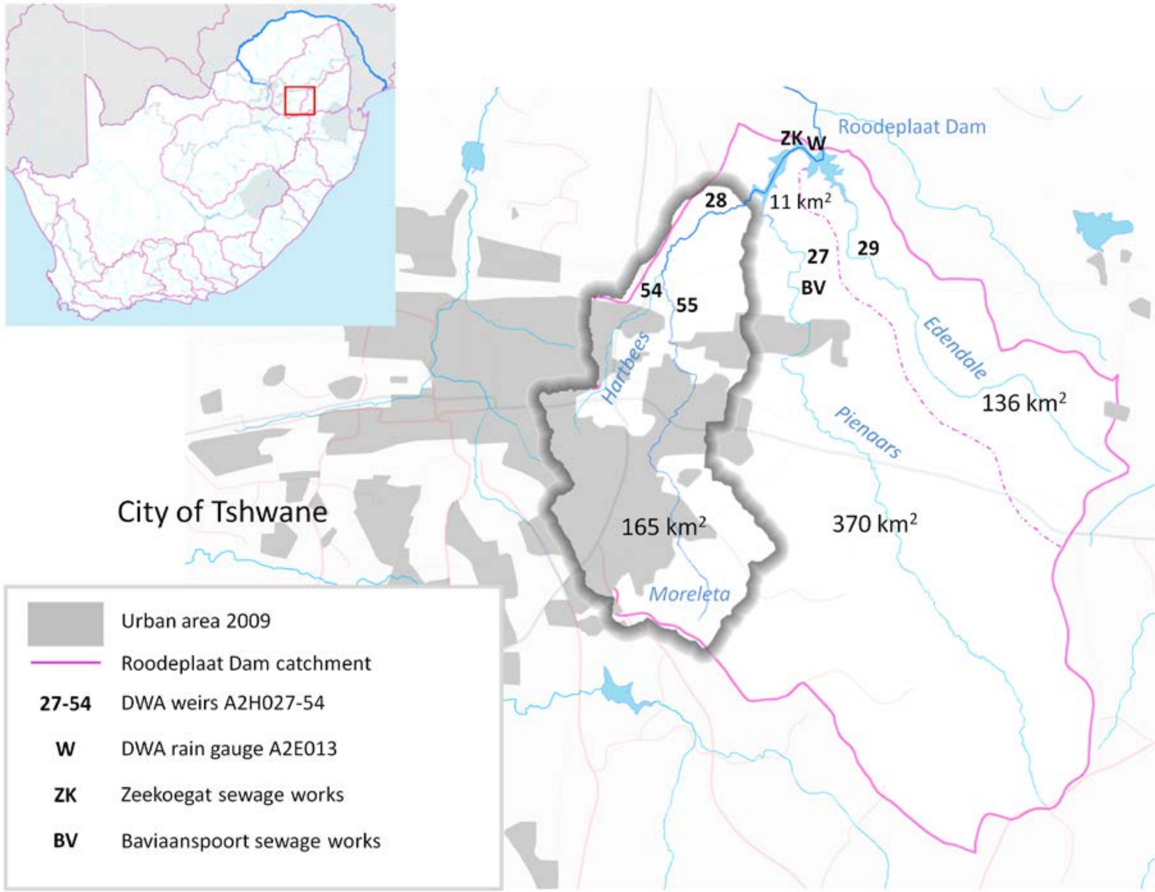

Figure 1. The catchment of Roodeplaat Dam, showing the subcatchment areas, monitoring sites, rivers, waterbodies and urban landuse. The total surface area upstream of the dam wall is about 682 km^2. The highlighted area is the Moreleta-Hartbees catchment.

2. Methods

Several reports and papers provide historical information on the limnology and hydrology of Roodeplaat Dam and its catchment, for example Walmsley *et al*., (1978), Hohls *et al*. (1998) and van Ginkel and Silberbauer (2007). Monitoring data are also available from local and national government databases.

2.1 Data sources

Flow and phosphorus data for the Pienaars River are from the national Department of Water Affairs (DWA) monitoring site A2H027 and for the Edendale Spruit from site A2H029 (27 and 29 in Figure 1). The dataset for the Moreleta Spruit is a combination of the partially overlapping time series for site A2H028 and sites A2H054 and A2H055 (28, 54 and 55 in Figure 1) (DWA-HS, 2014 and DWA-QS, 2014: flow data are from A2H054 + A2H055 and chemical data from A2H028). Precipitation measurements are from DWA site A2E013 and dam levels from site A2R009 (DWA-HS, 2014). Data for sewage works were obtained from the City of Tshwane (CoT) municipal records for 2004-2013

(CoT, 2014), and summaries in earlier reports (Weilbach 1979, Grobler and Silberbauer, 1984; Hohls et al., 1998).

2.2 Calculations

Load calculation was by the simple method of multiplying total monthly flows by median monthly total phosphorus concentrations (e.g. Rossouw *et al*., 2008). Where necessary, gap-filling was applied using adjacent records: large gaps were present in the river phosphate records for 1960-1979 and 1991-1992 and the sewage data for 1996-2003. An estimate for the total annual discharges before catchment development was made by apportioning the WR90 flow for quaternary catchment A23H between the three subcatchments.

Flow monitoring, but not chemical sampling, for the combined Moreleta and Hartbees Spruit site at A2H028 ceased in 1995, so the flow data for A2H054 and A2H055 were combined for subsequent years. The Moreleta Spruit dataset is therefore a composite of information from three sites.

An estimate of the contribution of the Baviaanspoort sewage works to the flow and load in the Pienaars River was made by subtracting the sewage values from the river values. This did not always give sensible answers, as will be seen.

3. Results and discussion

The mean annual runoff into Roodeplaat Dam has gradually increased since measurements began in 1962 (Table 1), although long-term median rainfall has remained fairly constant at around 700 mm per year in the lower part of the catchment (Figure 2). Peaks in the data reflect the occasional extreme flooding that occurs in the catchment, where the mean annual flow can occur within a few hours: for example, the estimated peak flow after a storm over Pretoria in 1978 was 1 900 m^3s^{-1} (Kovacs, 1978). The load of phosphorus has also increased steadily, although exact figures are not available for every year since completion of the dam (Table 2).

The different monitoring cycle for DWA and CoT can lead to anomalies in load estimates. An extreme example is the unusually high value for Pienaars River downstream of Baviaanspoort sewage works in 2013 (last row of Table 2 and the final value in the total phosphorus time-series plot in Figure 2). In this case, the peak is the result of a single value of 10.5 mg P/L recorded in the DWA dataset for Pienaars River. The corresponding orthophosphate reading for the sample was 8.0 mg P/L so the analysis seems consistent. Two WRC projects are currently dealing with aspects of flow data processing and phosphorus load calculation, and the final reports should provide a more solid basis for consistently estimating runoff and load.

Much of the increased flow into Roodeplaat Dam from the Moreleta-Hartbees subcatchment appears to come from outside the catchment in the form of the municipal water supply which eventually enters the sewage network. The gauging stations in the Moreleta-Hartbees catchment reflect a gradually-increasing flow rate, and the source of this is unclear because the sewage reticulation by-passes the river completely. Possible sources are leakages from the water supply or sewage systems, and changes in the rainfall to runoff ratio resulting from urbanisation.

The decision to site the Zeekoegat sewage works on the banks of Roodeplaat Dam may have been controversial, especially with regard to contamination of a recreation site, but it has had some benefits. The considerable volume of water used for sewage transport in the catchment is retained for reuse after treatment. Furthermore, the Moreleta-Hartbees river channels are spared the fate of becoming a channel for treated effluent, as has happened to the Pienaars downstream of the Baviaanspoort sewage works.

Table 1. Annual inflows as $10^6 m^3$ to Roodeplaat Dam from the three subcatchments in Figure 1, including sewage effluent volumes. WWTW = sewage works. WR90 = Midgley *et al*. (1994) "naturalised" flow. Sequences of identical flows are estimates. The negative flow for Pienaars minus Baviaanspoort in 1992 is a result of combining flows from different sources.

Year	Moreleta Spruit	Zeekoegat WWTW	Pienaars minus Baviaanspt. WWTW	Baviaanspoort WWTW	Edendale Spruit
WR90	7.0	0.0	15.6	0.0	5.7
1963	0.9	0.0	4.2	0.0	1.0
1964	2.6	0.0	7.4	0.0	0.8
1965	0.8	0.0	3.3	0.0	0.2
1966	2.5	0.0	5.5	4.0	1.3
1967	12.2	0.0	53.3	4.0	13.8
1968	4.3	0.0	3.6	4.0	1.8
1969	7.8	0.0	9.8	4.0	2.5
1970	4.0	0.0	1.8	4.0	1.0
1971	8.0	0.0	13.8	4.0	3.0
1972	5.6	0.0	6.4	4.0	1.3
1973	3.8	0.0	5.2	4.0	0.4
1974	5.8	0.0	8.7	4.0	1.8
1975	21.1	0.0	44.3	4.0	11.2
1976	18.4	0.0	28.0	4.0	8.9
1977	8.1	0.0	9.7	4.0	3.6
1978	20.4	0.0	48.8	4.0	14.4
1979	6.2	0.0	9.2	4.0	1.4
1980	10.9	0.0	18.7	4.5	4.0
1981	7.9	0.0	6.7	4.5	1.3
1982	6.6	0.0	5.2	4.5	0.4
1983	7.1	0.0	9.1	4.5	1.1
1984	4.7	0.0	1.7	4.5	0.4
1985	8.2	0.0	4.5	4.5	0.3
1986	8.0	0.0	5.4	4.5	0.7
1987	8.4	0.0	12.3	4.5	2.1
1988	8.4	0.0	3.7	7.7	0.4
1989	11.8	0.0	11.2	7.7	1.0
1990	8.7	0.0	7.4	7.7	0.9
1991	13.9	0.0	18.9	7.7	7.4
1992	3.0	11.5	**-1.9**	11.1	0.0
1993	9.3	11.5	2.8	11.1	0.4
1994	9.3	11.5	4.7	11.1	0.7
1995	13.5	11.5	5.8	11.1	1.3
1996	23.6	11.5	38.9	11.1	9.7
1997	22.6	11.5	34.0	11.1	8.8
1998	14.2	11.5	8.9	11.1	3.4
1999	3.1	11.5	5.2	11.1	1.9
2000	11.6	11.5	47.0	11.1	7.5
2001	1.9	11.5	7.1	11.1	2.1
2002	8.2	11.5	2.7	11.1	1.4
2003	10.7	11.5	4.4	11.1	1.6
2004	16.0	11.5	14.7	11.1	4.3
2005	14.7	14.8	7.8	13.7	3.8
2006	25.4	16.2	21.8	15.0	7.6
2007	13.9	15.9	6.0	15.4	2.7
2008	25.9	16.2	29.9	16.8	13.3
2009	28.1	18.2	21.4	19.7	7.2
2010	23.7	18.3	22.1	19.3	7.4
2011	34.1	17.9	34.0	20.6	10.6
2012	23.0	18.9	17.4	18.0	4.2
2013	21.7	22.0	13.0	19.2	6.1

Table 2. Annual total phosphorus load estimates in tons from the three Roodeplaat Dam subcatchments in Figure 1, including sewage effluent sources. WWTW = sewage works. Sequences of identical loads are estimates. The negative values for the Pienaars River minus the Baviaanspoort load are a reminder of the limitations of load calculation methods.

Year	Moreleta Spruit	Zeekoegat WWTW	Pienaars minus Baviaanspt. WWTW	Baviaanspoort WWTW	Edendale Spruit
1974	0.40	0.00	9.00	24.00	0.10
1975	0.40	0.00	9.00	21.20	0.10
1980	0.93	0.00	31.78	16.40	0.15
1981	0.57	0.00	22.25	16.40	0.04
1982	0.84	0.00	17.33	16.40	0.01
1983	0.32	0.00	18.01	16.40	0.15
1984	0.21	0.00	**-1.63**	16.40	0.03
1985	0.20	0.00	**-4.74**	16.40	0.03
1986	0.34	0.00	7.21	16.40	0.08
1987	0.19	0.00	11.63	16.40	0.17
1988	0.30	0.00	2.27	14.80	0.02
1989	0.44	0.00	3.84	14.80	0.13
1990	0.33	0.00	2.37	14.80	0.03
1991	0.40	0.00	18.11	14.80	0.28
1992	0.16	24.50	**-1.83**	13.70	0.00
1993	0.52	24.50	10.24	13.70	0.06
1994	0.41	24.50	**-0.75**	13.70	0.09
1995	0.67	24.50	3.27	13.70	0.30
1996	0.84	24.50	22.61	13.70	1.04
1997	0.94	24.50	27.74	13.70	1.19
1998	0.79	24.50	48.32	13.70	0.29
1999	0.11	24.50	20.06	13.70	0.24
2000	0.55	24.50	24.07	13.70	0.82
2001	0.11	24.50	7.02	13.70	0.23
2002	0.36	24.50	**-2.96**	13.70	0.35
2003	0.47	24.50	6.10	13.70	0.14
2004	1.27	24.50	19.84	13.70	0.77
2005	0.70	25.46	**-1.26**	24.75	0.49
2006	1.46	28.12	7.11	26.18	1.25
2007	9.56	12.73	**-3.93**	40.63	0.65
2008	1.16	13.99	36.20	40.51	3.82
2009	0.60	21.35	**-24.99**	80.44	5.81
2010	2.30	15.33	11.47	39.90	6.90
2011	2.04	9.22	27.50	22.16	2.53
2012	0.57	8.48	**-0.70**	42.49	0.57
2013	0.73	11.61	62.44	55.31	1.57

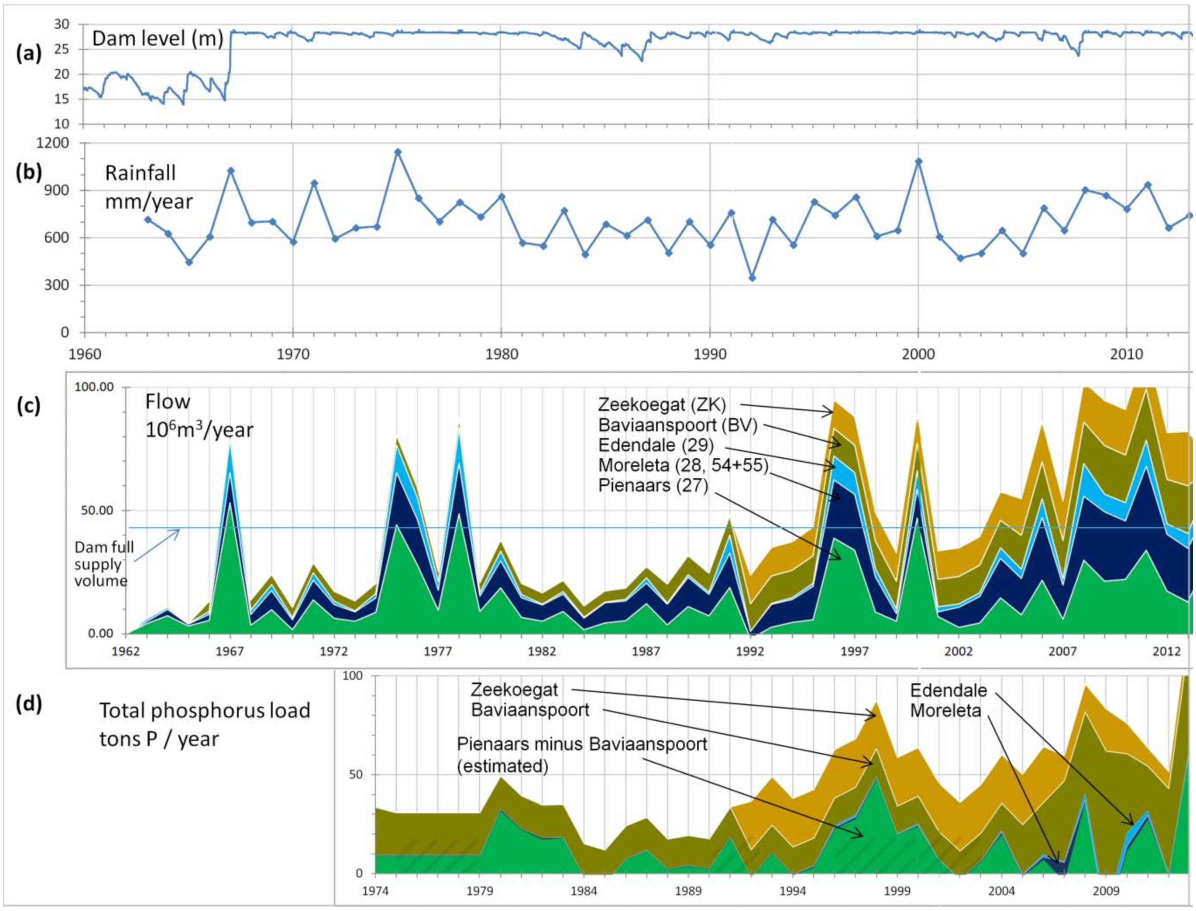

Figure 2. Summarised time series data from several sources, aligned as closely as possible to a single time axis. (a) Roodeplaat Dam levels from the gauge plate at the dam wall; (b) Annual rainfall from records at Roodeplaat Dam; (c) Flows estimated for the Roodeplaat Dam catchment (cf. Table 1): the monitoring site map codes are in parentheses and cross-hatching marks extensively interpolated data—the horizontal line indicates where annual inflow has exceeded the full supply volume of the dam; (d) Loads estimated for the catchment (cf. Table 2).

The volumes of effluent entering Roodeplaat Dam make up a large proportion of the total inflow, and this is not only important as a factor in eutrophication, but also a matter of concern for water users downstream. Already, municipal water providers use the dam as a source, extracting water at the dam wall and treating it to potable standards. Water released from the dam flows downriver for nearly 1 700 km before it reaches the sea, and many of those who abstract it for various purposes are probably unaware of where it comes from and what it contains.

4. Conclusion

The present flow regime of the Roodeplaat Dam catchment is very different from the probable "natural" conditions, in that treated sewage effluent provides a continuous source of water throughout the year, much of it derived from outside the catchment via the municipal water supply system. The network of pipes transporting sewage to the Zeekoegat works functions as a sort of cryptic drainage system running parallel to the Moreleta Spruit, with comparable volumes to the surface drainage. The sewage works also deliver large amounts of phosphate to the system, despite removal of a great deal using the best available methods. The results of excess nutrients in the aquatic system are eutrophication and increased treatment cost for downstream users.

Not all the information about the hydrology is readily available, and a model of inputs and outputs to the catchment using the data reported here along with municipal water consumption figures would be of assistance in visualising how the whole system works, and would be helpful for managing the catchment. Such a model would also provide a basis for investigating the transport of solutes and pathogens through the system. Components of this approach are already available or under development under the auspices of the Water Research Commission (Harding, 2008).

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