The rising costs of both sewage treatment and the production of potable water associated with increasing levels of pollution in a portion of the Crocodile-West Marico water management area (A Case Study)

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Abstract

Substantial quantities of water can be made available for use if the quality of return flows is of sufficient quality or treated to the desired quality. In 2006, in the order of 50% of urban and industrial drainage were returned for re-use in urban and industrial areas such as Johannesburg and Pretoria (DEAT, 2006). The reuse potential of return flows is however largely dependent on the quality of the return flow combined with the quality requirements of the users. The WRC therefore commissioned this study to compare the costs associated with measures to control pollution at source with those required to treat the consequences associated with polluted water for four of the most important water quality contaminants, namely salinity, eutrophication, microbial pollution and sediments.

The results of this study clearly indicate that pollution reduces the quality and therefore the economic value of the available water in the case study area. This deterioration of water quality impacts on users abstracting water directly from the streams for irrigation and domestic use purposes and may even affect the value of property adjacent to polluted streams. The most measurable impact in economic terms however, is the analysis of the costs incurred by municipal and private entities responsible for water purification for potable use. Technology used to treat relative good quality water less than a decade ago must now be viewed as outdated and inadequate based on the deteriorated quality of intake water. The cost of recent technology upgrades in order to continue to produce water of potable quality clearly indicates the financial impact of pollution in the study area.

The long-term results of poor control of pollution practices is identified as health impacts on informal users, deterioration in the quality of agricultural produce and the inevitable increase in costs associated with providing the public with potable water. These costs will eventually have to be recovered from the end users (general public and industry) and will increase of living costs.

This investigation clearly indicates the importance of pollution prevention over attempts to control the inevitable effects of current pollution practices in this study area through comparing direct and indirect costs associated with pollution.

Introduction

The White Paper on Integrated Pollution and Waste Management for South Africa (DEAT, 2000) identifies salinisation of fresh waters, nutrient enrichment of fresh water bodies, microbial degradation of water quality and sediment and silt migration as key water pollution issues that need to be addressed. In addition, the national water policy for South Africa (DWAF, 1997) set as a principle that water quality management options shall include the use of economic incentives and penalties to reduce pollution. The Department of Water Affairs has already started the development of the Waste Discharge Charge System (WDCS) aimed at providing economic incentives and penalties to implement the "polluter pays principle", as adopted by both policies mentioned above. The level at which the charges will be set, however, will have to be determined on the basis of the costs associated with prevention measures (abatement costs) as compared to the costs of treating polluted water and the associated environmental impacts (damage costs).

The purpose of this study was therefore to estimate the cost of prevention and treatment, associated with pollution of the water resources in a portion of the Crocodile-West Marico water management area.

Background

In 2006, in the order of 50% of urban and industrial drainage were returned for re-use in urban and industrial areas such as Johannesburg and Pretoria (DEAT, 2006). The potential for return flow reuse depends largely on the quality of the return flow combined with user requirements and the affordability of the required treatment to meet these user requirements. Increasing urbanisation combined with progress towards meeting basic human requirements for water and industrial activity, increases the pressures on existing sewage and industrial effluent collection and treatment infrastructure. Shortages in capacity at these facilities to cope with the increased demand require expensive upgrades of existing infrastructure, the construction of new wastewater treatment facilities and/or improvement of the technology available for wastewater treatment to meet user requirements. Although the upgrade or expansion of wastewater treatment infrastructure is capital intensive, the release of untreated or inadequately treated wastewater into surface water resources will have a negative impact on the environment and downstream water users due to deteriorating water quality.

Eutrophication, salinisation, sedimentation and microbial contamination are all symptoms of polluted water resources which require increasingly sophisticated treatment technologies to render the available water fit for downstream use. Currently, most industries in urban areas use water of potable quality obtained from the distribution system of a water services provider (municipality or water utility) and discharge their wastewater into the municipal sewer system in accordance with the requirements of the Water Services Act, 1997 (Section 7) (RSA, 1997). As such, wastewater treatment facilities are considered to be pollution prevention measures for the purposes of this study. Therefore, the costs of pollution prevention is taken as equal to that of wastewater treatment and compared to the cost of supplying water of potable quality from polluted water resources. The results of this cost comparison will provide valuable insight into the cost implications of current water pollution management strategies.

The question to be answered is: Is it more cost effective to invest in the treatment of increasingly polluted surface water at point of use (potable standards) or should the focus of future water pollution management strategies be aimed at preventing water pollution by investing in improved wastewater treatment systems as suggested by national legislation through the implementation of a Waste Discharge Charge System (WDCS).

Study area selection

Since the focus of the study is on urban and industrial water use, a portion of the Upper Crocodile-West Marico water management area (sub-catchment A21) was chosen. The study area selected comprises the entire southern region of the A21 catchment area but excludes the area north of the town of Brits in the Madibeng local municipality. The area includes parts of Johannesburg, Pretoria, Krugersdorp and Kempton Park. Wastewater from this area includes contributions from mining activities and light industries as well as urban and agricultural areas. The surface water pollution in this catchment area impact on the water quality of the Rietvlei- and Hartbeespoort dams, both of which are water resources used for the provision of potable water as well as human recreational activities and irrigation farming in the case of Hartbeespoort Dam.

Another important point in selecting this study area is the availability of analytical and flow data for the rivers of this catchment area. This information is vital in describing the pollution load carried by the rivers. Water quality and flow data for the period January 1990 to May 2008, incorporating exceptionally wet and dry periods, seasonal flow and rainfall patterns was obtained from the Resource Quality Services (RQS) website of the Department Water Affairs of the Republic of South Africa (DWA) [http://www.dwaf.gov.za/iwqs/wms/data/000key.asp]. In addition, data on changes to the existing wastewater treatment infrastructure and Rietvlei water purification works (WPW) over this period was sourced from the operators of the various treatment facilities (table 1).

Detailed description of study area

The study area (Figure 1) stretches from Kempton Park in the East to Krugersdorp in the west with the Witwatersrand Mountains forming the Southern border and the Brits water purification works the northern boundary.

Figure 1: The Study Area (A portion of catchment A21) (GoogleEarth)

The main rivers of the study area are schematically presented in Figure 2 to provide a clearer picture of the rivers and water related infrastructure of concern.

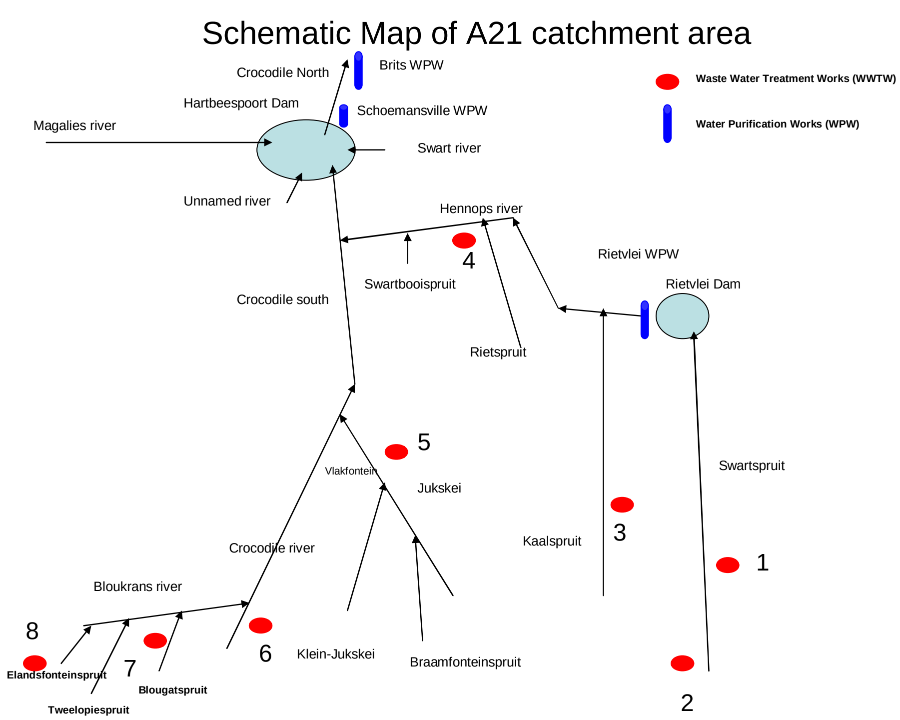

Figure 2: ***A schematic representation of the rivers, WWTWs, WPWs and major water reservoirs in the selected study area.***

On the eastern side of the study area the Swart River flows from Kempton Park and Esther Park where the Esther Park WWTWs discharges into it, through residential areas and past the new Serengeti golf and housing estate. The Hartbeesfontein WWTW discharges treated wastewater into this river before it flows through agricultural land, Marais Lake and wetland until entering the Rietvlei Reserve and finally discharges into the Rietvlei dam. The stream discharging from the Rietvlei dam is known as the Sesmyl spruit and joins the Kaalspruit which flows through Centurion. This river then becomes the Hennops River.

Several streams from the Modderfontein/Chloorkop area join the Kaalspruit in the Thembisa, Ebony and Ivory Park residential areas upstream of the Olifantsfontein WWTW discharge point. The Kaalspruit then continues north through agricultural land past the Irene Research Institute and is joined by the Sesmylspruit from Rietvlei Dam near the Smuts House museum just to the south of Irene. The Kaalspruit flows north through Centurion and Centurion Lake where it becomes known as the Hennops River. This river flows past the Zwartkops golf course (GC) and then west past the Zwartkop nature reserve. The Hennops is joined by the Rietspruit from the residential areas of Raslow, Wierda Park and Rooihuiskraal that flows past the Sunderland Ridge industrial park. The Sunderland Ridge WWTW discharges into the Hennops just after it receives water from the Rietspruit. From here the Hennops flows mainly in a westerly direction, is joined by the Swartbooi Spruit from Gerhardsville until it discharges into the Crocodile River just before Kalkheuwel.

The Magalies River flows from the west of the study area past Skeerpoort mainly through agricultural land and discharges into the Hartebeespoort dam.

The Braamfonteinspruit, upper-Jukskei and Klein Jukskei originates in the Alexandra, Sandton and Randburg areas. These rivers join up to continue north as the Jukskei River and receive treated effluent from the Great Northern Works WWTW.

The Crocodile River originates near Krugersdorp and Roodepoort and is joined by the Bloukrans River that flows past Randfontein and Krugersdorp. The Blougatspruit, Tweelopie spruit and Elandsfontein spruit joins the Bloukrans River carrying pollution generated from mining activities in the Randfontein area as well as treated effluent from domestic origin. The Randfontein WWTW discharges into the Elandsfontein, the Percy Stewart WWTW discharges into the Blougatspruit and the Driefontein WWTW discharges into the Crocodile River. The Tweelopie Spruit flows from Robinson’s lake and is polluted with mining effluent. The entire pollution load is therefore carried by these rivers into the Crocodile River. The Crocodile River is joined by the Jukskei River (carrying pollution from informal settlements) and later also by the Hennops River before discharging into the Hartbeespoort dam.

The Crocodile River that flows northwards from the Hartbeespoort Dam represents the only large outflow of water from this dam and supports the farming activities as well as the inhabitants of the town of Brits further downstream at the Northern Border of the study area. The impacts of the water quality of this river downstream of Brits are not included in this study.

The two major surface water reservoirs are the Rietvlei dam and the Hartbeespoort dam.

The WWTWs in this area are represented in Figure 2 by the numbers allocated to them in table 1.

Table 1: *WWTW in the selected study area. The capital value is supplied according to the information supplied by the owner/operators of the different WWTWs. Various factors including location, specific design and size determine that the different WWTWs are valued at different capital amounts/ML.day. The capital value of these plants are only supplied for those WWTWs that uses activated sludge technology.*

No	WWTW	Discharge River	Treatment Capacity (ML/day)	Average flow (ML/day)	Operating costs ZAR/ML	Planned expansion of facilities	Replacement value/ Capital value in ZAR	Source
1	Hartbeesfontein	Swartspruit	45	50		New 120 ML/day WWTW on the Swartspruit. Phase one (50 ML/day to be completed in 2013 @ R260m	315m at R7m/ML.day	ERWAT
2	Esther Park	Swartspruit	0.4	0.4				ERWAT
3	Olifantsfontein	Kaalspruit	105	70			735m at R7m/ML.day	ERWAT
4	Sunderland Ridge	Hennops River	65	58	794.1	Increase capacity to 95 ML/day by 2010 – 2013 @ R300m; New 50 ML/day WWTW near Skurweberg on Hennops River to be completed in 2016 @ R260m	585m at R8m/ML.day	Municipality of Tshwane
5	Great Northern Works	Jukskei	450	380		Phase two to be completed in 2013 with phase 3, (an additional 50 ML/day) planned for 2025	2 700m at R6m/ML.day	Johannesburg Water
6	Driefontein	Crocodile	35	35		Expansion of additional 25 ML/day @ R150m	210m at R6m/ML.day	Johannesburg Water
7	Percy Stewart	Blougat Spruit	20.5	n/a				Mogali City Municipality (Krugersdorp)
8	Randfontein	Elandsfontein Spruit	19.5	n/a				Mogali City Municipality (Krugersdorp)

WPWs in the study area are the Rietvlei WPW, the Schoemansville and Brits WPWs. Unfortunately data from the latter two facilities has not been made available for inclusion in this study.

Data used for this study

The available analytical data from the DWA chemical water quality monitoring programme sites as well as DWA flow rate monitoring points in the study areas was used. Additional analytical data was also supplied by the Rietvlei WPW and Tshwane municipality.

The information in Table 1 also includes the recent technology and capacity upgrade costs, operating costs and information regarding planned future upgrades and related capital expenditure that were obtained from the various treatment plant operators.

Methodology

The analytical data as well as the flow data supplied by the various sources was extracted into a database and converted to monthly averages. This allowed the calculation of monthly pollution loads carried by the various rivers and streams. The aim of this analysis was to obtain a clear indication of pollution loads entering the water resources, especially the Rietvlei and Hartbeespoort dams. As sufficient data for the outflow quality of Rietvlei dam was not available, Hartbeespoort dam data was used to demonstrate the build-up of pollution in these dams. The effect of pollution on the production of potable water is demonstrated by the Rietvlei facility only as similar data from the Madibeng municipality was not forthcoming.

The costs associated with increasing wastewater treatment infrastructure and the cost required to improve the efficiency and available technology for the production of potable water of adequate quality was used as indication of the costs of pollution prevention and treatment measures.

Results and discussion

Flows

All the rivers and streams included in this study area flow towards and ultimately contribute to the water volume and pollution load entering the Hartbeespoort dam. The results indicate monthly average flows as observed for the period 1990 to 2008 and highlight the pollution contribution by the main rivers that discharge into the Hartbeespoort dam.

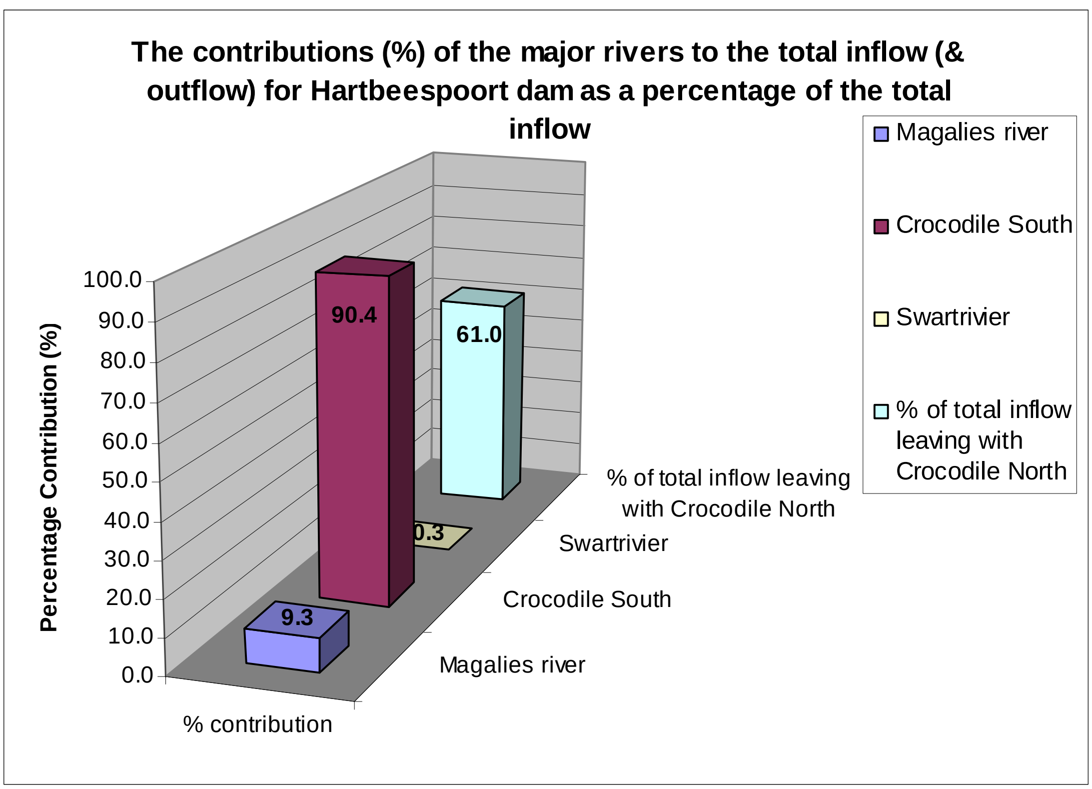

Figure 3: *A graphic representation of the flow contributions of major rivers to the inflow into the Hartbeespoort dam.*

As illustrated in Figure 3, the Crocodile River contributes 90.4% of the total inflow of water into the Hartbeespoort dam. The contribution of the other rivers is comparatively small with the Magalies River contributing 9.3% and Swart River only 0.3% of the total inflow into the dam. It is further illustrated that only 61% of the water flowing into the Hartbeespoort dam continues downstream *via* the Crocodile River towards the town of Brits (Figure 3). The remaining 39% water loss can be attributed to direct abstraction from the dam for irrigation and other consumptive uses and evaporation.

Pollution loads

The data presented in figures 4, 5 and 6 indicates that nutrients and salts contributing to eutrophication and salinisation respectively are trapped in the dam resulting in a steady decrease in dam water quality. This build-up of the phosphate and nitrogen load in the dam is one of the major causes of eutrophication. The data presented in figure 6 suggests that the fraction of salinity leaving the dam downstream is significantly higher (53.5%) than that of the nutrients phosphate (18.1%) and nitrogen (22.6%). Salinity build-up therefore occurs at a slower rate than nutrient enrichment.

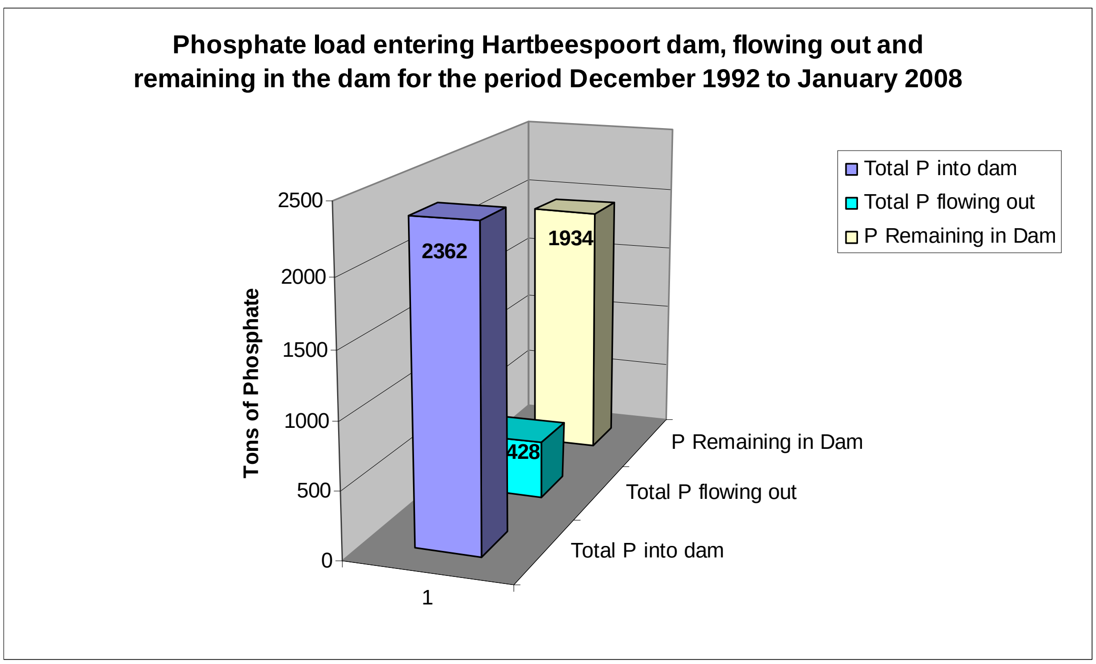

Figure 4: *Phosphate loads in the Hartbeespoort Dam.*

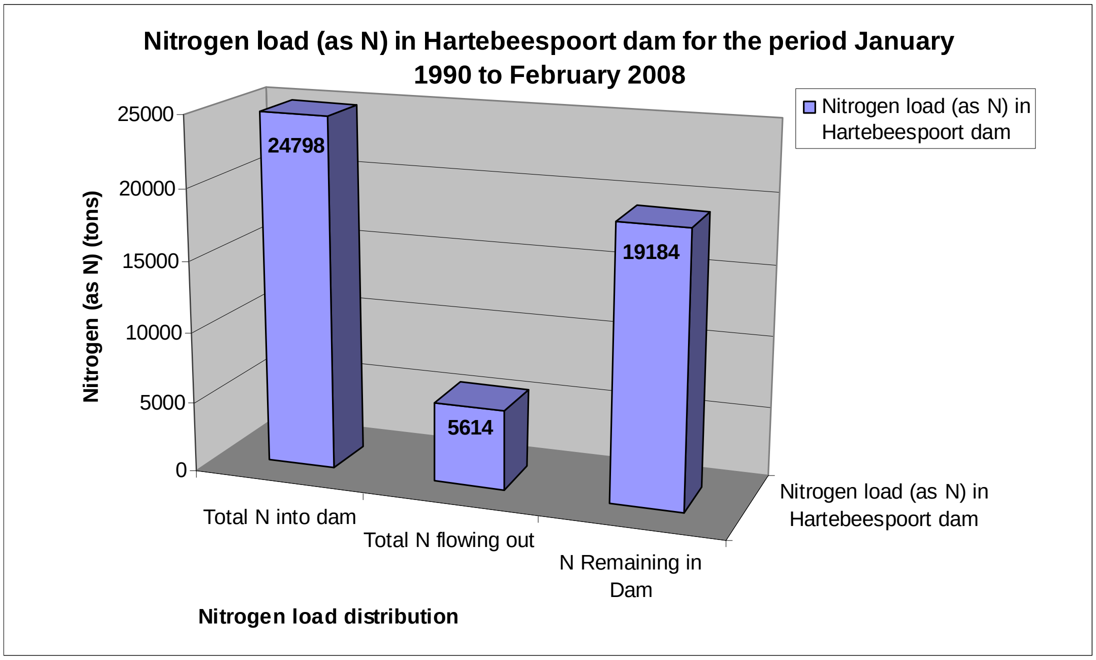

Figure 5: *Nitrogen load in the Hartbeespoort Dam.*

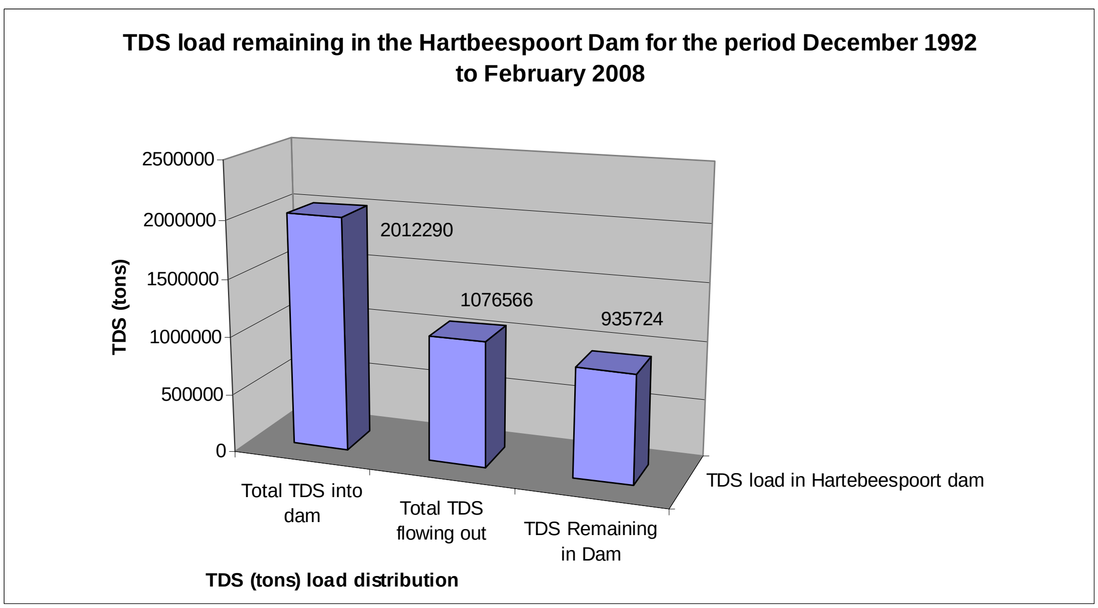

Figure 6: *Salinity in the Hartbeespoort Dam.*

Origins of pollution

The main sources of the different pollutants can be traced back by following the pollution load contributions of the various upstream rivers and streams feeding into the Hartbeespoort Dam. This information can assist in identifying target areas for intervention and inform pollution prevention strategies.

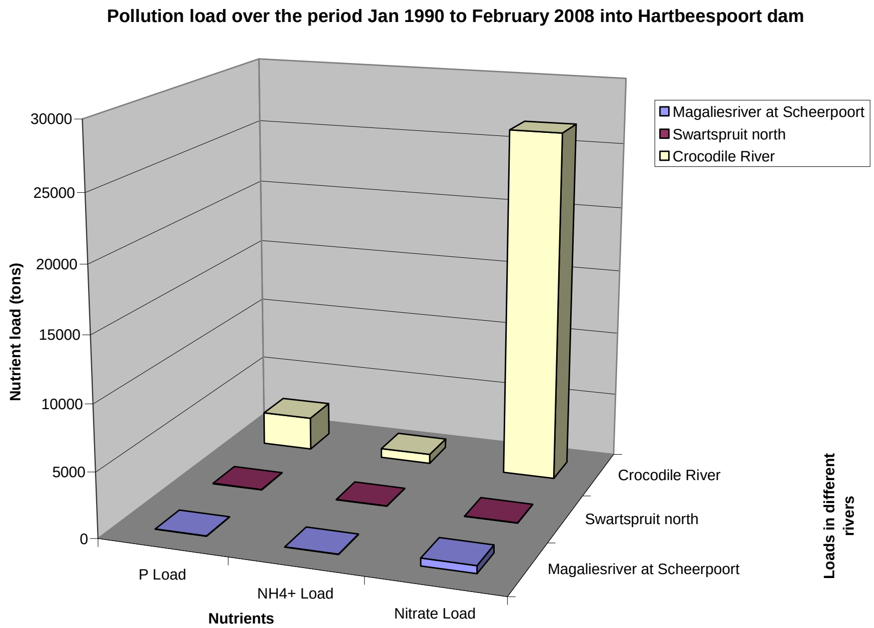

Figure 7: *Nutrient contributions by the rivers discharging into the Hartbeespoort Dam.*

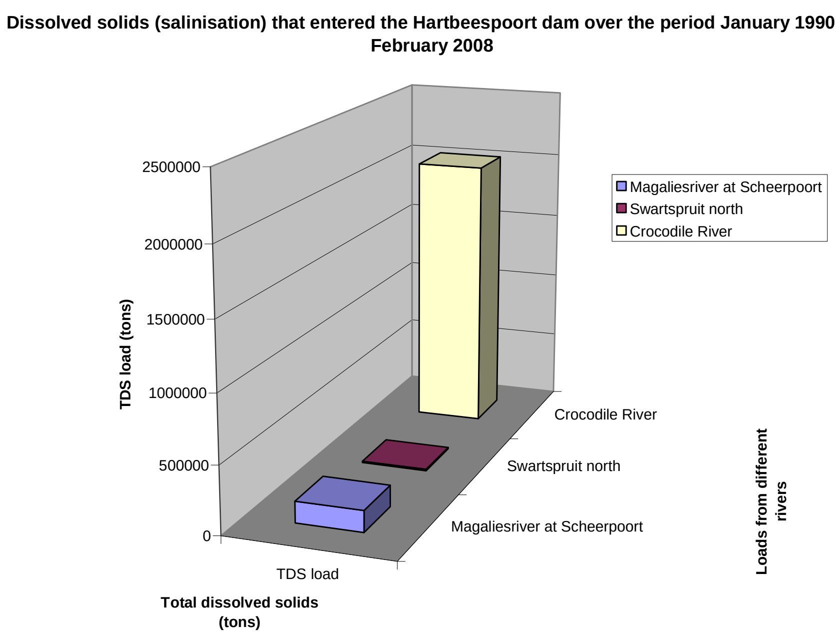

Figure 8: *The contributions of TDS by the major rivers discharging into the Hartbeespoort Dam.*

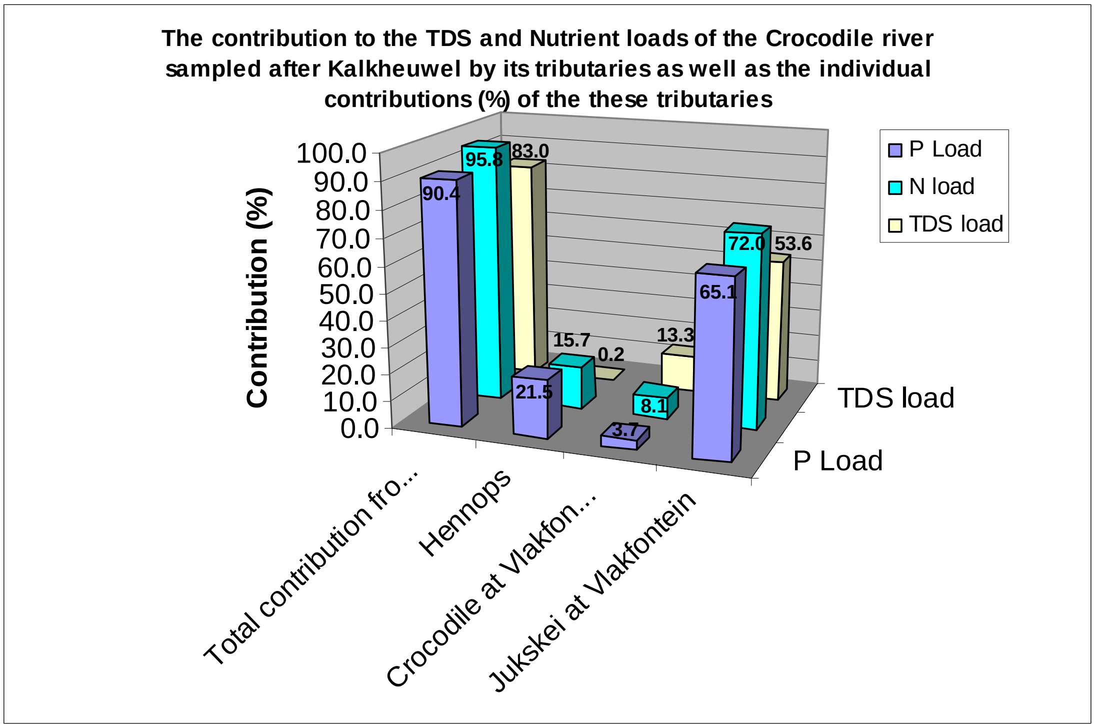

Figure 9: *Pollution load contributions from the Tributaries of the Crocodile River upstream of the Hartbeespoort Dam.*

The Crocodile River not only contributes the highest flow volume to the Hartbeespoort Dam (Figure 3) but also the biggest pollution load in terms of P and N (Figure 7) as well as TDS (Figure 8). The Magalies River and Swartspruit contributes significantly less flow and pollution loads (Figure 3, 7 and 8 respectively).

In light of the magnitude of the flow and pollution coming from the Crocodile River, it is further broken down into the tributaries upstream. The flow contribution by the Hennops, Jukskei and Crocodile Rivers upstream of their confluences is illustrated in Figure 10. The Jukskei contributes 56.7% of the flow followed by the Hennops at 27.5% and the Crocodile with 14.1%.

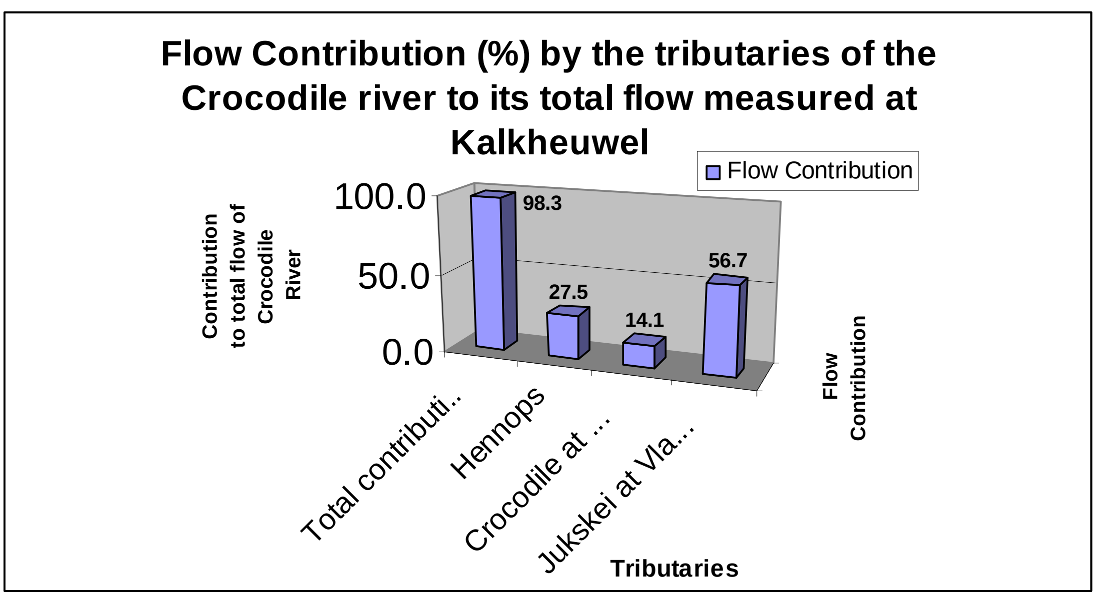

Figure 10: Percentage contribution of the tributaries of the Crocodile River.

The Jukskei River sampled prior to its confluence with the Crocodile River at Vlakfontein also contributes the most of the nitrogen (72%), phosphate (65.1%) and salinity (53.6%) load measured for the Crocodile River just prior to its discharge into the Hartebeespoort dam (Kalkheuwel). This is however not only due to the fact that the Jukskei contributes the highest volume of water of the three tributaries of the Crocodile River. Comparing the percentage contribution of pollutants versus the contribution to flow volumes, the Jukskei can be identified as the most polluted river of the three tributaries. Both the Crocodile and Jukskei rivers appear to contribute to TDS contamination equally in relation to their flow contributions.

Pollution Trends over time

The trends of pollution loads entering the Hartbeespoort Dam is illustrated in Figures 11 to 13. All pollution loads (P, N and TDS) are showing an increasing trend over time.

Although there is currently not enough data available for the Swartspruit upstream of the Rietvlei dam, a similar trend in pollution loads is expected based on Figure 14 indicating an increase in chlorophyll a in the intake water of the Rietvlei water purification works.

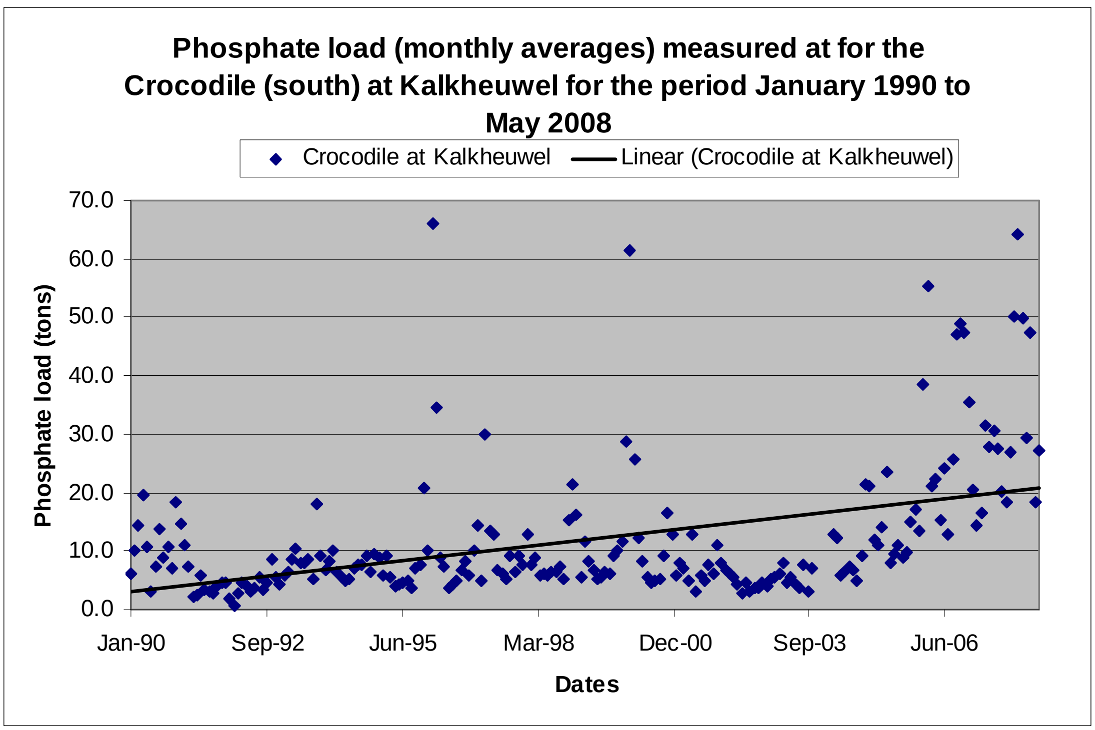

Figure 11: *Trend in phosphate loads entering the Hartebeespoort dam via the Crocodile River for the period indicated.*

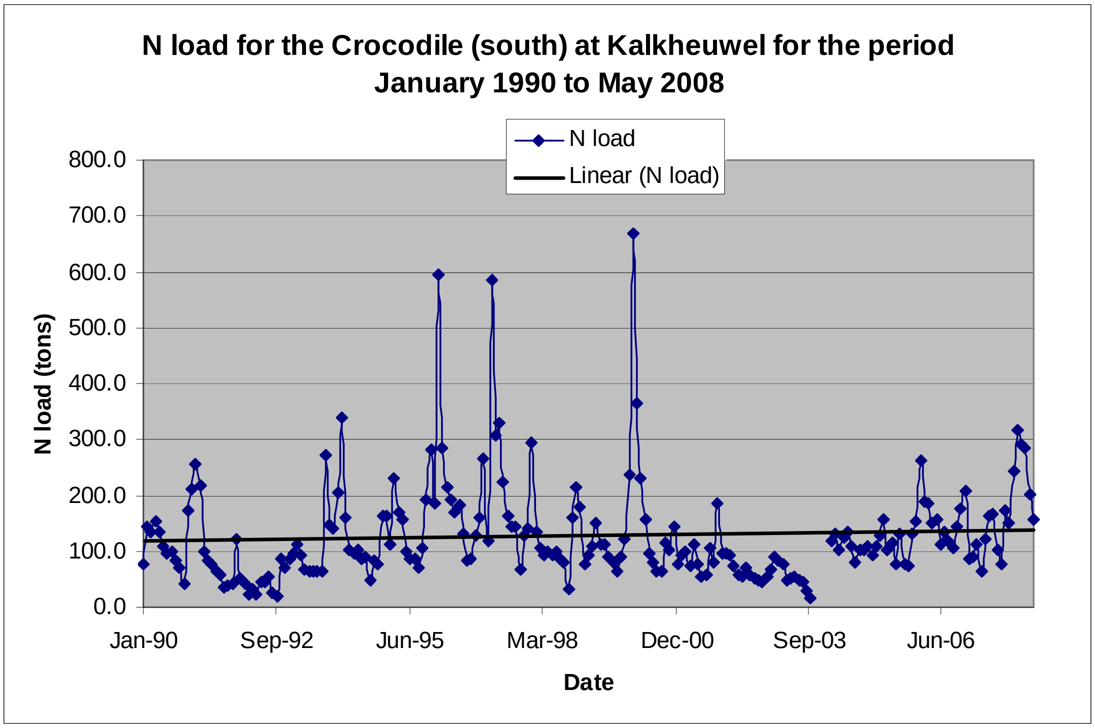

Figure 12: *Trend in N loads entering the Hartebeespoort dam via the Crocodile River for the period indicated.*

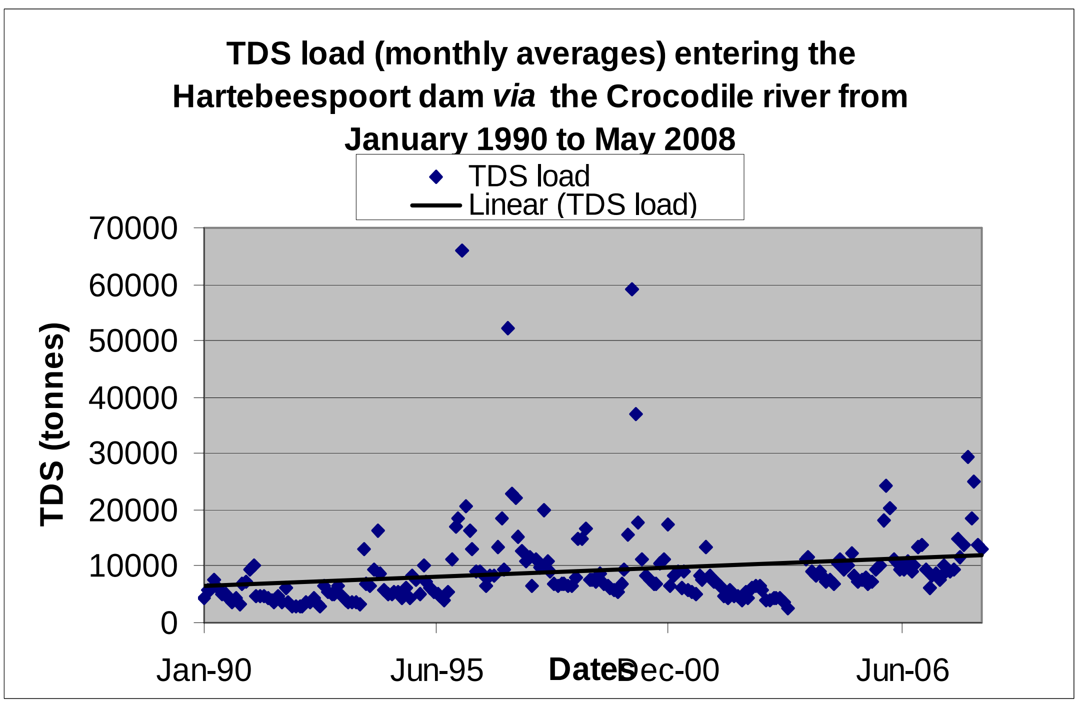

Figure 13: *Trend in TDS loads entering the Hartebeespoort dam via the Crocodile River for the period indicated*

The increasing trend in pollution load entering the dam must be viewed in conjunction with the data indicating that much of these pollutants remain behind in the receiving water body. Although there is not enough data currently available for the Swart Spruit until it discharges into the Rietvlei dam, it is assumed that a similar situation exists for the Rietvlei dam. The continuous increase in pollution of these two surface water resources causes eutrophication, already indicated by the DWA classification of these two dams as hypertrophic [The Trophic Status classification of South African impoundments, DWA 2003], and negatively impacts on the quality of the water in these dams and potable water treatment processes.

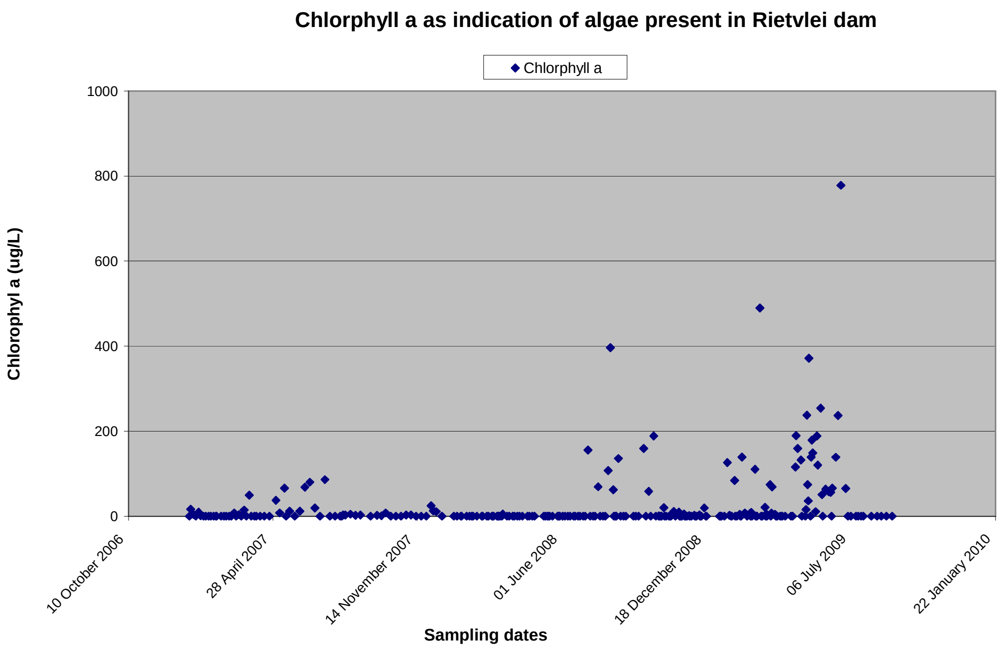

Figure 14: *Chlorophyll a counts in the intake water of Rietvlei WPW.*

This is extremely important as both dams are used to supply potable water to certain areas. This ongoing situation whereby pollution not only continues year after year but actually increases in magnitude on a yearly basis can only be combated by increasing the available infrastructure and regulations required to deal with this problem.

The data in figure 14 shows how algal growth in Rietvlei dam has become a serious problem, especially in the last two years. This problem is exacerbated by the fact that the so-called blue green algal species have become the dominant algal species in this dam as is also the case in the Hartbeespoort dam. Blue-green algae are difficult to remove *via* flocculation during water treatment processes and releases toxins that causes objectionable odour and taste problems. This toxin can also be harmful to human health under certain conditions.

The data analysed does not indicate any specific entity responsible for this increasing pollution loads. The current plans to upgrade many of the existing WWTWs in this study area do indicate that domestic and industrial wastewater discharged into this catchment area is a matter of concern to the authorities. The planned upgrades and expansions to existing WWTWs are inspired by the increasing volumes of wastewater that is generated in this catchment area. Increasing volumes of wastewater directly affects the efficiency of existing waste water treatment facilities.

The impact of the increased pollution loads of water resources on agriculture and human health cannot be estimated with a great degree of accuracy as yet.

Costs associated with expanding WWTW

The current capital costs of building the infrastructure for an activated sludge WWTW are estimated at between R6 – 9 million per ML/day capacity (table 1). This value varies depending on location and the capacity of the facility. This allows the valuation of the WWTWs in this study area. The calculation of the capital value of the WWTWs in this study area only take into account those with a treatment capacity of more than 30 ML/day (Table 1).

The current capital replacement value of these WWTWs can therefore be estimated at approximately R4.55 billion for the treatment capacity of 700 ML/day of mixed domestic and industrial wastewater (Table 1) and a cost of treatment capacity of R6.5m/ML.day.

The operational cost of waste water treatment at Sunderland Ridge WWTW's is given as R794.1/ML [Tshwane Municipality].

Potable water treatment

The increasing severity of the algal blooms occurring in the Rietvlei dam is illustrated in Figure 14. This problem requires specific technology interventions for the continued production of good quality potable water from this resource. A dissolved air flotation (DAF) system was installed in 1980 followed by an activated carbon system in 1999. More recently ozonation equipment was introduced. The latest technology intervention is the introduction of the "Solarbee" system aimed at the management of the algal population in the dam to curb toxic algal blooms. This is an excellent example of how eutrophication affects the technology interventions and costs required for the production of potable water.

The water purification works at Brits is another example where increasing pollution of the water resource is now impacting on the ability of the WPW to deliver good quality water. This plant is failing and the inhabitants of the town revert to buying bottled water for human consumption. Unfortunately no analytical or operational data were made available for this study by the Madibeng municipality officials.

The current replacement value of this facility is R175m [Tshwane Municipality]. This capital value can be normalised against the volume (ML) of potable water produced and this provides a value for the capital investment in the water purification infrastructure of R4.6m/ML.day capacity.

Production costs

Rietvlei WPW is producing approximately 37 – 38 ML/day of potable water and supplies an estimated 18% of the potable water for Pretoria. Their current operating costs are estimated at R1 030/ML of potable water [Rietvlei WPW].

According to the information presented in this paper the capital costs for waste water treatment facilities is higher than the capital costs for a modern water purification plant. However, an almost complete reversal of this cost structure occurs for production costs where the production of potable water is more expensive than the treatment of waste water. Over the long-term potable water production will therefore be more expensive/ML produced and these costs will continue to increase as more sophisticated technology is required to combat the effects of increasing pollution.

Conclusions

Pollution reduces the quality and therefore the economic value of the available water in the case study area. This deterioration of water quality impacts on users abstracting water directly from the streams for irrigation and domestic use and may even affect the value of property adjacent to polluted streams. The most measurable impact in economic terms however, is the analysis of the costs incurred by municipal and private entities responsible for sewage treatment as well as water purification for potable use. Technology used to treat relative good quality water less than a decade ago must now be viewed as outdated and inadequate based on the deteriorated quality of intake water. The cost of recent technology upgrades in order to continue to produce water of potable quality clearly indicates the financial impact of pollution in the study area.

It is clear from the results that the main source of inflow water into the Hartbeespoort Dam is the Crocodile River. The dam acts as a sink for nutrients and to a lesser degree salts, with the result that the quality of the dam water is inevitably deteriorating over time. The data further clearly indicates that the pollution loads carried by rivers in the study area, are steadily increasing over time. It is specifically of note that the phosphate load from the Crocodile River continues to increase, despite the implementation of the so-called special standard for phosphate of 1 mg/l-1 ortho-phosphate, since 1988 (Hohls *et al*, 1998). The pollution prevention measures implemented in the catchment of the Crocodile River is therefore not very efficient. The cost implications for downstream users to treat the water to acceptable quality for use or to use alternative sources of water such as bottled water, is therefore a direct cost of the water pollution.

The cost of nutrient enrichment over time is clearly outlined in the technology interventions implemented at the Rietvlei Dam. It should further be noted that more sophisticated technologies are also more expensive. It can therefore be concluded that increasing pollution results ever rising treatment costs to users. Both industrial and human activities demands access to clean water but the current trends of increasing pollution and associated treatment costs could affect the availability and affordability of potable water in the near future.

It is clear from this analysis that more should be done to prevent pollution and reduce the influx of wastewater to the surface water resources of this study area but equally in any catchment area. Legislation limiting the use of potable water for the sewerage systems, gardening and other non-critical water uses should be explored while industrial water use and waste production should also be minimised through cleaner production practices. The costs of potable water can be expected to rise sharply as the quality and availability of water continues to be reduced. The data presented in here also indicate that waste treatment measures should be given a high priority by the authorities of any catchment area or municipality as the costs of remediation of polluted water in the environment will be much more expensive, therefore directly influencing the concept of water as a basic human right.

References

City of Tshwane (2008) Approved Second Revised Tshwane Integrated Development Plan 2008/9-2010/11. Available online: www.tshwane.gov.za

Department of Environmental Affairs and Tourism (DEAT). (2000). White Paper on Integrated Pollution and Waste Management for South Africa: A Policy on Pollution Prevention, Waste Minimization, Impact Management and Remediation.

Department of Environmental Affairs and Tourism (DEAT) (2006). South Africa Environment Outlook: A Report on the State of the Environment. (Department of Environmental Affairs and Tourism: Pretoria).

Department of Water Affairs and Forestry (DWAF) (1997). White Paper on a National Water Policy for South Africa. (Department of Water Affairs and Forestry, Pretoria).

Hohls BC, Quibell G, Du Plessis BJ and Belcher T. (1998). Assessment of the Implementation of the Phosphate Standard at the Baviaanspoort and Zeekoegat Water Care Works. Report No N/A230/01/DEQ0797. Institute of Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

Mogale City (2003) State of the Environment Report for Mogale City Local Municipality, Gauteng.

Republic of South Africa (RSA) (1997) Water Services Act, 1997. Act No 108 of 1997.

Website of the Department Water Affairs of the Republic of South Africa (DWA) [http://www.dwaf.gov.za/iwqs/wms/data/000key.asp]

ERWAT, J. Terblanche, 011 929 7006 (Telephonic Interview), W. Rosslee, 083 676 7027 (Telephonic Interview and documentation)

Municipality of Tshwane, S. Van der Merwe, 011 358 0691, 082 897 1994 (Telephonic Interview and documentation)

Johannesburg Water, S. Deacon, 011 688 1400, Telephonic Interview, D. Schutte, 011 688 1432 & R. Coetzee (Telephonic Interview and documentation)

Mogali City Municipality, J. Van Eck, 011 668 0724; 083 522 5038 (Telephonic Interview)

Rietvlei WPW (Municipality of Tshwane), K. Taljaard, 012 358 1802, L. Coetzee 012 358 1803, D. Lues 012 853 8017 (Telephonic Interview and documentation)

The Trophic Status classification of South African impoundments, October 2002 to September 2003. http://www.dwaf.gov.za/iwqs/eutrophication/NEMP/default.asp