Control options for river water quality improvement: A case study of TDS and inorganic nitrogen in the Crocodile River (South Africa)

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Abstract

Using a simple conceptual dynamic river water quality model, the effects of different basin-wide water quality management options on downstream water quality improvements in a semi-arid river, the Crocodile River (South Africa) were investigated. When a river is impacted by high rates of freshwater withdrawal (in its upstream reaches), and receives polluted side-stream inflows and wastewater effluent discharges (in the middle reaches), river water quality can deteriorate seriously over time. This study focused on two water quality problems: Progressive increases in the concentrations of total dissolved solids (TDS) as a measure of salinity, and the concentrations of nitrate-plus-nitrite and ammonia (as inorganic nitrogen) as a measure of eutrophication. Based on a low-flow analysis for the period prior to construction of the Kwena Dam (1960 to 1979), the 7d low flows that could be expected to occur every 10 years (7Q10) are generally very low ($< 0.5\ m^3 \cdot s^{-1}$), both in the upstream (Montrose Weir) and the downstream (Kruger National Park) sections of the Crocodile River. During such critical periods of low river flow, very low effluent standard limits would be required to prevent adverse river water quality. However, these options are not economically feasible. Furthermore, inflows from the highly polluted tributary stream, the Kaap River, which drains an area where considerable gold mining takes place, govern water quality in the Crocodile River downstream of the Crocodile-Kaap confluence. Subsequently, two additional water quality control options (setting limits for maximum water withdrawal and low-flow augmentation) were analysed. The results show that a decrease in maximum water withdrawal could reduce the TDS concentration. Furthermore, controlling water release patterns from a dam at the Montrose Weir can have a remarkably positive effect on the downstream river water quality. On the basis of the 1989/90 monitoring data, a minimum flow of $5\ m^3 \cdot s^{-1}$ at the Montrose Weir can reduce concentrations of TDS and ammonia nitrogen by about 20% and 60%, respectively, in the Kruger National Park (at the downstream point of the considered river). However, this management option does not reduce nitrate nitrogen concentrations. The proposed model used in this study is relatively simple and can be used as a tool for the evaluation of short-term (monthly) basin-wide water quality management options.

Keywords: Dynamic model; flow regulation; water quality management; tank in series model

Introduction

As the demand for water increases in line with human population pressure and economic development activities, river ecosystems will continue to deteriorate unless they are managed in a sustainable way. The main causes for this, particularly in their downstream reaches, are related both to water quantity and water quality. The problem related to water quantity (e.g. the occurrence of extremely low flows) is governed by both natural events (drought) and human-induced factors (e.g. large upstream freshwater withdrawals). Because it reduces the dilution capacity of the river, high levels of water withdrawal or loss from upstream river sections or tributaries can considerably affect the water quality of downstream river reaches. High upstream water losses result in the reduction of dry weather flows. In turn, reduced flows can cause accelerated sedimentation and increases total dissolved solids (TDS) concentrations in downstream reaches of the river (Qader, 1998; Mokhlesur et al., 2000). Many other studies have also shown that extremely low flows can have severe effects on river ecosystems, e.g. the failure of natural reproduction processes of many fish species, declining fish yields, and reduced biological productivity (Dubinina and Kozlitina, 2000). In addition, reduced flows also have adverse effects on benthic macro-invertebrate communities, either through direct changes in habitat and flow hydraulics, or through indirect changes in water quality (Caruso, 2002).

While methods for basin-wide water quantity controls are well established, though not yet fully implemented, similar considerations are less common for optimum water quality management. When an extreme low-flow event is combined with inflows from highly polluted tributaries or wastewater effluents, there will be a dramatic decline in the water quality status of downstream river reaches. To deal with problems of this nature, the setting of effluent quality standards and non-point source pollution regulations are usually ineffective. Hence, additional cost-effective control options must be considered.

The objective of this study was to investigate a range of possible management control strategies for the Crocodile River, which receives several inflows from polluted side-streams and also experiences high levels of water withdrawal. Salinity and eutrophication are the major water quality problems in this river. Using a conceptual dynamic hydrological model, the seasonal dynamics of TDS (as a measure of salinity) and inorganic nitrogen concentrations (nitrate plus nitrite and ammonia, as measures of eutrophication), were simulated in the downstream reaches of the Crocodile River, and the results were compared with monitoring data.

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