Integrating quality and cost of surface raw water: Upper and Middle Vaal Water Management Areas South Africa

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ABSTRACT

The user-pays principle encourages use of a water tariff structure that incorporates pollution and/or depletion of a water resource because that water represents a capital resource base. Development of a tool that models variability of surface raw water quality in order to predict cost of treatment thus makes economic sense. This paper forms the backbone for an on-going doctoral study in South Africa’s Upper and Middle Vaal Water Management Areas (U&MVWMAs) of the Vaal River (VR). Specific objectives of the overall research are; to carry out pollutant tracer hydrochemistry of specific reaches of the U&MVWMAs including producing an integrated ecological functionality for the whole study area, and to develop a tool that models the variability of surface raw water quality using surface raw water tariffs and water quality data for years 2003–2008. This paper concluded that downstream water boards (WBs) paid a higher water resources management charge (WRMC) for more polluted raw water than upstream WBs. It was recommended that a quality-cost model be incorporated at tier1 of the cost chain for water services to ensure fairness of service delivery and spread of burden to consumers.

Key words | cost of treatment, pollutant tracer, quality-cost model, raw water quality, tariff structure, Vaal River

INTRODUCTION

On-going research in South Africa’s U&MVWMAs (the Upper and Middle Vaal Water Management Areas, as defined in DWAF (2004a)) intends to carry out pollutant tracer hydrochemistry of specific reaches of the U&MVWMAs including producing an integrated ecological functionality for the whole study area and develop a tool that models the variability of surface raw water quality using surface raw water tariffs and water quality data for years 2003–2008. The output quality-cost model will provide an invaluable water management pricing tool that correlates surface raw water quality variability to cost of treating that water to potable standard. The objectives of this paper, however, were to analyse the raw water tariff structure as well as perform a pollutant tracer hydrochemistry for the U&MVWMAs bounded by the Vaal Dam (VD) and Sedibeng Water board (SWB). Results of this paper will inform approaches for further study to complete the overall research.

The Vaal River system (VRS) runs through the economic heartland of South Africa (Stevn & Toerien 1976; Grobler et al. 1987; Van Steenderen et al. 1987; DWAF 2004a, b). Here demand for water has long exceeded the exploitable potential of the system. To meet that extensive demand, the VRS is regulated for most part of its length (Cambray et al. 1986). The basin is however impacted by mining, industrial and domestic waste (Stevn & Toerien 1976; Pieterse et al. 1987; Cloot & Roux 1997; Gouws & Coetzee 1997; Naicker et al. 2003; Winde & Jacobus van der Walt 2004; DWAF 2007; Ochse 2007). DWAF (2007) further
notes that while the VRS’s high salinity status was not expected to increase substantially in future, eutrophication was a looming threat, with the system considered to be at high risk from it.

Research elsewhere reports that the cost of water due to diminished quality is significant, especially as the cost of raw water contributes about 50% of the total cost of treating water to potable water standard (Van Wyk 2001). Dearmont et al. (1998) notes that there should be provision for information on the marginal municipal costs of treating polluted water as affected by pollutant volume. The information could provide a lower bound on the benefits of cleaner water. Although the polluter-pays principle is based on the belief that polluters will be less inclined to over-use the assimilative capacity of watercourses in an unsustainable way, Correljé et al. (2007), though, notes that some difficulties often encountered relate to the problem of how to designate the real originator of costs, hence a lack of clarification of the economic concept of value. However, Moore & Mccarl (1987) indicates that in the case of water purification, only a third of a percent of the average cost is mitigated by a one-percent marginal change in the sediment load. For the VRS which supports an increasingly urbanized population, and while highly impacted in some sections, further study is necessary to determine if water could be used more efficiently by applying statutory instruments in combination with economic decision support tools in the form of quality-cost models.

Electrical conductivity (EC), a surrogate indicator

According to Wepener et al. (2005), relating observed effects of pollution to specific pollutants or even classes of pollutants remains a very difficult task due to the usually unknown, complex and often highly variable composition of effluents. Ochieng’ (2007) notes that total dissolved solids (TDS) provide an indication of salinity. Since TDS is not easily measured its common to utilise EC and then multiplying it by a correction factor of 0.7 to obtain TDS (Walton 1989). Walton (1989) suggests using factors ranging from 0.50 to 0.75 for increasingly saline waters. Thus EC was used as a surrogate for tracing pollution in this paper.

In South Africa, a pricing strategy for raw water charges allows the Department of Water Affairs (DWA) which is the custodian of national water resources, to sell raw water to bulk potable water treatment plants (water boards). This is done generally at a fixed price determined annually. The cost of this water does not, generally, take into account the quality of water that the water boards (WBs) receive. WBs are then expected to treat this water to specified potable water standard for distribution to local authorities which then supply to consumers. Consumers are charged based on the volume they consume, presumably a charge that would recover the cost of treatment and other associated overheads, which are agreed upon in advance. A consumer charge, according to Dearmont et al. (1998), also incorporates an internalised cost of potable water treatment due to diminished water quality and this represents an important component of societal costs of water pollution at the last tier of the cost chain for water services.

**METHODS**

The tariff structure

The tariff structure of the U&MVWMAs was investigated and related to quality of raw water in the Vaal River (VR), the major source of water for treatment to potable use. Tariffs for years 2003 to 2008 were analysed. Data sources were DWA and annual reports from the Trans-Caledon-Tunnel-Authority (TCTA), the Water Research Commission (WRC) and Rand Water board. The tariffs were clustered and discussed in relation to surface raw water quality trends for the U&MVWMAs.

Pollutant tracer hydrochemistry

Use of EC as a surrogate for tracing pollution was informed by literature as well as availability of fairly consistent data for the period of study. From the layout of monitoring points in Figure 1, EC values for specific monitoring points were compared to guideline values of the ideal catchment background (ICB) raw water quality objectives applicable to the U&MVWMAs (obtained from http://www.reservoir.co.za/, accessed September 2008).
Values for the Vaal Dam ideal catchment background (VDICB—10 mS/m), Vaal barrage ideal catchment background (VBICB—18 mS/m), Blesbok/Suikerbosrant Rivers ideal catchment background (BSICB—45 mS/m) and Klip River ideal catchment background (KRICB—80 mS/m) sub-catchments were used for comparing quality of raw water. Although current national monitoring campaigns use sub-catchment-specific guidelines; this study used the four ICBs mentioned because it was felt that the approach provided a fair baseline for comparisons within the study area which covered more than one sub-catchment. The VR main channel points were V1RWB, V4, V5, V9, V11, V16, V17MWB and V19SWB. EC values for VR tributary entry points were employed to trace pollution by comparing their EC values to those at/or just downstream of a tributary’s confluence with the VR main channel: S4 on Suikerbosrant River (SR), K9 on Klip River (KR), T1 on a stream from Webb’s Farm and for this study was named Webb stream (WS), L1 on Leeuspruit River (LR), M3 on Mooi River (MR) and Vs3 on Vals River (VsR). A layout indicating entry points is provided in Figure 1.

The EC values were pre-processed into quarters of a year to represent the periods January to March, April to June, July to September and October to December. All stacked graphs were plotted using Matlab 2009b. The points V1RWB, V17MWB and V19SWB represented Rand Water Board’s potable water treatment intake works located in the UVWMA and intake works for Midvaal Water and Sedibeng Water Boards located in the MVWMA, respectively. EC trends for 2003–2008 for these WBs were also stacked among themselves and in relation to the ICBs.

RESULTS AND DISCUSSION

Tariff structure

Generally at tier1, the cost chain level at which the raw water transaction between WBs and DWA occurred, the following charges applied to South Africa’s WMAs:

- Water Resources Management charge (WRMC) for both domestic and industrial use. This supported management activities within each management area, for example pollution mitigation.
- Water Research Commission levy (WRCL), a charge which was collected by the WBs. It supported various research activities.
- Raw water abstraction tariff (RWAT).
- Trans-Caledon-Tunnel Authority charge (TCTAC) for specific catchments and used for various water resources infrastructural development like the Lesotho Highlands Water Project responsible for supplying raw water to South Africa from Lesotho.
- Bulk water distribution cost (BWDC).

Figure 1 | Layout of VR monitoring points in relation to tributaries.
Specific to the U&MVWMAs and between the WBs and DWA, both upstream and downstream WBs paid: WRMC, TCTAC and RWAT. The WBs paid a very similar RWAT (Figure 2), although in 2006 it was 28.30 cents/m$^3$ for WBs in the MVWMA and 26.82 cents/m$^3$ for those in the UVWMA.

WBs in both the U&MVWMAs were charged the same amount of TCTC (Figure 3). Figure 4 however, indicates that a WB in the MVWMA (downstream) generally paid a higher WRMC than a WB in the UVWMA (upstream). The colour code key (charge ranges) shows a dominance of the UVWMA for the lower clusters 0.50–1.00 cents/m$^3$ and 1.00–1.50 cents/m$^3$ while the MVWMA predominantly covered the higher cluster of 1.50–2.00 cents/m$^3$.

**Pollutant tracer hydrochemistry**

EC results for all points are presented in Table 1. The zero (0) values in the table represent a no value for that quarter but for tracing purposes, the blank values were padded with zeros. For example for V19SWB, there were no values for 2003, 2004 and the first 2 quarters of 2005. The x-axis of the stacked graph plots represents the quarters numbered numerically from 1 to 24. The y-axis represents the EC values. ID represents the identity of the monitoring point.

Figure 5 shows that, apart from the 120 mS/m in 2008, V1RWB water quality fell close to the VBICB of 18 mS/m. This was considered to be good quality water. S4’s EC values were above the KICB’s 80 mS/m value making that water poorer in quality than that at V1RWB. SR’s impact on the VR was noted at V4, whose values were above BSICB’s 45 mS/m, although they were lower than the value for KICB. A dilution effect by water from the VD could be attributed to this drop in EC values. Impact of K9 was monitored at V5 which was directly at the confluence of KR and VR (Figure 6). K9 values were generally higher than those for V5 but VR’s quality remained significantly poor. Although EC values for WS were higher than for KICB, WS did not have a significant influence on VR at V9 (Figure 7).

Similarly, pollution contributions of LR, MR and VsR to VR were investigated using the same approach as with K9 and S4. It was noted that although the tributaries were polluted, their impact on the VR’s water quality was either insignificant or their pollution maintained the high EC values at their points of entry (generally between 80 and 100 mS/m).
<table>
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Figure 8 compared the quality of raw water abstracted by RWB (V1RWB), MWB (V17MWB) and SWB (V19SWB), among themselves and against the ICBs. RWB treated better quality water for potable use than MWB and SWB for which EC values of raw water fluctuated around 80–100 mS/m.

Figure 8 | Quality of raw water treated by RWB, MWB and SWB.
CONCLUSIONS

Results indicated that VR water deteriorated towards downstream from V1RWB to V19SWB. SR highly impacted the VR and the VR did not re-generate towards downstream. The quality of water introduced into the VR by KR, WS, LR, MR and VsR was already of poor quality but it either did not significantly impact on VR quality in the main channel or helped maintain the EC levels generally high. The results from the tariff structure analysis indicated that the WRMC generally increased towards downstream in the study area, resulting in those WBs situated after SR abstracting poorer quality water than those upstream of SR confluence with VR.

It was concluded that downstream WBs paid a higher WRMC for more polluted raw water than upstream WBs. It was recommended that raw water quality variability, in the form of a cost-quality model, be incorporated at tier1 of the cost chain for water services to ensure fairness of service delivery and spread of burden to consumers based on quality requirements. Towards achieving better quality water in the VR, especially downstream of the VD, measures aimed at reducing the pollution load of SR could make a significantly positive effect.

ACKNOWLEDGEMENTS

The financial assistance of the Department of Labour (DST) is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the authors and are not necessarily to be attributed to the DST. The authors would also like to thank Tshwane University of Technology for hosting and also funding this research. Rand Water, Midvaal Water and Sedibeng Water Boards, DWAF, DWAF, 2004a National Water Resources Strategy: Our Blue Print for Survival, Pretoria, South Africa.

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