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# ROLE OF NON-POINT SOURCES IN THE DEVELOPMENT OF A WATER QUALITY MANAGEMENT PLAN FOR THE MGENI RIVER CATCHMENT

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## ABSTRACT

Integrated river basin management depends upon information about existing and potential water quality problems. In the Mgeni River basin, the major water quality problems are sediment, nutrient and bacterial with at least 85 percent of the total contamination derived from non-point sources. This paper shows that it is of paramount importance that the development of management objectives and approaches be based on the understanding, quantification and interpretation of the seasonal and spatial variation in export from non-point source areas. Management and analysis requires the grouping of all non-point source areas into diffuse, concentrated and incident sources, with the emphasis on the source area and pollutant delivery rather than the water quality response. Traditionally monitored data is not sufficient for detailed interpretation of non-point source pollution. Comments are made regarding the problems associated with obtaining representative loading data for non-point sources. The choice of appropriate analysis techniques, which assist in the interpretation of the available data, is based upon an assessment of the information requirements for management, the conditions and the water quality problems in the study catchment. GIS-based basin scale and individual source area maps of pollution potential and export are used to support the time-series of catchment export. These techniques will be incorporated into the management information system (MIS).

## KEYWORDS

Management information; Mgeni River; non-point-source pollution; river basin management.

## INTRODUCTION

The Department of Water Affairs and Forestry (DWAF) together with Umgeni Water have to ensure that the water resources in the Mgeni River system are managed to meet the requirements of all recognised users on a sustainable basis. The Mgeni River and its tributaries supply most of the water requirements of the industrial and residential users in the Pietermaritzburg/Pinetown/Durban urban complex, the majority of the domestic use for the rural settlements in the basin and the agricultural, environmental and recreational water demands. Increasing population and the associated agricultural and industrial activity have resulted in a highly stressed system, in terms of greater use of the water resources that are available in the Mgeni River catchment, and increased pollution entering the river system from point and non-point sources.

Ninham Shand Inc. was appointed by DWAF and Umgeni Water to develop an affordable and implementable integrated water quality management plan for the Mgeni River basin, i.e. the Mgeni

Catchment Water Quality Management Plan (MCWQMP). A multidisciplinary approach is being followed, addressing scientific, engineering, social and administrative aspects of the system. A central component of this system requires the qualitative and quantitative description of the impacts of non-point source pollution within the catchment, which provides management information about the availability and export of pollution associated with non-point sources.

This paper outlines some of the pertinent issues and findings of the study, which provides valuable insights into the analysis of non-point sources for management purposes. The central objective of the study was the development of a management plan, therefore the emphasis of all the non-point source analysis was toward obtaining management information as opposed to the detailed description and development of non-point source models. Furthermore, the unit of the non-point analysis was the source area, in terms of pollutant availability and export, rather than the system (water body) response. This focused the analysis on the natural basin and land-use characteristics, rather than an investigation of the water quality monitoring data alone.

A management plan requires that the non-point source analysis describes seasonal variations and long-term changes in pollutant availability and delivery. It also incorporates the major pollutant export processes, represents the natural basin and land-use characteristics found in the catchment, and can identify key source areas associated with the key constituents within the catchment. The two main features of the non-point analysis are the Geographic Information System (GIS) and the suite of analysis techniques used for description of the availability and export of non-point source pollutants.

## INTEGRATED WATER QUALITY MANAGEMENT

Integrated river basin management for water quality requires an holistic view of the sources and processes causing water quality problems. The associated development of a water quality management plan comprises three main phases:

- analysis of the present and potential situation to identify and describe water quality problems;
- the development of receiving water quality objectives describing the required water quality and management approaches to meet those objectives; and
- the formulation of a management information system (MIS) to aid in the implementation and auditing of the plan.

This implies a *systems management approach* which focuses on the cost-effectiveness of a number of management strategies rather than individual management practices. *Management strategies* are possible strategies for controlling the export or discharge of contaminants from new and existing sources of pollution (e.g. sediment yield reduction). *Management practices* are specific approaches which are implemented to achieve a management strategy (e.g. contour ploughing to reduce sediment delivery). Certain practices by themselves may not be very effective, but provide key supporting functions in an effective management system. The process of management system building should begin by stating the strategies required to address situation-specific water quality problems and setting receiving water quality objectives to define the short- and long-term management goals. This is followed by the identification of specific management practices, which combined result in the implementation of appropriate situation (and site) specific sets of practices. An individual or combination of management practices which provide an affordable, effective and applicable means for preventing or reducing pollution to achieve specified water quality objectives, represent the *Best Management Practices* (BMPs) in a catchment. Selection and application of BMPs depend upon the land-use activities, pollutants to be controlled, catchment and site-specific conditions (eg climate, soils and slopes), and the type and condition of the water resource to be protected (e.g. groundwater aquifer, river or reservoir). In a receiving water quality objective context, practices for the management of pollution may be grouped into four main categories or "management sites":

- source control of critical areas or land-use activities;
- collection, control, reduction and treatment of pollutant delivery to receiving waters;

- management or treatment of water quality once pollutants have entered the receiving waters; and
- management or treatment of water for the recognised users.

The management of pollution (point and non-point) sources involves the first two categories. Source control (including removal, treatment or keeping the pollutant where it is at the source) is the most effective approach to water quality management, because the difficulty in managing water quality problems increases with dilution and distance from the source.

## DEFINITION OF NON-POINT SOURCE POLLUTION

The management of water quality is the fundamental objective of a management plan, so all the associated analysis should provide management-oriented information. This implies that pollution sources should be investigated according to the most appropriate management practices, which in turn are based on pollutant availability (deposition, application or production) and mechanisms of delivery (discharge or export). The most appropriate representation of a source's contribution to pollution for analysis purposes also differs according to its areal extent (size), the pollutant availability and dominant delivery mechanisms. Based on these differences, pollution sources were grouped into the following categories.

- *Point Sources* discharge from a single point.
- *Non-point Sources* include all other sources.
- *Diffuse Sources* export from a widely dispersed area.
- *Concentrated Sources* export from a localized developed area.
- *Incident Sources* discharge infrequently from any point in an area.

These categories have been developed for practical purposes as outlined above. Management decisions may be made to change the nature of a particular source type, i.e. diffuse or concentrated source export may be collected and treated as a point source (e.g. storm water runoff collection) or point sources may become concentrated or diffuse sources (e.g. irrigated industrial effluent).

### Diffuse sources

Diffuse sources contribute to air, surface and groundwater contamination over a widespread area, with intermittent and highly variable export occurring during hydrometeorological events (rainfall, surface runoff, percolation, groundwater discharge and wind). The greatest diffuse source impacts occur during storm runoff events. The origin of most diffuse source contamination may be attributed to natural background characteristics, atmospheric deposition, agricultural cropping and grazing, formal and informal residential settlements, or commercial and industrial development. Management of diffuse sources is usually related to land-use management, although some structural controls may be used to reduce delivery or assist treatment. Appropriate methods of analysis reflect the differences in pollutant availability and hydrological response of different source areas (soil-land use combinations).

### Concentrated sources

Concentrated sources have characteristics of both point and diffuse sources, in that their discharge is relatively localised (they may be represented as a point relative to diffuse sources in a catchment), but usually occur during hydrometeorological events, as with diffuse sources. Confined animal facilities (eg feedlots, dairies and piggeries), waste disposal sites, irrigated effluent sites (e.g. waste water works and tanneries), or mines and quarries are included in this category. Management practices to reduce the export (and/or slurry discharge) derive from both point source (storage and treatment) and diffuse source (land management) management approaches. In fact, some of these sources (e.g. waste disposal sites and mines) are legally required to collect and treat surface runoff and leachate in South Africa, and are defined as statutory point sources in the United States of America (USA) (e.g. mines and feedlots). The small areas and concentrated localised pollution inputs indicate that inclusion into diffuse source export analysis may not be

appropriate. Detailed site-specific analyses and discharge at a point in the catchment should provide more accurate representation.

Incident sources

This group of potential pollution sources is different from the others in that releases are accidental, which implies that they should occur infrequently and at unspecified locations. Usually, the pollutant application (spill) is localised and transport away from the area is associated with hydrometeorological processes, similar to concentrated sources. However, liquid spills may discharge into local water resources similar to point sources. Transport-related (HAZMAT) spills, industrial spills (storage or effluent) or pipeline failures may be included in this category. The risk (impact) of an incident is related to sites of increased activity (e.g. major transportation corridors), while the severities of the impacts are related to the materials (e.g. toxicity) and characteristics of the accident site. Analysis and management approaches need to address the probabilistic nature of this type of pollution.

## THE ANALYSIS OF NON-POINT SOURCES FOR MANAGEMENT PURPOSES

The particular analysis techniques used for any investigation (task) associated with a management plan needs to be based on the management information requirements, specific conditions and water quality problems in the study catchment. The non-point source analysis begins with the identification of general information needs and analysis requirements. This is followed by an investigation into the observed and possibly unmonitored water quality problems, supported by an *Intuitive Assessment* of the water quality implications associated with the spatial distribution (GIS) of the hydrometeorological and physical basin characteristics. This indicates the specific analysis techniques that should be employed.

General management information needs

The *situation assessment* for a management plan requires a description of the current water quality situation including sources, quantities and impacts of pollution. It must also provide sufficient information to allow management decisions to be made to improve the problems in places where the water resources are not fit for use. Particular issues that the pollution source analysis should attempt to address are:

- the types and locations of pollution sources associated with water quality problems;
- the key constituents and the seasonal variation in export or discharge;
- potentially critical areas/sites and source types for different key constituents;
- an indication of relative contribution to total catchment export; and
- potential positive impacts of different management alternatives.

This information should enable the following information to be evaluated during the analyses of *assimilative capacity* and *future developments* tasks:

- the relative contribution from each source to total catchment export and reservoir loadings;
- catchment export and input loadings to reservoirs under changing physical (land-use) conditions.

Overview of the water quality problems in the Mgeni River basin

The *intuitive assessment* and *water quality status* analyses of the MCWQMP identified potential and observed water quality problems throughout the Mgeni River basin. The major non-point source related water quality problems include the following.

*In storm flows*: Wash-off of bacteria, sediment, nutrients and litter from subsistence, transitional and informal settlements; sediment, organic matter, nutrients, bacteria, heavy metals and litter in wash-off and from overflowing and ill-maintained sewers in urban areas; and sediment and nutrient loads from agricultural lands.

*During low flows*: Bacteria and nutrients associated with direct human and livestock activity in the rivers; bacteria, nutrients and COD from blocked sewers in formal urban areas; illegal discharges or spills from industrial and domestic areas; and bacteria, nutrients and COD in slurry discharges or groundwater contamination from confined animal facilities.

Based on these water quality problems, key indicator constituents were identified. The key constituents associated with non-point source pollution in the Mgeni River basin are usually related to surface runoff from diffuse or concentrated sources during storm events. Some diffuse and concentrated source problems may be manifest during dry periods due to introduction directly into the river. The main water quality problems (*italic*) and their associated key indicator variables (**bold**) are:

- *sediment* represented by **suspended solids**;
- *nutrients* represented by the limiting nutrient **total and soluble phosphorus**; and
- *bacterial* contamination represented by the faecal bacterial indicator ***E.coli***.

Most of the significant non-point source pollution in the Mgeni River catchment is represented by these indicators, although site specific studies should be conducted on pesticide runoff from commercial agricultural crop lands and heavy metal studies in formal urban areas.

Approaches used in the analysis of non-point sources for the Mgeni River basin

Investigation of water quality problems must be based on observed data (hydrological and water quality monitoring), physical description (natural and land-use characteristics) or simulation results (modelling). Point source investigation and description may be performed using observed discharge data. However, there is little direct sampling of the water quality impacts of diffuse, concentrated or incident-related source contributions to surface runoff or groundwater quality. Observations are only made at discrete points in space, representing multiple source areas, and usually consist of grab-samples, which do not capture the highly time-varying pollution associated with storm events and incidents. Desegregation of monitoring data into the various non-point source contributions and associated transport processes is a formidable task, so non-point source modelling techniques are used to estimate the potential and probable contributions from different source areas. The observed data should be used for verification of the results and to indicate potential water quality problems, but should not be viewed as the sole indicator of pollution type and quantity. In support of this assertion, Seed (1994) found that the correlation between weekly grab-samples and composite-samples of suspended solids and nutrients on an agricultural tributary to the Mgeni River, was only about 10 percent, while the grab-sample loading estimates underestimated the composite load by between 18 percent and 34 percent.

The approach adopted for the analysis of pollution sources in the MCWQMP was to begin with an *intuitive assessment*, which assessed the potential water quality problems based on an investigation of the natural basin characteristics such as climate, geology, soils, topography and anthropogenic influences, including land-use and management practices. GIS coverage of these features was used to provide spatial information and thus the location of potential water quality problems. This analysis provided a reference which guided the investigation of key constituents and source areas, based on potential water quality problems.

Simple models were then used to investigate the impacts of different source areas on certain key constituents. Analyses included the description of potential sources of pollution, based on the availability of the pollutant and actual sources of pollution, based on the export of the pollutant. These techniques depend upon the spatial description (GIS coverage) of land-use and natural characteristics, and may represent the seasonally varying nature of application and export of different pollutants. Hydrologically based models were also implemented to provide a time-series of pollutant export. These techniques are outlined for diffuse, concentrated and incident sources.

A number of pollution source analysis techniques and models have been developed both locally and internationally to aid the quantification and evaluation of non-point source export. Based on the management

information requirements and Mgeni catchment description, the most important features for application to the Mgeni River catchment are that the techniques:

- are not too data intensive;
- provide quantitative estimates of pollutant availability and export;
- explicitly incorporate important pollutant mobilisation and transport processes;
- enable the identification of critical source areas and periods of interest;
- have been applied, verified or are supported locally; and
- are transferable to ungauged (streamflow) and/or unmonitored (water quality) catchments.

Based on these criteria, various models and approaches were used for the analysis of non-point sources.

## DIFFUSE SOURCES

Diffuse source pollution should be investigated at both a catchment scale and at an individual source area scale. Appropriate techniques for the "macro-analysis" (catchment) may be grouped into three categories, namely *source area potential maps*, *source area export maps* and *loading functions*. More detailed "micro-analyses" may be conducted on potentially critical source areas with particular water quality problems, such as pesticide wash-off from commercial vegetable lands, heavy metal wash-off from urban areas, or bacterial contamination associated with informal settlements, or to evaluate the effectiveness of management approaches. Different models (usually based on the macro-analysis approaches) may be used for these micro-analyses.

### Macro analysis

These techniques are applied to the whole catchment to indicate the potential and actual relative contributions of different source areas, as well as indicate time-varying loadings from a subcatchment. The diffuse source investigation addresses the sources of sediment (suspended solids), nutrient (total and soluble phosphorus) and bacterial (*E.coli*) problems as representing the three main problems in the Mgeni basin.

*Source area potential maps* provide an indication of the relative availability of a pollutant in a source area, based on its application and removal, and weathering processes. This availability may have a seasonal component, so seasonal variations are estimated. Runoff potential was defined by the soil and cover characteristics of the source area, based on the Soil Conservation Service (SCS) curve number (SCS, 1985). Erosion potential (sediment availability) was based on rainfall erosivity, soil erodibility, topography, vegetation or land-use cover, as defined by the RUSLE approach (Kienzle *et al.*, 1995). Nutrient availability was based on natural background concentrations (in the soils and through atmospheric deposition) and application rates based on fertilizer use, livestock and population densities. Bacterial availability was based on livestock, population densities and infrastructural development. Although the availability of a pollutant affects the yield from that source, potential maps do not address transport processes, so do not indicate the export of pollutant from a source area of catchment.

*Source area export maps* indicate the relative export of a pollutant from different source areas, based upon the availability of the pollutant and the potential for it to be transported. Transport mechanisms for diffuse sources include percolation and groundwater discharge, with surface runoff representing the major mechanism for sediment, bacterial and nutrient export. Surface runoff and baseflow associated with source areas was estimated using the ACRU model (Kienzle *et al.*, 1995) and SCS curve number analyses (SCS, 1985). Sediment export was estimated from erosion potential and an estimate of the carrying capacity of surface runoff as defined by the MUSLE model (Kienzle *et al.*, 1995), which indicates the sediment delivery ratio. Nutrient and bacterial export was based on the sediment export, with a potency factor representing the nutrient availability for each land use.

Generalized watershed loading functions (Haith and Shoemaker, 1987) are potency factors associated with sediment yield, surface runoff and baseflow, representing the three major transport mechanisms from diffuse

sources. This provides an indication of the long-term loading from different source areas and may be used to calculate time-series of pollutant loading. The hydrological and sediment export time series were derived from the ACRU modelling analysis (Kienzle *et al.*, 1995; Haith and Shoemaker, 1987) while the nutrient and bacterial loading function coefficients were based on literature values and relationships between observed water quality constituents and flow.

Micro analysis

These represent localised investigations to provide detailed information about the pollution impacts of a particular land use and/or key pollutant. This may be related to one of the constituents investigated during the macro-analysis or a different constituent related to a site-specific problem. These types of studies were performed on critical source areas, to provide information for management purposes. Possible investigations include:

- heavy metal accumulation and wash-off from formal urban areas
- pesticide application, decay, infiltration and wash-off from commercial crop lands
- bacterial and nutrient wash-off from informal shack settlements with limited sanitation infrastructure
- the impacts of management practices applied to critical source areas

## CONCENTRATED SOURCES

The analysis of concentrated sources differs from diffuse sources, because the areas are relatively small and many sites already have management practices which reduce the discharge into local water resources. Micro-analysis is performed on these sites to evaluate the average export or discharge of pollutants under different hydrological regimes and seasons, taking account of pollutant application rates, surface runoff and infiltration and possible failure of the management practices. The impacts of implemented management practices, such as detention ponds, can be evaluated using site-specific modelling approaches. Important concentrated sources that were investigated for the MCWQMP include feedlots, dairies, piggeries, waste disposal sites and waste water works effluent and irrigation lands.

## INCIDENT-RELATED SOURCES

These sources are infrequent by definition. Therefore, incorporating them in an analysis of other pollution sources is not appropriate. This study drew on other reports in an attempt to provide an overview of potential incident sites. Possible further analysis may include the investigation of the surface or groundwater response to a "spiked" input under various conditions, while risk assessment methodologies may be used to evaluate the probabilities of incidents and the associated impact severity. An inventory of possible incident sites and corridors was provided and response facilities (and capabilities) were described.

## DECISION SUPPORT FOR MANAGEMENT

Ranking and interpretation of the different pollution sources requires integrated analysis of the contributions from point, concentrated and diffuse sources. This task will be addressed during the *assimilative capacity* analysis, and involves simulation of river and reservoir responses. The non-point source analysis was based purely on comparison of the inputs from each source, rather than the impacts of assimilation, dilution and precipitation in the system. This provided a means for identifying critical source areas, either diffuse or concentrated, as well as threatened areas which might be critical (threatened) under future development possibilities.

The techniques and the results are incorporated into the management information system, to provide decision-support capabilities. The ranking of sources and the evaluation of the effectiveness of potential water quality management approaches informs the setting of receiving water quality objectives, both in terms of the present situation and what may be achieved, and at what cost. Finally, these techniques have a role in auditing the implementation of the plan through interpretation of lumped monitoring data.

## CONCLUSIONS AND RECOMMENDATIONS

At least 85 percent of the contamination associated with the major water quality problems in the Mgeni River basin (sediment, nutrients and bacteria) may be attributed to non-point sources. Investigation of non-point source export is therefore a crucial component in the development of a water quality management plan. However, the transient nature and limited data for non-point source analysis present particular problems for the evaluation and management of non-point source pollution. Traditional grab-sample data alone are not adequate for the investigation and quantification of non-point source pollution from different source areas. Even comprehensive sampling programmes are not always adequate for this purpose, which illustrates the need for designing water quality monitoring programmes around the management information needs of the catchment, and the decision support tools and analysis methods used to derive this information.

The use of various analysis techniques aids the understanding and interpretation of the contributions from different source areas, and the identification of critical areas for management purposes. However, the discrete nature of grab-sampling reduces its use for calibration and verification of these analysis techniques. This indicates the need to implement continuous sampling programmes and the use of long-term or seasonal loading patterns or probability distributions for model verification, as opposed to direct comparison of the simulated and observed value for a given day.

The needs of the MCWQMP indicated that non-point sources should be separated into three categories (diffuse, concentrated and incident sources), reflecting the management, pollutant behaviour and analysis requirements of different source areas. The choice of analysis techniques was based on an assessment of the management information needs and the specific conditions and water quality problems identified through an intuitive assessment of the natural and anthropogenic basin characteristics. Potential (availability) and actual (export) pollution sources were investigated on a catchment-wide basis, while detailed source area analyses aided the evaluation of localised pollution problems and the effectiveness of different management practices. The results and analysis techniques will inform the setting of receiving water quality objectives and will be integrated into the interpretative and auditing role of the management information system associated with the plan.

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