GUIDELINES FOR THE APPROPRIATE MANAGEMENT OF URBAN RUNOFF IN SOUTH AFRICA

INTEGRATED REPORT

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EXECUTIVE SUMMARY

South Africa is experiencing massive increases in urbanisation, a large proportion of which is in the form of high-density, informal settlements that develop around existing metropolitan areas. Simpson (1991) projected that the extent of this type of development would treble within twenty years.

The rapid growth of urban areas in South Africa, especially formal and informal high-density housing settlements, has been accompanied by increased quantities of contaminated runoff from these settlements and this, in turn, has accelerated the degradation of nearby streams, rivers, lakes and estuaries. For example, smaller municipalities in the Gauteng Province already experience major problems in streams, rivers, lakes, ponds and dams within their jurisdictions due to contaminated drainage from informal, high-density, housing areas. Often the polluted water in the drainage lines, water courses and streams that drain these urban areas end up in impoundments that are used for drinking water supply and recreation. Loss of amenity value and potentially higher purification costs are associated with the degradation of water resources, particularly if the water is to be used for domestic supply. Management of the quality of water resources into which urban runoff may be discharged is closely linked to the management of the urban runoff and to a variety of allied pollution problems.

All developing countries face serious urban runoff problems, the severity of which is related to population growth rates, living standards, rates of urbanisation, the types and densities of housing settlements and several other factors that are dealt with in this report. In combination, these factors give rise to high volumes of runoff that are often severely contaminated and, as urbanisation rates increase, water pollution increases accordingly. This has a multitude of adverse effects on the specific urban community, adjacent and downstream communities, the natural environment and, ultimately, the economy and health of the country and its people. Urban runoff acts as an efficient transport mechanism for bacteria, viruses, nutrients, organic substances, heavy metals and other pollutants. These cause water quality problems, pose potentially serious human and environmental health risks through contact recreation and through the use of untreated water, result in higher drinking water purification costs and cause a loss of amenity value and diminished recreation potential.

The primary aim of the overall project was to develop a set of general guidelines for the management of urban runoff in South Africa (with particular reference to high-density urban developments). The study placed special emphasis on water quality and the downstream environmental impacts of urban runoff and has produced a series of reports as well as a computer program. The specific outputs emanating from this project are as follows:

Ashton, P.J. and Bhagwan, J.N. (2001) Appropriate Management of Urban Runoff in South Africa: Integrated Report. (This report). WRC Report No TT 155/01

Schoeman, A-M., MacKay, H.M. and Stephenson, D. (2001) A Synthesis of South African Urban Runoff Studies with Special Reference on Runoff from High-density Settlements. WRC 598/1/01

Campbell L.A., Coleman T.J. and Brooksbank, L. (2001) Options for the Interception and Treatment of Urban Runoff. WRC 598/2/01

Campbell L.A. (2001) A Study on the Fate of Urban Stormwater Runoff from Alexandra Township in the Jukskei River. WRC 598/3/01

Coleman T.J. (2001) Expert System for Design of Stormwater Management Systems for Urban Runoff Quality. WRC Report No TT 156/01

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Batchelor, A.L. (2001) Some Observations on the Response of a Created Wetland to Simulated Flood Hydrographs. WRC 598/4/01

In addition, one paper was presented at the International Conference on River Basin Management held at Skukuza in 1994 and has been published in the proceedings of that conference:

Schoeman, A-M. and MacKay, H.M. (1995). Planning for sustainable development of urban catchments.

Based on a synthesis of the available literature and case study reports, three key conclusions could be drawn, namely:

- **Urban runoff water quality is a countrywide problem whose causes must be addressed urgently.**

  Past attempts to intercept urban stormwater and channel it through a single stormwater system to receiving waters have failed. Whether the stormwater arrives via non-point sources or via stormwater systems, it inevitably discharges directly to the receiving waters without any prior treatment. As stormwater quality may often be worse than treated sewage effluent, and sometimes even raw sewage, treatment of stormwater at some stage before discharge to the receiving waters has to be considered. Present engineering options for stormwater management do not cater for processes or systems to improve stormwater quality. Therefore, there is an urgent need to identify water quality treatment options that can be integrated with existing engineering structures for stormwater volume control and which can also be used as stand-alone solutions for diffuse sources of urban runoff.

- **Urban runoff problems need to be abated in order to prevent the spread of diseases, keep water purification costs as low as possible, and to minimise adverse impacts on the aquatic environment**.

  Critical attention needs to be paid to the issues of land use choice, selection of appropriate environmental planning options and minimisation of riverbank encroachment. Alternative land use options that will help to prevent and counteract the widespread tendencies of informal settlements mushrooming into areas that are not suitable for development (such as below the 1:50 year floodline on river banks) are crucially important. Conversely, areas of land that are suitable for habitation need to be identified and proclaimed, whilst land-use practices that minimise environmental degradation, enhance conservation and promote a rich biological diversity need to be implemented as a matter of urgency.

- **Where previous or existing stormwater management strategies in South Africa were examined, the following problem areas were highlighted**:

  1. Planning and development strategies prior to 1994 did not include long-term planning options for urban runoff problems or management strategies to cope with increased runoff due to rapid increases in settlement area and density;
  2. Generally, insufficient (if any) space was reserved for future stormwater management or treatment facilities to accommodate further expansions in urban areas;
  3. The encroachment of shacks onto river banks endangers both lives and property during floods and causes serious water quality problems that must be dealt with urgently; and
  4. Remedial actions that did not involve the active participation of the affected residents have invariably failed.

In South Africa, we are fast approaching the limit of our exploitable water resources. As the population grows and demands for economic development increase, so do the demands for clean and sufficient water. New water sources are often too expensive to exploit or are located too far away from the point of use for practical development purposes. As a result, we have entered an era in which we must protect the water resources we have, in order to ensure that sufficient water is available in the future. This philosophy of sustainable management of water resources is neatly encapsulated in the slogan of the Department of Water Affairs and Forestry: “Some, for all, forever”.

The demands placed on our water resources take several forms, including: abstraction of water from rivers to support urban, agricultural, industrial or domestic use; discharge of wastewater to water courses, to make use of the natural, but limited, capability to transport and purify some waste, and thereby also to make the water available for re-use downstream; exploitation of biological resources, such as fish and reeds, that are entirely dependent on aquatic ecosystems. These are examples of direct demands on the water resources. Less easy to identify, quantify and control are the wide variety of more indirect impacts of land uses on water resources, such as: changes in flow patterns due to urban or agricultural development; changes in land cover which affect both the quantity and the quality of water resources; damage to stream bank habitat through construction activities, erosion and mining.

The National Water Policy of 1997[1] sets out the principles on which water resources will be protected and managed in the future. Several key issues contained in this policy provide the context for this project. Firstly, the recognition that water must be managed on the basis of the entire hydrological cycle. Water is continually in motion, flowing from atmosphere to earth surface, to ground and surface water bodies, to the seas and back to the atmosphere. If we fail to manage and protect the water resource adequately in one phase of the hydrological cycle, then the resource is affected everywhere else in the cycle. For example, even if we control atmospheric pollution and reduce acid rain, and impose strict controls on effluent discharge quality, but we do not adequately control sources of pollution that affect water in its movement over or beneath the soil surface, water quality in rivers and supply reservoirs will still be degraded.

The impact that low-cost, high-density urban land use has on the catchment warrants serious attention. Seen in the context of the extreme variability in township growth rates (due to several factors) and the vast difference between official and unofficial figures, historical population growth rates for a specific community cannot be used to plan for the precise future urban needs of that community. However, whilst these growth rates are far too variable and the ranges of variations are far too great for precise planning purposes, they can still be used to plan the maximum carrying capacity/population density of an area. This will at least allow for new areas to be developed once current areas reach their maximum density. One can also look at examples such as Alexandra and then use historical worst-case figures to plan for future developments.

There are a variety of possible solutions to manage urban runoff volumes. Traditionally, stormwater drainage only provided rapid removal of stormwater from a development site to the nearest watercourse or sewer. Owing to the cost of upgrading existing sewers and the frequent flooding of watercourses, other control measures have to be developed. The three main choices to be considered in urban runoff volume control are:

- Reduction of flows entering the drainage system;
- Increasing the capacity of the drainage system; and
- Attenuating flows within the drainage system, for example, through the use of wetlands.

[1] White Paper on a National Water Policy for South Africa, DWAF 1997.

The first option is extremely difficult to implement in areas where development already exists, especially in densely settled areas. The second option becomes increasingly expensive as the catchment becomes urbanised and the area of impervious surfaces enlarges. Attenuation is the option that is most likely to provide a useful solution since it combines some water storage with the slow release of floodwaters. This has the advantage of delaying the timing of peak flow rates and reducing the magnitude of peak flows by providing storage for floodwaters. If storage can be combined with a simultaneous cost-effective reduction of pollutants, this option would become even more attractive as a management strategy. Properly constructed and managed urban wetlands could provide a useful solution to many of the problems posed by South Africa's microbiologically polluted urban runoff.

The problems caused by polluted urban runoff appear to be ubiquitous and inevitable. However, with careful planning, design and management of urban areas and of stormwater reticulation systems, it is possible to reduce the pollutant loads carried by urban runoff, and, hence, to mitigate the adverse effects on receiving water quality. Some states in the U.S.A. have promulgated a series of "Best Management Practices" for urban catchments. These are similar to those for agricultural catchments and are designed to protect downstream water resources. Such an approach is likely to be of benefit in South Africa, too.

The environmental impacts of urban development have been well-documented in the international literature. In many countries, urban planning now takes into account the environmental aspects of different urban land uses. Mitigation or minimisation of environmental impacts, both within urban areas and in areas 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.

Urban runoff can and does have a serious impact on the quality of surface waters in South Africa. A balanced combination of sound urban environmental management practices, active participation of affected parties and improved legislation (such as stormwater discharge permits), will be required to achieve adequate reduction in pollution levels in runoff from urban areas.

Appropriate solutions to urban runoff management problems are multi-faceted, reflecting the diversity and complexity of the problems themselves. Solutions encompass 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. Issues such as installation costs and required maintenance levels may become key deciding factors when specific solutions or combinations of solutions are selected.

The wide range of adverse impacts that low-cost, high-density urban land use has on South African catchments warrants concerted and urgent management attention. The selection and implementation of appropriate sanitation and waste disposal systems for peri-urban area requires fundamentally new approaches. In particular, diffuse sources of pollution from urban runoff and informal settlements need to be tackled as part of an integrated catchment management plan.

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"APPROPRIATE MANAGEMENT OF URBAN RUNOFF IN SOUTH AFRICA".

This integrated report has been compiled and edited by Dr P.J. Ashton and Mr J.N. Bhagwan, based on the research results and technical information produced during the research programme conducted by scientists and engineers at the CSIR's Division of Water, Environment and Forestry Technology (CSIR – Environmentek) and the Water Systems Research Group of the University of the Witwatersrand. The project team consisted of the following individuals:

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INTRODUCTION

South Africa is experiencing massive increases in urbanisation, a large proportion of which is in the form of high-density, informal settlements that develop around existing urban and metropolitan areas. Simpson (1991) projected that the extent of this type of urbanisation would treble within twenty years.

The rapid growth of urban areas in South Africa, especially formal and informal high-density housing settlements, has been accompanied by an equally dramatic increase in the quantity of contaminated runoff and this, in turn, has accelerated the degradation of streams, rivers, lakes and estuaries (Kloppers, 1989; Allanson et al., 1990; MacKay, 1993). Smaller municipalities, such as Midrand and Centurion in the Gauteng Province have already experienced serious problems in streams, rivers, lakes, ponds and dams within their areas of jurisdiction due to inflows of contaminated drainage from informal, high-density, housing areas. Polluted water in the drainage lines, water courses and streams that drain urban areas flows into impoundments used for drinking water supply and recreation. Significant loss of amenity value and potentially higher water purification costs are associated with the degradation of water resources, particularly if the water is to be used for domestic supply. Management of the quality of water resources into which urban runoff may be discharged is closely linked to the management of the urban runoff and to a variety of allied pollution problems.

All developing countries face serious urban runoff problems, the severity of which is related closely to population growth rates, living standards, rates of urbanisation, the types and densities of housing settlements and several other factors that are dealt with in this report (Van Ginkel et al., 1992). In combination, these factors give rise to high volumes of often severely contaminated runoff; as urbanisation rates increase, so too does water pollution. In turn, this has a multitude of adverse effects on the specific urban community, as well as adjacent and downstream communities, the natural environment and, ultimately, the economy and health of the country and its people. Urban runoff is an efficient transport mechanism for bacteria, viruses, nutrients, organic substances, heavy metals and other pollutants. These cause water quality problems, pose potentially significant human and environmental health risks through contact recreation and the use of untreated water, result in higher drinking water purification costs and diminish recreation potential.

1.1 About this project

The primary aim of the overall project is to develop a set of general guidelines for the management of urban runoff in South Africa, with particular reference to high-density urban developments. Special emphasis is given to water quality and the downstream environmental impacts of urban runoff. To achieve this, the following activities were conducted:

- A review of previous urban runoff studies in South Africa, synthesis of the information and examination of the quantitative and qualitative relationships between water quantity and quality, and urban communities and their environments, to see how these relationships are affected by other factors under varying circumstances;
- A review of the typical pollutants detected in urban runoff, concentrations and loads that might be expected and the pathways of these pollutants to the receiving waters;
- Research into local and international biological treatment technologies (e.g. wetlands, vegetated canals, etc.) for urban runoff;
- Research into local and international engineering technologies for urban runoff treatment;
- Synthesis of all the information gathered;
- Compilation of general guidelines for urban runoff water quality management and planning;
- Development of a simple Expert System to support the guidelines.

1.2 Target audience

The products of this research are intended for use by agencies involved in urban development, such as local and regional authorities, planners, landscape architects, development agencies, resort developers, pollution control agencies and catchment management agencies.

This report, the “Integrated Report”, synthesizes the outputs and findings from this study and also provides the framework for the general urban runoff management guidelines that are contained in this document.

Management of the urban environment has to take account of many features, including: the built environment; human health and safety; visual and aesthetic aspects; air quality; provision of services; provision of infrastructure. The urban runoff management guidelines and the supporting documents address only one aspect of the urban environment, and the impacts of urban or peri-urban development on surrounding natural resources, specifically water resources. We hope that the outputs from this project will provide one of the range of tools needed by authorities to promote the management of a healthy, safe and aesthetically pleasing urban environment and contribute to ensure sound river basin management.

1.3 Context for this work

1.3.1 New national water policy

In South Africa, we are fast approaching the limit of our exploitable water resources: as population grows, and the demands for economic development increase, so too do the demands for sufficient supplies of clean and wholesome water grow. New water sources are often too expensive or are located too far away from the point of use for practical development purposes. We have entered an era in which we must protect the water resources we have, in order to ensure that sufficient water of appropriate quality remains available in the future. This philosophy of sustainable management of water resources is neatly encapsulated in the slogan of the Department of Water Affairs and Forestry: "Some, for all, forever".

The demands placed on water resources take several forms, including: abstraction of water from rivers to support urban, agricultural, industrial or domestic use; discharge of wastewater to water courses, to make use of the natural, but limited, capability to transport and purify some waste, and thereby, also to make the water available for re-use downstream; exploitation of biological resources such as fish and reeds that are entirely dependent on aquatic ecosystems. These are examples of direct demands on the water resources. Less easy to identify, quantify and control are the wide variety of more indirect impacts of land uses on water resources, such as: changes in flow patterns due to urban or agricultural development; changes in land cover which affect both the quantity and quality of water resources; damage to stream bank habitat through construction activities, erosion and mining.

The National Water Policy of 1997[2] sets out the principles on which water resources will be protected and managed in future. Several key issues embodied in this policy provide the context for this project; in particular, recognition that water must be managed on the basis of the hydrological cycle. Water is continually in motion, flowing from the atmosphere to the earth's surface, to ground and surface water bodies, to the seas and back to the atmosphere. If we fail to manage and protect the water resource adequately in one phase of the hydrological cycle, then the resource is affected everywhere else in the cycle. For example, even if we control atmospheric pollution and acid rain, and have strict controls on effluent discharge quality, but do not adequately control sources of pollution that affect water in its movement over or beneath the soil surface, water quality in rivers and supply reservoirs will be degraded.

1.3.2 Impacts of urban land use on water resource quality

Land use for urban development is one of the key human activities that can exert an enormous range of impacts on the quality of water resources. Resource quality in this context refers to the wider definition of resource quality, as used in the National Water Act[3]:

"*(xix) Resource quality means the quality of all the aspects of a water resource including –*

(a) The quantity, pattern, timing, water level and assurance of in-stream flow;

(b) The water quality, including the physical, chemical and biological characteristics of the water;

(c) The character and condition of the in-stream and riparian habitat, and

(d) The characteristics, condition and distribution of the aquatic biota"

[2] White Paper on a National Water Policy for South Africa, DWAF 1997.
[3] Chapter 1, Section 1 of the National Water Act, Act 36 of 1998

These four aspects of resource quality are all essential to the protection and maintenance of healthy, functioning aquatic ecosystems, which, in turn, are essential for supporting the varied demands that are placed on water resources.

Urban development has the potential to impact in different ways on each of the above four aspects of resource quality, often to the detriment of the aquatic ecosystems and the overall resource quality both within and downstream of urban areas. This is discussed in more detail in later sections of the report. In this project, the focus was mainly on water quality.

1.3.3 Integrated catchment management

Management of water resources within the hydrological cycle leads to the river catchment area as a logical geographical management unit. Most phases of the hydrological cycle are connected and nested within catchments, allowing management actions to be tailored to the appropriate scale for optimum efficiency and effectiveness. The new national water policy sets out integrated catchment management as the approach that will be followed in the protection, management, development and use of water resources. This requires all impacts on water resources within a catchment to be considered. The catchment management agency can compare the contributions of different activities, land uses and water uses to their overall impact on water resource quality, and focus corrective actions in those areas where they will be most effective. This promotes the efficient use of money, time and human resources.

Water quality problems in most catchments in South Africa arise from two main areas: point - source discharges of treated, partially treated or untreated wastewater, and non-point sources of pollutants. Non-point sources are varied - they can include surface runoff from agricultural land, which contains chemicals, pesticides and suspended sediments; runoff from urban areas; sub-surface flow from agricultural or industrial areas, which may be contaminated. Point sources are relatively easy to identify, and some form of control has been in place since the promulgation of the 1956 Water Act. Non-point sources, however, are very difficult to identify and quantify, and the only effective methods to control non-point source pollution remain those that, as far as possible, prevent, such pollution from reaching watercourses.

The relative contributions of point sources and non-point sources to the total pollutant load reaching a water course show considerable variation between catchments. They are often site-specific and depend on land use, land cover, human activities, soil conditions and climatic factors. Successful integrated catchment management requires, amongst other aspects, tools that will allow management agencies to identify point and non-point sources of pollution and impacts, and enable them to design efficient and effective management plans to address these impacts. Both proactive and retroactive capabilities are required: proactive tools, which will allow potential pollution and impacts to be addressed in the planning stages of developments, and retroactive tools, which will allow existing problems to be addressed, either through the removal of pollution sources or through "retrofitting" management and treatment options.

The guidelines for urban runoff management contained in this report are intended for use in the context of integrated catchment management. As such, they provide first estimates of the magnitude and nature of existing or potential impacts on water resource quality, and preliminary guidance as to appropriate options for managing these impacts.

1.4 Approach

The various impacts of urban development on water resources and on water resource quality have been recognised for some time, both in South Africa and in many other countries around the world. The particular problems associated with high-density settlements became evident in South Africa only with the relatively recent but extremely rapid urbanization that has taken place during the last two decades. This manifested itself in both formal and informal settlements both within and around most South African towns and cities.

In the last decade, several monitoring studies have been carried out in South Africa, during which the quality and quantity of urban runoff was recorded. However, for a variety of reasons, most of these studies focused only on the runoff at the point of discharge into the watercourse. Frequently, the source of runoff was not given sufficient attention and, as a result, site-specific causes of contamination of runoff were often overlooked. Consequently, few of the studies yielded information that could be used to provide firm management guidelines on how to address the root causes of the problem; instead a relatively large amount of attention was focused on the impacts and their remediation. In many cases these impacts were severe and concerted management action was required in order to achieve a reduction in the scale and intensity of these problems. However, focusing management attention on the remediation of such severe impacts was not sufficient to solve the problem at its source.

The approach followed in this project was to collate all available data from monitoring studies of urban runoff in South Africa, and from that to synthesise our current level of knowledge and understanding of the magnitude, extent and causes of the problem. With an improved understanding of the various causes of contaminated urban runoff and their associated impacts, it has been possible to recommend various management or treatment options which are readily available, and which have been previously applied in the treatment and management of urban runoff, or of pollution from other kinds of sources (such as domestic wastewater and agricultural or industrial activities).

The focus of this project was on high-density settlements because they present us with some of the most intractable problems to be faced when addressing causes of pollution. They are usually very significant sources of pollution in developed or semi-urbanised catchments. Because they are often informal in nature, whether in their establishment or their development, high-density settlements are generally not amenable to solutions that rely on high levels of maintenance, infrastructure provision or costs of installation. Hence the management and treatment options presented here were selected on the basis of their effectiveness and appropriateness for South African conditions.

The general urban runoff management guidelines referred to in this report are intended to be used at a planning level and have not been prepared for engineering design purposes. Accordingly, this report and the expert system have deliberately been written in a style that is as non-technical as possible. The supporting reports, however, do contain a substantial amount of technical detail and serve as a valuable information resource in that respect.

1.5 Project reports and products

A series of reports, as well as a computer program, have emanated from during this project. Their details are as follows:

Ashton, P.J. and Bhagwan, J.N. (2001) Guidelines for the Appropriate Management of Urban Runoff in South Africa: Integrated Report. WRC Report No TT 155/01

Schoeman, A-M., MacKay, H.M. and Stephenson, D. (2001) A Synthesis of South African Urban Runoff Studies with Special Emphasis on Runoff from High-density Settlements. WRC 598/1/01

Campbell L.A., Coleman, T.J. and Brooksbank L. (2001) Options for the Interception and Treatment of Urban Runoff. WRC 598/2/01

Campbell L.A. (2001) A Study on the Fate of Urban Stormwater Runoff from Alexandra Township in the Jukskei River. WRC 598/3/01

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Schoeman, A-M. and MacKay, H.M. (1995). Planning for sustainable development of urban catchments.

2. INFLUENCE OF URBAN RUNOFF ON THE QUALITY OF WATER RESOURCES

An increase in the area of impervious surfaces in a catchment (e.g. roads, parking areas, industrial areas and rooftops) has a wide variety of often dramatic effects or impacts on stream flows arising from that catchment. These effects can be summarised as:

- Short, high-volume peak discharges;
- Increased peak flow duration;
- Increased total runoff volume;
- Higher stream temperatures;
- Decreased base flow;
- Gradual recession; and
- Reduced sediment loads.

Increased runoff volumes and velocities from urbanisation give rise to a wide variety of water quality problems that are linked to flooding and wash-off. The typical categories of problems that arise are: sedimentation, erosion (channel widening and streambed alteration) and habitat changes, as well as loss of aquatic or riparian habitats. The specific impacts that occur are the result of sediment transported from new developments and construction areas, toxic chemicals from automobiles and industry, nutrients and pesticides from gardening, heavy metals from industrial sites and bacteria and viruses from failing or inadequate sewage systems.

Pollutant concentrations vary considerably during the course of a storm event and from one storm event to another at different sites in urban areas. The typical sources and types of urban runoff pollutants are summarised in **Table 1**.

Table 1: Sources and types of urban runoff pollutants.

Basis or Source	Pollutant
Erosion, soluble and adsorbed nutrients	Sediment and attached soil organic matter and other pollutants adsorbed onto soil particles and organic matter
Atmospheric deposition	Hydrocarbons emitted from automobiles, dust, aromatic hydrocarbons, metals and other chemicals released from industrial and commercial activities
Construction sites	Metals from gutters, galvanised pipes, metal plating, paint and wood preservatives
Industrial sites	Heavy metals and other volatile compounds, pesticides
Plants and animals	Plant debris and animal excrement
Non-storm water connections	Discharges of sewage and industrial wastewater to storm drainage systems result in increased nutrient concentrations and bacterial numbers
Spills	Pollutants dependent on the nature of the specific spill

3. CATEGORISATION OF URBAN LAND USE

3.1 Introduction

The information collected during the review of monitoring studies was insufficient to permit an accurate assessment of the relative effects of different forms of land use on all the parameters that could influence pollution levels in runoff. However, the available information did make it possible to derive broad categories of factors that could affect the potential and quality of runoff from urban areas, by comparing the pollutant concentrations and the pertinent catchment characteristics highlighted in the literature. This categorisation can be used to indicate potential pollution problems, and their possible causes, at the planning stage of a development and can also be used to guide identification of problems in existing developments. Although the categorisation is, of necessity, broad and qualitative, it represents the synthesis of much experience gathered in site-specific studies in South Africa.

The potential for pollution of urban runoff and the delivery of pollutants to receiving water resources is influenced in two primary ways: first, through the natural hydrological characteristics of the catchment itself, and, secondly, through the range of activities associated with specific types of urban land use in the catchment. The impacts of the runoff on water resources are also influenced to some extent by the hydrological, chemical and ecological characteristics of the receiving water.

The broad categorisation of urban land use is discussed in this section. The expert system, discussed later, allows the integration of land use activities with natural catchment characteristics to generate management information about the expected pollution potential and impact of urban runoff on receiving water resource quality.

3.2 Effects of catchment characteristics on urban runoff

The natural hydrological features of a catchment affect the quantity, quality and timing of urban runoff that is delivered to a watercourse. Catchment slope, local climatic conditions and soil permeability act together to determine whether runoff is rapid and “flashy”, with significant “first flush” effects on water quality, or whether infiltration of the soil occurs, leading to lower incidence of first flush effects, but potentially greater impacts on the quality of groundwater resources in the catchment.

The hydrology of a catchment determines the loads of pollutants that eventually reach a watercourse following rainfall events. In contrast, the ubiquitous dry-weather flow that is observed in the storm drainage networks in many high-density settlements is less a function of natural weather and catchment conditions, being linked more closely to human activities.

Table 2 below shows how natural catchment characteristics are used in the expert system to determine the likely volume and nature of stormflow. The runoff coefficient is a measure of how much of the rain falling on a unit area of catchment surface actually runs off, with the associated potential to wash pollutants off the surface and into the receiving water resource. The vegetation cover classes in the table reflect the effects of human activities, either through removal of vegetation for firewood or house construction, or through building of paved surfaces in the catchment.

Table 3 summarises the regional variability (in relative terms only) that has been observed in South African studies. However, it should be noted that the data in **Table 3** are based on the results of very few studies. Indeed, many of the studies reviewed did not generate the types of data that could support this kind of assessment.

Table 2: Influence of catchment surface characteristics on runoff coefficients.

Feature	Category	Mean Annual Precipitation (mm)		
		<600	600-900	>900
Component steepness	3%	0.01	0.03	0.05
	3% to 10%	0.06	0.08	0.11
	10% to 30%	0.12	0.16	0.20
	30% to 50%	0.22	0.26	0.30
Soil permeability	Very permeable	0.03	0.04	0.05
	Permeable	0.06	0.08	0.10
	Semi-permeable	0.12	0.15	0.20
	Impermeable	0.21	0.26	0.30
Vegetation cover	Dense bush	0.03	0.04	0.05
	Cultivated land	0.07	0.11	0.15
	Grassland/lawn	0.17	0.21	0.25
	Bare surface	0.26	0.28	0.30

Table 3: Regional variations in urban runoff quality as observed in South African studies.

Characteristic	Rainfall pattern		
	Summer rain High rainfall intensity	**Winter rain Low rainfall intensity**	**All year rain Low rainfall intensity**
Region	Highveld and KwaZulu/Natal	South west Cape	South east Cape
Occurrence of first flush effect	Yes	Yes	Yes
Pollutant concentrations	High for first major wet season runoff, decreasing with time	Low for storm flow; high for low flow; maximum in summer	Low for storm flow; high for low flow; maximum in winter
Loads	High for summer; pollutant build-up on catchment in winter	High for storm flow; low for low flow; maximum in winter	High for storm flow; low for low flow; maximum in summer

3.3 Effects of land use on urban runoff

The review of South African urban runoff studies highlighted the following characteristics of the catchment land use that could be related to the differences in the levels of pollution observed in the runoff:

- Predominant type of land-use activity (residential, industrial or commercial);
- Development type (formal versus informal);
- Development densities (expressed as number of people or residential units per unit area);
- Standard / cost of development (low-cost, high-density versus high-cost, low-density); and
- Levels of services provided, and degree of service maintenance.

3.3.1 Industrial and commercial land use

The types of pollutants found in the runoff from these catchments depend on the types of industry, and on the management and pollution control measures employed by the industries in the catchment. The information available from South African monitoring studies did not allow for a further categorisation of commercial and industrial catchments into sub-categories that would allow for a more accurate estimation of pollutant concentrations based on the land-use and catchment characteristics. The concentrations used in the expert system for this type of catchment are listed in **Table 4**.

Table 4 Pollutant concentration ranges representing industrial land use in the expert system.

Pollutant	Concentration/Conductivity range
NH_3 (mg/ℓ as N)	1-8.2
TKN (mg/ℓ as N)	1-74
EC (mS/m)	9-80
SS (mg/ℓ)	40-2 000
PO_4 (mg/ℓ as P)	1-6
COD (mg/ℓ)	80-250
DO (mg/ℓ) Faecal Coliforms (/100 mℓ)	3-6 5 000-750 000

3.3.2 Residential land use

Most of the catchments that have been monitored in South Africa tend to be residential catchments. Therefore, the Expert System is primarily aimed at assessing the impacts of runoff from residential areas, particularly informal settlements; the residential land-uses are further subdivided into categories based on development type and density, cost of housing, and standard of services.

3.3.2.1 Development type

The two main development types identified in the literature review are formal and informal developments. A formal development is one that has been planned with laid out stands and a defined road network. A wastewater disposal system has been installed that consists of either a formal waterborne system, septic tanks and soak-a-ways, or pit latrines. A formal development also has a piped water reticulation system into the houses or at least a standpipe per stand.

In contrast, an informal settlement has little or no planning and has taken place in an *ad hoc* fashion, with minimal provision of municipal services. If a sewage disposal system is present, it will normally consist of a bucket or pit latrine system, whilst the water supply consists of a standpipe, borehole supply, tanker delivery, or simply a nearby stream.

3.3.2.2 Development density

The density of a development appears to exert a significant influence on the quality of urban runoff. Two categories were identified, namely: high- and low-density developments. Although a medium-density category could possibly be added, insufficient data were available to justify the creation of such a category. Plot sizes, population density, and the percentage of impervious area are the main criteria used to determine the development density, as shown in **Table 5** below. The development density used is chosen on the basis of any two of the three criteria in **Table 5** being true.

Table 5: Definitions of development density used in expert system.

Development Density	Plot Size	Population Density	Impervious Area
High Density	> 500 m^2	≥80 p/ha	≥50%
Low Density	≥500 m^2	<80 p/ha	< 50%

3.3.2.3 Level of investment in development (Development Cost)

The development cost refers to the standard of the home or structure erected on the plots. Analysis of data available from the literature showed that a distinction could be made between the level of pollution from low-cost and high-cost developments, with the cost of the development reflecting the socio-economic standing of the community resident in the catchment. A high- and a low-cost category were included in the expert system. A guideline cost figure of R30000/unit is suggested as a cut off between low- and high-cost developments.

The low-cost category includes housing types from site-and-service through to very basic owner-built or contractor-built brick units.

3.3.2.4 Service levels and maintenance

The state of services and levels of maintenance in the catchment were found to be important in determining pollution potential. One of the common causes of the high concentrations of pollutants found in runoff is the standard and level of maintenance of the wastewater disposal systems. Poor runoff quality can, in part, be attributed to misuse of the sanitation system. This can be due to overflowing sewage from a waterborne system, infrequent emptying of buckets, or the absence of, or abuse to, a sanitation system. The presence of domestic refuse in the catchment and the lack of vegetation are also factors that contribute to the pollution potential of a catchment.

A catchment can be categorised as having a low or high pollution potential. A high pollution potential implies that the catchment has a poor standard of services and low levels of service maintenance. The high pollution potential catchments also generally have sparse vegetation cover. A catchment with a low pollution potential implies that it is well maintained and has a high standard of services with good vegetation cover.

An emerging problem, which was not addressed directly in any of the South African studies reviewed, is that of "grey water" - water used for domestic purposes, such as washing and cleaning, and which is not disposed of to a septic tank or sewerage system. In high-density settlements where basic services such as standpipes and pit latrines are provided, the disposal of grey water will require attention. Grey water has the potential to cause severe pollution of water resources as well as possibly impacting the local soils, when it is disposed of onto the catchment surface or into the storm drainage network.

3.4 Observed pollutant concentration ranges for categories of residential catchments

The expected concentration ranges of various water quality constituents are indicated in **Table 6** below. These data represent a summary of our available knowledge from the review of South African studies. Although the categorisation should be seen as qualitative only, it is nevertheless a useful indication of when and where to expect pollution problems, and the likely nature of those problems.

Table 6: Expected pollutant concentration ranges for categories of residential catchments.

Development type	Development density	Development costs	Pollution potential	NH_3 (mg/ℓ as N)	TKN (mg/ℓ as N)	EC (mS/m)	SS (mg/ℓ)	PO_4 (mg/ℓ as P)	COD (mg/ℓ)	DO (mg/ℓ)	Faecal coliforms (/100 mℓ)
Formal	High Density	High Cost	High	3-7	4-14	13-100	20-1 000	0.2-6.0	60-500	3-6	10 000-100 000
			Low	1-3	2-8	12-50	40-450	0.2-3.0	40-300	3-6	100-10 000
		Low Cost	High	1-30	10-40	70-2 500	40-1 850	0.4-14.0	150-400	1-6	10 000-1 000 000
			Low	1-5	2-8	15-200	21-400	0.2-3.0	15-70	3-6	10 000-1 000 000
	Low Density	High Cost	High	1-21	1-16	3-200	1-2 500	0.1-6.0	5-800	3-6	1 000-10 000
			Low	0-3	1-5	10-50	21-350	0.0-3.0	20-80	1-6	0-1 000
		Low Cost	High	-	-	-	-	-	-	-	-
			Low	-	-	-	-	-	-	-	-
Informal	High Density	Low Cost	High	5-24	7-103	25-700	800-8 000	1.0-8.0	70-3000	1-3	10 000-10 000 000
			Low	1-5	4-18	8-180	180-3 500	0.2-5.0	40-400	3-6	10 000-1 000 000
	Low Density	Low Cost	High	-	-	-	-	-	-	-	-
			Low	-	-	-	-	-	-	-	-

3.5 Synthesis of literature reports

3.5.1 Urban runoff quantity and quality

Informal areas and the older portions of low-cost, high-density townships usually contribute the largest proportion of the pollution present in urban runoff. In addition, both of these types of housing units are very often situated in relatively dangerous areas, such as close to receiving waters and/or below the 1:50 year flood line. These features contribute to the scale of urban runoff problems in two ways. Firstly, it is seldom possible to intercept the urban runoff from these areas before it discharges to the receiving waters and, secondly, the problem of flood control in areas below the 1:50 year flood line complicates the situation greatly. These additional, closely-related problems have to be catered for in possible solutions for urban runoff water quality problems.

Litter is arguably the most visual and widespread water quality problem that is associated with virtually every low-cost, high-density residential area. The informal squatter areas and old formal portions of townships have particularly acute litter problems (Wright et al., 1992; Van der Merwe, 1993/4). However, faecal pollution originating from these areas is recognized as posing the most serious human health problems (Van Veelen and DWAF, 1994a). Untreated faecal material and pollutants that originate from domestic refuse invariably enter urban runoff because of the inadequate provision or maintenance of sanitation and refuse collection services. The presence of excessive quantities of nutrients in runoff is responsible for another serious pollution problem, namely: the eutrophication of receiving water bodies.

Coastal urban catchments also contribute loads of sediments that are often contaminated with a variety of pollutants, including trace metals, nutrients and organic substances, as well as particulate material. These sediments are transported to the sea through sewerage outlets, stormwater outlets, rivers and natural overland flows, to become deposited in coastal bays and harbours. It is extremely difficult to dispose of these sediments since international water quality laws prevent them from being dumped at sea.

All runoff that originates from low-cost, high-density urbanised (sub-) catchments normally remains polluted throughout the year and the stormwater that drains from these areas is inevitably polluted to varying degrees. In all cases, the most important water quality problems are microbiological pollution, high nutrient concentrations and high concentrations of organic substances (Wimberley, 1992; Wright et al., 1992; Van Veelen and DWAF, 1994a). However, litter is once again the most visible and widespread symptom of pollution (Van der Merwe, 1993/4), though this does not pose the same human health problems. With the exception of certain “special cases” such as Khayelitsha, urban runoff from low-cost, high-density housing areas normally displays a “first flush” effect and is characterized by relatively low concentrations of total dissolved salts (Kloppers, 1989; Wright et al., 1992).

The provision of additional infrastructure to low-cost, high-density urban developments does not necessarily reduce the pollution problem. Indeed, the installation of water-borne sewerage and stormwater collection systems facilitates pollutant transport from the different (sub-) catchments and often results in increased contamination, although this may occur via a slightly different pathway (Wright et al., 1992). Some urban runoff pathways include processes that treat the runoff to improve the water quality, while others do not. Untreated runoff presents the main causes of concern with regard to human and environmental health. Runoff from low-cost, high-density urban areas usually follows a direct pathway to the receiving waters, without treatment prior to discharge, and should be the main focus of concern.

High population densities, poor living conditions, inadequate funding and a general lack of environmental awareness within communities living in low-cost, high-density urban areas ensures the generation of far greater pollution levels than those arising from high-cost, low-density urban catchments (Wright et al., 1992; MacKay, 1994; Van Veelen and DWAF, 1994a, b). In addition, ongoing violence and crime, as well as periodic labour strikes and other management problems, adversely affect the provision of basic services in low-cost, high-density urban areas. The worst records of pollution from these areas usually coincide with periods of unrest (Wright et al., 1992).

Stormwater detention basins in township areas may function as pollution reduction mechanisms during baseflow conditions, but during storm events the retention time is too short to improve the water quality (Wright et al., 1992).

Several studies have revealed general relationships between pollution levels, land use, population density and living standards (e.g. Wimberley, 1992; Wright et al., 1992; MacKay, 1993; Archibald, 1994a). In general terms, low-density, high-cost residential developments tend to have far slower rates of population growth than those recorded from low-cost or informal housing developments. The occupation of low-cost or informal housing developments results in an immediate increase in nutrient concentrations in the runoff and the receiving waters, quickly followed by increased microbiological counts. In contrast, rapid increases in pollutant loads do not occur when high-cost, low-density housing areas are populated, because of the slower population growth rates, lower population densities and better living standards in these areas.

Low-cost, high-density urban developments usually produce low trace metal pollutant loads in contrast with high-cost, low-density type urban catchments (Kloppers, 1989; Wright et al., 1992). Where formal housing areas are developed, pollutant loads are greatly reduced (especially during baseflow conditions) and concentrations tend to be similar to those from high-cost, low-density residential catchments. However, the formal residential (sub-) catchments tend to produce higher concentrations of trace metals than the other (sub-)

catchments, reflecting the higher income of residents and resultant increase in traffic volumes (Dallas and Day, 1992; Wright et al., 1992).

In theory, the provision of serviced site areas to eliminate uncontrolled squatting should improve conditions and reduce pollution, especially that of a faecal nature. However, this does not always work in practice, as shown in Khayelitsha (Wright et al., 1992), since serviced site areas merely became controlled squatter areas. Water quality data for Khayelitsha and other South African studies (e.g. Wimberley, 1992; MacKay, 1994) suggest that any form of new low-cost, high-density urban development will cause increased pollution and that this pollution will be related more closely to population density than the type of housing (Wright et al., 1992).

Low-cost housing areas generally yield higher pollutant loads than those areas with more durable, expensive housing. Pollution from peri-urban areas is heavily linked to population density and socio-economic status, in contrast to formally developed (low-density) areas where urban runoff pollution is linked to the type of land uses and the degree of infrastructure. Generally, areas that are characterised by high living standards produce the highest loads of heavy metals and hydrocarbons. Settlements of lower socio-economic status and less efficient (if any) services tend to yield the highest loads of faecal bacteria and nutrients.

In every case, urban land use comprises a small percentage of the total catchment area, but makes the biggest contribution to the total pollutant loads in the receiving waters. Stephenson and Green (1988) and Wimberley and Coleman (1993) have also shown that, in general, the average pollutant load of runoff, expressed in terms of rainfall, varies with urban land use, population density and the living standard of the population. In all cases, the higher the population density, or the lower the living standard of the community, the greater the resulting pollution load.

3.5.2 Influence of urbanisation on catchment characteristics

Generally, urbanisation causes a decline in low flows and an increase in high flows compared to natural conditions. This is because urbanisation expands the relative area of impervious surfaces, thereby reducing the contribution of groundwater and reducing the interchange between surface and groundwater. Urbanisation is characteris ed by an increase in impervious areas (e.g. buildings, paved areas and road surfaces), decreased natural storage capacity and canalisation of rivers into drainage canals. Urbanisation thus leads to increased runoff volumes and discharge rates. An average intensity storm over an urbanised area may produce 5-10 times the dry-weather flow contribution from the same area before urbanisation (Dallas and Day, 1992).

Urbanisation in KwaZulu-Natal has been shown to increase the runoff factor for the area, resulting in larger runoff volumes, higher erosion rates and larger pollutant loads being transported out of the catchment. The Lovu Development Project in the little Amanzimtoti catchment in KwaZulu Natal provides excellent evidence for this feature. Archibald (1994c) demonstrated that the runoff factor of 0.1 for the previous land use (19% sugar cane cultivation) had doubled to 0.2 when the area of sugar cane was replaced by 20% urbanisation.

3.5.3 Sources of catchment information

There are huge differences between the characteristics of low-density, high-cost housing developments with their very low population densities (in the order of 14 persons/ha) and those of high-density or informal township areas with their enormous population densities (of up to 612 persons/ha). It is logical that urban runoff problems and treatment technologies should also be quite different for these totally different types of settlements.

Urban townships in South Africa are highly urbanised and usually very densely populated, and informal housing constitutes a large portion of urban land use in South Africa. These types of settlements are mainly the result of the superimposition of an informal settlement structure (backyard and free-standing shacks) onto the former formal (one dwelling/stand) settlement structure (Wimberley, 1992). This informal type of housing contributes most of the pollution in township.

3.5.4 Urban runoff quality

Similar difficulties have been experienced in obtaining sufficient water quality information from studies on high-density, low-cost township developments. Once again, widespread crime and the virtual absence of security have prevented effective routine sampling from being conducted. As a result, more attention has had to be paid to the development of broad-scale evaluations based on regional approaches. In addition, more attention has been paid to the development of suitable modelling approaches that can provide first estimates of runoff quality and the degree of influence exerted by the major driving forces (Wright et al., 1992). In several areas (e.g. Botshabelo and Mdantsane), mass balance approaches provided excellent first approximations that were suitable for runoff management purposes.

3.6 Case Study – Alexandra Township

A 6-kilometre stretch of the Jukskei River just downstream of Alexandra Township was monitored in order to determine the different biological, physical and chemical processes that pollutants undergo during natural assimilation, as well as the rates and efficiencies of assimilation in rivers and the impact of pollutants on the aquatic environment downstream of the urban area. A series of "grab" samples were taken over a period that included both low-flow (dry season) and storm events.

It was found that microbiological pollution, nutrients and litter, typical of runoff from townships, were the major pollutant problems. Owing to the high concentration of nutrients in run-off from Alexandra Township, the major changes seen were seen as low to very low dissolved oxygen concentrations (between 1.1 and 1.5 mg/ℓ O_2) and high BOD concentrations in the river as a result of the biological conversion of organic nitrogen compounds and ammonia to nitrates. High concentrations of ammonia were recorded at Alexandra where most of the pollution is discharged into the river. These concentrations decrease rapidly as the ammonia is nitrified to nitrate. Unusually, chloride concentrations were much lower than those recorded during other South African studies of urban runoff.

Urban runoff discharged into the Jukskei River also results in a very rapid rise in the numbers of faecal coliform bacteria; a high value of 31 million/100 mℓ of water sample was recorded at Alexandra in September 1994. This type of situation poses a distinct health risk but, fortunately, these high numbers decrease rapidly with increasing distance downstream due to the inability of these bacteria to survive for long periods in water and to their sensitivity to ultraviolet radiation from sunlight.

Large concentrations of *Ascaris* (roundworm) eggs, indicative of human sewage pollution, were found down the whole length of the 6-kilometre reach of the Jukskei River examined during the study. *Ascaris* eggs are used as indicators of pollution and they are often found in large numbers. When *Ascaris* eggs were detected, tests for other parasites were carried out.

A number of the pollutants, especially those that area adsorbed or complexed to the suspended solids (phosphates, lead and iron) or those that occur in particulate form (organic nitrogen and BOD in the form of organic matter), appear to settle out of the water column onto the bottom sediments. This process seems to be a major removal process for non-point source pollution during steady state (low flow) conditions. During storm events, the major process occurring is the entrainment of pollutants from the riverbed into the water.

The QUAL2E water quality model, developed and used by the United States EPA, was used in this study to model the reactions that nutrients, BOD and DO, undergo. This model provided very good representation of the BOD and DO, with r^2 of 0.98 and 0.94 being calculated, respectively. However, the QUAL2E model under-predicted the concentrations of dissolved pollutants, dissolved phosphorus and ammonia. For these substances, the observed (measured) results showing a greater reduction in these pollutants than predicted by the model, suggesting that these pollutants adhere to suspended solids and settle out of the water onto the sediments. American rivers are less turbid than those in South Africa, and contain lower concentrations of suspended solids onto which pollutants can adsorb.

The main problem associated with non-point source pollution derived from catchments such as Alexandra, is that costly at-source diversion treatment processes are unlikely to be viable. This is because there is a constant influx of people to the area, resulting in a perpetual shortage of amenities. In the case of Alexandra, processes within the Jukskei River itself may then be the only option available for treatment of any runoff that is discharged into it.

Due to the constant influx of people to the townships, there is little chance that the provision of formal water-borne sewerage can keep up with the ever-increasing demand. However, diversion systems such as ponds or wetlands could be implemented to collect and treat runoff before it is discharged into the river. Buffer strips and other vegetated infiltration systems could also be built to reduce the pollution potential. Chemical treatment systems such as disinfection with chlorine or associated derivative compounds could be used to reduce the numbers of faecal coliform bacteria. This would also reduce the health risk to downstream water users.

4. MANAGEMENT OPTIONS

4.1 Introduction

The problem of polluted urban runoff and the associated impacts on the quality of receiving water resources can be managed at different points in the process of:

- Generation at source;
- Transport over the catchment; and
- Delivery to receiving water resources.

Clearly, in the long-term, the most effective point at which to manage the problem is by reducing the pollution potential at source. However, in the short-term "quick-fix" solutions are required to reduce present levels of pollution from urban areas; these options mostly involve interception of the polluted runoff at a point between its source and its discharge to a watercourse. Managing the problem in the watercourse itself is perhaps the least attractive option, for this relies on the natural ability of aquatic ecosystems to recover from impacts. While aquatic ecosystems can indeed recover from impacts if they are in a healthy, functioning state to begin with, many urban rivers and water bodies have already been severely impacted by construction, canalisation and destruction of habitat, and so have limited capability to recover from the additional impacts of untreated urban runoff.

Interception and treatment options formed the major focus of this study, and are covered in detail in a separate report.

4.2 Options for interception and treatment

There are a number of water treatment methods that can be applied to the management of urban runoff. Some of the systems such as ammonia stripping, activated carbon and ion exchange systems are expensive and require skilled operators. As such, these processes are more suited to the treatment of water for domestic and industrial supply, or possibly to the on-site treatment of runoff from certain industrial premises.

The management methods that were reviewed for this study are those that are cost-effective, do not require skilled operators and mostly make use of natural processes for treatment. These types of treatment systems will have a wider area of application for South African conditions than the more sophisticated chemical treatment technologies.

The treatment systems can be grouped into: pond systems, filtration systems, chemical systems and wetlands. Runoff treatment methods within each group tend to employ similar fundamental processes. All runoff treatment methods require some degree of control over the flow rate of the water that passes through them. At high flows, treatment options such as wetlands, vegetated filtration methods and ponds, are ineffective, because the water is not retained in the system long enough for biological and chemical reactions to take place. Settling out of particulate matter will also only take place at lower flows. Low flows can be achieved by placing attenuating structures such as balancing dams in series with the treatment system, either immediately upstream or downstream, in order to regulate flows through the treatment system. **Table 7** shows the processes that may be used to treat particular kinds of pollutant, and the treatment systems in which these processes are likely to occur.

Table 7: Impacts, associated pollutants, treatment processes and treatment systems.

Impact	Pollutant	Treatment processes	Possible treatment systems
Sedimentation	Suspended solids	• Settle • Filter • Flocculate/ Settle	1. Pond/In-stream systems 2. Filter systems 3. Wetlands 4. Vegetated infiltration systems 5. Chemical treatment systems
Oxygen depletion	Organic material BOD / COD	• Settle • Filter • Bacterial oxidation • Aeration	1. Pond/In-stream systems 2. Filter systems 3. Wetlands 4. Vegetated infiltration systems
	Nitrogen Ammonia NH_3	• Bacterial oxidation • Aeration • Filtration • Plant/algal uptake	1. Pond/In-stream systems 2. Wetlands 3. Filter systems
Eutrophication	Organic N	• Settle • Hydrolosis • Filtration	1. Pond/In-stream systems 2. Filter systems 3. Wetlands 4. Vegetated infiltration systems
	Nitrate NO_3	• Plant/algal uptake • Bacterial conversion to N_2 (anaerobic)	1. Pond/In-stream systems 2. Vegetated infiltration systems 3. Wetlands

Table 7: (Continued).

Impact	Pollutant	Treatment processes	Possible treatment systems
Eutrophication (Continued)	Ammonia NH_3	• Bacterial oxidation • Aeration • Filtration • Plant/algal uptake	1. Pond/In-stream systems 2. Wetlands 3. Filter systems 4. Vegetated infiltration systems
	Organic Phosphorus P	• Settle • Filtration • Mineralisation to PO_4	Pond/In-stream systems Filter systems Vegetated infiltration systems Wetlands
Toxicity	Heavy Metals	• Precipitation • Settle • Filtration	5. Pond/In-stream systems 6. Filter systems 7. Vegetated infiltration systems 8. Wetlands
	Biocides	• Plant/algal uptake • Filtration • Bacterial oxidation • Settle	1. Pond/In-stream systems 2. Filter systems 3. Wetlands 4. Vegetated infiltration systems
	Hydrocarbons	• Plant/algal uptake • Filtration • Bacterial oxidation • Settle	1. Pond/In-stream systems 2. Wetlands 3. Filter systems 4. Vegetated infiltration systems
Health aspects	Bacteria, viruses and parasites	• Settle • Filtration • Disinfection • Sunlight/UV radiation	1. Pond/In-stream systems 2. Filter systems 3. Wetlands 4. Chemical treatment systems
Aesthetics	Litter, plastic, cans	• Filter • Settle	1. Gross pollutant traps 2. Filter systems 3. Pond systems 4. Wetlands

4.2.1 Pond systems

Pond systems include stabilisation ponds, wet and dry ponds, urban lakes, maturation ponds, aerated lagoons and oxidation ditches.

Pond systems are one of the most widely applicable methods of treating wastewaters in hot climates. Treatment occurs through natural, physical, chemical and biological processes with no machinery or energy input (except for the sun's energy) being required for most pond systems. Detention and retention dams are also used for flood management and for treatment of urban runoff.

Pond systems provide a site in which water can be contained for a period of time. During the retention period the processes of settling, oxidation, uptake of pollutants by algae and plants, aeration, bacterial die-off, and thermal and wind mixing are all active in improving the water quality. To a large extent, the length of the retention time will determine the processes that will have the most significant effect on water quality. Settling is one of the main pollutant removal processes in pond systems. In some pond systems, the retention time may be short, of the order of hours, and improvement of the water quality will be by the process of settling with little or no contribution due to the decay of organic material.

Some ongoing maintenance of pond systems is required in order to preserve their effectiveness. Due to one of the main treatment processes being the settling and sedimentation of pollutants, a sludge layer will build up on the bottom of the pond. If this layer becomes anaerobic, offensive odours can result. Ponds should be dredged from time to time and the sludge safely disposed of. Vegetation that encroaches on a pond should be cut back, and the edges of the pond should be stabilised to prevent erosion.

4.2.2 Filtration systems

Filters include rock filters, sand filters, gross pollutant traps and grit channels. These systems allow wastewater or runoff to percolate through a material such as sand or crushed stone or, in the case of gross pollutant traps, through a grid that removes litter. The performance of filter systems depends on the incoming pollutant loads, the oxygen supply to microorganisms that break down some of the pollutants, and the prevailing temperature. Filter systems are usually installed after a detention pond, in order to control the rate of flow of water through the filter system. Regular cleaning and maintenance of filter systems is required, in order to ensure their effectiveness.

4.2.3 Vegetated infiltration systems

These include grass swales, grass plots and buffer strips over which runoff flows before reaching the receiving water or next treatment system. These systems encourage pollutant removal by filtration through grass and soils, but because they are unlined, water is also discharged to underground water bodies that may become contaminated.

Very little maintenance is required for vegetated infiltration systems, expect for the clearing of gross pollutants such as plastics, tins and organic debris. The grass must be maintained since it is the presence of the grass that ensures the correct functioning of the system.

4.2.4 *Chemical treatment systems*

Chemical systems which are appropriate for the treatment of runoff include those that utilise processes of chemical precipitation and disinfection. However, these systems are high-cost, high-maintenance options, and are not suited to treatment of runoff from residential areas.

4.2.5 *Wetland systems*

In South Africa, constructed wetlands are used predominantly for the treatment of domestic wastewater. Their application in the treatment and management of urban runoff is still limited, but wetland systems are perhaps the most appropriate available interception and treatment options. They harbour many of the processes that remove and/or transform common pollutants from urban runoff, require little maintenance, and add greatly to the aesthetics of urban areas.

Pollutant removal in wetlands is usually achieved by a combination of processes including filtration, settling, adsorption, uptake and microbial transformation. Wetlands can be configured to include both free water surface and sub-surface flow zones, depending on the expected nature of the contaminants as each zone supports different contaminant removal processes.

The successful operation of wetland systems depends entirely on the biological, physical and chemical interactions between the plants, the substrate or sediments and the microbial organisms in the wetland. For this reason, proper design and operation is important.

Since constructed wetlands have been used primarily for domestic wastewater treatment, their functioning under relatively steady flow and load conditions is fairly well understood. However, flow volumes, flow rates and pollutant loads in urban runoff tend to be extremely variable, and the performance of wetlands under these conditions has not been well researched. As part of this project, therefore, a series of experiments was carried out using small test wetlands, to ascertain the behaviour of these systems under rapidly varying flow and load conditions. The results of this study are covered in a separate report (Batchelor, A.L. and Loots, P.A.).

Careful maintenance of constructed wetland systems is essential to ensure optimum performance. Litter and excessive amounts of suspended sediments should preferably be prevented from entering the system, as they are difficult to remove. Sediments within the wetland system will need to be removed on an infrequent but regular basis to ensure maintenance of the original design hydraulics.

Wetlands and detention ponds form useful combinations of process units, particularly where the detention ponds can be used to manage the hydrology in ways which complement wetland functionality.

4.3 In-stream processes

As the last line of defence, it may be necessary to enhance or support natural in-stream processes that contribute to downstream recovery from the negative impacts of urban runoff. Virtually all aquatic ecosystems have the ability to recover from a variety of adverse impacts if they are maintained at an appropriate level of ecological health. The use of natural in-stream processes to mitigate against the impacts of urban runoff can take place in three ways:

- Within the urban area itself, so that the downstream extent of the impacts is minimised;
- Downstream of the urban area, although this approach then may result in a loss of any amenity value within the urban area itself, plus a greater downstream extent of impact and, hence, negative effects on more water users downstream;
- A combination of measures implemented within the urban area as well as downstream, to improve the situation both within and downstream of the urban area.

Low to medium flows of urban runoff tend to contain high levels of organic substances with high oxygen demand, leading to reduced oxygen levels or even anoxia downstream of the discharge. Natural processes of aeration and biological degradation of wastes lead to recovery of in-stream oxygen concentrations, but the distance within which this occurs can be reduced by implementing various remediation measures.

Providing opportunities for turbulent flow can enhance aeration. Cascades and small weirs can help to increase physical entrainment of oxygen into the water column, and the inclusion of riverine habitats with significant "roughness" will also promote turbulence and aeration. As an example, instead of smooth concrete storm canals, construction methods which utilise grassed canals or combinations of concrete, rocks and grass, which include restoration of riparian vegetation as far as possible, or which encourage shallow, swift flows are preferable. This then provides the added benefit of providing safer habitats for small organisms, within which they can find shelter from strong scouring flows. If small organisms such as detrital feeders can be encouraged to colonise an area, they will also assist in the more rapid breakdown of waste materials through natural decomposition processes.

Urban rivers should be seen as having value in an urban landscape: riverine corridors can provide significant opportunities for recreation, aesthetic and educational benefit. These are ecological services that are often overlooked on the balance sheets of many local authorities. If carefully managed, urban rivers can sustain a balance between flood protection, remediation of water quality, and provision of habitat corridors and enhancement of the human landscape. However, sustaining this balance requires maintenance of healthy aquatic ecosystems at a level where the ecosystems can recover from the impacts imposed on them, whilst, at the same time, still providing the full range of ecosystem services.

5. EXPERT SYSTEM

5.1 Purpose of the expert system

The expert system has been developed to assist urban planners to evaluate the impacts of urban storm water runoff on receiving water bodies and to undertake preliminary design of storm water management systems to mitigate against these impacts.

The expert system allows for an assessment of the concentrations of pollutants in a river, a specified distance downstream from the discharge point of the urban runoff into the river. At this stage only the effect of urban runoff on rivers as the receiving water body can be investigated. Other water bodies such as lakes, dams, estuaries and the sea have not been included. The system allows for the examination of the effect of pollutant reduction at source, the planning of townships, and the preliminary sizing of management methods.

The system allows an urban planner to categorise the catchment of interest. Based on the catchment category, typical runoff pollutant concentrations are provided by the expert system. The catchment characteristics such as area, percentage impervious area, slope and length of the longest watercourse are also input by the user. These catchment parameters are used to generate a typical storm runoff for the area. The concentrations, together with a flow estimate, are used as input into the management and receiving water modelling sections. The pollutant concentrations output from the receiving water model can be compared to water quality objectives set for the stream. This will allow an assessment of the impacts and the abilities of the management systems tested in improving the quality of the runoff.

A separate report describes fully the structure of the expert system, the decision support or decision-making methodology, the algorithms used to determine the pollutant removal abilities of the management methods and the receiving water system, and the operation of the program.

5.2 General description of the expert system

The Expert System consists of two databases and a set of algorithms describing the pollutant treatment processes that can be used to determine the pollutant removal abilities of the storm water management structures. Database 1 contains the categorisation of the different types of urban developments and the pollutant concentrations that can be expected in the storm water runoff from each type. Database 2 contains the water quality standards to which the impacts of the storm water runoff on the receiving water can be compared. The pollutant types that are included in the model are suspended solids (SS), ammonia (NH_4), ortho-phosphate (PO_4), chemical oxygen demand (COD), Total Kjeldahl Nitrogen (TKN), dissolved oxygen (DO), and faecal coliform bacteria (FC).

The treatment options that are included in the management part of the expert system are:

- Wet and dry pond systems;
- River systems;
- Grass swales; and
- Grass buffer strips.

The expert system allows management options, consisting of up to three of the individual management elements, to be designed and used in series to treat the expected urban runoff. The simulated treated runoff quality can be compared to the water quality standards set for the receiving waters. An iterative procedure can then be followed, whereby the sizes of individual management elements can be changed or more elements added until the required water quality objectives are reached at the point of interest in the receiving water system.

The modelling of runoff water quality is difficult and essentially empirical. Many of the available water quality models of the different components that make up the management system require measured data for calibration. The same holds for the modelling approaches used in the expert system. Although default parameters are given in the expert system, they can only serve as a guide to the performance of any of the elements in the management system and the impacts on the receiving water resource.

6. POLICY TOOLS AND REGULATORY INSTRUMENTS

The national Water Policy of 1997 and the National Water Act of 1998 allow for a range of policy and regulatory tools to be applied in management of the impacts of urban runoff on water resources. The discharge of runoff collected from an urban area can be classified as a water use under Section 21 of the National Water Act since it involves the disposal of waste or water containing waste, either directly to a water resource, or in a manner that may impact on a water resource. In keeping with the requirement in the Act to protect water resources, activities such as disposal of urban runoff, which may have various kinds of impacts on water resources, should be subject to some form of control or management in order to minimise or prevent such impacts. This would also apply to changes in hydrological characteristics.

Policy and regulatory tools are now available which can be used to address the urban runoff problem at short-, medium- or long-term time scales.

6.1 Short-term policy and regulatory options

Section 19 of the National Water Act deals with prevention and remedying of the effects of pollution, and pollution prevention. This section allows for a directive to be issued by the catchment management agency where an activity is undertaken on land and that “causes, has caused or is likely to cause” pollution of the water resource. The person or body responsible for the activity must take steps, which can be set out in the directive, to remedy the situation, to reduce or remove the sources of pollution and to remedy the effects of the pollution or the effects of disturbance to the bed and banks of the affected watercourse. Ultimately the owner of the land, or the person or body in control of the land, can be held responsible for pollution of a water resource that is caused by the land-based activity.

While directives can be used as a short-term control option, the spirit of co-operative governance requires that the catchment management agency or the responsible national government department should preferably offer constructive assistance to the local authority, where a local authority is in charge of the disposal of urban runoff. This assistance need not be financial, but could also involve technical support, guidance and capacity-building in order to address the problem in a sustainable manner in the longer term.

Technical options for short-term remediation of the impacts of urban runoff could include interception of the most polluted fraction of the runoff, in order to divert that for additional treatment, or installation of remedial works in-stream to encourage recovery of the impacts aquatic ecosystem. These options are discussed in more detail in the technical reports that were produced during this study.

6.2 Medium-term policy and regulatory options

Since the discharge of urban runoff can be classified as a water use, it also requires authorisation under the National Water Act. Authorisation for a water use can be provided in three ways:

- Through a schedule of authorisations such as Schedule 1 of the National Water Act;
- Through general authorisations, with minimum conditions attached; and
- Through a site-specific water license with site-specific conditions attached.

Schedule 1 is intended for those water uses whose impacts are so small that they require no additional control measures, or for those discharges that are routed to a licensed treatment works. While diversion and treatment of urban runoff in a sewage treatment works may be an option for low flows, it is not generally realistic to divert high flows to sewer for treatment.

Site-specific licenses for water use may include conditions such as concentration-based discharge standards that limit the concentration of substances that may be discharged. However, although this has been implemented in some other countries with varying degrees of success, the highly variable nature of urban runoff, in flow, in concentration and in composition, makes effective compliance with discharge standards very difficult, in addition to the problems of auditing compliance in such cases. Also, one urban area may have several points for discharge of urban runoff, again making end-of-pipe standards impractical to set and very difficult to implement.

If licensing is considered as a medium-term option, then licenses could be issued for areas of urban development, with requirements for on-site management practices. In the medium-term these may include retrofitting of interception options before the urban runoff reaches the water resource (as described in the technical reports).

Bio-monitoring in the water resource downstream of urban runoff discharges can support the application of best management practices on the land, prior to discharge. Since bio-monitoring indicators (such as invertebrate, fish or vegetation communities) provide a measurement of impacts integrated over various time scales, bio-monitoring is a more appropriate tool both for ascertaining the success of management interventions on land, and for auditing compliance with required conditions.

6.3 Long-term policy and regulatory options

The only way to deal effectively with the negative impacts of urban runoff on water resources is through long-term measures – anything else will remain a “quick-fix” solution and can probably only be partially successful. However, long-term management options can take time to put in place, so there is a need to address the problem in the short- and medium-term, in order to slow or halt degradation of water resources caused by urban runoff.

Long-term options for management of urban runoff include:

- Effective community education and communication efforts about the proper disposal of wastes is urban areas;
- Improved efficiency in service provision by local authorities; and
- Planning of urban layout and construction that includes options for balancing the need for flood protection with the need to minimise the negative impacts of urban runoff.

Ideally, these longer-term options can be designed within the framework of the Catchment Management Strategy. The National Water Act allows for the development of the catchment management strategy, which should set out the agreed vision of all stakeholders for the sustainable management of the catchment. Protection requirements, phrased as the class, Reserve and resource quality objectives, are a key element of the strategy. The strategy should also establish how the protection requirements will be achieved, and who will take what actions and responsibilities. Hence the catchment management strategy lends itself as a tool for setting out the long-term commitments of various agencies, authorities and stakeholder groups towards maintaining or improving the quality of water resources, including those actions that will minimize the negative impacts of urban runoff.

6.4 Issues that still require attention

Inevitably, in studies of this nature, several issues are still incompletely understood and will require further attention in future. These issues are outlined briefly as a basis for further work.

6.4.1 The derivation of accurate relationships between urban runoff and land use

In general, the adverse effects of urban runoff become more pronounced as areas go through a development cycle from rural to residential to commercial (industrial/business district zone) and are accompanied by an increase in traffic volumes (Dallas and Day, 1992). Formally developed (low-density, high-cost) residential areas produce smaller pollutant loads on average than commercial areas of equivalent size (Stephenson and Green, 1988). The geological setting, geographical characteristics, nature of the urban development and population density are key factors that are responsible for driving the different stormwater qualities in different (sub-) catchments (Wright et al., 1992).

6.4.2 Quantification of regional runoff patterns

South Africa is extremely diverse in terms of its climate, geomorphology, geology, soils and aquatic biota. These factors vary spatially over South Africa and, as a result, different regions exhibit considerable diversity in terms of their water quality, even when these regions have experienced relatively modest anthropogenic influences. Indeed, very few South African rivers can be considered to be entirely unaffected by some form of urbanisation, formal agriculture or other human activities. Therefore, these natural differences are of extreme importance in assessing and planning for the impacts of urban runoff on receiving waters (Dallas and Day, 1992). A further complication will arise when the effects of global climate change become more evident and this aspect will require considerable attention if the anticipated changes alter the existing patterns of rainfall over South Africa.

6.4.3 Pollution sources and pathways

There are a wide variety of pollutant sources and numerous pathways by which these substances may reach receiving waters. Some work has already been conducted to develop methods for estimating pollutant loads and pathways (Weddepohl and Meyer, 1992; Hughes and Van Ginkel, 1993). However, these studies need to be expanded to take account of the vastly different situation that prevails now compared to the time when the studies were carried out.

When planning remedial measures to treat polluted runoff, or when designing new urban areas, it is essential to have sufficiently accurate information on the expected runoff flows, as well as the types, sources and pathways of pollutants, and the potential loads of these pollutants, that are likely to be derived from the catchment area.

6.4.4 Modelling approaches versus Empirical approaches

To date, hydrological modelling of South African township urban runoff (using hydrological simulation models) could not be performed satisfactorily. This was because the data required for such an operation could not be collected from townships under the prevailing conditions. With the changing political and social climate in South Africa, such studies may become possible in the future. Even so, great care will still have to be taken in selecting a study area, as underground stormwater systems in low-cost, high-density type catchments provide unique problems with regard to flow gauging (Wright et al., 1992).

The low levels of accuracy and relatively coarse scale (time increment) of the input data for the Khayelitsha urban catchment made simulation with a model such as WITSKM of limited value (Wright et al., 1992). Clearly, the use of relatively coarse data in a sophisticated computer model is of little or no value with regard to model evaluation. The level of confidence placed in such results would be no greater than those obtained when using more simple approaches such as rational methods with their wide margins of error. It would be an injustice to the model to attempt to evaluate it using poor input data, whilst the results would be unlikely to offer any reliable insights (Wright et al., 1992).

The Khayelitsha exercise showed very clearly that sophisticated models could be used successfully and properly evaluated in hydrological studies of high-cost, low-density types of urban catchments. However, the same cannot be said for similar attempts in low-cost, high-density type urban catchments. Indeed, the level of sensitivity required for most modern models was extremely difficult to obtain in catchments like Khayelitsha under the unstable political conditions that prevailed in South Africa during the study (Wright et al., 1992).

7. CONCLUSIONS

Sufficient evidence exists to indicate that urbanisation will lead to a deterioration of the quality of water resources, both at the point of urbanization as well as downstream, unless concerted steps are introduced to mitigate against the consequences of urbanization.

The only effective way to reduce the impact of urbanisation on the quality of water resources in urbanizing catchments is to establish at an early stage a strategic objective for the catchment. This should take into account the following issues, in line with the protection of resource quality, as used in the National Water Act[4]:

> "*(xix) Resource quality means the quality of all the aspects of a water resource including -*
> *(a) The quantity, pattern, timing, water level and assurance of in-stream flow;*
> *(b) The water quality, including the physical, chemical and biological characteristics of the water;*
> *(c) The character and condition of the in-stream and riparian habitat, and*
> *(d) The characteristics, condition and distribution of the aquatic biota"*

These four aspects of resource quality are all essential for the protection and maintenance of healthy, functioning aquatic ecosystems that, in turn, are essential for supporting the varied demands placed on water resources.

Once the strategic objectives for the catchment have been established, appropriate local administrative guidelines can be promulgated. These guidelines can guide both authorities and developers in the selection of the most appropriate approach to ensure the adoption of best management practice. For example, the strategic objective may be to ensure that at a particular point in the catchment, the post development hydrograph will not deviate by more that 10% from the pre-development hydrograph, using the 1:50 year flood event as reference. This does not specify a particular technology but ensures that all parties need to incorporate in their development plans, appropriate actions that will be implemented to ensure attainment of this objective. This approach allows the setting of multiple objectives that could include, for example, aspects such as water quality. It may further also include a description of the desired extent and distribution of riparian habitat and vegetation type. Finally, such an approach would ensure that all stakeholders share responsibility for water resource quality management.

Finally, one of the problems associated with the management of urban drainage is the lack of monitoring information, particularly with respect to flow measurements. Appropriate gauging stations in urban and peri-urban areas will be required to effectively measure and manage water resources emanating from urban areas.

A series of key management issues that require attention and a list of future research needs and priorities were identified during this study. These are listed separately, below.

[4] Chapter 1, Section 1 of the National Water Act, Act 36 of 1998

7.1 Key management issues that require attention

This study revealed a variety of critical management issues. These need to be addressed urgently by the authorities that are engaged in catchment management and integrated water resource management. These issues are listed below:

- Concentrations of faecal bacteria should meet given water quality standards for recreational use of receiving water bodies at all times
- Unsightly litter in and along drains and natural water courses should be kept to a minimum
- Dissolved oxygen concentrations should not be depleted to below 60% of saturation in the initial mixing zones of coastal stormwater outfalls and, ideally, should not fall below 80% of saturation in any part of a freshwater body that receives urban runoff
- Urban runoff should not contain high loads of suspended sediment so as to ensure that water clarity is not adversely affected in the long-term
- The nutrient balances in rivers, estuaries and lagoons receiving urban runoff should not be changed significantly (< 15%) from their present status
- No toxic chemicals should be discharged into receiving waters (this includes pesticides and heavy metals)
- Salt marshes, fringing wetlands, mud flats and lagoons should not be disturbed by urban runoff to the point that their structure or functions become adversely affected (MacKay, 1994a)
- Management actions aimed at reducing diffuse source pollution from urban runoff and informal settlements must form part of an integrated catchment management plan so that all management actions can be properly integrated (Wright et al., 1992).

An examination of the management strategies that have been used on existing stormwater systems in South Africa revealed the following problem areas:

- Prior to 1994, planning and development strategies did not include long-term measures for dealing with urban runoff problems or options for coping with increased runoff due to rapid increases in settlement area and rising population densities
- In general, insufficient (if any) consideration was given to reserving sufficient space or facilities for future stormwater management or treatment facilities
- Despite the fact that the encroachment of shacks and buildings onto river banks poses a serious danger to lives during floods and exacerbates the seriousness of water quality problems, very little attention was given to providing alternative options to the residents concerned
- All previous attempts to implement remedial actions without the full and active participation of the affected residents have failed.

7.2 Future research needs and priorities

The general scarcity of appropriate quantitative information on the characteristics of urban runoff hampers the selection of suitable management options that can be deployed to reduce or ameliorate the impacts of this runoff. Consequently, it is essential that carefully targeted research should be conducted to fill these information gaps. The most important information gaps are as follows:

- The extent to which groundwater contamination has occurred as a result of low-cost, high-density types of urbanisation
- The appropriate use of groundwater as a water supply for informal settlements and the most suitable management options to prevent its contamination (Wright et al., 1992)
- Specific studies need to be conducted on the urban runoff situation in the Lovu and Cato Manor communities so as to provide specific management guidance for these communities
- The extent to which geographic information systems (GIS) can be used as appropriate management and communications technologies to quantify urban runoff, select appropriate management strategies and to communicate choices to the communities concerned
- Low-cost, high-density type urbanisation, with its informal housing and shack areas, is an inescapable part of South Africa and will continue to play a major role in this country for many years to come. Experience has shown that well-proven engineering solutions from high-cost, low-density communities are not always applicable to low-cost, high-density urban areas. Therefore, it is vitally important that the scientific and engineering community continue to study these urban catchments and to develop new and innovative ways of dealing with the problems associated with urban runoff.

The wide range of adverse impacts that low-cost, high-density urban land uses have on catchments and their water resources warrants serious and urgent attention. The development and installation of appropriate sanitation and waste disposal for both existing and planned peri-urban areas will require fundamentally new management approaches. Therefore, it is imperative that carefully focused research is conducted in these priority areas to ensure the long-term protection of South Africa's limited water resources (Wright et al., 1992).

8. REFERENCES

Allanson BR, Hart RC, O'Keeffe JH and Robarts RD (1990) Inland Waters of Southern Africa: An Ecological Perspective. Monographiae Biologicae **64**. Kluwer Academic Publishers, Dordrecht.

Archibald C (1994c) Lovu Development Project. Report by the Division of Water Technology (CSIR - Durban), to Van Wyk and Louw Inc. (Pinetown). 37 pp.

Dallas HF and Day JA (1992) The Effect of Water Quality Variables on Riverine Ecosystems: A Review. WRC Report No 351/93.

Hughes DA and Van Ginkel C (1993) Nutrient loads in runoff from developing urban areas: A modelling approach. In: *Proc. of the Sixth S .Afr. Natl. Hydrolog. Symp.,* Pietermaritzburg, 8-10 September 1993.

Kloppers WS (1989) Urban Stormwater Runoff: A Water Quality Study. CSIR (Stellenbosch) Internal Research Report, November 1989. 54 pp.

MacKay HM (1993) The Impact of Urban Runoff on the Water Quality of the Swartkops Estuary: Implications for Future Water Quality Management. WRC Report No. KV45/92.

MacKay HM (1994) Management of Water Quality in an Urban Estuary. Ph.D. Thesis, University of Port Elizabeth. 262 pp.

Simpson DE (1991) Quantification of the Effects of Land Use on Runoff Water Quality in Selected Catchments in Natal. WRC Report No 237/1/91.

Stephenson D and Green IRA (1988) A simplistic mass balance of storm-water pollutants for two urban catchments. *Water SA* **14** (2) 93-98.

Van Ginkel CE, O'Keeffe JH, Hughes DA, Herald JR and Ashton PJ (1992) 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 **1.** Confidential Document 4/93.

Van der Merwe C (1993/4) A river runs through it... *Muniviro* **10** (4) 11.

Van Veelen M and DWAF (1994a) Jukskei River - Water Quality Management. BKS Inc. Final Water Quality Report No. 2/94 to Department of Water Affairs and Forestry, Pretoria 39 pp.

Van Veelen M and DWAF (1994b) Facts about the Jukskei River. BKS Inc. Draft Report to Department of Water Affairs and Forestry, Pretoria.

Weddepohl JP and Meyer DH (1992) Utilization of Models to Simulate Phosphorus Loads in Southern African Catchments . WRC Report No 197/1/92.

Wimberley FR (1992) 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 (M.Sc. Thesis) 182 pp.

Wimberley FR and Coleman TJ (1993) The effect of different urban development types on stormwater runoff quality: A comparison between two Johannesburg catchments. *Water SA* **19** (4) 325-330.

Wright A, Kloppers W and Fricke A (1992) A Hydrological Investigation of Storm Water Runoff from the Khayelitsha Urban Catchment in the False Bay Area, South Western Cape. WRC Report No 323/1/92.