

Syntheses of Urban Runoff Studies to Assist in the Development of Appropriate Management Strategies for Urban Runoff in South Africa

A Schoeman, H M MacKay and J N Rossouw

Water Quality Information Systems

Division of Water Technology

CSIR

P O Box 395

Pretoria, 0001.

INTRODUCTION

The environmental impacts of urban development have been well documented in the international literature. In many countries urban planning now takes the environmental aspects of different urban land uses into account. Mitigation or minimisation of environmental impacts, both within urban areas and adjacent to them, can be ensured at the planning and design stage. Alternatively, actions may be taken to reduce the negative impacts of existing urban development. Examples of planning tools for these purposes include guidelines for "best management practices"^(1, 2).

Many developing countries face the problem of rapid, largely uncontrolled, growth of low-cost, high-density urban settlements. South Africa has not escaped this phenomenon, and local authorities are struggling to keep up with demands for even the most basic services and infrastructure in such areas. The areal extent of these settlements is expected to treble in the next 20 years⁽³⁾.

The environmental impacts of these developments can be severe, in terms of soil, air and water pollution. The potential degradation of water resources in or adjacent to low-cost, high-density housing developments is of particular concern, as demands on water resources increase with population growth. While urban development is an inevitable fact of life in South Africa, many of the most severe impacts on water resources could be avoided through sound, integrated planning and design⁽⁴⁾.

It is likely that South Africa will follow other countries in enforcing discharge quality standards on urban stormwater outfalls, in order to prevent irreversible degradation of the quality of receiving water bodies. Local authorities will then have to plan their stormwater management strategies to meet receiving water quality objectives. This approach may be justified, since discharge permits are required for treated effluent, yet urban runoff may be of much poorer quality than discharged effluent.

The results of Dallas and Day⁽⁵⁾ demonstrate the need for more control of urban runoff. When these authors compared general urban runoff water quality with that of treated sewage effluent in South Africa, they found the following:

- the concentration of non-filterable residues was twenty times higher for urban runoff than for treated sewage effluent,
- biochemical oxygen demand of urban runoff was twice that of treated sewage effluent,
- the phosphate and total nitrogen concentrations were fifteen times higher for urban runoff than for treated sewage effluent, and

- urban runoff contained higher concentrations of suspended solids than treated sewage effluent.

This paper deals with an ongoing research initiative to develop appropriate planning tools for the management of urban runoff and its impacts on water resources, with specific reference to low-cost, high-density housing. The aim of the research is to provide guidelines for stormwater management and urban planning and design which will contribute to sustainable urban development in South African river basins.

APPROACH TO THE DEVELOPMENT OF GUIDELINES

Appropriate solutions to urban runoff management problems are multi-faceted, reflecting the complexity of the problems themselves. Solutions range from the control or reduction of pollution at source, through to interception and treatment of runoff prior to discharge to receiving water bodies. Socio-economic, environmental and technical aspects need to be integrated at the planning level when designing management options⁽⁶⁾. Issues such as installation costs and required maintenance levels may become key deciding factors in the selection of appropriate management strategies.

The approach used in this phase of the research project entails review, synthesis and organisation of available data, expertise and experience into useful information, within a framework of management guidelines for urban runoff.

Many studies have been carried out to monitor urban runoff at a variety of sites in South Africa. These studies were reviewed in order to derive, where possible, semi-quantitative or qualitative relationships between:

- types of urban development,
- socio-economic status (including housing type, income, levels of service provision),
- population density and demographic characteristics,
- biophysical catchment characteristics (soil, relief, climate, hydrology), and the types of urban runoff problems (i.e. pollutants, loading rates, patterns of discharge) which can be expected from an urbanised catchment.

Local and international literature was reviewed and local expertise was consulted to identify possible management solutions for various types of urban runoff problems. These included:

- suggestions for pollution reduction at source,
- conventional "engineering" treatment options such as gross pollutant traps, settling ponds or detention basins, and
- more recently developed biological treatment options such as wetlands and vegetated canals.

It is intended that the management guidelines would assist planners to:

- assess the type, severity and pattern of waterborne pollution to be expected, based on the results of other studies of urban runoff,
- assess, in a very preliminary manner, the possible impact of discharging the urban runoff to the receiving water (using a broad and simple tool such as a limnological classification system), and
- determine which types of management solutions would be most appropriate for a particular

urban situation, given the expected or existing biophysical, environmental, social and economic characteristics.

Used in this way, the guidelines could become a valuable scoping and planning tool for the determination of appropriate management and remediation options prior to the detailed urban design phase. The guidelines would be applicable in the cases of both existing and new urban developments.

Much of the information base for the development of the guidelines has now been established.

Already relationships and trends have emerged, which have provided important learning points. In the rest of this paper, we focus on the results of the review of urban runoff studies, and the application of these results in planning for sustainable urban development.

REVIEW OF SOUTH AFRICAN URBAN RUNOFF STUDIES

The incidence of urban runoff pollution is widespread and several studies have monitored runoff from urban settlements in South Africa. These have included sites in areas such as the Gauteng province (formerly PWV)^(7, 8, 9) the south western Cape⁽¹⁰⁾, the eastern Cape^(11, 12), Natal/KwaZulu^(13, 14) and the Orange Free State⁽¹⁵⁾. The studies covered a wide range of situations, with variations in local climate, catchment topography, soils, hydrology and background water quality, as well as different demographic aspects and environmental concerns.

Of the more than fifty case studies conducted in South Africa, very few could contribute meaningful data with regards to simultaneous water quality and flow measurements of urban runoff, which might allow the derivation of even semi-quantitative relationships. For an assessment of this kind, at least the minimum, maximum and median values for flow and pollutant concentrations, loads and export coefficients of water quality constituents are required for base flow and storm flow. However, for most studies, only mean values were reported, and flow was very seldom measured simultaneously with water quality. Detailed physical, geographical and demographic information was often not recorded.

Types of pollutants

Even though the quality of the data imposed limitations on interpretation, some very useful relationships and general trends could be found. *Table 1* lists the pollutants of most concern and their most common sources in urban areas of South Africa.

Table 1. Pollutants of concern & pollutant sources in urban areas(Includes information from Wimberley⁽⁷⁾ and Dallas & Day⁽⁵⁾)

Pollutants	Sources
<ul style="list-style-type: none">● Nutrients, Faecal bacteria, Viruses, Organic matter● Heavy metals, Hydrocarbons, Oils, Toxins, NO_x, SO₂● Plastics, Paper, Glass, Organic compounds● Suspended solids● N-compounds● P-, N- & Organic compounds● Dust, Chlorides, S-compounds, Leachates● Dissolved solids, Chlorides, Phosphates● Dissolved solids, Sulphates, Carbon, Particulate matter	<ul style="list-style-type: none">● Domestic wastes, Overloaded sanitation systems, Night soil dumping, Surcharging sewers, Absence of sewerage services● Vehicle emissions, Industrial emissions, Spills, Atmospheric deposition, Pavements, Roads● Litter, Inadequate services, Solid waste dumping● Erosion, Construction, Vegetation removal● Urban pesticide spraying, Fertilizers & Herbicides● Vegetation, Pollen, Atmospheric deposition● Wind, Rain & Groundwater● Washing of clothes, vehicles, etc.● Burning of litter, wood & coal (deposition)

Regional variability

Generally, urban runoff water quality depends on local climate, hydrology, topography, geomorphology, geology and soil conditions, extent of impervious area, urban geography, existing storm water reticulation systems, land use and available land area.

Many of these factors vary from region to region in South Africa. *Table 2* summarises how urban runoff water quality varies with geographical location, climate and hydrological regime. Seasonal rainfall patterns and rainfall intensity, for instance, determine the occurrence and severity of the "first flush" effect.

Table 2 summarises how urban runoff water quality varies with geographical location, climate and hydrological regime. Seasonal rainfall patterns and rainfall intensity, for instance, determine the occurrence and severity of the "first flush" effect.

Table 2. Regional variations in urban runoff with variations in seasonal rainfall patterns & rainfall intensities

Characteristic	Rainfall pattern		
	Summer rain High intensity	Winter rain Low intensity	All year rain Low intensity
Region	Highveld, Natal, E. Tvl.	SW Cape (sandy areas)	SE Cape
First flush effect?	Yes	No	No
Pollutant Concentrations	<ul style="list-style-type: none"> ● high for 1st major wet season runoff ● decreasing with time 	<ul style="list-style-type: none"> ● low for storm flow ● high for low flow ● summer maximum 	<ul style="list-style-type: none"> ● low for storm flow ● high for low flow ● winter maximum
Loads	<ul style="list-style-type: none"> ● high for summer ● pollutant build-up on catchment in winter 	<ul style="list-style-type: none"> ● high for storm flow ● low for low flow ● winter maximum 	<ul style="list-style-type: none"> ● high for storm flow ● low for low flow ● summer maximum

Regional differences in the sensitivities of receiving water bodies are also of significance in designing stormwater management and discharge options. For example, the clear to dark brown acidic waters the southern and south-western Cape rivers have a much higher sensitivity to heavy metal pollution than the alkaline, sediment-laden waters of the eastern Cape. These regional characteristics and variations can be put to valuable use in planning for and management of urban runoff in both existing and future developments.

Low-cost housing areas generally yield higher pollutant loads than areas with more durable, expensive housing. The socio-economic status of communities also influences the type of pollutants found in urban runoff. Generally, those areas where living standards are higher, produce the highest loads of heavy metals and hydrocarbons. Settlements of lower socio-economic status, where less efficient (if any) services are provided, tend to yield the highest loads of faecal bacteria, organic material and nutrients. Pollutant loads tend to increase with increased population density and flow volumes.

Atmospheric deposition (wet and dry) may also influence the type of pollutants washed off an urban catchment, particularly in the vicinity of certain industries or in a settlement without electricity, where coal and wood are used as fuels.

Where previous or existing stormwater management strategies in South Africa were examined, the following problems were highlighted:

- planning and development prior to 1994 did not include long-term planning for urban runoff problems, or strategies for coping with increased runoff due to rapid increases in settlement area and density,
- generally, insufficient (if any) space was reserved for future stormwater management or

- treatment facilities,
- the encroachment of shacks onto river banks endangers lives during floods and causes serious water quality problems that have to be dealt with urgently, and
 - any remedial actions which did not involve active participation of the affected parties invariably failed.

CONCLUSIONS

Urban runoff can and does have a serious impact on the quality of surface waters in South Africa. It is unlikely that improvement of conditions and provision of services to low-cost, high-density settlements will improve the problem in the short- to medium-term. A combination of sound urban environmental management practices, active participation of affected parties and legislation (such as stormwater discharge permits), may be required to achieve adequate reduction in pollution levels in runoff from such settlements.

Whilst we cannot wish urban development away, we can learn from other studies, and the developments in other countries. At least a qualitative predictive ability has been developed through the approach of analysing previous studies and situations. This allows local authorities to undertake proactive scoping and planning for pollution before pollution occurs.

According to South Africa's new constitution and the Reconstruction and Development Programme, every citizen has the right to an environment which is not detrimental to that person's health or well-being. Decision makers are obliged to demonstrate that they have taken environmental considerations into account in all decisions and development strategies must incorporate environmental consequences in the planning phase. Active community participation in environmental management must also be promoted⁽¹⁶⁾. These constitutional guarantees add heavily to the responsibilities of urban planners and water quality managers with regard to environmental quality and the rights of individuals and communities.

Urban runoff is only one aspect of the environmental impacts of urban development. The management guidelines (under development) for urban runoff should form part of an integrated urban environmental management strategy that covers other issues such as air pollution, soil and vegetation degradation. Only in this way can we ensure that, in the long term, the environmental impacts of urban development do not outweigh the benefits of improved living standards for previously disadvantaged communities.

ACKNOWLEDGEMENTS

This project is being carried out by the Division of Water Technology, CSIR, and the Water Systems Research Group, University of the Witwatersrand. The research is funded by the Water Research Commission (WRC), Pretoria.

REFERENCES

1. USEPA. *Overview of the storm water programme*. United States Environmental Protection Agency Report No. 833-F-93-001, Cincinnati, 1993, pp.1-20.
2. UWRRA. *Benchmarking and best practice for urban waterway management*. Urban Water Research Association of Australia Report No WR-31 (93/130). Melbourne Parks & Waterways, Melbourne, Australia, 1993, pp.1-149.
3. Simpson, D S. *Quantification of the effects of land use on runoff water quality in selected catchments in Natal*. Water Research Commission (WRC) Report No. 237/1/91 by the Division of Water Technology (Durban), Council for Scientific & Industrial Research (CSIR), 1991, 141pp.
4. MacKay, H M. Community-based planning for utilisation and management of natural resources: lessons from the Chatty River floodplain project, Port Elizabeth, South Africa. Submitted to "*Journal of Environmental Management*" for review, 1994.
5. Dallas, H F and Day, J A. *The effect of water quality variables on riverine ecosystems: a review*. Water Research Commission Report No. 351/93 by Dallas, H F and Day, J A, 1992, 240pp.
6. Britz, E and Roos, Z N. Omgewingsryd is verlore as behoeftes geïgnoreer word. *Die Bult*, Bemakingsdienste, Universiteit van die Oranje Vrystaat, 1994, pp. 12-13.
7. Wimberley, F R. *The effect of polluted storm water runoff from Alexandra Township on the water quality of the Jukskei River*. Water Systems Research Group, University of the Witwatersrand, Report no. 13, 1992, 182pp.
8. Van Veelen, M and Department of Water Affairs & Forestry. *Jukskei River - Water Quality Management*. BKS Inc. report no. 2/94 to Department of Water Affairs & Forestry, Pretoria, 1994, 39pp.
9. Stephenson, D and Green I R A. A simplistic mass balance of storm-water pollutants for two urban catchments. *Water SA*, 1988, 14(2):93-98.
10. Wright, A, Kloppers, W, and Fricke, A. *A hydrological investigation of storm water runoff from the Khayelitsha urban catchment in the False Bay area, south western Cape*. Water Research Commission Report No. 323/1/92 by the Division of Water Technology (Stellenbosch), CSIR, December 1992, 130pp.
11. MacKay, H M. *Management of water quality in an urban estuary*. Unpublished Ph.D. thesis, Faculty of Science, University of Port Elizabeth, 1994, 262pp.
12. Van Ginkel, C E, O'Keeffe, J, Hughes, D A, Herald, J R and Ashton, P J. *A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape, with special emphasis on the impacts of low-cost, high-density urban development on water*

quality. Final Report, Volume 1, Confidential Document 4/93.

13. Archibald, C G. *Lovu Development Project*. Report by the Division of Water Technology (Durban), CSIR to Van Wyk & Louw Inc. (Pinetown), 1994, 37pp.
14. Palmer Development Group and University of Cape Town. *Technical, socio-economic and environmental evaluation of sanitation for developing urban areas in South Africa*. Palmer Development Group Report No. B5.1 to the Water Research Commission, 1992, 21pp.
15. Grobler, D C, Ashton, P J, Mogane, B, & Roosenboom, A. *Assessment of the impact of low-cost, high-density urban development at Botshabelo on water quality in Modder River catchment*. CSIR Report to the Department of Water Affairs & Forestry, Pretoria, 1987, 47pp.
16. African National Congress. *A basic guide to: The Reconstruction and Development Programme*. Aloe Communications, Johannesburg, 1994, 29pp.