A GUIDE TO NON-POINT SOURCE ASSESSMENT

by
G C PEGRAM AND A H M GÖRGENS

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Water Research Commission

A GUIDE TO NON-POINT SOURCE ASSESSMENT

TO SUPPORT WATER QUALITY MANAGEMENT OF SURFACE WATER RESOURCES IN SOUTH AFRICA

by

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PREFACE

Background to the Project

A perceived deterioration in the quality of South African surface waters has drawn the attention of water managers and planners during the last decade. As urbanisation and development continues and limited water resources are increasingly used and re-used, this deterioration appears to be unavoidable. DWAF's task of supplying water of acceptable quality is undertaken in this context, where more users place increasing demands on a finite resource.

DWAF is consequently involved in an ongoing process of evaluating and adapting its water quality management philosophy to address the threat of deteriorating water quality. The development of a new water law and policy for South Africa has provided greater possibilities for managing all sources of contamination, including non-point sources, at a catchment scale.

A significant amount of research has been conducted into the topic of non-point source contamination. However, these studies have been in danger of not fulfilling their potential due to inadequate linkages between the water quality management philosophies, strategies and information needs, and the processes governing water quality in the catchment, particularly with respect to non-point sources.

The Water Research Commission recognised this need and funded a project to develop a Guide for the Assessment of Non-point Sources, which represents an attempt to link together the understanding of non-point source problems, the assessment techniques and available information, to provide for the appropriate management measures associated with non-point source contamination. The ultimate aim of this project is to provide relevant information for water quality (and ultimately water resource) management and planning.

This Guide is explicitly focused on the impacts of ***non-point sources on surface water in South Africa***. The impacts on groundwater are also important, but the nature of the contaminant processes and techniques for their assessment are significantly different and should be the focus of a similar Guide.

Phases of the Project

The scope and complexity of the topic led to the project being conceived in three phases.

- *Phase I* was to perform a Situation Assessment of the current state of knowledge about non-point sources and their assessment in South Africa, presented in:

  Pegram, GC, G Quibell and AHM Görgens (eds) (1998) ***Non-point Sources in South Africa: A Situation Assessment****. Project Working Document.*

- *Phase II* involved a series of case studies to evaluate and illustrate the application of assessment techniques in South Africa, presented in:

Quibell, G (ed) (2000) ***Development of a Non-point Source Assessment Guide: Test case studies****. WRC Report No. 696/2/01 Pretoria.*

- *Phase III* was to develop the Guide itself - this document represents the culmination of this phase and the project as a whole.

In addition, the project team was requested to provide input to the *Water Law Review* process, and the policy options for non-point source management in particular:

Pegram, GC and AHM Görgens (1999) ***Policy considerations for non-point source management in South Africa****. WRC Report No. 696/1/198.*

Towards the end of the project, the project team was also requested to explore the provisions for non-point source management in the National Water Act:

DWAF (1999) ***A Framework for Implementing Non-point Source Management Under the National Water Act****. WRC Report No. TT 115/99.*

Objective of the Guide

The primary focus of this Guide is to support water quality management of surface water resources, and particularly non-point sources management, through the provision of appropriate and cost-effective information for decision-making.

The Guide aims to assist users in understanding their non-point sources assessment needs in a particular situation, and thereby enable them to identify and apply appropriate non-point source assessment techniques. Although evaluating the manageability of a non-point source impact may be part of the assessment process, techniques for management (i.e. measures and practices) are not presented in this document.

Target Group

The Guide has thus been primarily targeted at non-point source *decision-makers* and those *practitioners* who are involved in non-point source studies aimed at providing management oriented information. Decision-makers are assumed to include water quality managers, whether at DWAF, Catchment Management Agencies or other water management institutions, as well as representatives of non-point polluters and affected parties, that may be involved in either catchment management processes or authorisation of non-point sources. Water quality practitioners include the technical officials in these organisations or their consultants who are appointed to perform a non-point source assessment.

Both decision-makers and practitioners are assumed to have an understanding of water resource issues, but not necessarily non-point sources. Therefore, the document has been written to be accessible to people with varying expertise and knowledge, including relatively uninformed readers. This implies some redundancy for experienced users, but an attempt has been made to enable quick referencing of pertinent information, thereby avoiding the need to read the entire document. It is hoped that the document will provide all groups involved with non-point source assessment, with a tool that facilitates communication and a joint understanding of the problems and needs of non-point source assessment in

South Africa.

Although scientists and researchers are not the main audience of this document, it should provide a useful contextualisation for research studies addressing non-point source assessment, as well as to indicate shortcomings in the present state of knowledge.

Key Concepts

A brief explanation of the fundamental concepts used throughout this document are presented below (these concepts are expanded in Part 1).

Assessment technique — Any approach or model for performing or supporting water quality or non-point source assessment, which may provide either qualitative or quantitative information.

Non-point source — Land use areas and activities that result in the mobilisation and discharge of pollution in any manner ***other*** than through a discrete or discernible conveyance

Non-point Source Assessment — Any qualitative or quantitative investigation into the nature, impact or effect of non-point sources on the water quality in the receiving water environment, or an investigation into the consequences of implementing non-point source management approaches.

Resource quality — The quality of all characteristics of a water resource, including the quantity of water, the water quality, the instream and riparian habitat, and the aquatic biota.

Source area — A land use area with relatively homogeneous non-point source related characteristics and hydrometeorological response, which represents the basic unit for non-point sources assessment.

Report Structure

This document has been presented in four parts, each serving different but interrelated purposes (see the figure below):

- ***Part 1*** provides a brief overview of the management context of non-point source assessment, which provides the user with an understanding of the policy and legal environment of non-point source management.

- ***Part 2*** provides an overview of the issues and information needs associated with non-point source assessment, as related to the non-point source area character, water quality concerns and management goals.

- ***Part 3*** presents the guide itself, which assists the user in defining their non-point source task, translating this into criteria for non-point source assessment and indicating appropriate assessment techniques.

- ***Part 4*** describes the non-point source assessment techniques referred to in the guide, and in some cases presents relevant information which is necessary to apply them and illustrated by South African case studies.

- ***Part 5*** Outlines further research that is required to promote the statutory and non-statutory management of non-point sources in South Africa, as well as to support the further development of tools for non-point source assessment.

How does the water resource management environment affect nonpoint source assessment?

Part 1: Role of nonpoint source assessment in water resource management
- Water resource mangagement and the policy environment
- Role players
- Nonpoint source management - a key component of water quality management
- Implications for nonpoint source assessment - to support water resources management

What impacts do nonpoint sources have on water quality and how can these investigated?

Part 2: Nonpoint source assessment
- Water quality concerns - what are they and what is the effect of nonpoint sources
- Nonpoint source character - and its impact on water quality
- Management goals - and the information needs of different decision makers

What type of techniques suit a particular nonpoint source assessment need?

Part 3: A guide to nonpoint source assessment
- Procedural guide - linking information needs to assessment criteria
- Scoping guidelines - to identify the nonpoint source assessment issues
- Evaluation guidelines - to understand the nonpoint source impacts
- Prioritisation guidelines - to choose what needs to be managed
- Selection guidelines - to indicate how to manage

What are the characteristics and applicability of particular nonpoint source assessment techniques?

Part 4: Nonpoint source assessment techniques
- The generic character of nonpoint source assessment techniques
- The basic principles of nonpoint source assessment
- Knowledge based approaches - for qualitative and consultative investigation
- Data analysis techniques - to process data where it is available
- Potential and hazard maps - to indicate critical sources
- Unit area loading - to estimate total catchment land use effects
- Loading functions and potency factors - to estimate high level source impacts
- Simple process models - for general understanding of impacts
- Detailed process models - for mechanistic understanding of impacts
- Single source models - for localised small-scale evaluation
- Heuristics - to support the selection of appropriate management solutions

Where to find relevant nonpoint source assessment information in this document

HOW TO USE THIS GUIDE

Text Boxes

The following text boxes are used throughout the document, to highlight and support key concepts and issues:

☞ This type of box provides a brief summary or conclusion to a discussion, and in some cases how this links with the next section.

This type of box presents an example or illustration to support the text discussion or to explain an important point.

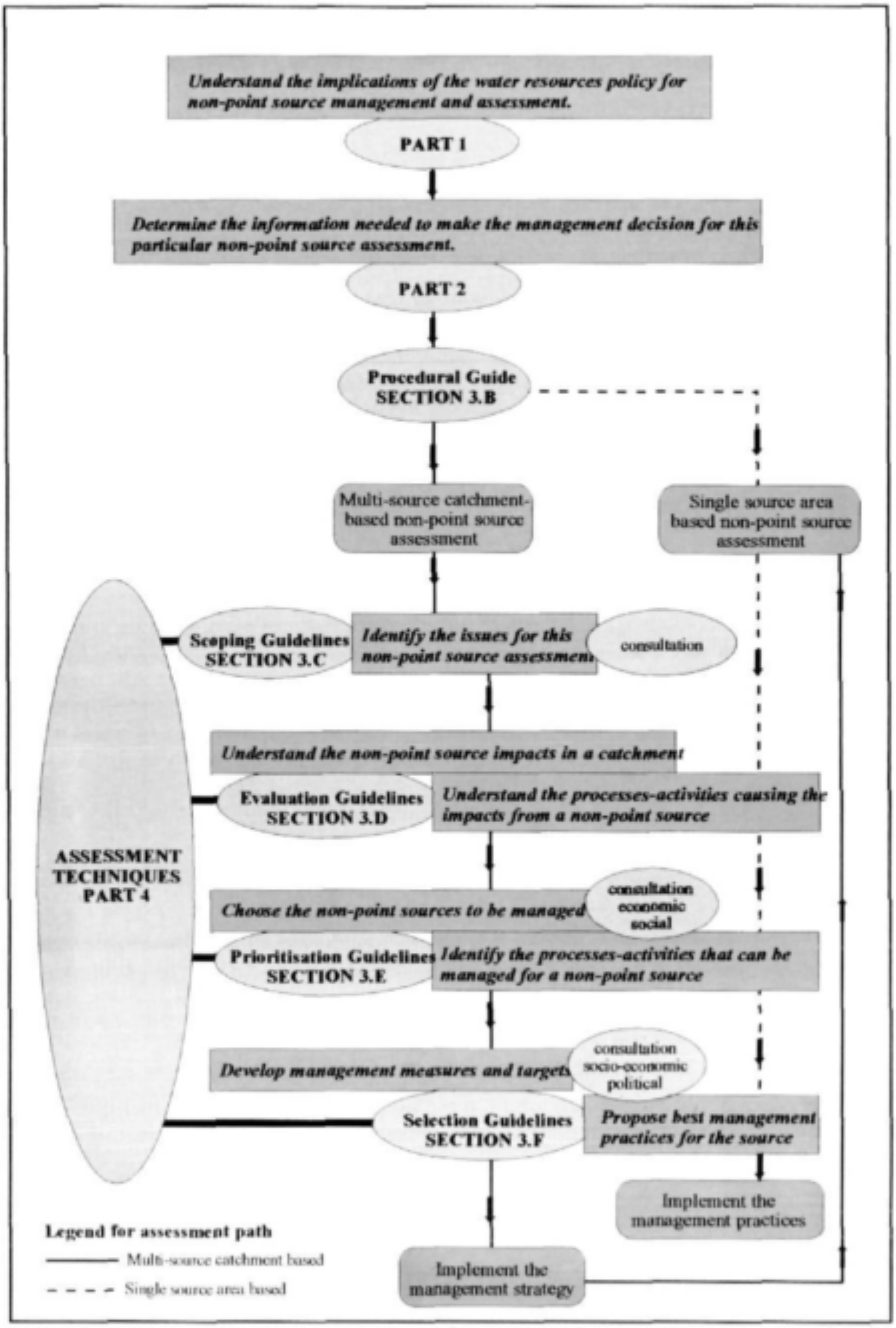
Roadmap for Non-point Source Assessment

The document structure presented in the Preface, indicated where particular issues and topics may be found in this document. A roadmap to non-point source assessment is presented below. This outlines the process of non-point source assessment and indicates where the various parts of the document may be used to support it. Thus, the roadmap provides the first reference point for a user wanting to access information in the document, with reference to a particular non-point source assessment. It is worth noting two issues that are raised by the roadmap:

Firstly, there are two main types of non-point sources assessment, namely those that are catchment based and those that are source-area based.

- The former may be done to support the development of a *catchment management strategy* (see Part 1) or as part of an investigation for catchment wide water quality management purposes. This is indicated by the solid line in the roadmap.
- The latter may be required for the *statutory nonpoint source control* (see Part 1) or for an investigation of a particular non-point source, as part of a water use license application or catchment management process. This is indicted by the dashed line in the roadmap.

Secondly, non-point source assessment in support of water quality management, needs to take account of more than the purely technical issues. This requires consultation and socio-economic evaluation to be part of the assessment process. This document does not provide guidance on how these should be done, but does indicate when they are necessary - as indicated in the roadmap.



ROADMAP FOR USE OF THE NONPOINT SOURCE ASSESSMENT GUIDE

PART 1 : THE ROLE OF NON-POINT SOURCE ASSESSMENT IN WATER RESOURCE MANAGEMENT

1A. WATER RESOURCE MANAGEMENT IN SOUTH AFRICA

Water Law Review

In 1995 a process of reviewing and formulating a new water law for South Africa was begun to bring it in line with the objectives of the new democratic government, the changing pressures on water resources in South Africa, as well as local and international trends and developments in water resource management. The distribution of a discussion document *You and Your Water Rights* in 1995 was followed by the formulation of the *Fundamental Principles and Objectives of a new Water Law in South Africa*, which were accepted by Cabinet early in 1997.

The National Water Policy and Act

In 1997 these principles were translated into the *White Paper on a National Water Policy for South Africa*, which provided the basis for the National Water Act (Act No 36 of 1998). The National Water Act was formulated as a framework act, for which the details of implementation are currently being formulated. Thus, the following discussion outlines the important provisions of the Policy and the Act, as well as the strategies for implementation based on the authors' understanding at the time of writing.

Integrated Water Resource Management

Underlying the new approach to water resource management is the recognition that water should be managed in an integrated manner. *Integrated Water Resource Management is simultaneously a philosophy, a process and an implementation strategy to achieve equitable access to and sustainable use of water resources by all stakeholders at catchment, regional, national and international levels, while maintaining the characteristics and integrity of water resources at catchment scales within agreed limits.*

National Water Resources Strategy

At a national level, the national water resource strategy as required by the National Water Act, authorise to the need for integrated water resource management by providing a framework for water resource management between water management areas.

Catchment Management

The recognition that water resource management should be performed at a catchment scale, with input from all stakeholders, led to the requirement for catchment management strategies to be formulated and established in law. This strategy should outline a framework for water resource protection, use, development, conservation, management and control within a water management area, which is consistent with the national water resource strategy.

Resource Protection

The need to ensure sustainable utilisation of South Africa's water resources, led to the recognition that the resource itself must be protected from over-utilisation, that would cause their irreversible degradation. The concept of resource protection addresses all water uses defined by the Act, including water abstraction, waste discharges, streamflow reduction, water storage, instream activities and recreation. Although this guide focuses on surface water resources, resource protection in the context of integrated water resources managment requires the link between groundwater and surface water to be explicitly addressed.

Resource Directed Measures

The resource protection approach integrates two key features in a structured decision-making framework, namely resource-directed measures and source-directed controls. Resource-directed measures focus on the water resource as an ecosystem and specify clear objectives reflecting the required level of protection. These are the resource quality objectives, based on the water resource classification and the Reserve.

Water Resource Classification

The resource protection approach is given effect through the national water resource classification system. This is a procedure that leads to the specification of an acceptable level of risk of irreversible damage for a particular water resource. It is developed through a process of consensus-seeking among water users and stakeholders, based on the required level of protection and/or needs for short- to medium-term use. Resources requiring greater protection will demand lower risk of damage, and thus greater caution in water resource development and use.

The Reserve

The Reserve is the quantity and quality of water required to provide for basic human needs and to protect the sustainability of the aquatic ecosystem. It is the only water allocation that is guaranteed as a right and reflects the level of risk implicit in the resource classification.

Resource Quality Objectives

Resource quality objectives are based on the acceptable level of risk which is appropriate to the water resource class and provides the clear and enforceable statement of the requirements for maintenance of the Reserve. This acceptable level of risk is translated into numerical or descriptive statements of the flow, water quality, habitat and biotic conditions that should be met in the water resource. These are the resource quality objectives specified to ensure that the resource is protected for sustainable utilisation.

Source Directed Controls

A wide range of regulatory, economic and/or persuasive measures are required to control the impacts on water resources, in order to achieve the objectives for resource protection. These include requirements or incentives for achieving end-of-pipe effluent discharge standards, implementing on-site management practices to control diffuse impacts, and performing instream mitigation and rehabilitation.

Water Use Authorisation

The abovementioned measures for sustainable water resources management are supported by measures controlling water utilisation. Water use is broadly defined in the National Water Act, to include all activities that are likely to impact detrimentally on a water resource.

Granting of water use authorisations must consider the following criteria: optimal beneficial use, economic efficiency and equity. Certain water uses must be authorised by a licence in accordance with the conditions of any pertinent regulations, as well as being consistent with the relevant catchment management strategy.

1B. ROLE PLAYERS

Custodianship and the DWAF The *National Water Policy for South Africa*, states that the National Government is "custodian of the nation's water resources and its powers in this will be exercised as a public trust". DWAF is the primary agency responsible for water resource management. In exercising its mandate, DWAF must reconcile, integrate and co-ordinate diverse and often conflicting interests of different stakeholders, within the framework of sustainable and equitable utilisation of South Africa's water resources.

Catchment Management Agencies The new Policy also provides for the phased establishment of Catchment Management Agencies (CMAs) to undertake water resources management in defined water management areas. Water management institutions, including CMAs and water user associations (WUA's), are largely responsible for water resource management in South Africa.

Stakeholders The Policy promotes a participatory approach to water resource (including water quality) management. This implies that responsibility for water quality management is shared among national, provincial and local government departments, public sector agencies, private sector organisations, community based organisations and non-governmental organisations. From a water quality perspective, the stakeholders include the interests of both polluters and those affected by pollution.

Assessment Practitioners In terms of this Guide, assessment practitioners are key role players. They provide the information to support management decision making and include technical staff in government departments and consultants hired by DWAF, CMAs or various stakeholders. Although the Guide provides information for the other role players, and is intended to foster communication, the practitioners are the primary focus of this Non-point Source Assessment Guide.

1C. NON-POINT SOURCE MANAGEMENT

Non-point Sources

Non-point sources represent land use areas and activities that result in the mobilisation and discharge of pollution in any manner other than through a discrete or discernible conveyance (see Section 2.A). The management of non-point sources is complicated by the dispersed and variable nature of the impacts, being primarily driven by hydrometeorological events. The potential lag between polluting activity and effect also complicates non-point source management, particularly for groundwater contamination and discharge into surface water resources.

These characteristics obscure the impacts from different sources and restrict the opportunities for their measurement. However, the importance of non-point source management is increasing as point sources are controlled and catchments are developed. Thus, the only realistic way of obtaining adequate information to support non-point source management is through non-point source assessment.

Statutory Non-point Source Control

The National Water Act requires that all water uses must be authorised through source directed controls, such as licences and general authorisations. This includes those non-point sources that are defined as water uses. There are three clauses in the definition of water use in Section 21 of the National Water Act that may relate to non-point sources:

(e) engaging in a controlled activity identified as such in section 37(l) or declared under section 38(1);
(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;
(g) disposing of waste in a manner which may detrimentally impact on a water resource;

Controlled Activities

Section 38(2) of the Act enables an activity to be declared a controlled activity if the minister is satisfied that activity *is likely to impact detrimentally on a water resource*. This is likely to be the most appropriate approach to non-point source management, and may be done at different scales, i.e. at the national, resource class, catchment or site-specific level. However, the declaration of a controlled activity and any associated general authorisation conditions, licence requirements or regulations must follow an extensive process of consultation. This process will be complicated by the lack of certainty about the impacts of non-point sources on receiving water resources. Provision of this information is an important function of this Non-point Source Assessment Guide.

Best Management Practice

Non-point source discharge can seldom be monitored; the exception are sources for which surface runoff is collected, such as urban storm water or feedlot runoff. Non-point source management should, therefore, be based on management practices for land use. Management practices may range from land use management approaches, which reduce washoff of contaminants, through to engineering structures to intercept and treat this washoff. These management practices should be technically and economically feasible and should control the potential contamination from the source at an acceptable level of risk, as defined by the class of the receiving water resource.

Thus, the *Best Management Practice* (BMP) in a particular situation, is the individual or combination of management practices that provide an affordable, effective and sustainable means for preventing or reducing pollution from a non-point source, to achieve specified resource quality objectives.

☞ It must be emphasised that although the selection of management practices for non-point source management is a crucial element of the implementation of the National Water Act, this is not the role of this document. This document provides guidance to the understanding and assessment of the impacts of non-point sources to support the non-point source management process.

Measures for the control and management of non-point source pollution in the developing country context are extensively dealt with in US EPA (1993) *Guidance Specifying Management Measures for Non-point Pollution in Coastal Waters*. EPA-840-B-93-001c. Atlanta. (www.epa.gov/OWOW/NPS/MMGI/index.html), while the management of informal settlements in developing countries is addressed in DWAF (1998) *Managing the water quality effects of settlements: Guidelines for Implementation.* DWAF WQM - Operational Guideline U1.2.

Licensing and Regulation

Following the approach adopted in the Act, non-point source management practices will generally be defined as licence conditions or regulations for controlled activities, as part of the water use authorisations. The development of a licensing procedure for non-point source related activities has been identified as a priority by DWAF.

1D. IMPLICATIONS FOR NON-POINT SOURCE ASSESSMENT

The preceding discussion has provided a very brief overview of the current approach to water resources, water quality and non-point source management in South Africa. This places the Non-point Source Assessment Guide within the management context as specified in the the National Water Policy and Act, and indicates the approach to this document. For this Guide, non-point source assessment is focussed on supporting decision making for water quality management.

The water resource management overview has outlined three key issues that non-point source assessment must address:

- Non-point source impacts are often central to catchment management, which implies that assessment must support the development of catchment management strategies, and follow the catchment management process, involving scoping of issues, evaluation of impacts, prioritisation of sources and selection of solutions.

- Non-point source management requires the declaration of controlled activities and associated management practices, which must be supported by information about the impact of relevant land use activities, as well as the effectiveness of alternative management practices.

- Control and enforcement for non-point source management requires the evaluation of licence applications and possibly the specification of site-specific conditions, which requires source specific assessment of the impacts and possible solutions.

☞

Throughout this document, the focus of non-point source assessment is to support management decision making. Thus the guide indicates the most cost-effective technique/s to provide adequate information for a particular assessment need.

Part 2 assists the practitioner to define this non-point source assessment task, thereby supporting the selection of appropriate assessment techniques.

PART 2 : NON-POINT SOURCE ASSESSMENT

2A. OVERVIEW

Introduction

Efficient and effective non-point source management requires information about the non-point source areas that contribute to water quality concerns. Providing this information is the role of non-point source assessment, but this, in turn, implies an understanding of the cause and effect relationships between the non-point source areas and the water quality concerns, as well as the type and detail of the information required to support the management decision-making process.

The aim of this section is to provide relatively inexperienced readers with a background to non-point source assessment. It should assist users of the guide in understanding non-point source characteristics, impacts and interactions so as to inform the selection of appropriate assessment techniques (Part 4) using the Guide (Part 3). Furthermore, it outlines a systematic approach to identifying information needs to support management decision-making.

What is Non-point Source Pollution?

The National Water Act (Act 36 of 1998: 1xv) defines *pollution* as:

alteration of the physical, chemical or biological properties of a water resource so as to make it:-
(a) less fit for any beneficial purpose for which it may reasonably be expected to be used; or
(b) harmful or potentially harmful -
(aa) to the welfare, health or safety of human beings;
(bb) the any aquatic or non-aquatic organism;
(cc) to the resource quality; or
(dd) to property.

Non-point source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, interflow, seepage, groundwater flow or river course modification. Technically, non-point sources are all sources of pollution that are not defined as point sources. Although there is currently no definition of "point sources" in the National Water Act, these are *discernable and confined sources of pollution that discharge from a single (point) conveyance, such as a pipe, ditch, channel, tunnel or conduit*. Non-point sources represent those sources that are not included in this definition.

Non-point source pollution of surface waters in South Africa is largely caused by rainfall and the associated surface runoff or groundwater discharge. Non-point sources may be diffuse and intermittent, contributing to contamination of water resources over a widespread area, such as storm washoff and drainage from urban or agricultural areas. Alternatively, they may be concentrated, associated with localized high activity areas, such as mines, feedlots, landfills and industrial sites.

Although non-point source impacts of surface washoff are relatively immediate, the non-point source impact of groundwater discharge is often delayed, due to the time taken for contaminants to mobilise and move through the soil matrix into the receiving surface water environment.

Although storm runoff and irrigation return flow are often collected into a “discernable conveyance”, these are diffuse in nature (with the containment system representing a management practice) and are, therefore, included as non-point sources. Streamflow modification associated with land use change is also a type of non-point source pollution, which can adversely affect the physical and biological integrity of surface waters. Incidents (accidental spills) are not included as non-point sources in this guide, while instream activities are addressed as part of the associated land use activities (eg. agriculture).

The Four Elements of Water Quality Pollution

A conceptual framework of the physical catchment system, provides the conceptual "platform" for water quality monitoring, assessment and management. This involves the separation of the physical processes governing the mobilisation, movement, impact and effect of contaminants into four conceptual elements, as indicated in Figure 2.1. It is based on the location and types of processes, but also considering the approaches for assessment and management of these elements. The four elements are:

- ***Production*** at source, including generation, deposition, application and the natural availability of pollutants, as well as their mobilisation and attenuation; management requires the isolation, reduction, recycling or removal of pollutants before they are mobilised into non-point source discharge (delivery).

- ***Delivery*** from the source to the surface water environment, through surface washoff, interflow and groundwater flow, with physical, chemical or biological attenuation and assimilation; management requires the interception, detention, treatment or assimilation of pollutants before they reach the surface water environment.

- ***Transport*** through the surface water environment (i.e. wetlands, rivers, estuaries and impoundments), involving advection, dispersion and diffusion, with assimilation or dilution. Management requires enhancement of the natural assimilative functioning of the aquatic environment or manipulation of the hydrodynamic regime through river-reservoir system operation to achieve resource quality.

- ***Use*** of the water by the recognised users, either directly within the water resource (eg. recreation) or after abstraction (eg. irrigation); management requires the provision of water which is fit-for-use, by providing treatment after abstraction, obtaining an alternative source, or by restricting direct use of the water resource.

The first two elements are related to the source area impact and are addressed through source directed controls, with production being managed through source control and delivery being managed through delivery reduction. Transport and use are associated with the water quality effect and are associated with resource directed measures. Sections 2.B and 2.C explore the water quality concern and source area characterisation.

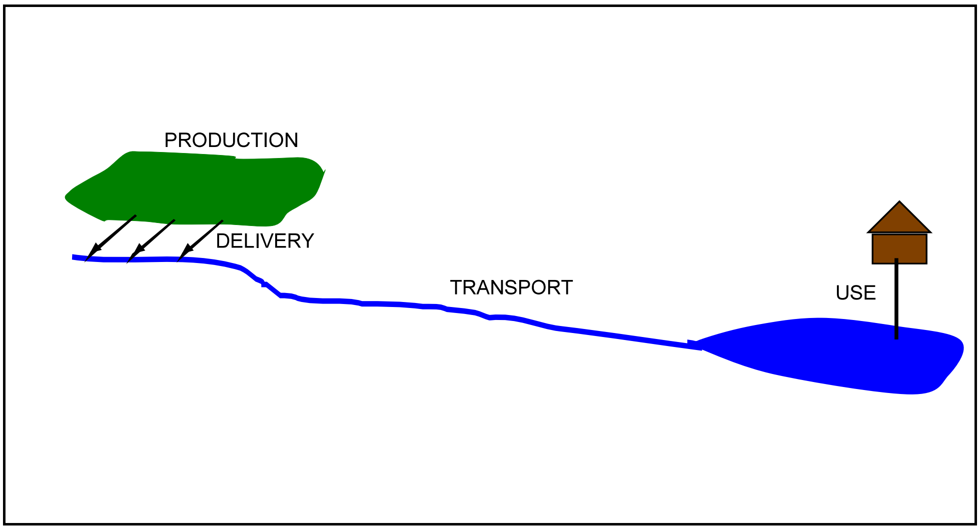


Figure 2.1. Conceptual physical elements of non-point source pollution.

The Non-point Source Assessment Task

The task of non-point source assessment may be viewed as consisting of three components, namely the management goal, the water quality concern and the source area (or catchment) character, as indicated in Figure 2.2. The *management goal* is related to who the assessment is for (i.e. the decision maker) and the particular management decision/s that they are attempting to make. This is influenced by the particular *water quality concern* to be addressed, which, in turn, is determined by the land use activities (causes) and sensitivity of the surface water environment (effects). Finally, the *source area character* reflects the land use activities (and natural features) in the catchment, but its representation for non-point source assessment is governed by the management goal for the assessment.

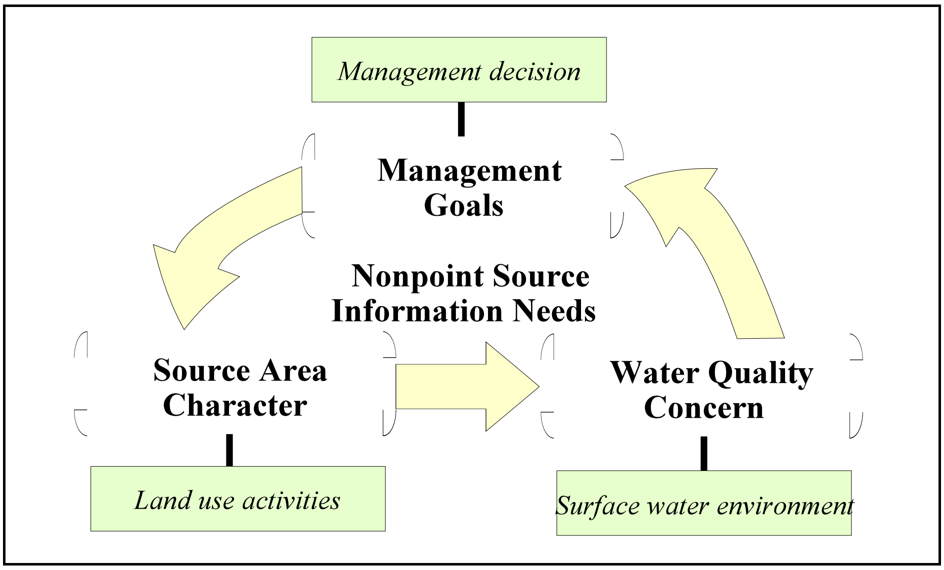


Figure 2.2. Representation of the Non-point Source Assessment Task.

The combination of management goals, water quality concerns and source area character outline the information needs of assessment, and are referred to as the *non-point source assessment task*. The information needs indicate assessment criteria which can guide the choice of appropriate assessment techniques. This concept underlies the Guide presented in Part 3, which provides a simplified procedure for identifying and selecting appropriate assessment techniques (Part 4), based on a characterisation of the non-point source assessment task.

The following two examples of a non-point source assessment task will be used to illustrate many of the issues and discussions presented in Parts 2 and 3. The general water quality concern, source area character and management goal are described.

- A 500 km² rural agricultural catchment, consisting of 40% sugar cane, 40% forestry and 20% undisturbed land (with a paper and pulp effluent discharge) is causing a major sedimentation and eutrophication problem in a downstream water supply reservoir. The local water quality managers want to know where the problems are coming from, so they can focus their effort into the appropriate sectoral extension programmes, if it is non-point source in nature.

- A 2 km² (200 hectare) peri-urban settlement with a small stream flowing into a municipal park, consists of 2000 fully reticulated dwellings, but this has densified with another 3000 unserviced informal dwellings in open spaces and backyard shacks. Instream faecal indicator concentrations (and diarrhoeal rates of both the local inhabitants and downstream recreators) are particularly high. The local authority has a R2 million grant to address the problem, and wants to know what is causing the problem and how they should spend the money.

☞ The management goals, water quality concerns and source area character must be identified, together with the required management information needs, in order to guide the selection of appropriate techniques for a particular assessment.

The following sections define the key attributes of the non-point source assessment task and indicate their relevance for non-point source characterisation. The attributes of this characterisation appear throughout the guide. The discussion therefore provides the basis for the guide, as well as a valuable introduction to non-point sources assessment for those users who have limited knowledge and experience in the field.

2B. WATER QUALITY CONCERNS

Introduction

From a water quality management perspective, non-point source assessment is usually only necessary where there is a concern about an existing, threatened or perceived water quality effect on the aquatic environment or recognised users, i.e. domestic, industrial, agricultural and recreational. The characterisation process should, therefore, reflect the resource quality, in order to focus the assessment on the critical non-point sources. *Resource quality* includes:

- the quantity, pattern, timing, water level and assurance of instream flow;
- the water quality, including physical, chemical and biological characteristics;
- the character and condition of the instream and riparian habitat; and
- the characteristics, condition and distribution of aquatic biota.

This section provides an introduction to water quality in the context of resource quality with an emphasis on non-point source related issues. It begins with an explanation of water quality and the typical non-point source related concerns, and concludes with the implications of particular water quality characteristics for non-point source assessment.

What Makes a Water Quality Concern?

Water quality is the term used to describe how well the physical, chemical and biological character of water matches the requirements for functioning of the aquatic environment and human uses, i.e. its fitness for use. Good water quality is acceptable for all uses, while water of poor quality has an adverse impact on the health of the aquatic environment or is not suitable for one or more users. A water quality concern is related to existing, threatened or perceived poor quality.

Assessment of the fitness for use of a water resource is not the topic of this document, and is dealt with (extensively) in the DWAF Water Quality Guidelines (DWAF, 1997). This approach is currently being extended for implementation of the National Water Act, particularly in terms of the Water Resource Classification System and Resource Quality Objectives. These reflect the sensitivity of the receiving water environment and users in a catchment, and indicate the resource quality required for the level of protection associated with an acceptable degree of risk. The range of non-point source related quality problems in South Africa are highlighted in the following discussion, the most critical of which are sediment, nutrients, pathogens and salinity.

Streamflow

Changing streamflow regime is not strictly a water quality effect, although it does represent a component of the resource quality. Internationally, runoff hydrology is included as a non-point source impact, because it is related to land use activity. Furthermore, surface runoff and groundwater discharge are the two primary pathways through which non-point source contaminants are mobilised at source, delivered into and transported through the receiving surface water resources, and thus their management is at the heart of many non-point source management approaches. Detailed non-point source assessment requires an understanding of the hydrological processes causing contaminant mobilisation, assimilation and dilution from non-point source areas.

Some agricultural and forestry activities are associated with streamflow reduction, while urbanisation and human settlements generally cause increased streamflows with higher peak storm flows. Both of these can have an impact on the aquatic habitat and biota, with reduced streamflow impairing ecological functioning and increased streamflow resulting in flooding, channel erosion and bank destabilisation.

Sediment Sediment is mineral and organic matter that is eroded and washed off the land surface by storms and wind. It is the most widespread pollutant of surface water and has a negative effect on most water users. Increased turbidity and sedimentation affects the functioning and productivity of the aquatic environment, by decreasing light penetration for aquatic plants, smothering aquatic habitat, stressing filter-feeders and interfering with predators' feeding. Sedimentation of streams and impoundments decreases storage capacity, reduces recreational opportunities and can increase flooding. Many pathogens, nutrients, heavy metals and toxic substances are transported through the environment adsorbed to sediment, and thus after hydrology, understanding sediment erosion and washoff is essential for non-point source assessment.

Sediment erosion occurs from all land uses, including natural vegetation, and is related to climate, soil and topographic conditions. However, increased erosion occurs where the vegetation cover is disturbed, such as agricultural crop and grazing lands, forestry, and construction sites in urban areas.

Nutrients Although many elements and compounds are required for plant growth, phosphorus and nitrogen are generally associated with degraded water resource quality. Nitrogen and phosphorus may be adsorbed to sediment, but it is the biologically available soluble forms that are of greatest importance. Phosphorus tends to be the limiting nutrient in South African fresh water systems, the presence of which can contribute to excessive algal blooms. These blooms are termed eutrophication and can result in algal scums and blooms, cloudy or discoloured water, strong odours, lack of oxygen due to decay of algae and plant material, production of toxins by algae and bacteria, disagreeable tastes and odours in drinking water, and diurnal variations in pH and dissolved oxygen concentrations.

Nonpiont source related nutrient enrichment is generally associated with surface runoff and sediment yield from agricultural fields where fertiliser is applied, as well as atmospheric deposition and washoff from urban residential, commercial and industrial areas. Frequent failure of sullage drainage and sanitation in poorly serviced settlements also provides a source of nutrient loading. Many concentrated sources can contribute nutrients to surface waters, including feedlots and waste disposal sites.

Pathogens The presence of pathogenic bacteria, viruses and other microorganisms in surface water resources pose a risk to the health of people using the resource for recreation or domestic purposes. Pathogens are usually represented by indicator organisms, such as faecal coliform or *E.coli*, which are not necessarily pathogenic themselves. Many pathogens attach to particulate matter, and thus are mobilised and transported through the environment in similar ways to sediment. The die off rate for pathogens may vary from less than a day to a couple of weeks. Higher temperatures, solar radiation, nutrient deficiency, pH and predation increase bacterial die-off rates.

Pathogenic contamination is largely related to human and animal activities in and around water bodies, with the main non-point sources being washoff from urban areas, including inadequate or failing sanitation infrastructure, livestock grazing areas and concentrated sites, such as feedlots and waste disposal sites.

Salinity Inorganic salts influence salinity, acidity and alkalinity in water resources. The most common individual elements include calcium, magnesium, sodium, potassium, chloride, carbonate and sulphate. The salinity and pH of a water body may negatively affect the growth of aquatic plants or the fitness of water for agricultural, domestic or industrial use. pH also influences the solubility and toxicity of heavy metals and other compounds such as ammonia.

Background salinity of surface water resources is usually related to the natural processes of weathering and leaching of soil and geological material, which is influenced by the climatic conditions in a region. However, the evapotranspiration associated with irrigation concentrates salts in the soils and return flows. Intensive agricultural irrigation along a river results in increasing salinity, and this is the most widespread human related non-point source of salts. Runoff and groundwater discharge from mining, quarrying, urban and industrial areas can also provide significant salt inputs to surface water resources. Atmospheric washout of salts can produce "acid rain", caused largely by sulphate emissions from energy and industrial facilities. Salt concentrations are highest during low dry flow and drought conditions when leachate and return flows dominate.

Heavy Metals Although many metals are essential trace elements, they can be toxic to aquatic and animal life if they are present in high concentrations. Radioactive isotopes also present a threat to aquatic ecosystems and human use of water resources. They may accumulate in fish and shellfish, making them unfit for consumption. Metals may be adsorbed to particulate matter, or be present as insoluble salts, organic compounds or in solution, depending upon pH, hardness and sediment concentrations. Metals are usually transported (and settled) with sediment during high runoff and flow periods, but may be dissolved as environmental conditions change.

Metals may be found naturally in low concentrations associated with the weathering of soil and geology. However, atmospheric deposition and washoff from urban, industrial, mining and transportation land uses tends to have high metal concentrations, particularly copper, lead, chrome, zinc and cadmium.

Toxic Organics Artificial compounds for agricultural, domestic or industrial application are often highly toxic to aquatic biota, animals and humans. The main non-point source related toxic organics are pesticides, polychlorinated biphenyls (PCBs) and phenols. Many of these compounds are strongly adsorbed to particulate and organic matter, and therefore move with surface runoff. The more persistent chemicals may bio-accumulate in higher order animals, although lower order organisms exhibit far lower concentrations. Pesticides are associated with washoff from agricultural crops, forestry and residential areas, while most other toxic organics are washed off urban industrial and transportation areas.

Hydrocarbons Soaps, oils and greases associated with petrochemical, animal and vegetable processing adversely affects the operation of waste water treatment plants, delaying and increasing the cost of treatment of other wastes. In the environment they may attach to sediment particles, increase BOD loads and reduce oxygen diffusion through the surface, cause aesthetic and odour problems, create a fire hazard, and adversely effect aquatic organisms through toxic and physical impairment. They are generally washed off impervious areas during storm events, often attached to sediment particles. The major non-point sources include transportation corridors, urban streets, parking lots and industrial areas, as well as careless disposal of oil into storm water drains.

Litter and Solid Waste

Litter and household solid waste (and in some cases animal carcasses) impair the functioning of the aquatic environment and degrade the aesthetic quality of surface waters. It can also pose serious health problems for recreational and domestic users of the water resource, and contribute other water quality contaminants, such as pathogens, nutrients and metals. Gross pollutants are washed off poorly serviced urban commercial and residential areas. This represents an important non-point source pollutant in urban areas, not only because of the direct pollution impacts, but also because litter can cause the failure of other services that are designed to prevent or mitigate water quality contamination from urban areas, namely sanitation and storm water infrastructure.

Organic Matter

Some river systems have naturally high organic content. However, when organic matter is present at higher concentrations, it exerts an oxygen demand, thereby reducing the dissolved oxygen content of the water resource. This, in turn, can harm the functioning of the aquatic biota, as well as have a negative affect on the solubility of nutrients and the toxicity of metals. Increased organic matter washoff into surface water resources is associated with debris from forestry, agricultural croplands and urban residential areas. Although it is not a widespread non-point source problem, apart from its contribution to sediment loads, it may be an issue in certain catchments.

Physical Properties

Physical properties of water include temperature, appearance, colour and odour. They describe the aesthetic state of the water body, as well as indicating potential problems with other constituents. Temperature may have a significant impact on aquatic biota and the impact of other contaminants, such as ammonia. An increase in runoff temperature occurs as it flows over heated impervious urban areas, while limited shading of river channels and detention in shallow ponds may result in elevated instream water temperature. Alternatively, afforestation can contribute to reduced temperature. The non-point source contributions to other physical properties are generally associated with the problems discussed above, namely sediment, organic matter and litter.

Instream and Riparian Habitat

Both the instream and riparian habitat of a water resource are included as part of the resource quality. Therefore, deterioration of aquatic habitat is a resource quality problem in line with the Water Act. Furthermore, degradation of riparian and instream habitat exacerbates other water quality problems by reducing the attenuation and assimilation of contaminants during delivery and transport. Habitat destruction is associated with agricultural crop, livestock and forestry practices, as well as development in urban areas.

The Nature of Water Quality Concerns

Water quality effects may be *localised* within and immediately downstream of a non-point source activity, or they may develop *regionally*. Furthermore, the effects may be *acute* (or transient) related to concentration levels, or *cumulative* related to long-term loads.

The nature of the water quality effect indicates the time period and time steps (i.e. resolution) required for an assessment, and thus the possible range of techniques which may be used for the analysis. Acute (short-term), transient or event-driven problems, with local impacts require sub-system analysis at finer spatial and temporal resolutions than cumulative (long-term) or relatively time-invariant problems with regional impacts.

Faecal contamination problems in the peri-urban settlement may be indicated by *E.coli* concentrations. These problems are localised, because pathogens die-off in the aquatic environment, and are acute, in that the health risks of contact with water on a particular day are related directly to concentration on that day. Storm flow concentration are more variable and an order of magnitude higher than low flow concentrations. Thus the analysis should distinguish between flow regimes and possibly seasonal temperature differences, which affect die-off.

Sedimentation and eutrophication of the reservoir are regional effects, with the impacts being indicated by cumulative suspended solids and phosphorus loads. The analysis may therefore be based on average or annual loading estimates.

Finally, a distinction should be made between the *background* water quality in a catchment, associated with pristine undisturbed conditions, and *cultural* impacts associated with human activities and land use change. These issues are revisited in Section 2.C, which addresses source area character.

Identifying Water Quality Concerns

There are four approaches to identifying water quality concerns, a combination of which should be used to characterise the water quality problem.

i. Consulting the inhabitants of the catchment (or source area) to provide an indication of locally perceived water quality problems and concerns. This may be a combination of anecdotal evidence, local perceptions and manager's intuition developed over a number of years. Non-point source management should build on local co-operation, therefore using these issues as the focus for any interventions increases their chances of success.

ii. Screening for symptoms (effects) of water quality problems associated with the receiving water environment which is based on field surveys and data. This may include impacts on human health (from clinical data) associated with the use of surface or ground water resources, degradation of the ecological health or aesthetic quality of the aquatic environment, eutrophication of downstream impoundments or slow flowing river reaches or siltation of river reaches and sedimentation or impoundments. Such symptoms are often associated with the abovementioned consulted issues.

iii. Sampling water quality problems through appropriate water quality indicators (physical, chemical, biological or ecological) or reviewing data where ongoing monitoring has been conducted. This provides an objective indication of the level or severity of water quality problems, which may be compared to a desired resource state and/or fitness-for-use as defined by DWAF water quality guidelines or resource classification and quality objectives.

iv. Surveying for "tell-tale" features at source areas, which indicate water quality impacts, such as erosion gullies, continual dry weather runoff from settlements or salinisation of irrigated fields. This should be supported by an understanding of the causes of non-point source related water quality problems as outlined in Section 2.C on the source area character. These features are associated with the production and delivery mechanisms within a settlement, and thus provide a valuable link between the water quality problem and the appropriate focus of management at the source.

Availability of Water Quality Data

Monitored water quality data provides an objective indication of the severity of water quality impacts and/or effects, while hydrological data provide the driving force in most approaches to non-point source analysis. Water quality data also provide a means of verifying the results of a non-point source analysis or the application of an assessment technique. Certain techniques require water quality data for calibration, before an assessment can be performed. Where data are not available, a balance must be found between the potential benefits of accuracy through verification or greater resolution, against the time and resource costs of collecting further data.

The availability of water quality and hydrological data are therefore a key criterion in the selection of non-point source assessment techniques.

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> The water quality concern focuses the non-point source assessment task because this is the reason underlying water quality management. The nature of water quality concern/s and the availability of monitored data also determine the techniques which may be appropriate for a particular assessment task.
>
> The following section relates the water quality concern to the key characteristics of the non-point sources in a catchment.

2C. SOURCE AREA CHARACTER

Introduction

Different types of non-point sources cause different water quality effects, both in terms of the key constituents and the processes governing the production and delivery of contaminants. The character of non-point sources in a catchment indicates the particular water quality concerns that are likely to occur.

Each non-point source assessment technique is based on certain assumptions and is appropriate for analysis of particular non-point source types and their associated water quality impacts. The selection and application of these techniques should be based on a sound understanding of the characteristics of different non-point sources.

This section provides an overview of the character and water quality impacts from non-point sources typically found in South Africa. It indicates the implications for non-point source assessment, including issues of spatial resolution.

What is a Source Area?

The water quality impacts from non-point sources are related to the climate, natural features and human activities on any land area. These characteristics work together in governing the production and delivery of contaminants from that area. Although land use is generally assumed to be the over-riding determinant of water quality impacts, there is generally more variation in loading within a land use category, than between categories, as illustrated in Figure 2.3.

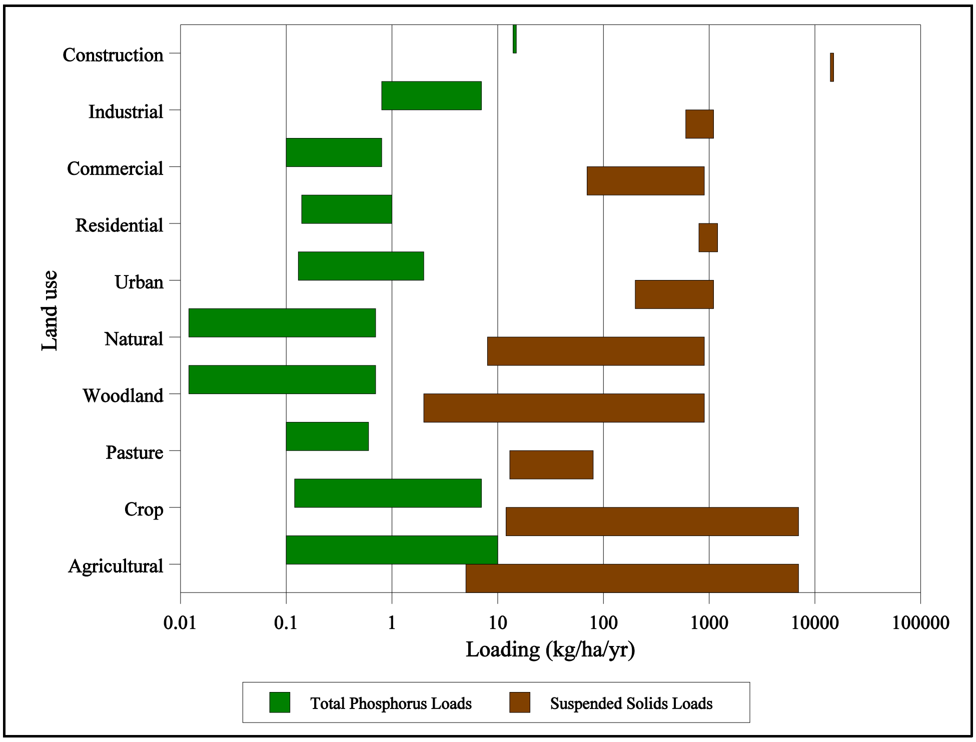

Figure 2.3 The range of annual total phosphorus and suspended solids loads per unit area (kg/ha/a) associated with different land uses.

This implies that non-point source assessment should be based on:
- the combination of hydrometeorological and natural conditions, as well as the land use in an area; and
- the transition from one land use to another, generally as a progression from undisturbed land, through agricultural activities, to urbanised areas.

The non-point *source area* concept reflects these two issues by separating a catchment or sub-catchment into areas with relatively homogeneous non-point source characteristics, based on:
- *land use*: natural, agricultural, human settlement, industrial etc;
- *natural features*: soils, topography, geology etc; and
- *climate*: rainfall, temperature, evaporation etc.

The combined characteristics of the source areas within a catchment govern the hydrological and water quality impacts on the receiving surface water environment. The following discussion highlights the impacts of different land uses, but first the impact of key climatic and natural features are outlined.

Climate and Hydrology

Rainfall, surface runoff, interflow and groundwater discharge are the driving hydrological forces causing water quality impacts from a non-point source.
- *Rainfall* depth and erosivity affect the mobilisation of particulate contaminants, while its variability determines seasonal and "first-flush" effects.
- *Surface runoff* washes off and delivers particulate and dissolved contaminant, but can also dilute their concentrations as runoff increases.
- *Interflow* and *groundwater discharge* deliver dissolved contaminants, which have infiltrated and leached from the land, into the surface water environment.
- *Temperature* influences potential evaporation as well as affecting assimilation through biological die off and chemical reaction rates.
- *Evapotranspiration* results in concentration of dissolved groundwater contaminants, thereby increasing the concentration of groundwater discharge.

Natural Features

Land uses determine the impact that climate and hydrology has on the underlying character of a source area. Conversely, the following three natural features largely influence the severity of the water quality impact from a particular land use.
- *Soil* permeability affects the rate of infiltration and thus the ratio between surface runoff and groundwater discharge, while its erodibility determines the sediment yield from an area.
- *Geology* is directly related to the salts leaching from an area, as well as having an impact on deep percolation and groundwater discharge.
- *Topography* influences the surface runoff, as well as the washoff and delivery of particulate matter, because it reflects the slopes and lengths from source to streams.

Undisturbed Areas

Undisturbed lands do have water quality impacts on the receiving water environment. This non-point source impact is referred to as the *background contribution*. In some cases, it renders the water less fit for certain human uses (eg. irrigation from salininised streams) , even though the aquatic environment is suited to those levels.

Salinity, sediment, nutrients and organic matter are the typical water quality impacts in undisturbed catchment areas. The type and level of water quality impact is largely related to the rainfall, evaporation, geology, soils and topography, together with the type of vegetation in the area.

For the purposes of this non-point source assessment guide, four general vegetation groups may be identified for undisturbed land (excluding mountains). These four vegetation groups have various forms, the nature and condition of which is largely determined by the climate, geographic location and elevation.

- *Arid lands*, including deserts, are generally associated with salinity during low flow periods and sediment during the infrequent storm events.
- *Grasslands*, including savannah, veld, bushveld and fynbos, tend to have minor sediment and nutrient impacts.
- *Wetlands*, including vlei areas, usually have good quality due to the cleansing properties of the vegetation.
- *Woodlands*, including coastal, mist belt and kloof forests, may be associated with elevated organic matter and nutrients.

Other more detailed ecoregion and vegetation typologies are available for South Africa, and may be used if that degree of detail is appropriate. The procedures for resource directed measures have developed an ecoregion classification of catchments throughout South Africa.

Atmospheric Deposition

The quality of surface water resources is often correlated with air quality in the surrounding area. Atmospheric contaminants may be from natural or human sources, and may be deposited onto land and water surfaces during dry periods or be washed out with rainfall. The latter is generally the main deposition mechanism, with the concentration of some chemicals in rainfall accounting for the majority of contamination in the associated runoff.

Wind erosion and fire are probably the two main natural sources in South Africa, while emissions from vehicles, industries, energy production and domestic fuel burning comprise the major human sources. These human sources are generally concentrated around urban and industrial areas, and urban deposition is generally far greater than rural deposition. Atmospheric deposition is a significant contributor to non-point sources of heavy metals, nutrients, and sulphates, which can have a great impact on rainfall acidity.

Agricultural Activities

Agriculture is the predominant land use in most rural catchments in South Africa. The following generic land use categories may be used:.

- *Livestock grazing* on grasslands or arid areas can contribute to sediment yield through removal of the natural vegetative cover (overgrazing), while nutrients and pathogens are associated with livestock faecal matter. These impacts are exacerbated and significant bank destabilisation (habitat destruction) can occur where livestock have direct access to wetlands and rivers.

- *Croplands* are often a major rural source of sediment, particularly if agricultural management practices are not adhered to. Washoff of nutrients from fertilizers and pesticides can also have a significant impact, where these are applied. Croplands are particularly vulnerable during ploughing and harvesting when the soil is disturbed.

- *Irrigation* of crops is usually associated with the more arid parts of South Africa, and the major water quality impact is salinisation associated with concentration of return flow. However, nutrient (fertilizer) and pesticide contamination can occur from irrigated crops where these are applied, while nutrient and pathogen impacts can occur from irrigated pastures.

- *Commercial forestry* reduces runoff, but can cause increased sediment and organic matter washoff during and after harvesting. The major non-point impacts during the growing period is from the typically unpaved access roads and habitat destruction where an inadequate riparian buffer zone is maintained. Washoff of pesticides is also a threat where these are used.

- *Confined animal facilities*, such as feedlots, can contribute significant nutrient, organic matter (BOD) and pathogen loads from faecal waste, either in storm runoff or during cleaning. This is the main concentrated agricultural source, and may include dairies and piggeries.

Formal Urban and Industrial Areas

The highest levels of non-point sources of contamination are associated with formal urban land use and industrial activity. Their general character and impacts in South Africa are similar to those in developed countries, and are as follows.

- *Formal residential* areas range from sparse small holdings on the outskirts of cities, through core suburban and former "township" areas, to high density multi-dwelling "flatlands" in the urban centre (informal settlements are dealt with below). They generally have intermediate to high levels of waste management services (sanitation, solid waste and storm water). Residential areas cause increase storm runoff from impervious surfaces, with an associated washoff of sediment, nutrients, pathogens, organic matter, litter, heavy metals, hydrocarbons and toxic substances. These impacts tend to increase with population density and are exacerbated in areas where the waste management services are inappropriately used, overloaded or inadequately maintained. Increased streamflow and encroachment into the riparian zone causes habitat destruction.

- *Commercial* and *light industrial* areas are generally located near the urban core and have similar water quality impacts to formal residential areas. Storm runoff increases with impervious area and heavy metal loading tends to be higher, associated with greater pedestrian and vehicle traffic. However, pathogen and sediment washoff is often lower than in formal residential areas.

- *Heavy industrial* areas are located both within and away from urban centres, and include the metal, energy and manufacturing sectors. They are major contributors to atmospheric emissions, with high rates of deposition in the surrounding area. They are generally associated with increased storm runoff and washoff of heavy metals, toxic organics and nutrients, depending upon the processes and management practices at the site. Other water quality impacts are similar to commercial areas.

- *Roads* within and between urban centres are a major non-point source of heavy metals and hydrocarbons. Sediment, nutrient, litter, pathogens and organic matter loads from these roads are comparable to commercial and industrial areas. On the other hand, dirt and gravel roads in rural areas can cause severe soil erosion.

- *Construction* and urban development sites represent the greatest source of sediment loads in urban areas; often an order of magnitude higher than other land uses. This also results in an increase in adsorbed contaminants, such as nutrients and heavy metals, particularly where the construction is in an area with high atmospheric deposition rates.

- *Mining* and quarrying should be dealt with separately as a concentrated source, because the washoff and groundwater discharge from active or abandoned mining areas and dumps often have very high concentrations of salts and heavy metals at low pH. Furthermore, strip mining can cause significant sediment in surface runoff and atmospheric contamination through wind erosion of dust particles.

- *Waste disposal* sites represent the major concentrated source associated with formal residential and industrial areas. These include solid waste landfills, sludge disposal sites and effluent irrigation fields, which may be associated with nutrient, organic matter, heavy metal, toxic substance and litter impacts in surface washoff or discharge of leachate.

Informal Rural and Peri-urban Settlements

Informal settlements are a feature of developing countries and have been distinguished from urban land uses because most non-point source assessment techniques do not explicitly address the particular characteristics of these areas.

- *Peri-urban settlements* are those settlements in and around the formal urban areas, but which consist of informal shack dwellings, usually with limited waste management services. They include the low to medium density (5 to 30 dwellings per hectare) informal areas on the periphery of urban centres, as well as the very dense shack areas on marginal land within the urban centre. The main water quality impacts increase with density, and are largely associated with inadequate services, namely pathogens and nutrients from sanitation, litter from solid waste, organic matter and sediment from storm water. These impacts are exacerbated, because these settlements are usually on the most marginal urban land or within the riparian zone. The latter situation also leads directly to habitat destruction.

- *Rural settlements* are generally located in the former homelands of South Africa, and differ from urban areas in that there is seldom an economic centre and waste management services are extremely limited. They may range from quite sparse densities covering entire catchments to relatively dense villages, with similar appearance to peripheral peri-urban settlements. The water quality impacts are similar to peri-urban settlements, albeit at a lower level associated with lower densities. Many of these settlements also conduct informal agricultural activity, particularly livestock and crop gardens, which can contribute for sediment, nutrient and pathogen loads, as well as habitat destruction when it occurs in the riparian zone.

Internal Loading

Nutrients, metals and toxic organics tend to accumulate in the sediments of rivers and impoundments. These contaminants may be remobilised under certain flow (storm events), acidity or dissolved oxygen (anaerobic) regimes. This represents an internal source of contaminants within the surface water environment, which can have a contribution as great as the point or non-point sources.

However, internal loads are not directly addressed by this non-point source guide, because firstly they are associated with instream water quality management and should be assessed using transport-related analysis techniques, and secondly they only exist due to a historical point or non-point source loads. Thus, an assessment of long-term point and non-point source loads, linked to appropriate transport modelling, should indicate the current possibilities for internal loading.

Source Area Processes

A number of physical activities, processes and/or mechanisms may cause non-point source impacts. The importance of these processes may vary for different water quality concerns, but all are related to either the production or delivery of contaminants.

Efficient management of a source area, therefore, requires an understanding of these processes, in order to focus energy and resources. Characterisation of a source area for non-point source assessment may need to distinguish the processes causing non-point source impacts within the source area, in addition to the differences between source areas. However, the former is only necessary for more detailed assessment, as discussed below.

> Although the peri-urban settlement may be defined as a single source area, faecal contamination may be caused by surcharging sewers or washoff from simple pit latrines (sanitation), runoff of household clothes wash water (sullage drainage), livestock defecating in the stream, and storm washoff of accumulated pathogens (storm water management). Furthermore, sanitation or storm water failure may be caused by litter blockages (solid waste), rather than inadequate infrastructure. The main cause/s of the problem in the particular settlement will determine the appropriate management response, but this requires detailed assessment of the various production and delivery processes within the settlement.

The Issue of Scale

The spatial representation required for a non-point source assessment is influenced by the range and diversity of non-point sources within the area of interest, together with management goal (as discussed in Section 2.D) and the nature of the water quality concern (see Section 2.D). There are two key components of the spatial representation.

- *Scope* refers to the spatial extent of the investigation. This ranges from the analysis of a particular source area, possibly addressing only production and/or delivery, to the non-point source impact from several source types within an entire catchment area, including transport within the receiving water environment.

- *Resolution* refers to the degree of spatial disaggregation for the analysis. This varies from fine resolution of individual source areas, with separate representation of the mechanisms of production, delivery and possibly transport, through to lumping of the water quality impact from all non-point sources in an entire catchment.

The scope of the agricultural assessment is the entire catchment area, but it only requires coarse resolution analysis of sectoral land use contributions, i.e. sugar cane, forestry and undisturbed lands. If the most critical contributing areas (mixture of land use, natural features and climate) were to be identified for focused attention, the catchment would have to be broken up into finer resolution homogeneous source areas, within each land use type.

Conversely, only the 200 ha peri-urban settlement needs to be analysed as an individual source area, but the different processes within the settlement must be differentiated. This, together with the finer temporal resolution (required for *E.coli* analysis) implies disaggregation of production and delivery mechanisms, possibly at a fine spatial resolution.

The spatial scope and resolution required for an analysis is a key criterion in the selection of an appropriate non-point source assessment technique. It also has a significant impact on the required temporal resolution (time step) for the analysis, because finer spatial or process resolution requires finer temporal resolution.

Availability of Spatial Data

Non-point source analysis at fine spatial resolution requires supporting spatial information at a high level of detail. If this is readily available, there is no constraint on the selection of an assessment technique. However, where additional data must be collected, the potential benefits and improved accuracy of greater spatial scope and resolution, should be weighed against the high time and resource costs of data collection.

Thus, evaluation of the availability or collection requirements of spatial data is fundamental to the selection of non-point source assessment techniques, particularly in the relatively data scarce and resource-limited situation in South Africa.

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The source area characteristics indicate the water quality problems and possibilities for management in a catchment. They also influence the spatial scope and resolution required for an analysis, and indicate the appropriate types of assessment techniques which may be applied, given adequate spatial data.

The following section addresses the management goals for a non-point source assessment. Together with the water quality concern and non-point source areas character, this then indicates the information needs for the assessment.

2D. MANAGEMENT GOALS

Introduction

The source area character and water quality concerns dictate the physical processes which should be incorporated into a non-point sources assessment, and should indicate the type of assessment technique that may be used. However, they do not indicate the purpose of the assessment, which dictates the required level of detail, accuracy and reliability of the analysis. Rather, these are dictated by the questions that decision makers are asking, i.e. the management information needs required to satisfy the goals of management.

This section develops the concept of management goals, linking these to four different levels of non-point source assessment. Each of these levels has particular information needs, which indicate criteria for selecting assessment techniques at the appropriate complexity. This approach underlies the Guide presented in Part 3, and provides the linkage between the needs of water quality managers and the tools available to non-point source assessment practitioners.

Why Identify Management Information Needs?

There are a wide range of techniques for non-point source assessment, all of which may provide valuable information to assist management decision-making. The costs, time, data and experience required to apply these techniques vary considerably, with results at a range of detail and potential accuracy. Therefore, each technique provides a particular type of information for a specific purpose.

The non-point source management problems in South Africa are both significant and diverse. Furthermore, the financial and human resources available for non-point source assessment and management are severely limited. Non-point source assessment should direct management attention to the most pressing non-point source problems, while assessment techniques should be selected to provide this information at the least possible cost.

Matching the information needs required to support management decisions, with the assumptions and approaches of non-point source assessment techniques is the central aim of the Guide. This requires an understanding of the management goals of various decision makers for whom non-point source assessment is performed.

Decision Makers and Management Goals

The decision makers may be divided into three groups, each of which has different management goals and information needs. This target audience is distinguished from practitioners who are responsible for performing the assessment.

- *Water management institutions* usually have the greatest need for non-point source assessment. This ranges from identifying catchments with the greatest non-point source impacts, through evaluating and prioritising non-point source types or particular areas requiring management within a catchment, as well as those processes that are causing impacts from a particular source type or area, to selecting generic management practices that are potentially most effective for managing statutorily controlled non-point sources. Their focus tends to be on critical issues at a catchment scale, or on generic non-point source types within a sector.

- *Affected parties* tend to focus on the non-point source causes and water quality effect at a catchment or sub-catchment scale. They are usually aware of the water quality concerns and require information about the level and causes of non-point source contributions from different source areas, in order to prioritise sources for management, set management targets and evaluate the impact of preposed solutions.

- *Polluters* are most interested in evaluating the cost-effectiveness of different management practices at a source area scale. This may be for a particular source area in response to proposed management targets in a catchment, or for a generic non-point source type which requires statutory authorisation.

Levels of Non-point Source Assessment

The previous discussion has indicated the range of management goals and information needs that must be supported by non-point source assessment. These may be grouped into four general levels of assessment, represented by the following questions:

Scoping:	What are the issues for non-point source assessment ?
Evaluation:	Which non-point sources are causing the water quality concerns?
Prioritisation:	Which non-point sources and processes should be managed ?
Selection:	How should these be managed ?

Two other possible assessment levels were identified as part of the conceptual framework during the Situation Assessment phase of the project, namely:

Operation:	What must be done to implement the management approaches ?
Auditing:	Are these approaches achieving the intended impacts ?

Although operation and auditing may require assessment, they are not directly addressed by the Guide, because the relevant assessment techniques are oriented towards the management process at a source scale and monitoring in the water resource, rather than non-point source problem analysis.

The implementation of the National Water Act has its own particular requirements in terms of non-point source assessment. On the one hand, the development of *catchment management strategies* or performing *water quality investigations* will require assessment at a catchment scale. This would follow the four levels of assessment, starting with identification of the critical water quality concerns and contributing non-point sources, and ending in the selection of management approaches.

On the other hand, the specification of management practices (standards) following the definition of *statutorily controlled non-piont sources* or *source area investigations* would require consultation and negotiation between DWAF and the relevant sectors. This should be supported by detailed assessment at a source area scale, also following the four levels, beginning with identification of the critical activities causing non-point source impacts from a controlled source, through to the selection of appropriate generic management practices to address them (see the Roadmap presented in the Preface of this document).

Scoping Before any non-point source assessment is done, there is often only a perceived water quality concern, with little understanding of the importance of the non-point source contributions. As with many assessment processes (such as Environmental Impact Assessment and Strategic Environmental Assessment), a scoping exercise is necessary to identify critical issues, and thereby focus the more detailed analyses. Scoping should involve the characterisation of the non-point source assessment task, in terms of the management goals, water quality concerns and source area character. The assessment should indicate the critical water quality concerns, whether non-point sources contribute significantly, and which sub-catchments require further non-point source assessment.

In cases where the assessment task is clearly defined, and the practitioner has an understanding of the issues, scoping may be bypassed, moving directly to the level of assessment that is appropriate to their assessment purpose.

Evaluation Focussing the management of non-point sources requires an understanding of the non-point sources that have the greatest impact on the critical water quality concerns, as well as the particular activities and processes associated with those non-point sources that control or govern the impacts. The understanding gained from this assessment should support the prioritisation and selection assessments (see below) and should focus further analysis on those sources and activities with the greatest water quality impact. The assessment may be appropriate at coarse or fine spatial and temporal resolutions, depending upon the nature of the critical water quality concerns, the non-point source character and the management information needs (goal), as defined during the scoping assessment.

The information gained from the evaluation assessment is necessary for effective non-point source management, and is a central component of any non-point source assessment process.

Prioritisation The limited resources in South Africa requires management energy to be focussed on the most pressing problems, but also on those that have the greatest chance of success. The assessment requires information about the current and potential future impacts of the major non-point sources, the manageability of particular activities and processes associated with those sources, and the likely cost effectiveness and sustainability of management approaches. These factors must be balanced against the resource quality objectives required for the level of protection defined by the water resource classification. Prioritisation assessment should be based on the techniques and information obtained during evaluation.

The prioritisation process may be relatively straightforward, or may be political rather than technical, in which case there is little need for a prioritisation assessment.

Selection Interventions or management measures that are chosen for non-point source management must be effective, efficient and sustainable. These are commonly engineering structures, but may also include programmes for improving community involvement or institutional capacity. Non-point source interventions are usually source oriented, which implies that the supporting assessment should estimate the impact of that intervention in reducing the non-point source discharge at source area scale. However, the effect on the water quality concern at a catchment scale should also be investigated, particularly in the context of catchment management. Selection assessment may be the responsibility of an individual polluter involved in an application for a non-point source requiring water use authorisation, or may be required by the water management institution as part of a broader catchment management process.

Selection assessment is the ultimate aim of many non-point source assessment processes which supports water quality management, and it is likely to be required to some degree for most management processes.

Operation The implementation of non-point source management interventions may require *fine-tuning* for changing circumstances, *reaction* to mitigate an observed situation, or *proactive* action to prevent a potential problem. Each of these may require "real-time" assessment based on monitoring of conditions on a source area or the performance of a management intervention, but would usually be based upon rules developed during the selection assessment. This would be the responsibility of the impactor.

Auditing The effectiveness of management approaches and interventions should be assessed on a regular basis, in order to determine whether the resource objectives and source targets are being achieved. This would generally include the evaluation of the implementation process, as well as assessment of sampled data. Auditing is the responsibility of the water management institution and may lead to reassessment at any one of the other levels.

Process of Non-point Source Assessment

As indicated above, these levels of assessment represent a process, beginning with a scoping of the non-point source issues and leading towards the selection of non-point source management measures. Assessment as a process is particularly relevant for proactive and holistic catchment management, rather than reactive and *ad hoc* water quality management.

If an investigation is likely to be part of an assessment process, rather than a once-off investigation addressing a particular issue, this should be considered in the selection of techniques, in order to facilitate continuity and efficiency. On the other hand, the results from different levels of assessment are not known with certainty at the outset, which implies the need for flexibility. Furthermore, assessment techniques generally require greater resolution and predictive powers for the latter levels.

A hierarchical approach to non-point source assessment is thus required, with each level of assessment building on information provided (and, where possible, the techniques used) by the previous investigation. Assessment should be a transparent process which promotes understanding and communication about non-point source related issues in an attempt to identify effective and implementable solutions.

The Guide attempts to enable this flexibility and transparency, noting that different decision makers (with differing knowledge of non-point sources) may be responsible for the various levels of assessment, while practitioners with diverse backgrounds may be conducting the assessment. The Guide tries to meet the diverse needs of all these decision-makers and practitioners and reflects the assessment and management process, in an attempt to foster communication and understanding between the various groups.

☞ Non-point source assessment supports a management process, the needs of which may evolve as greater understanding and clarity is gained. The assessment process must therefore be flexible, following a hierarchical approach which enables analysis with greater detail.

PART 3 : THE GUIDE FOR NON-POINT SOURCE ASSESSMENT

3A. OVERVIEW

Introduction

The Guide to non-point source assessment should assist the user in identifying the non-point source assessment task, as outlined in Part 2. It should also support the translation of this task into criteria which may be used to guide the selection of appropriate assessment techniques, the details and attributes of which are presented in Part 4. Thus, the Guide itself is not a description of techniques, but an approach to "unravelling" a non-point source task. This may be a once-off investigation or a series of investigations supporting an ongoing process.

The guide itself has two components, presented as schematic flow diagrams supported by more detailed explanatory text:

- The *Procedural Guide* (Section 3.B) outlines the assessment process and information requirements for the different levels of non-point source assessment, in order to assist the user in narrowing down the focus of their investigation.

- The *Assessment Guidelines* match the non-point source assessment task with relevant selection criteria and cross-referencing with techniques in Part 4, for each level of non-point source assessment (from the Scoping to Selection).

The Form of the Guide

The ultimate purpose of the guide is to assist the identification, selection and application of appropriate techniques for non-point source assessment, in order to provide information which supports decision making for water quality and non-point source management. Thus, the development of the guide has been based on a number of principles. The guide should:

- be easy to use and practical to apply;
- support the needs of water quality and non-point source management;
- be accessible to users who may be relatively uninformed about non-point sources, although an understanding of water resource management is assumed;
- assist the user in understanding the non-point source assessment task;
- provide clear directions (cross-referencing) from this understanding to appropriate assessment techniques;
- be hierarchical, enabling the user to complete a process of non-point source assessment that supports the management process;
- be flexible enough to guide assessment associated with different non-point source assessment tasks; and
- not be prescriptive, but rather encourage innovation in the selection and application of assessment techniques, within certain parameters.

3B. THE PROCEDURAL GUIDE

Introduction

The Procedural Guide leads the user through the process of non-point source assessment in support of management decision-making. It is hierarchically structured around the four levels of assessment (Section 2.D) and the associated management questions (information needs). The Procedural Guide refers to and is supported by the detail in the Assessment Guidelines, which identify appropriate criteria for the selection of non-point source assessment techniques.

The graphical procedure presented in Fig 3.1 reflects the management questions. The issues corresponding to each of these questions are reviewed in the subsequent discussions, in order to assist the user. Further detail is provided in the detailed Assessment Guidelines, which should be used when the information presented in this Procedural Guide is not adequate.

Have the non-point source issues been identified?

This question is linked to scoping, which is based on identifying the non-point source assessment issues, as well as the character of non-point source assessment tasks. The following issues determine the non-point source assessment task, and thus should be clarified during the Scoping Assessment (Section 3.C) if they are not initially understood:

- *Management goals* for the non-point source assessment, require knowledge of the target audience for the assessment results and the decisions that they wish to make (Section 2.D).
- *Water quality concerns* imply the nature of the problem, where in the surface water environment they occur, and the representative constituents for analysis (Section 2.B). Concerns that have the greatest social, economic or environmental impact should be identified as being critical for management, as reflected by the water resource classification.
- *Non-point source character* governs the impact of the catchment or source areas and indicates the important and representative source types or source areas (Section 2.C).
- *Information needs* for the non-point source assessment define the spatial, temporal, constituent and process scope and resolution required for the management goals, but taking account of the water quality concern and source area character.
- *Data availability* to address these information needs determines whether the information needs are achievable, which analysis techniques may be used or whether additional water quality and hydrometeorological monitoring and/or catchment and source area surveys are required.
- *Non-point source contribution* to the water quality concern in different sub-catchments indicates whether a significant non-point source impact exists and which sub-catchment areas should be evaluated.

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SCOPING OUTPUTS
- Understanding of the non-point source task.
- Non-point source contribution to the water quality concerns.
- Important non-point source types and areas with non-point source problems.

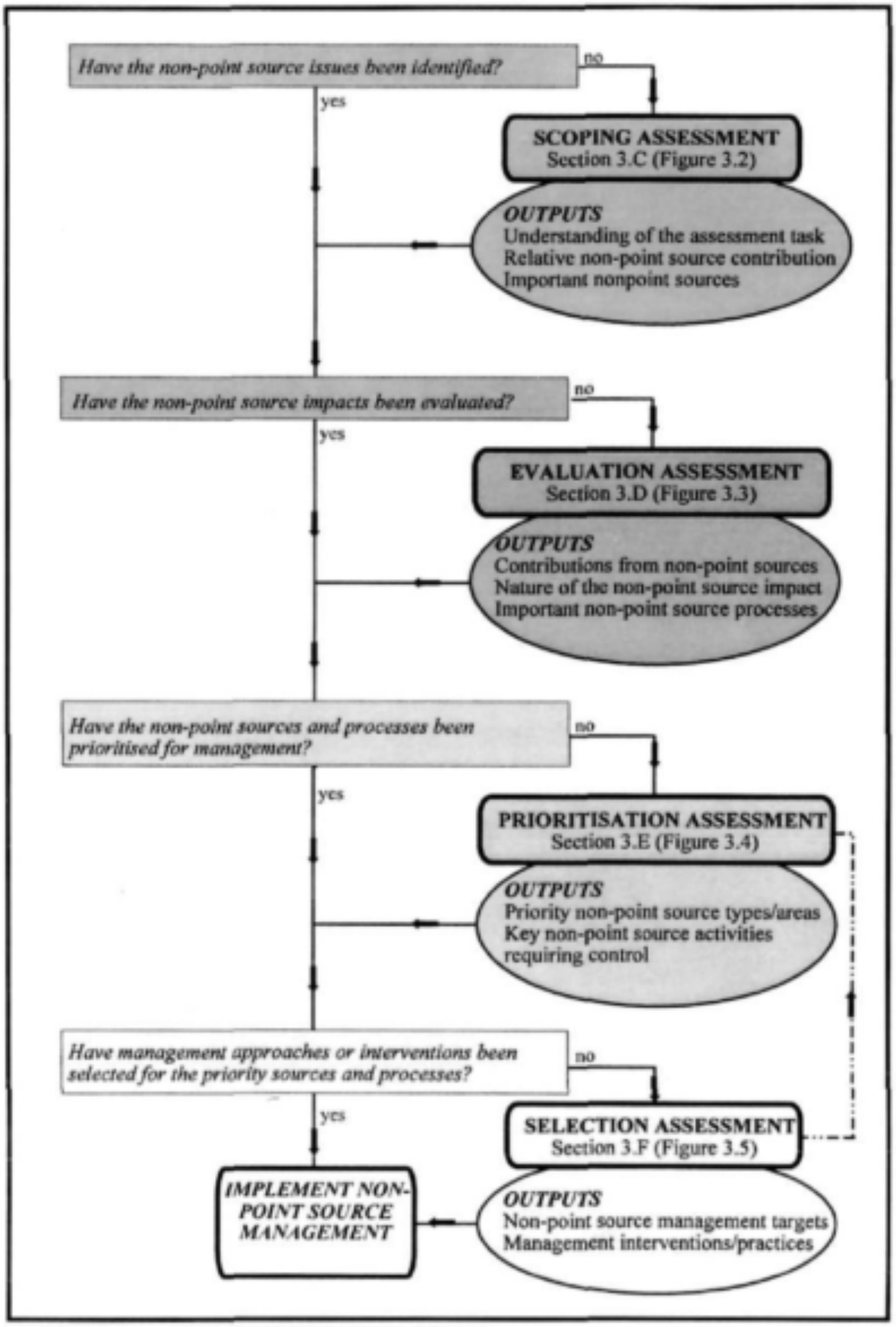

FIGURE 3.1. THE PROCEDURAL GUIDE

Have the non-point source impacts been evaluated?

Where non-point sources have an impact on the surface water environment, the impact should be investigated in order to prioritise sources and guide the selection of management interventions. This is the role of Evaluation Assessment (Section 3.D), which is a technical analysis exercise with four main components:

- *Analysis of non-point source contributions* to the critical water quality concerns, either for different non-point source types or even individual source areas, depending upon the resolution dictated by the management information needs.
- *Estimation of background contributions* associated with different sub-catchments or non-point sources, based on an evaluation of water quality conditions associated with natural vegetation without human land use activities.
- *Description of the non-point source impact* in terms of the temporal variation of the impact and interrelationships between constituents, and the effects on the water quality concern.
- *Identification of the processes and activities* causing the impacts from different non-point sources and the influence of production and delivery.

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EVALUATION OUTPUTS

- Quantification of non-point source contributions.
- Nature of the non-point source impacts.
- Important processes and activities for different non-point sources.

Have non-point sources and processes been prioritised for management?

Those non-point sources and associated processes or activities which cause the greatest problems should be prioritised for management and control, as part of the Prioritisation Assessment (Section 3.E). The following issues may influence this prioritisation:

- *Total magnitude* of each non-point source's impact on the critical water quality concerns, based on a ranking of source type or area contributions.
- *Relative contribution* from a non-point source type or area, based on the total magnitude of impact relative to a measure of its size, such as area or population.
- *Impact of future development scenarios* may influence the magnitude of the contribution from different non-point source types, and is potentially more manageable through proactive planning and development.
- *Resource Quality Objectives* which have been agreed for the relevant river reach and/or catchment, based on the Resource Classification and Reserve (Part 1).
- *Statutorily-controlled non-point sources* and whether they meet the legal requirements, as specified by regulations or their authorisation conditions.
- *Manageability of the non-point source impacts* in terms of the technical possibilities and the relative magnitude of the relatively unmanageable background contribution, based on the understanding gained during the Evaluation Assessment.
- *Non-technical considerations*, such as the political, legal, institutional, economic and social possibilities for managing particular non-point source types or sectors.

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PRIORITISATION OUTPUTS

- Priority non-point source types or areas for management.
- Key non-point source activities requiring control.

Have management approaches or interventions been selected?

The priority non-point sources which have been identified for management require the analysis of the following, as part of the Selection Assessment (Section 3.F):

- *Non-point source management targets* should be developed to achieve the Resource Quality Objectives. These should be based on consultation with the stakeholders, and reflect the magnitude and manageability of different non-point (and point) source contributions, taking account of equity between sectors.
- *Management interventions* which may be general measures or specific management practices, ranging from the minimum requirements through to the best available technology
- *Effectiveness* of the interventions in reducing the non-point source impact must be evaluated according to the non-point source management targets.
- *Efficiency* of the interventions indicating the reduction of non-point source delivery associated with an intervention relative to the resources required for its initial and ongoing implementation.
- *Affordability* and *acceptability* of that intervention by those responsible for its implementation.
- *Sustainability* of an intervention, which is largely determined by its technical efficiency, financial affordability and social acceptability.

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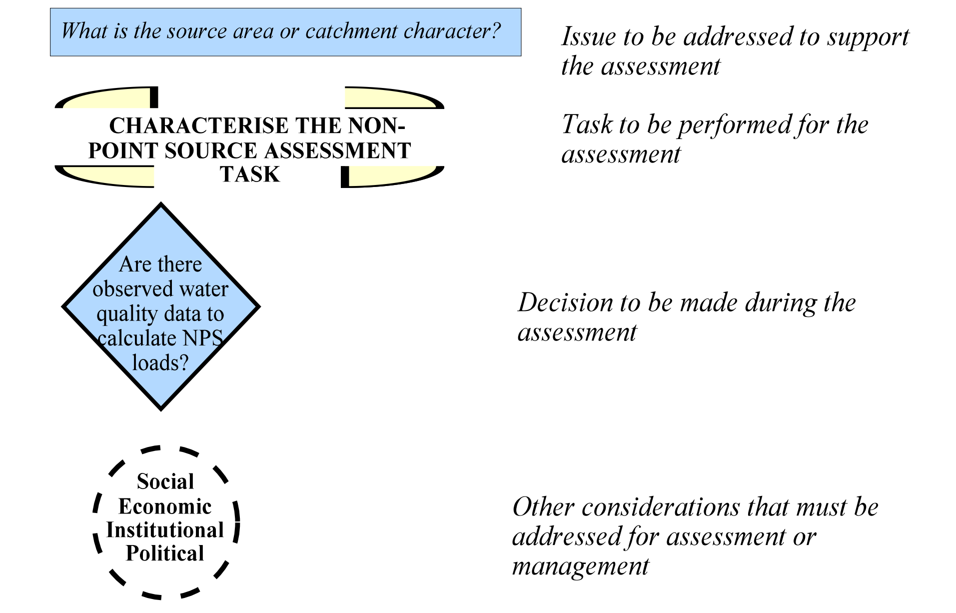
SELECTION OUTPUTS

- Targets for non-point source management to meet resource quality objectives.
- Management intervention and practices required to meet these targets.

Completion of the Selection Assessment implies that the assessment procedure has been completed and the implementation of non-point source management should begin. However, the cyclical nature of assessment and management implies that different levels of assessment may be revisited, either to reassess the non-point source impacts or investigate an impact in more detail (see the Roadmap presented in the Preface).

More detail about the analysis required to support the different levels of assessment are presented in the Assessment Guidelines in the following sections. Schematic Guidelines which highlight the important issues are also presented. The box below provides a generic legend for these Schematic Guidelines.

GENERIC LEGEND FOR THE SCHEMATIC GUIDELINES



3C. SCOPING GUIDELINES

Objective

The scoping assessment should determine the relative significance of total non-point source contributions to the water quality concerns, compared with the point source contributions. This involves screening of the dominant non-point source types and the sub-catchment areas with the highest non-point source contributions and impacts. Furthermore, the non-point source task should be characterised, in terms of the management goals, water quality concerns and source area character, which determine the information needs.

The scoping exercise is necessary for appropriate selection and efficient application of non-point source assessment techniques. However, if the user already has a general knowledge of their non-point source task and is confident that non-point sources are a significant problem, they may bypass this process and move on to the level of assessment that is relevant for their purpose.

Primary Target Audience

The identification of critical water quality problems and the sub-catchments in which they occur is primarily the responsibility of water management institutions. Therefore Scoping Assessment should be oriented towards these managers. However, this process should involve stakeholders and should foster communication about the impacts of non-point sources and the needs of the assessment.

Criteria for Scoping

Scoping Assessment should start with a characterisation of the non-point source assessment task, which consists of the management goals, the water quality concerns and the non-point source character. Together these indicate the information needs for the assessment, which may be related to the criteria for selecting techniques for the other levels of assessment. This characterisation does not require the use of typical assessment techniques, but rather depends upon a systematic conceptualisation of the task to be done. The basis for this characterisation has been outlined in Part 2.

The choice of techniques for screening the total non-point source contribution and the sub-catchment areas that have the greatest impact depends largely upon the availability of water quality, hydrological and catchment data. The key questions for the Scoping Assessment are presented in Figure 3.2 and are described below.

What are the goals of the assessment?

The goals of a non-point source assessment are dictated by the management decision that it must support. Section 2.D provides a thorough discussion of the various management goals of different decision-makers and provides the basis for this characterisation.

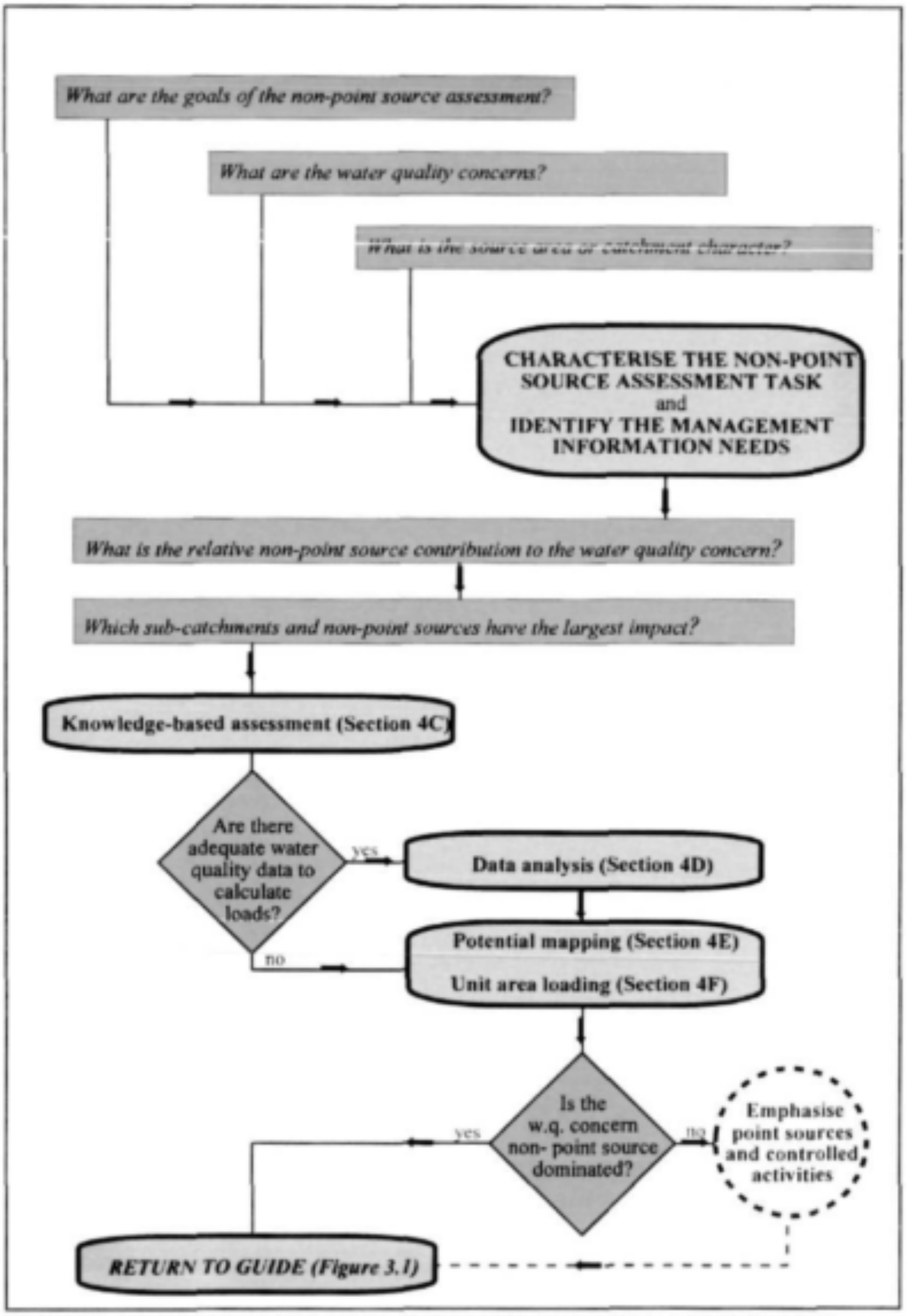


FIGURE 3.2 SCHEMATIC GUIDELINE FOR SCOPING ASSESSMENT.

What are the water quality concerns?

The water quality concerns provide the focus for the assessment, both in terms of the nature of the constituents and the types of non-point sources to be analysed. Section 2B provides a thorough discussion of non-point source related water quality concerns, their estimation and implications for non-point source assessment.

What is the source area character?

The non-point source area character indicates the types and nature of water quality impacts that may be expected and dictates the assessment techniques that are appropriate. Section 2C presents a thorough discussion of non-point source areas, their water quality impacts and the implications for assessment.

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> The management goals, water quality concerns and source area character dictate the non-point source assessment task. Their characterisation should guide further assessment, through the identification of information needs.

What is the relative NPS contribution?

As part of the identification of issues, the Scoping Assessment must determine whether non-point sources actually pose a problem. This requires high level screening and, where possible, quantification of the non-point source loads and/or impacts. These estimates may be compared with point source contributions.

Which sub-catchments and non-point sources have the largest impact?

The relative impacts of large sub-catchment areas may also be compared, in order to focus the more detailed Evaluation Assessment on those areas which cause the problems. This may be based on qualitative investigation and/or quantitative analysis.

Similarly, it is valuable to make a high level evaluation of the types of non-point sources that are likely to have the greatest impact on the water quality concerns, in order to focus more detailed assessment. Qualitative assessment is most appropriate for this task.

Are there adequate water quality data?

This issue determines whether data analysis may be used for the scoping assessment, or whether the situation can only be modelled. In evaluating this issue, consideration should be taken of the variable nature of non-point source impacts, where the major loads occur during occasional hydrological events. Thus, more frequent sampling is usually required for data-based non-point source assessment than for point source analysis. As a rule, bi-weekly data for one year is the minimum requirement (i.e. 26 samples).

Is the water quality concern non-point source dominated?

This question should be answered after the Scoping Assessment, and indicates the need for further non-point source assessment to support management decision making. If the total non-point source contribution is insignificant relative to the total water quality impact, the water quality concerns are likely to be point source dominated, and thus assessment and management of point sources should be emphasised. However, this does not imply that non-point sources should be ignored, but rather that resources are allocated to ensuring that authorised non-point source activities are meeting their statutory conditions (management practices).

Under these circumstances, very detailed non-point source Evaluation and Prioritisation Assessment may be avoided. In making a choice about the required detail for further non-point source assessment, the timing and nature of the likely non-point source impacts on the water quality concerns should be considered. In some cases a relatively low non-point source load at the "wrong" time may have a significant impact.

Assessment Techniques for Scoping

The assessment techniques which support this level of assessment are not typically non-point source oriented. Firstly, the characterisation process is entirely non-quantitative and may be based on the discussions in Part 2.

The characterisation process results in an understanding of the issues which need to be addressed and provides the information required to guide the selection of non-point source assessment techniques associated with the other assessment levels.

Estimation and comparison of the total non-point source contribution is oriented towards the receiving surface water environment and is more closely related to other catchment and water quality assessment procedures.

Knowledge-based approaches (Section 4C) are integral to the characterisation of the non-point source assessment task, and provide a preliminary qualitative indication of the likely non-point source contribution from different sub-catchments and source types, and their comparison to point source contributions.

Data analysis techniques (Section 4D), involving statistical analysis of observed data, provide an approach to quantifying the contribution from point sources and comparing this to the total loads from different sub-catchments, where there is adequate and reliable water quality and hydrological (streamflow) data.

Potential mapping (Section 4E) provides a qualitative indication of the source areas with the greatest probability of impact. The spatial representation of these "red-flag" areas may be used to highlight sub-catchments or source areas that require detailed analysis.

Unit area loading (Section 4F) provides a technique for estimating the average long-term impact from different source types, which may be compared to estimates of the point source load.

3D. EVALUATION GUIDELINES

Objective

Once the non-point source task has been characterised, the next step is to determine and understand the causes. In other words, what is the contribution from different non-point sources to the water quality concern at a catchment scale, with the focus being on current conditions. Obviously, this type of analysis may be performed at varying degrees of detail, ranging from higher level coarse assessment of the contributions from general non-point source (land use) categories through to detailed assessment of the magnitude and temporal variation of contributions from different source areas.

Primary Target Audience

Coarse analysis at this level of assessment is primarily aimed at water management institutions, as well as stakeholders in the catchment management process. It should result in the identification of "red-flag" areas which require management. As the level of detail increases, the assessments tend to be oriented towards technical water quality managers and practitioners who are required to provide recommendations about the management of non-point sources, based on their behaviour. The more detailed analyses provide the background understanding for the Prioritisation Assessments (Section 3E).

Criteria for Evaluation

The spatial and temporal resolution required of the results has the greatest bearing on the choice of technique for non-point source evaluation, while the availability of water quality data for calibration may restrict the use of certain techniques. Once the type of model has been selected, the actual modelling approach must be based on the source character and the behaviour of the water quality constituent of interest. Furthermore, if the assessment will lead into prioritisation of non-point sources for management, more detailed and potentially accurate techniques should be adopted.

The criteria governing the choice of an assessment technique for Evaluation are reflected in the questions in the Evaluation Assessment Guideline (Figure 3.3). The issues which influence the criteria are outlined in the following discussions.

What spatial detail is required?

Spatial resolution may be grouped into the following classes at increasing detail, but possibly at a smaller scope:

- *sub-catchment areas* indicating the combined non-point source contribution to a water quality concern at a catchment/sub-catchment scale.
- *land use types* representing the combination of similar land use activities per sub-catchment.
- *individual source areas* either distributed as homogenous areas within a sub-catchment or as a single impact source on a surface water body.

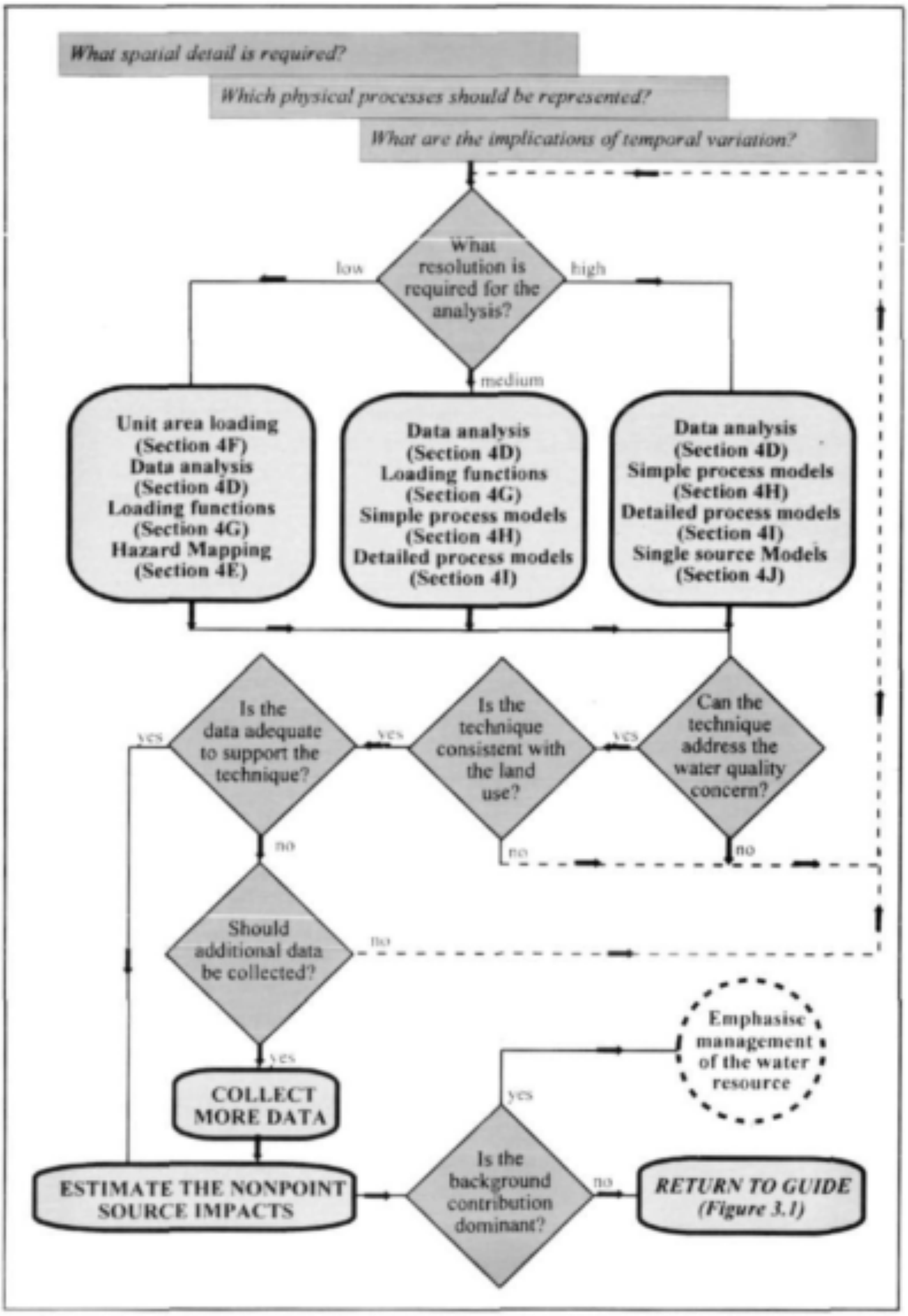

FIGURE 3.3 SCHEMATIC GUIDELINE FOR EVALUATION ASSESSMENT.

The choice of spatial resolution may be affected by the:
- *management goal* which indicates the appropriate detail of the non-point source assessment for evaluation of impacts and behaviour.
- *diversity of the area*, with more uniform areas requiring less differentiation of source areas.
- *water quality concern* being assessed, in that constituents with acute-localised impacts or assimilation require greater spatial resolution.

Which physical processes should be represented?

The degree of lumping or disaggregation of the physical processes causing contamination from non-point sources can be generally represented by the following three groups, reflecting increasing disaggregation of the underlying processes.
- *sub-catchment export*, which lumps the production, delivery and transport process elements from the non-point sources in a catchment.
- *non-point source yield*, which lumps the production and delivery from non-point sources to indicate the local discharge into the surface water environment.
- *source area mechanistic* analysis of the processes governing contaminant production and delivery from a non-point source area.

> Analysis of the microbiological impact of an informal settlement on the local stream should be performed at a fine spatial resolution, with representation of *e.coli* production, delivery and transport. On the other hand, analysis of the impact of sediment on an impoundment may be based on the lumped non-point source export from the upstream catchment.

The appropriate disaggregation is largely dependent upon the:
- *spatial resolution*, because detailed process disaggregation is not appropriate at catchment-based spatial resolution.
- *water quality concern*, governs the process resolution required to understand the behaviour of the problem and possibilities for its management.
- *management goal*, which indicates the mechanistic detail required to make the necessary management decisions.

What are the implications of temporal variation?

The time period variability and associated time steps for a non-point source analysis may be represented as:
- *long-term average*, usually on an *annual* or *seasonal* basis
- *continuous time series*, usually at a *monthly* or *daily* time step
- *event-based*, usually at a *sub-daily* time increment (hours or minutes)

> Using the previous example of local microbiological contamination from an informal settlement, continuous simulation at short time steps would be appropriate and consistent with the finer spatial resolution and process disaggregation. However, long-term average annual or monthly analysis of the catchment sediment loading into the impoundment would be adequate for the second example.

The choice of the appropriate time period variation and time step for a particular analysis may be influenced by:
- *management goal*, which indicates the degree of detail required to understand the non-point source impacts in order to make relevant management decisions.

- *water quality concern* and the finer temporal resolution is required to capture transient variation of acute water quality problems, while long term averages and coarser time steps are adequate to reflect the impacts of cumulative problems.
- *spatial resolution*, because fine spatial detail is required to reflect the relatively small contaminant movement distances associated with shorter time steps.
- *process resolution*, in that disaggregation of the physical process elements is required for shorter time steps.
- *climate* as the driving force governing non-point source contamination, with highly variable climatic conditions requiring shorter time steps, which may be represented on a single event basis.
- *land use activities*, particularly in terms of the within year variability of their management practices, such as crop rotations, and the transience of their response for hydrometeorological events, such as in impervious urban areas.

What resolution is required for the analysis?

The level of resolution required for the analysis should reflect the management goal, as well as a combination of the appropriate spatial, process and temporal detail. The resolution may be separated into the following three groupings:

- *low resolution*, which provides estimates of long-term average catchment export;
- *medium resolution*, which provides daily to monthly estimates of non-point source yield from source types within a catchment.
- *high resolution*, which provides short-term or event-based sub-daily simulation of the processes governing the production and delivery from one or more source areas.

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> The appropriate level of resolution should indicate the type of analysis technique for the evaluation assessment. The choice of particular techniques associated with the type of analysis (from Part 4) should be based on user preference, and then checked against the following questions in order to verify that it is applicable.

Can the technique address the water quality concern?

Once the appropriate type of technique has been identified, the particular technique must be selected according to the water quality concern. The technique must be able to represent the important processes governing the mobilisation, movement and assimilation of the relevant water quality constituent, particularly for non-conservative substances.

Is the technique consistent with the land use?

The choice of non-point source analysis technique is also related to the predominant land use character. Different techniques make assumptions about the contaminant response from source areas and the key processes which need to be reflected, which are only legitimate under particular land uses. These can generally be grouped into urban, rural-agricultural and mixed catchments.

Is the data adequate to support the technique?

Once the key criteria for selecting a non-point source analysis technique have been identified, the issue of data availability needs to be engaged. All techniques require spatial catchment, water quality and/or hydrometeorological data to support their application. More complex and mechanistic models and techniques tend to require data at greater detail and resolution. If this data is not available, the accuracy of the results and thus the advantages in applying the technique is doubtful.

Should additional data be collected?

There are two solutions to the problem of limited data, depending upon the information needs and the resources available for the analysis:
- Select a less data-intensive approach which will provide the required information.
- Invest time and resources in collecting the required data, if that is required to provide information at a greater level of accuracy and/or detail.

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If the chosen technique is appropriate, it may be applied to analyse the important issues for the evaluation assessment, namely:
- quantifying contributions from the non-point sources;
- estimating the background contributions;
- understanding the nature of the non-point source impacts; and
- identifying the important non-point source processes causing these impacts.

Is the background contribution dominant?

The analysis of the non-point source impacts relative to the background contribution, as well as the understanding of the non-point source impact, provides a preliminary indication of whether the non-point source impacts can realistically be managed. This should indicate whether a full Prioritisation Assessment is appropriate. Management of the water resource or water use should be emphasised when background contributions are dominant, as well as ensuring that authorised water users (including relevant non-point sources) are fulfilling their legal requirements.

Assessment Techniques for Evaluation

The choice of a non-point source analysis technique should be based on the answers to the preceding questions. In the following discussion, the suitability of the different types of analysis techniques is indicated with reference to these questions. Techniques or models that are appropriate for particular water quality concerns and land uses may be associated with each of these general types of analysis technique.

Data analysis techniques (Section 4.D) provide concentration or load estimates from catchments in which water quality sampling has been conducted:
- lumped sub-catchment export, based on the location of monitoring sites
- sub-daily to annual time series, based on the frequency of sampling
- completely dependent upon the water quality and hydrological data availability, although techniques exist for infilling missing data.

Potential and hazard maps (Section 4.E) provide a spatial indication of source areas from which non-point source problems may occur:
- non-point source type or area analysis, of urban and rural land uses
- representation (often qualitative) of contaminant production and delivery
- long-term annual or seasonal averages
- require detailed spatial catchment data at the required analysis resolution.

Unit area loading (Section 4.F) provides approximate estimates of total export loads at a catchment scale:
- export from different non-point source types in predominantly urban catchments
- long-term annual average export

- require limited spatial data, but improved by non-point source loading studies from similar sources types in neighbouring catchments.

Loading functions (Section 4.G) provide time series of loads from non-point sources, which reflect seasonal variations in hydrology and sediment yield:
- yield analysis from non-point source types or areas within urban or rural catchments
- continuous daily or monthly time series simulation
- require medium-level spatial data, but improved by water quality monitoring in catchments with similar land use types.

Simple process models (Section 4.H) provide time series of concentrations or loads from non-point sources, based on simplified representations of the contaminant processes:
- yield analysis from non-point source types or areas in rural and/or urban catchments
- continuous sub-daily to daily time series simulation
- require medium level spatial data, and are improved by calibration against water quality and hydrological data within the catchment.

Detailed process models (Section 4.I) provide fine resolution time series descriptions of various parts of non-point source contamination, based on detailed deterministic representations of the physical processes:
- yield analysis from source types or areas in a catchment
- analysis of production, delivery and transport processes from these sources
- continuous or event based sub-daily to daily time series
- usually either urban or rural (although some models may allow mixed) land use
- intensive data availability and processing, together with significant expertise and resources, are usually required to provide accurate results through calibration.

Single source models (Section 4.J) provide time series of non-point source contamination from a particular source, based on extremely detailed deterministic representations of physical processes and management interventions at a field level:
- analysis of production and delivery from a single usually rural land use source area
- continuous or event-based sub-daily time series
- detailed data availability on the source area and significant expertise are usually required to provide accurate results.

3E. PRIORITISATION GUIDELINES

Objective

Decisions about where to focus non-point source management resources require the identification of those sources that have the greatest existing or potential future impact on the critical water quality concerns. The main processes causing the impacts from these priority sources must also be identified. However, the prioritisation of these processes should also consider their manageability. Thus, prioritisation indicates the main sources and processes for the Selection Assessment (Section 3F).

Non-point source prioritisation should be based on the understanding gained from the Evaluation Assessment (Section 3D). Evaluating the manageability of a source must consider the processes causing the impacts from a particular source, as well as the likely "unmanageable" background contribution from that source area. In addition, the prioritisation should address the social, institutional and economic opportunities and constraints for management.

Primary Target Audience

Prioritisation of sources and processes for management is primarily the responsibility of water quality authorities, particularly in the catchment management context. Other stakeholders in the catchment management process should be consulted, including representatives of the polluters and affected parties.

Criteria for Prioritisation

If the assessment task has been well-conceived, the techniques used and information provided during the Evaluation Assessment (Section 3D) should be adequate to support the prioritisation process. In some cases, further information may be required, particularly in terms of the manageability of processes causing non-point source impacts and the potential impacts of future development. However, this should be an extension of the existing analyses, rather than the application of entirely new techniques.

The key issues for the non-point source prioritisation process are outlined in Fig 3.4. The interpretation and details of the relevant questions are discussed below.

Is this a single or multi-source assessment?

The first part of the assessment process concerns the prioritisation of different source types or areas. This may be omitted if the scope of the analysis is a single source area, rather than a multi-source catchment assessment. For a catchment-based assessment, the following information is required.

Which sources have the greatest total and/or relative impact?

Those source types or areas with the greatest total impact on a water quality concern should be a priority for management. However, those sources with the highest relative impact (eg. unit area or per capita loading) should also have a higher priority for management because the interventions may be more effective in these areas. The information required to address this question should have been provided by the Evaluation Assessment (Section 3D).

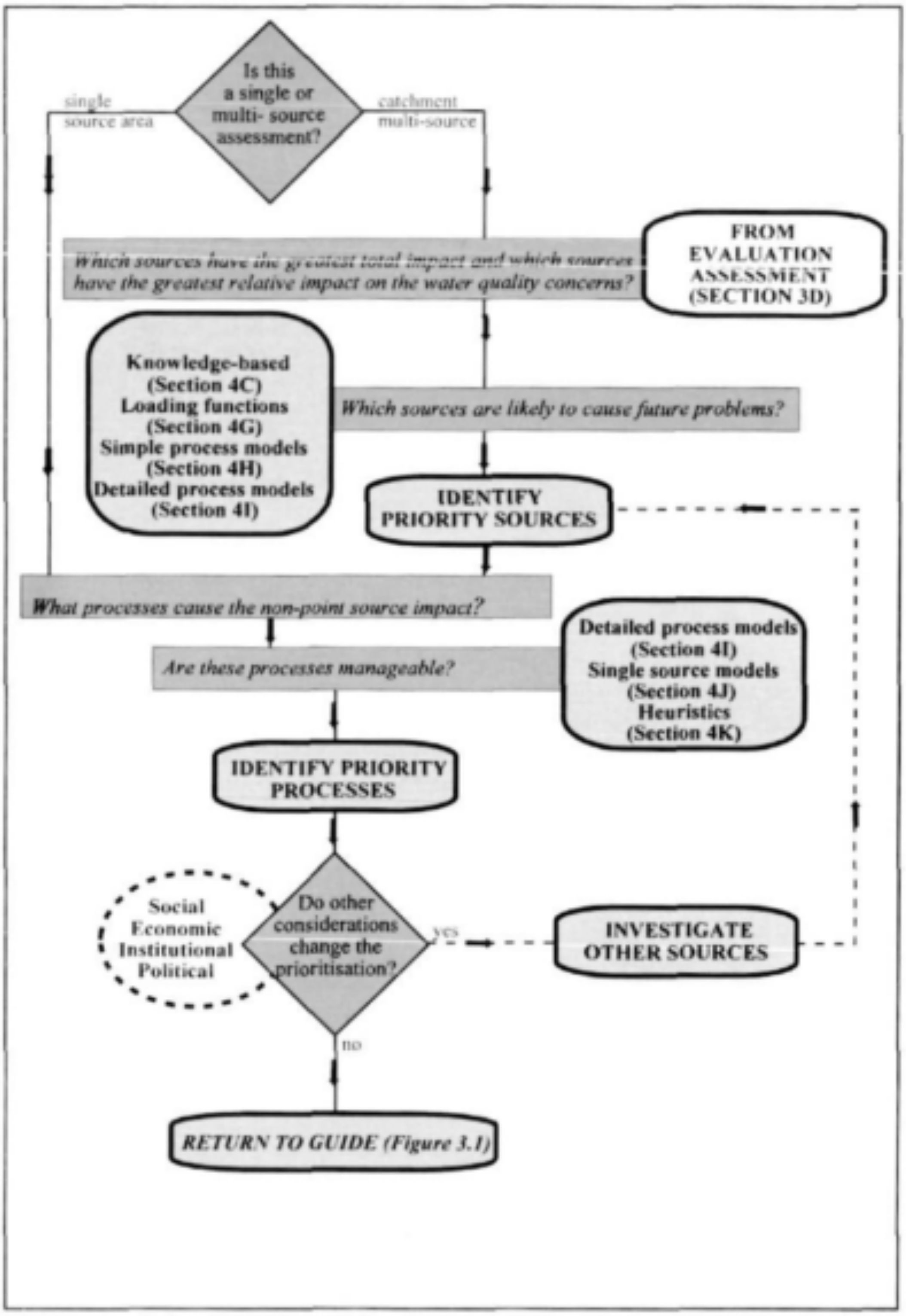

FIGURE 3.4 SCHEMATIC GUIDELINE FOR PRIORITISATION ASSESSMENT

The following issues need to be considered in estimating the magnitude and intensity of a non-point source impact on the receiving water environment:

- The impact of a non-point source on a local water quality concern may be based on the delivery of contaminants.
- A regional impact should include assimilation that may occur in the surface water resource during transport, particularly for non-conservative contaminants.
- The timing of the impact may be important, particularly for acute effects which only occur during certain flow regimes or seasons.

Example: A catchment where 50% of the non-point contribution comes from a rural settlement covering 80% of the catchment (which is populated by 10 000 people), and the other 50% comes from the remaining 20% of the catchment area, which is agricultural land (under the control of only 5 stakeholders). The allocation of management resources and effort may be more effective for the agricultural areas (which cause a relatively higher unit area impact), even though they have the same total impact. This 20% area should possibly be prioritised, with a longer term strategy for the remaining 80% of the area.

Which sources are likely to cause future problems?

The potential future impacts of different non-point sources is a major consideration for management, because if these source are prioritised, these impacts may be more easily mitigated. Future impacts may be evaluated for different development scenarios, but this requires techniques that predict the effect of changing land use on the water quality concerns. This analysis should build on the techniques used in the evaluation assessment, and in particular they should:

- represent those land uses that are likely to develop, as well as those that currently exist; and
- be able to extrapolate beyond historical conditions, i.e. not require calibration for scenario analysis.

☞ The source types or areas requiring management should be prioritised according to the existing total and relative impacts (or contributions) to a water quality concern, while taking consideration of the likelihood of future impacts associated with alternative development scenarios.

What processes cause the non-point source impact?

The Evaluation Assessment (Section 3D) should indicate which processes, activities and mechanisms cause the non-point source impacts from a particular source type or area. Those processes with the greatest contribution to the impact from the priority sources should be identified.

Are these processes manageable?

The manageability of these processes indicates whether the impacts from that source may be controlled. Evaluating of the manageability of these processes should consider:

- *background* contributions, which are largely unmanageable; and
- *technical* possibilities for management, based on existing practices and the nature of the source types and processes.

Evaluation of these issues requires a mixture of source analysis (possibly using a catchment-based analysis technique) and heuristic knowledge about the manageability of different sources.

☞

> Those processes with the greatest and most manageable contributions to the impacts from the priority sources should be prioritised. If the processes for a particular source are not manageable, then that source cannot be managed, even if it has a significant contribution to the water quality concern.

Do other considerations change the prioritisation?

Managing the priority non-point source types or areas requires a mixture of political will, legal mandate, institutional capacity, economic resources and social commitment. Even though it is not part of the technical non-point source assessment, the resources and environment required to manage the priority non-point sources should be determined as part of the prioritisation process. If these are adequate, then the prioritisation remains unchanged and the Selection Assessment may be performed (Section 3F).

Where the existing resources and/or environment are not currently adequate, but there is the possibility of accessing them, this should be the emphasis of management, before identifying approaches that may not be implementable. Alternatively, in those situations that an enabling environment or resources are unlikely to be available in the short- to medium-term, it may be necessary to review the prioritisation process and concentrate on sources and/or processes which have less stringent requirements.

Assessment Techniques for Prioritisation

Prioritisation assessment should build on the Evaluation Assessment (Section 3D). A number of other more qualitative techniques may also be required to address the "softer" side of the prioritisation assessment. The techniques presented in Part 4 that are most appropriate for prioritisation assessment are:

Knowledge-based approaches (Section 4.C) are most appropriate for evaluating potential future problems associated with changing development patterns, and are generally based on expert opinion.

Loading functions (Section 4.G) can assist the prioritisation of source types or areas, but are limited as far as prioritising processes within each source, particularly in terms of management. They may be used to evaluate background contributions and future scenarios.

Simple process models (Section 4.H) are also appropriate for prioritising sources, but are not particularly suited to prioritising the processes within each source.

Detailed process models (Section 4.I) can support catchment level analysis and, therefore, prioritise source types of areas for analysis. They may also support the prioritisation of processes, as the representation of different contamination mechanisms within these models provides the opportunity to evaluate manageability.

Single source models (Section 4.J) are the most appropriate techniques for individual source area assessment. They represent the different production and delivery processes causing the impact from a source area. However, their application to a number of different sources as part of a catchment wide assessment is generally too resource-intensive.

Heuristics (Section 4.K) may be used to determine the relative contributions of different processes to the non-point source impact from a particular source type.

The choice of the actual technique within each of these categories obviously depends upon the source character and water quality constituents to be assessed, as identified during the Evaluation Assessment (Section 3D).

3F. SELECTION GUIDELINES

Objective

The decisions about how to manage the priority non-point sources and processes must be supported by analysis at two levels:
- setting targets and evaluating the effect on the water quality concern in the catchment
- the effectiveness of a management intervention at a source area scale

Selection Assessment has a technical component, but this must be supported by thorough consultation and evaluation of the social, economic and institutional viability of any management solution. The efficiency, affordability, acceptability and sustainability of interventions must be determined.

Primary Target Audience

Water management institutions are responsible for setting non-point source targets and the impact reductions needed to meet them. Stakeholders in the catchment management process (i.e. polluters and affected parties) also have an important role to play in this, and may therefore interpret and/or use the results of the catchment wide Selection Assessment. On the other hand, the identification of management interventions and practices to achieve these targets is entirely the responsibility of the non-point source polluters, and thus they are the target audience for the source area assessments.

Criteria for Selection

The analysis required for Selection Assessment should follow directly from the analysis for the Prioritisation Assessment (Section 3E). The key issues that should be addressed before management interventions are selected are outlined in Fig 3.5.

Is the assessment catchment based?

Once again, the main distinction is between multiple source analysis and single source area analysis, because the appropriate approach and techniques differ for these two types of assessment. The catchment-based analysis first requires the setting of non-point source management targets for the catchment.

What reduction in non-point source impacts are required?

The resource quality objectives for a particular surface water resource, indicate the desired state for the surface water environment. This requires an evaluation of the non-point source contributions from the priority sources (in conjunction with point source contributions) that are required to achieve these objectives. This may imply a reduction of non-point source contributions from existing conditions, or alternatively, current conditions may be acceptable (i.e. no reduction). The effect of compliance with all relevant satutory point and non-point source authorisation conditions should be evaluated, because this may indicate that further reductions are not necessary to achieve the resource quality objectives.

The techniques used for this type of assessment should:
- reflect the issues outlined for the Evaluation Assessment (Section 3C)
- enable analysis of reduction in non-point source discharge from different sources, which implies differentiation of source type or area

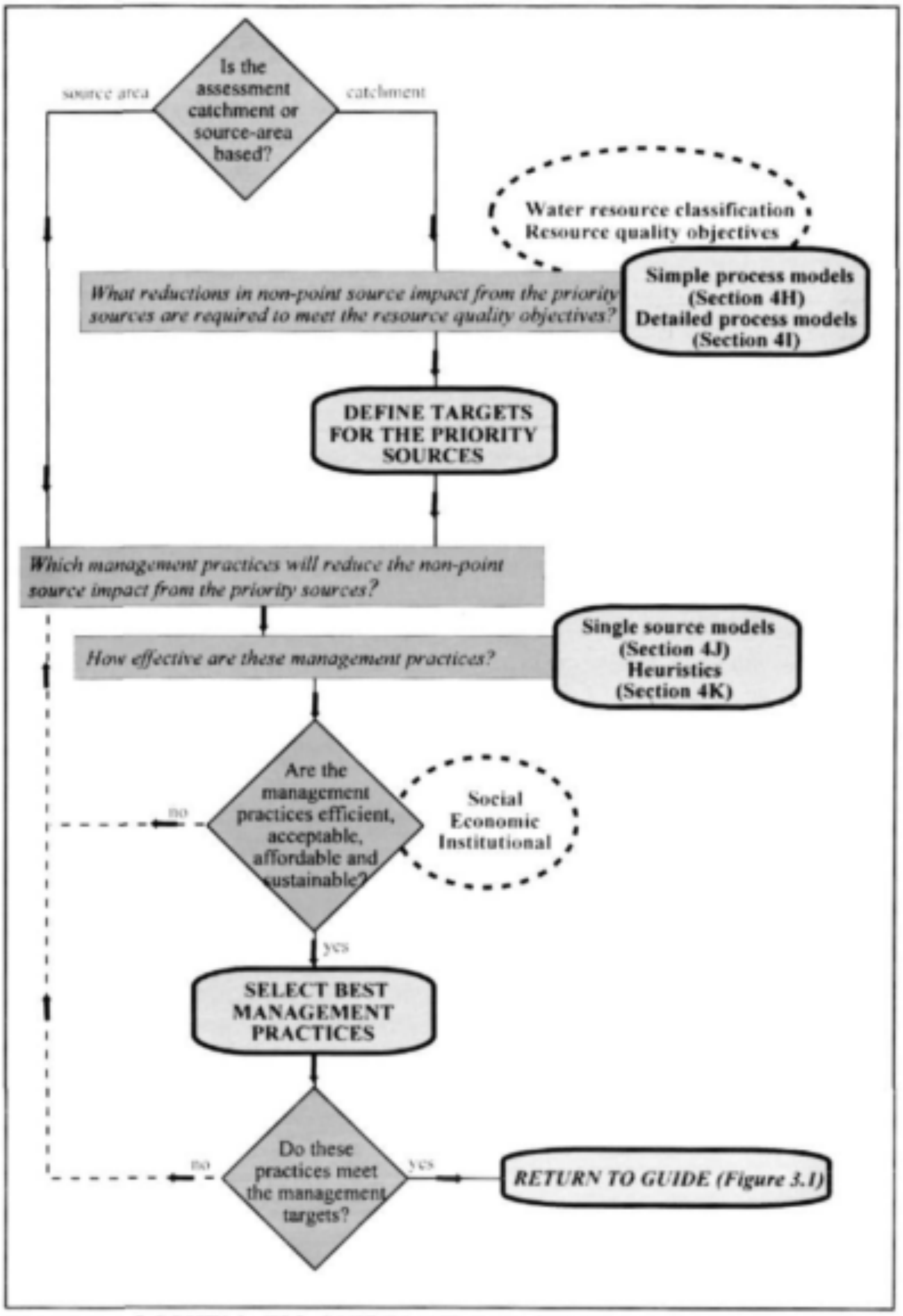

FIGURE 3.5 SCHEMATIC GUIDELINE FOR SELECTION ASSESSMENT

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> Non-point source management targets should be set for the priority non-point sources, based on the allowable contributions from those sources. In many cases, these targets would represent compliance with statutory conditions, but there may be situations that require more stringent source-directed controls. Targets should not be set below the relevant statutory requirements. These management targets are different to the resource quality objectives defining the water quality conditions for the receiving surface water resource.

Which management practices are suitable?

Whether the Selection Assessment is for a generic controlled activity or an individual source area, a range of management practices should be considered. These should address the processes causing non-point source impacts from that source. They may include structural planning, engineering and ecological interventions, as well as nonstructural education, awareness and consultation approaches.

How effective are these practices?

The effectiveness of these interventions should be estimated under different conditions. This represents the reduction in non-point source impact from the source, in the short-, medium- and longer-term. This generally requires analysis of the intervention, based on a combination of:

- heuristic or expert knowledge
- detailed non-point source area and process modelling

It may not be possible to define the absolute effectiveness of a management intervention, because site-specific conditions have a considerable impact. However, it should be adequate to assess the relative effectiveness of different interventions.

Are these practices efficient, acceptable, affordable and sustainable?

In addition to the effectiveness of a management intervention or practice, the following criteria should be evaluated.

- *Efficiency* reflects the cost-effectiveness of the intervention (i.e. the reduction for every unit of resource required). This should be assessed in terms of the initial implementation cost, as well as the ongoing operational costs.
- *Acceptability* indicates whether the polluters or those people who are affected will support the intervention. If not, the effectiveness of the intervention may be reduced through mis-use or sabotage, even though it may be technically appropriate.
- *Affordability* of an intervention depends both upon the efficiency (cost) and the acceptability (willingness-to-pay) of the polluters. Unaffordable interventions will not be implemented, unless severe penalties are applied.
- *Sustainability* is dependent upon technical criteria, such as the ongoing maintenance requirements, as well as the efficiency, affordability and acceptability of the intervention. In some cases, it may be necessary to adopt unsustainable short-term solutions, while implementing long-term sustainable solutions.

These criteria ensure that the economic, social and institutional requirements of the intervention have been addressed and should be evaluated against the available resources and the enabling environment.

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> The Best Management Practices (BMPs) for a particular source are the combination of interventions that are effective, efficient, acceptable, affordable and sustainable. The selection of BMPs should involve consultation of interested parties, particularly as part of the definition of controlled sources.

Do these practices meet management targets?

The final evaluation of a proposed management intervention is whether it achieves the non-point source management targets. If they do not, other more costly interventions may be required or the targets need to be revised, due to technical, financial, social and/or institutional considerations. However, this should have been considered during the setting of the management targets and the resource quality objectives upon which they depend.

Water use authorisations, management strategies and resource quality objectives are subject to auditing and review (usually every 5-years), which provides the opportunity to adjust management targets.

Assessment Techniques for Selection

Two groups of non-point source assessment techniques are appropriate for Selection Assessment, depending upon whether a catchment or source area analysis is being performed. They should be based on the techniques used in the Prioritisation Assessment (Section 3E) and should reflect the issues and criteria identified for the Evaluation Assessment (Section 3F).

Simple process models (Section 4.H) can provide an indication of the effect on the water quality concerns at a catchment scale of setting non-point source targets. They may need to be linked to water resource simulation (transport) models to assess regional effects.

Detailed process models (Section 4.I) are most suited to evaluating the impact of implementing management interventions in a catchment, whether this is for setting targets or evaluating the impact of particular management practices. Source area analysis can be done in these models by defining the source as an homogeneous catchment and simulating the impact of different management practices.

The following two models are particularly suited to assessment of management practices for a particular non-point source.

Single source models (Section 4.J) are the most appropriate techniques for analysing the impact of management practices within a source. The results of this investigation may be fed into detailed process models in order to evaluate the impact on the surface water environment.

Heuristics (Section 4.K) for the applicability of different management practices is based on expert opinion or the interpretation of the results of other physical studies. This is the most commonly used technique to screen the effectiveness of management practices for more detailed analysis, and is the basis for evaluating affordability, acceptability and sustainability.

PART 4 : NON-POINT SOURCE ASSESSMENT TECHNIQUES

4A. OVERVIEW

Introduction

Part 4 presents the non-point source models and techniques that have been most commonly applied in South Africa. This section is intended to provide an overview of the models or techniques and their application, including brief case study illustrations. However, it generally does not present the information or parameters necessary to apply the technique in a particular situation. Rather, relevant references to the user manuals or South African applications are provided. This is in keeping with the intention of this document as a guide, rather than a handbook for non-point source assessment.

Types of Techniques

The Guide (Part 3) indicated the types of non-point source assessment techniques that are appropriate for different purposes (i.e. assessment tasks). This choice should be based on the level of assessment, the required resolution and the data availability for the analysis.

The Guide also indicated the criteria that should be considered when selecting a particular technique or model associated with each type of technique. This selection should be based largely on the water quality concern and source area character.

The most commonly used non-point source models and techniques in South Africa have been presented under the following types:

Key Model Attributes

Non-point source assessment techniques may be further classified according to a number of basic assumptions, which influence the scale of analysis, the input data requirements, the type of output provided and the understanding of the underlying physical processes governing non-point source impacts. Thus, it is appropriate to outline these attributes, against which different techniques may be compared, and their applicability to a particular application may be evaluated.

The following provide a general overview of the basic assumptions differentiating most techniques. It should be noted that although these are useful concepts, few techniques fit perfectly into this characterisation. Rather these should be seen as ends of a continuum between which a particular technique or model may fall.

Numerical representation

- *Qualitative* approaches are based on expert knowledge or conceptual understanding of the important relationships in the physical system, which enables ordinal or subjective evaluation of the impacts.
- *Quantitative* analysis depends upon numerical relationships enabling cardinal ranking and evaluation, based on observed data or mathematical modelling.

Basis of the relationships

- *Physically-based conceptual* approaches explicitly incorporate relationships representing the important physical processes governing the non-point source impacts.
- *Empirical* approaches are based on fitted relationships describing observed behaviour or outcomes, without representing the underlying physical processes.

Representation of uncertainty

- *Deterministic* approaches assume that data and physical relationships are understood and may be represented with certainty and that each input set leads to only one possible outcome.
- *Probabilistic* (statistical and stochastic) approaches explicitly incorporate uncertainty into the representation of relationships and data, with each input leading to a number of possible outcomes with different probabilities of occurrence.

Calibration with observed data

- *Calibrated* techniques depend upon fitting sampled hydrological and/or water quality data to describe and estimate the cause-and-effect relationships in a particular catchment.
- *Transferable* techniques may be applied to unmonitored catchments, because the relationships and parameters are based on physical catchment characteristics and processes, although they usually do benefit from some level of verification.

Spatial resolution

- *Lumped* approaches combine a number of possibly heterogeneous areas together and represent them as a single average.
- *Distributed* approaches separate the area into homogeneous source areas and represent the relationships between them.

Temporal scope

- *Event-based* analysis reflects the impact of a single hydrometeorological event given initial conditions.
- *Continuous* simulation provides a time series of impacts over a period including a large number of events.

Format for the Description of Techniques

The description of the different types of techniques follows the same format. It begins with a general background overview of the technique, in terms of what it does, when it is appropriate and the type of information it provides.

Detailed descriptions of particular models and assessment techniques are then presented, together with important references to user manuals or land mark publications on the approach. General parameters that may be used for the application of certain of the more general techniques under South African conditions are presented. Although this is the exception, rather than the rule, this document is not intended to be a handbook.

Quick reference to a technique

A summary of the key attributes is presented at the beginning of the section in a quick reference box of the type presented below.

☞ WHAT ARE <*TECHNIQUE NAME*> ?

Assessment Aims

What does this technique do?

Approach

How does it do it?

Characteristics

When can it be used?

Requirements

What data and resources are required?

Limitations

When is it not appropriate?

Case studies of South African applications

The application of most of the techniques are illustrated by a brief description of a South African case study, with the following format.

CASE STUDY

Objective of this Assessment

What were the management information needs?

Application

How was the technique applied?

Key Results

What information was provided?

Limitations

What did the application indicate about the technique?

References

Where can you get more information?

4B. PRINCIPLES OF NONPOINT SOURCE ASSESSMENT

The Assessment Guidelines in Part 3 indicated the types of techniques that should be used for a particular non-point source assessment. The following principles provide some general guidance about the way in which an assessment should be conducted.

Have a clear statement of the management goals.

Clarify the management goals and these will dictate the information needs for the assessment. This is the aim of the Procedural Guide and Assessment Guidelines presented in Part 3. Verify the need for non-point source assessment, and particularly the need for modelling. It may be that the information needs can be satisfied without non-point source analysis.

Formulate a picture of the results you would expect before conducting an analysis.

Spending a little time on understanding the system behaviour and inter-relationships will guide the application of a technique and provide some indication of the likely results. This will help to evaluate whether unexpected results are realistic.

Use the simplest technique that will provide the required information.

The application of complex models in South Africa does not necessarily provide more accurate information, due to the limited data availability to support inputs and calibration. Parsimony and aggregation should guide the development and application of techniques, based on the premise "perfection is attained, not when there is nothing to add, but rather when there is nothing more to take away".

The assessment technique should be explained to decision-makers.

The focus of non-point source assessment should be to support management. Decision makers are generally more willing to implement the results of analyses, if they are comfortable with the approach. The analyst should determine the level of technical understanding of the decision-makers and explain the approach.

Match the technique to the time, budget and data available for the analysis.

Non-point source assessment is potentially a resource-intensive exercise, in terms of data requirements and analysts' time. More sophisticated models are not appropriate where these are serious constraints, because a thorough analysis using a more simple technique generally provides better results than an uncompleted or uncalibrated analysis using a complex model.

The assessment process should be iterative and become more focused.

A non-point source assessment process should move from broad screening of all the relevant issues to detailed analysis of specific critical issues. This narrowing of focus should be informed by the results of the previous level of assessment. This implies a hierarchical approach during which more detailed information is obtained on fewer, more critical non-point source concerns, areas and/or periods during subsequent analyses.

Attainment of adequate results, should determine the closure of an analysis.

The law of "diminishing returns" is applicable to non-point source assessment. In general 80% of the information is gained with 20% of the effort, and the additional information is often not worth the additional effort. Unfortunately, the evaluation of adequate results is subjective, but in a management context, it is determined by the information needs.

Matching observed patterns is usually adequate for management purposes.

Attempting to match simulated water quality with individual observations through a non-point source analysis is like *Don Quixote* tilting at windmills. The data imperfections and modelling simplifications are generally too large, particularly at the scales that are useful for management decision-making. Data and model accuracy associated with hydrology is relatively good, is fair for conservative substances (i.e. salts and sediment), but is generally poor for non-conservative substances (i.e. toxic organics and pathogens). Representing the general system behaviour in time and space should provide adequate information to support non-point source management.

Be realistic about the accuracy of observed data or model outputs.

The observed and input data generally have significant errors, particularly as they are usually spatial and temporal averages of point observations. This is particularly problematic for transient, non-conservative substances. Similarly, the results of an analysis are only as good as the inputs and relationships and should be viewed as an indication of system behaviour. The analyst should always interrogate the input data and results, based on their own understanding.

Calibrate and verify the analysis results, where data is available.

Most models benefit from calibration, including those that do not explicitly require it. Verification, using an independent data set, indicates the reliability of the application. If the data set is adequate, it should be split, with one part used for calibration and the other used for verification. If no data exists for the application area, data from a similar nearby catchment may be used.

Combine qualitative assessment, data analysis and modelling where possible.

No single assessment approach provides the whole picture, and each has different strengths and weaknesses. Qualitative assessment provides a basic understanding of the issues and expected problems, which should support the more detailed quantitative data analysis and modelling, and is an important component of the analyst's techniques. Where possible data analysis and modelling should be used together to cross-check and verify the results.

Conservative substances may be analysed at coarser resolution.

The more conservative substances, such as salts, sediment and even nutrients, can be relatively accurately analysed using techniques that aggregate temporally and lump spatially. Thus, the constituent behaviour has less influence on the appropriate level of detail than the particular management information need.

Analysis of non-conservative substances implies disaggregation.

Non-conservative substances are transient and have acute effects, which implies that analysis of their movement through the environment must be performed at relatively fine spatial and temporal resolution; coarse resolution techniques provide misleading results. However, qualitative assessment and identification of sources with high production rates are the most appropriate high-level techniques.

Care should be taken in using a technique under conditions for which is was not developed.

The assumptions and particularly the parameters for most models are specific to a particular hydrometeorological regime and/or land use. The validity of using the model under different conditions should be evaluated in terms of the assumptions and input parameters before it is blindly applied.

4C. KNOWLEDGE BASED APPROACHES

Background

Knowledge-based approaches provide qualitative descriptions of the possible non-point source impacts resulting from the combination of anthropogenic activities and natural catchment characteristics. It may be used to indicate what, where and when non-point source problems may occur. This approach is particularly useful in preliminary scoping investigations, because the impacts of individual sources and different physical processes can be considered. Furthermore, knowledge-based approaches can indicate the possibility of transient recurring problems which may have been missed by even comprehensive water quality monitoring programmes.

Knowledge-based assessment may be based on a combination of non-point source expert (specialist) opinions, the observations during site visits and catchment surveys, and anecdotal evidence of local inhabitants and water quality managers gained through consultation processes. Thus it is eminently suited to the scoping exercises required by the first level of assessment.

☞ WHAT ARE KNOWLEDGE-BASED APPROACHES?

Assessment Aims
Identification of the water quality concerns and the main causes, together with improved understanding of the likely nature of the non-point source impacts.

Approach
Qualitative investigation, based on a combination of expert (specialist) opinions, catchment surveys, and consultation for anecdotal evidence of local inhabitants.

Characteristics
Can be used to assess the likely impacts of any water quality concern and land use, and provides a valuable support to quantitative analysis.

Requirements
An understanding of the cause and effect relationships governing non-point sources (see Part 2), and an ability to apply this to locally obtained information.

Limitations
By themselves, knowledge-based approaches do not indicate the magnitude of a problem with any certainty, and thus must be supported by quantitative analysis.

Site visits and catchment surveys

An understanding of a catchment or non-point source area is absolutely necessary for non-point source assessment. Thus, the starting point of any comprehensive assessment should be a site visit to the relevant area. This provides an opportunity for scoping the issues and results in a greater appreciation of the nature of the assessment task. There are two general approaches that should be used to identify non-point source problems.

Firstly, screening for symptoms of water quality problems in the surface water environment, such as:

- impacts on human health associated with the use of surface water resources;
- degradation of the aquatic environment, in terms of ecological integrity or aesthetic quality;
- eutrophication of downstream impoundments or even slow-flowing rivers; or
- siltation of river reaches or sedimentation or impoundments.

Secondly, surveying for "tell-tale" features of non-point source problems at the source, such as erosion gullies, uncollected litter, accumulation of matter on urban streets and dry weather flows in under-serviced settlements.

Consultation

In many cases, local inhabitants have a clear knowledge of the water quality effects of non-point source contamination, even if they have not necessarily made the connection with the responsible land use activities. Furthermore, they have will have implicitly prioritised the issues for management, and they will be critical in terms of implementing non-point source management. Similarly, the perceptions and understanding of local water quality managers are invaluable to an assessment process, and these are the people who will generally be responsible for promoting the implementation of non-point source management.

Consultation is usually an important element of management processes at a catchment scale, and this provides an opportunity to gain an improved understanding of the activities causing non-point source problems, as well as the priorities for management. Community-based problem analysis processes provide a useful tool for informing people about non-point source problems and creating ownership for management solutions.

Expert review

The information obtained from the site visits and consultation process needs to be synthesised to provide an integrated picture of the non-point source-related water quality concerns, the land uses causing these problems and the nature of the non-point source impacts. Specialists with a thorough understanding of non-point sources can provide valuable insights about the non-point source issues that require further investigation. This is the role of the expert review, which should provide the platform for the scoping level of assessment.

References

See Part 2 of this Guide Document for background information to non-point sources and their water quality impacts.

NSI (1996) *Preliminary Assessment*. Mgeni Catchment Management Plan. DWAF report no. WQ U200/00/0194. Pretoria.

PRELIMINARY ASSESSMENT FOR THE MGENI CATCHMENT MANAGEMENT PLAN

Objective of this Assessment
A knowledge-based assessment was conducted on the Mgeni River catchment as a scoping exercise at the initiation of the Mgeni Catchment Management Plan. This Preliminary Assessment identified the key water quality (and non-point source) issues in the catchment that needed to be addressed by more detailed analysis during the study.

Application
The assessment was based on an evaluation of the characteristics of the catchment that were likely to have an important influence on water quality. In particular, the likely importance of non-point source impacts associated with land use patterns and natural characteristics throughout the catchment was assessed. This involved a synthesis of the impact of climate, soils, geology, topography and vegetation, with agricultural activities, rural settlements and urban areas, which was conducted by a specialist in non-point source impacts. The information used to perform this assessment was gained through spatial information (GIS coverages), site visits and stakeholder consultation.

Key Results
The likely water quality impacts (including those associated with non-point sources) were identified for 13 different 350 km² sub-catchments. A table was developed to indicate the potential severity of eight different types of water quality concerns in each of these sub-catchments, differentiating between impact during the wet (summer) and dry (winter) seasons. It indicated that sediment, nutrients and pathogens were the major water quality concerns, particularly in the middle and lower catchments. Further analysis confirmed these results.

Limitations
Knowledge-based assessment is only as good as the specialist that is conducting the study, the basic information about the catchment, and the consultation process. It can highlight issues for further analysis and improve understanding of the processes governing non-point source water quality impacts but it does not provide quantitative information upon which to make detailed management decisions.

References
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4D. DATA ANALYSIS TECHNIQUES

Background

As implied in the name, data analysis techniques depend upon the analysis of monitored water quality, ecological and/or hydrological data. Sampled data is usually only available for point source effluent discharges or receiving water bodies, but not non-point source discharge. The techniques provide quantitative (loading) information on point source delivery and catchment export, and thus provides a means of comparing the relative contributions from point and non-point sources.

The ability to differentiate between production, delivery and transport, as well as different non-point source areas, is limited, even in the most highly monitored systems. Furthermore, transient problems may be overlooked or underestimated, particularly when the assessment is based on grab-samples of water quality constituents. Intensive non-point source-oriented monitoring programmes are expensive, so are not conducted widely.

Data analysis techniques are commonly used for assessing fitness-for-use and the health of the aquatic environment, when compared to specified guidelines. They are thus suited to scoping assessment, particularly when used in conjunction with knowledge-based approaches.

☞ WHAT ARE DATA ANALYSIS TECHNIQUES?

Assessment Aims
Evaluation of the severity of water quality concerns, analysis of the causes of an impact, and processing of data sets to support the application of other techniques.

Approach
Statistical and stochastic analysis of observed data to provide complete time series or representative statistics, and statistical relationships between variables.

Characteristics
Used in all non-point source situations where data are available, particularly in conjunction with other non-point source assessment techniques.

Requirements
Availability of sampled data and sound analyst understanding of the assumptions behind different techniques.

Limitations
Limited predictive power outside the observed conditions, cannot distinguish the impacts of production, delivery and transport from different sources, and may be biased by errors in poor monitoring programmes.

More detailed and data intensive techniques are also available to interpret the relative contributions from different source types and to predict potential catchment (possibly non-point source) impacts, based on the analysis and extrapolation of observed data.

Finally, they provide a necessary means for developing inputs to other more detailed non-point source assessment techniques, often after infilling and manipulation of existing data sets, as well as calibration and/or verification of their application. Such data analysis techniques represent important tools for non-point source assessment, particularly when used in conjunction with other techniques.

The *stationarity* of the observed time series data must be evaluated before data analysis techniques are applied. This is particularly important in longer time series, because changing land use patterns and monitoring programmes can result in trends or discrete jumps in the data.

Statistical techniques

As indicated above, the main applications of statistical techniques for non-point source assessment, have included:

- infilling time series of water quality data to support non-point source analysis; and
- regression analysis for the identification of empirical relationships or the disaggregation of causal impacts.

The analysis of concentration distributions for constituents with acute impacts, possibly as part of fitness-for-use assessment, and loading calculations for cumulative impacts, is also performed, but this is more relevant to general water quality assessment and is not dealt with in this section (see DWAF, 1995: Task 10).

Regression analysis

Regression is often used to develop simple statistical relationships between a dependent variable, usually observed concentrations (or loads), and a set of independent variables, such as flow and/or concentrations (or loads) of other constituents. These relationships may be either inter-event, describing the change in event mean concentration (EMC), or intra-event, describing the changing concentrations along the rising and falling limbs of storm hydrographs.

They may provide valuable information, but by themselves they are only descriptive, and need to be evaluated against the expected behaviour of the constituent. In fact, this understanding should guide the regression analysis, in terms of assumptions about the underlying functional form for the relationship. For example, salinity, typically, is negatively exponentially related to flow, while sediment has a linear or positive exponential relationship (within a given range). These relationships cannot be used under changing conditions or reliably transferred to other catchments. However, they can provide input to other more complex models used for prediction or data infilling for time series.

Regression analysis has also been used to identify relationships between pollutant loads and physical, demographic and hydrological variables (Tasker & Driver, 1988). This addresses the transferability issue, although only in the range for which the equations were fitted. Unfortunately, this produces static (time-invariant) relationships, even when hydrologic and climatic variables are included. As with the time-series analysis, multiple regression provides a method for investigating statistical relationships in data. Although they are used as the basis of some simple procedures, they are not particularly accurate when transferred to ungauged catchments.

Data infilling

South Africa has a reasonable water quality monitoring system, with irregular samples of inorganic salts and nutrients at most monitoring stations. However, the availability of data on sediment, pathogens, metals and other constituents is highly uneven, and where they are available there are often missing data.

The difficulty of infilling water quality data is that different constituents have varying patterns, they are highly variable, and they are not strongly time-dependent between events. A number of techniques have been used by various analysts to overcome these problems, often drawing on the more extensive experience of infilling hydrological time series. Two commonly used techniques are described below, both of which are based on regression analysis.

FLUX (Walker, 1987) was originally developed to calculate nutrient export loads from a catchment, but this required the development of techniques to infill missing data. It is based on the estimation of regression relationships between instantaneous concentration and daily streamflow observations, for up to five flow stratified sample sets. These equations are used to infill the missing concentration data, based on the observed flow, and on estimate loads. This technique may be used for any water quality constituent, although the analyst should verify that the regressions are consistent with the nature of that constituent (i.e. increasing or decreasing with flow).

USE OF FLUX TO INFILL DATA FOR THE BERG RIVER

Objective of this Application
In a comparative study of simulation models for phosphorous production from smallish rural catchments in the Berg River Basin, it became necessary to estimate monthly PO4 loads by infilling weekly grab sample concentrations, on the basis of observed daily streamflows. It was deemed important to perform the infilling with a repeatable approach that could be regarded as an international "standard", viz. the use of FLUX.

Application
FLUX was used with a range of options regarding the number of stratified sample sets, as well as both linear and non-linear regressions, for a number of Berg River sub-catchments. Seasonality was recognised.

Key Results
FLUX was relatively easy to use and monthly PO4 loads were generated quickly. The results were, however, not completely transparent.

Limitations
It was not immediately apparent how to choose among the respective infilling options in FLUX. No option produced particularly convincing flow-weighted monthly concentrations. Graphical support of FLUX outputs was found to be a constraint.

References
Matji MP and Görgens AHM (1999) A comparative study of phosphorous production simulation models in rural catchments of the Western and Eastern Cape. Ninth SA National Hydrology Symposium, Western Cape, 29-30 November, 1999

Rolling regressions have been commonly used in South Africa to infill grab samples (CE Herold, Stewart Scott Inc, Pers. Comm., 1998). In this method the coefficients of the regression relationship are continuously re-estimated for a given number of grab sample values (a "window") that roll forward one value at a time. Each latest regression is then sequentially used to fill in the "missing" days covering the interval between the latest and the previous grab sample dates. In this way the systematic internal variations and cyclicity in relevant catchment processes are continually brought back into the infilling process, one step at a time..

REGRESSION FOR DATA INFILLING IN THE AMATOLE SYSTEM

Objective of this Application
Flow-weighted monthly TDS and PO4 loads were generated from daily flows and irregular grab sample concentrations for a range of gauging stations in the Amatole water resources system. These monthly values were used to calibrate the salinity and eutrophication components of system analysis support models.

Application
The rolling regression was applied to grab sample records in the Buffalo, Kubusi and Gonubi catchments, by means of spread-sheet tools.

Key Results
Monthly flow-weighted loads for TDS and PO4 were easily generated. Comparisons with monthly loads calculated from densely sampled periods were more than satisfactory.

Limitations
The rolling estimation “window” could not be expanded much beyond 12 grab samples, which typically would span more than a three-month period, and which could have caused loss of cyclicity in infilled values. Such small samples do not necessarily yield robust regressions. If grab samples are more frequent, this “window” can, of course, be improved.

References
DWAF (1998). Amatole Water Resources System Analysis, Phase II : Water Quality Modelling. Report No. PR 000/00/1798 by Ninham Shand (Pty) Ltd / Gibb Africa.

Stochastic techniques

Stochastic processes describe the probabilistic relationships between input time-series (usually streamflow) and output responses (usually concentrations or loads). However, the estimated parameters are lumped for the whole catchment and usually have no physical interpretation, so they are not particularly suited to non-point source assessment. The equations should not be extrapolated beyond the conditions for which they were derived. Thus, stochastic time-series models are not appropriate for transfer to other catchments or for use in catchments undergoing significant or abrupt change.

Stochastic hydrological flow series modelling techniques are well-established in South Africa. This provides the opportunity to link simple deterministic process descriptions or statistical relationships (see above) to provide stochastic water quality time series. State-space techniques have been used extensively for patching hydrological data in South Africa (Pegram, 1991). These provide a possible technique for infilling water quality data, or even to develop stochastic water quality models, because the underlying processes can be explicitly incorporated into the model form.

References

DWAF (1995) *Procedures to assess effluent discharge impacts*. South African Water Quality Management Series. WRC Report No TT 64/94. Pretoria.

Pegram, GGS (1991) *Patching monthly streamflow records using PATCHS*. Proceeding of the 5th South African National Hydrological Symposium. Stellenbosch.

Tasker, GD and NE Driver (1988) "Nationwide Regression Models for Predicting Urban Runoff Water Quality at Unmonitored Sites," *Water Resources Bulletin*, 24(5):1091-1101.

Walker, WW (1987) *Empirical methods for predicting eutrophication in impoundments - Report 4*, Phase III: Applications Manual, Technical Report E-87-9, US Army Corps of Engineers, Washington DC.

4E. POTENTIAL AND HAZARD MAPS

Background

Potential maps provide a spatial indication of the relative availability of a contaminant, based on the land use activity-related application and removal rates, which may be mitigated or exacerbated by natural characteristics. This availability may have a seasonal component, so seasonal variations may be reflected.

Most commonly, sediment, nutrient and microbiological availability (potential) are estimated, based on simple representation of the production mechanisms associated with each land use activity or source area. These availabilities may be associated with spatial GIS coverages of land use (source areas) in order to provide graphical representations of contaminant potential.

Potential maps only provide an indication of the potential non-point source impact, not the actual yield for a source area or export from a catchment. However, qualitative or quantitative representations of the non-point source delivery mechanisms may be incorporated into the source area analysis, particularly as part of GIS modelling. This produces hazard maps, which provides a spatial indication of the relative non-point source impacts.

☞ WHAT ARE POTENTIAL AND HAZARD MAPS?

Assessment Aims
Indication of the relative availability (potential maps) or impacts (hazard maps) of contaminants associated with different source areas in a catchment, usually to support scoping assessments by indicating the critical non-point sources.

Approach
Estimation of the application, removal and die-off of the contaminant (potential), and its delivery (hazard), based on simple representations of these processes associated with different land uses and natural characteristics.

Characteristics
Provides average annual or seasonal estimates in rural and urban catchments, particularly for sediment, nutrients and pathogens. Such estimates are obviously transferable in space, but should be informed by local contaminant production rates.

Requirements
Spatial data on land use and natural characteristics at the appropriate resolution, as well as an understanding of the processes governing production and delivery.

Limitations
Only provides relative average estimates, which do not necessarily coincide with the effects in the receiving environment. The incorporation of delivery processes is less reliable than production, so potential maps are applied more generally.

Potential mapping

Potential mapping is based on an assessment of the production or availability of contaminants associated with different source areas throughout a catchment. It is usually performed by overlaying (combining) a series of GIS coverages of the spatial distribution of key natural and land use characteristics that affect the contaminant generation, application, removal and/or assimilation. The most appropriate techniques for estimating sediment, nutrient and pathogen potential maps are outlined below. Similar approaches may be used to develop potential maps for other constituents.

Sediment

Sediment potential is usually estimated using the Universal Soil Loss Equation (USLE). This is based on rainfall erosivity (R), soil erodibility (K), slope-length (LS), cover (C) and management practice (P), as the five factors governing soil loss potential. Section 4.G discusses the USLE in more detail.

The estimation of soil loss potential may be quantitative, based on accurate numerical estimates of these factors (see the case study Kienzle *et al*, 1997). Alternatively, a more qualitative approach can be adopted, in which the factors are evaluated as being related to low, medium or high soil loss potential, and combined with appropriate rules to give an ordinal ranking of potential (see the case study by Moolman *et al*, 1999 on p. 72).

Nutrients

A phosphorus or nitrogen potential map may be produced by estimating the inputs of these nutrients through atmospheric deposition, fertilizer application, animal waste deposition and human waste disposal. These areal production rates may be estimated for different land uses, particularly agricultural croplands, extensive or intensive livestock grazing and rural or urban human settlements. However, the potential map needs to take account of the nutrient removal rates associated with crop harvesting and settlement sanitation systems.

Nutrient production rates associated with livestock and human land use is directly related to the density of animals and humans. A cow typically produces about 15kg to 25kg of phosphorus and 40kg to 50kg of nitrogen per year. On the other hand, a person produces about 0.9kg of phosphorus and 1.8kg of nitrogen per year, with an additional 0.5kg to 1.5kg of phosphorus in household wash water. In formal settlements, most of this is removed by the sanitation system, but it remains on the plot in many informal settlements. NSI (1996) estimated that production rates for human settlements were about 0.4kg of phosphorus per capita per year, taking account of the effectiveness of the sanitation system and the impact of animals within the settlement.

Table 4.E.1 presents typical areal nutrient production rates for key land use categories, based on a synthesis of data presented by NSI (1996) and Novotny and Olem (1994).

Table 4.E.1 Typical areal production rates on general land uses.

	Atmospheric		Agricultural		Settlement		
	Rural	Urban	Crops	Livest.	Rural	Informal	Urban
Total P (kg/ha/a)	0.25	0.5 - 3.5	35	5 - 10	0.1 - 2	1 - 20	0.2 - 5
Total N (kg/ha/a)	9.0	8.5 - 9.5	100	10 - 40	0.5 - 2	1 - 10	1 - 10
E.coli ($x10^6$/ha/day)	-	-	-	10 - 50	5 - 50	10 - 500	1 - 100

These production rates may be associated with a GIS coverage of land use to indicate the spatial distribution of nutrient potential loss. The selection of areal production rates from the presented ranges, for land uses in a particular catchment, should be based on the analyst's understanding of local conditions, and should be estimated using local livestock and population densities where possible.

MAPPING SEDIMENT POTENTIAL IN THE MGENI CATCHMENT

Objective of this Assessment
To estimate the soil loss potential throughout the Mgeni River catchment as part of the scoping assessment, in conjunction with the knowledge-based assessment. This identified land uses and areas requiring further detailed non-point source analysis and focused management attention, in terms of land use planning and strategy intervention.

Application
GIS coverages representing spatial estimates of the five elements of the USLE were combined to provide estimates of the soil loss from 250m x 250m square grid cells. 21 land cover classes were identified using a SPOT satellite image, ranging from pristine forests to dense informal settlements. This resulted in a total of 65 256 relatively homogeneous cells throughout the catchment, which provided a spatial indication of areas with high versus low soil loss potential.

Key Results
Soil loss potential maps were produced as average annual estimates for each month. The estimates ranged from 1 ton/ha in the flatter grasslands in the upper catchment to 50 tons/ha around steep overgrazed rural settlements. Informal settlements and areas with steep erodible soils around Pietermaritzburg, Durban and the Valley of a Thousand Hills were identified as having the major soil loss potential in the catchment. These were prioritised for interventions under the Mgeni Catchment Management Plan. However, when soil loss potential was compared to sediment yield, the issue of sediment delivery became apparent. Some areas with high soil loss potential only delivered 10% of this, while other areas with lower soil loss potential delivered 45%, resulting in higher sediment yield.

Limitations
Soil loss potential only provides an indication of the potential impacts from different sources. It does not reflect the effects of sediment delivery and transport from the source, and can be misleading. Furthermore, it is only as good as the quality of the spatial data and the accuracy of the relationships upon which it is based. Nevertheless, it provides a useful screen of the areas that are likely to cause problems and should be used in conjunction with knowledge-based approaches.

References
Kienzle, SW, SA Lorentz and RE Schulze (1997) *Hydrology and Water Quality of the Mgeni Catchment.* WRC Report TT 87/97. Pretoria.
NSI (1996) *Pollution Sources.* Mgeni Catchment Management Plan. DWAF Report WQ U200/00/0913. Pretoria.

Where more detailed spatial information is available about the factors contributing to nutrient potential, these can be combined according to some specified relationships in a GIS environment to produce the nutrient potential maps. Factors may include items such as livestock density, population density, level of sanitation and crop type. Combining these would require information, such the fertilizer application rate and nutrient uptake for different crops and the effectiveness of sanitation systems in removing nutrients.

Alternatively, a qualitative approach may be adopted, whereby the nutrient loss potential may be built up from these types of coverages with descriptive rather than numerical evaluations of their impacts. This is similar to the sediment approach. A rule-based system would be used to relate the relative contribution of different coverages to the potential nutrient loss.

Pathogens

Similar approaches may be adopted for pathogen production (NSI, 1996), except that the daily production rates should be used, because *E.coli* typically dies-off in a matter of days. The commonly used die-off equation is $E.coli_t = E.coli_0.e^{-kt}$, where t is the number of days. The die-off coefficient (k) on land and in soil typically ranges from $0.1day^{-1}$ to $0.5day^{-1}$, depending upon temperature, sunlight, etc.

Using this equation, the approximate "steady-state" *E.coli* availability (ignoring washoff) is equal to $(1-e^{-k})^{-1}$ times the daily areal production (application) rate. This implies that the steady state availability ranges from about 2.5 to 10 times the daily areal production rate, as k varies from $0.5day^{-1}$ to $0.1day^{-1}$. This may be related to the land use, because the dieoff rates associated with grazed grassland may be lower than for devegetated informal settlements.

The main sources of pathogens are human and livestock waste. Table 4.E.1 presents typical areal *E.coli* production rates for livestock grazing and human settlements, which is based on similar assumptions to the nutrient estimates (NSI, 1996; Novotny and Olem, 1994). These may be applied as with the nutrient potential maps.

On the other hand, a qualitative approach to identifying pathogen potential may be developed, based on population density, sanitation services, land use etc.

Hazard mapping

The development of hazard maps extends the potential maps, by incorporating delivery into the estimation procedure. This provides a spatial indication of the relative impact of different non-point sources.

Hazard maps are also based on the use of GIS coverages which reflect the factors governing the movement of constituents from the source into the receiving surface waters, usually combined with the relevant potential maps. The representation of these delivery factors may be qualitative or quantitative estimates, based on the hydrological, land use and natural characteristics of the source areas.

Sediment delivery is commonly estimated using the drainage density (Section 4.G) or the peak discharge (see ACRU in Section 4.I) associated with a source area or sub-catchment. The delivery of nutrients and pathogens can be related to the sediment yield, because these constituents largely move through the environment adsorbed to sediment. Therefore, the sediment delivery ratio (soil loss potential:sediment yield) can be used as an approximation for the nutrient and pathogen delivery ratios.

Hazard maps generally require more information than potential maps, and are more difficult to develop. Other modelling techniques are generally more appropriate for estimating the impact of source areas. However, in some cases, the outputs from these non-point source models are presented spatially using GIS. This provides detailed hazard maps which are more closely linked to water quality concern, particularly where these models estimate the yield from different source areas.

MAPPING SEDIMENT WASHOFF IN THE OLIFANTS CATCHMENT

Objective of this Assessment
Identify potential sediment production areas and evaluate their relative importance as part of a scoping assessment for the Olifants River catchment (east). This provides the initial information necessary to focus sediment management efforts within the catchment.

Application
A qualitative GIS-based approach was developed, using the USLE. Qualitative coverages, indicating high, medium and low erosion hazard, were developed for the catchment. These were based on specialist interpretation of rainfall, soil, topography and land cover categories associated with available spatial GIS coverages. Rules were developed that combined these individual coverages to produce coverages of sediment availability and washoff potential. These were then combined using similar rules to produce a map of sediment washoff potential throughout the Olifants catchment.

Key Results
A map of sediment production potential was produced, indicating areas of probable high, medium and low sediment washoff. The results were consistent with expert knowledge of the eroded areas in the catchment, as well as the areas of observed high in stream suspended solids concentrations. It indicated that the densely populated areas in the relatively steep and overgrazed Steelpoort and Makhutswi catchments had the highest sediment potential. This indicated that management attention be focused on these areas, and that care should be taken to avoid additional settlement in these areas.

Limitations
This method only provides a qualitative indication of the sediment potential, and cannot be directly linked to observed sediment concentration. Its application depends upon analysts with a good understanding of the processes governing the availability and washoff of sediment, and the translation of this knowledge into realistic rules and coverages. In theory, this type of approach can be developed to investigate the source of any water quality concern.

References
Moolman, J, G Quibell and B Hohls (1999) "A qualitative (GIS based) model of non-point source areas" in *Development of a non-point source assessment guide: Test case studies.* G Quibell (ed), WRC Report No. 696/2/01, Pretoria.

References

Novotny, V and H Olem (1994) *Water Quality: Prevention, Identification and Management of Diffuse Pollution*, Van Nostrand Reinhold, New York.

NSI (1996) *Pollution Sources*. Mgeni Catchment Management Plan. DWAF Report WQ U200/00/0913. Pretoria.

4F. UNIT AREA LOADING (EXPORT COEFFICIENTS)

Background

Unit area loads (often referred to as export coefficients) are empirical estimates of the mass of pollutant exported per unit area per unit time (usually annual) for a particular land-use. In the hands of experienced investigators, they are designed to provide estimates of the average pollutant loads for ungauged catchments, by matching the catchment or land use types. Whereas probability distributions are more appropriate for the acute effects of microbiological contamination, unit area loading is more suited to estimating loads for cumulative impacts.

Unit area loading does not evaluate the effect of seasonal and climatic variations, nor does it take account of the physical features affecting contaminant transport processes. Various techniques have been proposed to take account of the problems caused by grab-samples or non-existent streamflow records, and to evaluate uncertainty, but these do not remedy the time-invariant nature of this approach.

Most South African case studies have resulted in the estimation of annual non-point source catchment or land use based unit area loads, which may be used as export coefficients in unit area loading analyses. However, there is considerable variation in the reported values, which significantly complicates the selection and application of appropriate coefficients.

☞ WHAT ARE UNIT AREA LOADINGS?

Assessment Aims
Evaluation of average annual export loads from a catchment and relative load contributions by source area.

Approach
Calculation of annual catchment export as the sum of unit area loads times the areas under different land uses.

Characteristics
Used in urban and possibly rural catchments, particularly for sediment, nutrients, organic matter and metals. Generally transferable, but empirically based.

Requirements
Availability of loading studies in catchments with similar land uses (source areas) and natural characteristics, as well as experienced users to select coefficients.

Limitations
Does not explicitly account for the hydrometeorological or natural character of a catchment and is most appropriate for cumulative water quality problems, which makes it more appropriate for urbanised rather than agricultural catchments.

The Unit Area Loading Approach

The calculation of total annual export loads from a catchment is based on the total sum of the contributions from different land uses (j), as estimated by the product of the unit load (export coefficient) and the land use area.

$$\text{Total Export Load} = \ _j \{ \text{Export Coefficient}_j \times \text{Area}_j \}$$

The percentage contribution from each land use can be estimated from the individual load contributions to the total load. This approach may be used for urban or mixed catchments, as long as appropriate unit loads are available. However, the variability in export loads from agricultural land use activities limits its use to those catchments with adequate water quality monitoring to enable verification.

Atmospheric Deposition

Atmospheric deposition loading represents a large portion of the washoff load for certain contaminants, particularly nutrients and heavy metals. The following total dry and wet deposition loads have been synthesised from Pegram *et al* (1999 hopefully in press).

Table 4.F.1 Atmospheric deposition (kg/ha/a) in urban and rural areas.

	Total P	Total N	Lead	Copper	Zinc
Urban	0.5 - 3.5	8.5 - 9.5	0.4 - 0.6	0.07	0.7 - .085
Rural	0.25	9.0	-	-	-

Formal Urban and Industrial Areas

This technique has been most widely applied for urban land uses in the United States. Novotny and Olem (1994) and McElroy et al (1976) have reviewed and published unit loads associated with urban land uses. These estimates should be similar to formal urban land uses in South Africa.

The most accurate calculations will be derived using unit load estimates from observed water quality data associated with similar land uses in the area. Table 4.F.2 presents ranges and average export coefficients for selected water quality constituents from different urban land use categories. These default values are based on the international literature, together with published load estimates from South African studies (Simpson, 1991, 1992; Hoffman, 1995).

Table 4.F.2 Unit loads (kg/ha/a) from formal urban areas.

	Suburban	Township	Commerce	Industrial	Highways	Constr.
SS	620 - 2300	700 - 3000	50 - 830	450 - 1700	450 - 2000	27 500
Total P	0.4 - 1.3	0.5 - 4.0	0.1 - 0.9	0.9 - 4.1	0.7 - 2.5	23
Total N	5 - 8	6 - 10	1.9 - 11	1.9 - 14	2 - 5	63
Lead	0.06 - 2.3	0.05 - 1	0.17 - 1.1	2.2 - 7	3 - 10	3
Copper	0.03 - 0.5	0.02 - 0.4	0.07 - 0.13	0.29 - 1.3	0.3 - 1.3	-
Zinc	0.02 - 1.3	0.02 - 1	0.25 - 0.43	3.5 - 12	3 - 10	-
BOD	34	50	90	34	-	-

Informal Settlements

There is limited information about export loads from informal peri-urban and rural settlements in the international literature. Therefore, export coefficients must be derived from the unit area loads presented in South African case studies of these areas. The values presented in Table 4.F.3 are a synthesis of a number of South African studies, particularly Wimberley and Coleman (1993), Hoffmann (1995), MacKay (1993), Wright *et al.* (1993) and Kloppers (1989).

Table 4.F.3 Unit loads (kg/ha/a) from informal settlements and agriculture.

	Settlements		Agricultural - Rural			
	Informal	Rural	Natural	Forestry	Croplands	Livestock
SS	800 - 5000	500 - 2000	5 - 1000	5 - 1000	15 - 9000	11 - 90
Total P	1.0 - 3.0	0.45	0.02 - 0.8	0.02 - 0.8	0.2 - 8	0.1 - 0.7

Agricultural Land Use Activities

Although export coefficients are not generally used in rural catchments, they provide a technique to indicate the relative contributions from different agricultural land use activities. However, great care should be taken when applying these coefficients, particularly in unmonitored catchments. The variation in loads within a land use category is often greater than between categories, due to the significant impact of natural characteristics (eg. soils, topography and climate) and land use management practices. The values presented in Table 4.F.3 indicate the general range of values that may be used. Agricultural export coefficients should be applied by practitioners with detailed local knowledge of agricultural non-point source in a region.

References

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Pegram, GC, G Quibell and AHM Görgens (1999) *Non-point Sources in South Africa: A Situation Assessment*. Working Document for the WRC Project “The Development of a Guide for Non-point Source Assessment in South Africa”.

Simpson , DE (1991) *Quantification of the land-use effects of runoff water quality in selected catchments in Natal*, WRC Report 237/1/91, Pretoria.

Simpson, DE (1992) *Urban runoff pollution research in Natal*, Natal Town and Regional Planning Supplementary Report: Volume 37, Pietermaritzburg.

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

Wright, A, W Kloppers and A Fricke (1993) *A Hydrological Investigation of the Stormwater Runoff from the Khayelitsha Urban Catchment in the False Bay Area, South Western Cape*, WRC Report 323/1/93, Pretoria.

UNIT AREA LOADING ESTIMATES IN THE MGENI CATCHMENT

Objective of this Assessment

Unit area loading was used during the analysis for the Mgeni Catchment Management Plan, to disaggregate water quality loads between land use types. The loads were calculated for different sub-catchments using the intensive water quality monitoring programme conducted by Umgeni Water. The analysis indicated the relative annual contributions from eight land use types to the critical water quality problems in support of the Evaluation Assessment.

Application

Total annual loads of sediment, phosphorus and lead, were calculated from sampled data in selected sub-catchments of the Mgeni River. Export coefficients for eight general land use categories (natural vegetation, croplands, timber, livestock grazing, scattered rural settlement, informal peri-urban settlement, formal residential and commercial-industrial areas) were selected from South African and international literature values, as presented in Tables 4.F.1-3, adjusted according to the results from studies in the area. The selected export coefficients were applied to the total area of each land use category in a sub-catchment, thereby indicating the total contribution from that land use rather than from an individual source area.

Key Results

The total export coefficient load estimates were generally within 10% of the calculated sample loads. The percentage contribution was evaluated from the individual land use contributions relative to the total load. Due to the approximate nature of the export coefficients, the results were presented as a level of contribution (i.e. <10%; 10%-25%; 25%-50% and >50%) from each land use. This provided a preliminary ranking of the land use categories requiring management in each sub-catchment.

Limitations

This analysis was supported by the extensive water quality data available for the catchment and the number of previous studies that estimated export loads from different land uses in the region. Although, these factors improved the acceptability of the estimates, the analysis is not very accurate and only provides order of magnitude contributions from all areas under each general land use category. This analysis supported the identification of the land use sectors that should be managed, but not the prioritisation of individual source areas. The applicability of the export coefficient approach in catchments with less data is questionable, except if used by practitioners with an understanding of non-point source loading in that area to support Evaluation Assessment.

References

Ninham Shand (1996) *Pollution Sources*. Mgeni Catchment Management Plan. DWAF Report WQM U200/00/0913. Pretoria.

4G. LOADING FUNCTIONS (AND POTENCY FACTORS)

Background

Loading functions use simple hydrological and sediment yield estimation techniques to describe surface runoff, groundwater discharge and/or sediment fluxes, usually at a monthly time scale. The outputs from these components are used as input to the linear loading functions, which are based on the concept that any constituent may be exported via groundwater, surface runoff and/or with sediment. This approach incorporates greater detail of the processes governing non-point source impacts and thus requires a more thorough understanding of their behaviour. The reader is referred to Part 2 for background to non-point sources.

Generalised loading functions compute constituent load by multiplying the estimated runoff, baseflow and sediment yield by their respective empirically determined average loading concentrations (Haith and Schoemaker, 1987). These concentrations are related to the average dissolved and solid phase constituent concentrations. A simplified rural loading function approach assumes that total loads of certain constituents are largely solid phase, and thus only the sediment part of the loading function is applied (McElroy *et al*, 1976). Loading functions have been used widely for nutrient modelling, but have also been proposed for modelling pesticide, metal and pathogen yield from sub-catchments.

☞ WHAT ARE LOADING FUNCTIONS?

Assessment Aims
Estimation of monthly time series or annual averages of sub-catchment export loads from land uses or source areas, largely to support evaluation assessment.

Approach
Calculation of loads dissolved in groundwater discharge and surface runoff (from a hydrological model), together with solid phase loads in sediment yield (as estimated by the USLE), based on loading concentrations for different source areas.

Characteristics
Generally used for sediment and nutrient simulation from rural catchments, but extensions available for other constituents and urban land use.

Requirements
A hydrological model that estimates surface runoff from each land use or source area, as well as total groundwater discharge, together with experienced users to select loading concentrations, possibly supported by sampling in similar catchments.

Limitations
Based on a highly simplified representation of production and delivery processes, and it is most appropriate for cumulative load estimation rather than concentrations.

Potency factors are often used in urban pollutant modelling, where the concentration of a pollutant is estimated by multiplying the particulate-sediment yield by empirically determined "potencies" (mass of pollutant per mass of sediment). Simple impervious area accumulation and washoff functions are used to estimate particulate-sediment washoff from urban areas (Mills *et al*, 1985). The urban potency factor approach is combined with rural loading functions in mixed land use catchments. Many simple urban and rural deterministic models use loading concentrations or potency factors to estimate non-point source water quality impacts.

Hydrology

An important component of generalised loading functions is that they can differentiate between the dissolved fraction in groundwater discharge, the dissolved fraction in surface runoff from different sources, and the solid phase fraction in sediment yield from different sources. However, this requires the estimation of the surface runoff from these sources and total groundwater discharge at a monthly time step, which implies the use of a hydrological model.

A number of hydrological models are available, many of which are used for the non-point source process models described in Sections 4.H and 4.I. However, in the South African context, daily hydrological data may be developed using a simple SCS Curve Number based model (Mills *et al*, 1985; Pegram, 1993) or a more detailed model such as ACRU (see Section 4.I). These daily data may be aggregated to provide monthly time series, otherwise the WRSM90 (Midgley *et al*, 1994) model may be used. However, WRSM90 does not differentiate between land uses in a sub-catchment, and thus these need to be dissaggregated, using a technique such as the one described for the Amatole case study.

If it is not important to differentiate between land uses, all the land uses in a sub-catchment can be lumped and the total surface runoff differentiated from the total groundwater discharge. It should be noted that WRSM90 is only calibrated against total streamflow, so although it has a groundwater discharge component, it is not generally physically based. The WQT model (see Section 4.H) provides a feasible method for disaggregating WRSM90 simulated streamflows.

Finally, if the basic assumption that rural non-point source loads are associated with sediment yield is acceptable for the purposes of the analysis, hydrological analysis is not required. In this case, the modelling of other constituents is based on the sediment yield estimation techniques described below.

Sediment yield

Sediment yield estimation is generally based on the Universal Soil Loss Equation (USLE). This was derived empirically to predict average annual soil loss by sheet and rill erosion from source areas. The basic equation for annual soil loss per unit area is:

$$X = R.K.LS.C.P$$

Where X is the annual soil loss ($t.ha^{-1}.a^{-1}$), R is the rainfall erosivity ($N.h^{-1}.a^{-1}$), K is the soil erodibility ($ton.h.N^{-1}.ha^{-1}$), LS is the dimensionless slope-length factor reflecting topography and drainage density, while C and P represent the dimensionless land cover and management practice factors, respectively, which are associated with land use. The derivation of these factors should be based on catchment specific information.

The soil loss estimate is converted to a sediment yield, using a delivery ratio factor (dr), which represents the proportion of eroded soil that is delivered into the receiving surface water. This accounts for the deposition of soil during its movement from the source area. For loading functions, this ratio should be based on catchment area (Mills *et al*, 1985) or drainage density (McElroy *et al*, 1976). The annual sediment yield (S_j) from a source area (j) is estimated as the product of the sub- catchment delivery ratio, the area (A_j) and the annual soil loss (X_j):

$$S_j \quad = \quad dr\{ A_j . X_j \}$$

Lorentz and Schulze (1995) provide a comprehensive overview of sediment modelling in South Africa, while Smithen and Schulze (1995) present the information required to apply the USLE in a simple or comprehensive manner for South African conditions; they describe a modified version of the USLE, but the basic parameters are the same.

Generalised loading functions require estimates of monthly sediment yield. Mills *et al* (1985) describe an approach to disaggregate the average sediment yields between the months of the year, based on the total monthly surface runoff in the sub-catchment. This approach was used for the Amatole case study described below. They also outline an approach to use daily rainfall erosivity values to develop daily sediment yields.

Alternatively, if long-term average annual estimates of sediment and contaminants from different land uses are adequate, this temporal dissagregation is not necessary and the basic USLE and delivery ratio application will suffice (McElroy *et al*, 1976).

It should be noted that sediment yield estimates include suspended solids, settleable solids and bedload, and that a large portion of the total annual sediment load occurs during a couple of storm events, which are often missed by routine grab-samples. Therefore, loads estimates from observed suspended solids data tend to be only 20% to 35% of the sediment yield, because this is only a portion of the sediment load and there is a under-measurement bias in the grab-samples.

Nutrients and Organic Matter

Generalised loading functions for nutrients and organic matter are based on a separate estimation of the dissolved and solid phase fractions. This may be on a monthly or annual basis, depending on the temporal resolution selected. Thus, all the following equations may be annual or monthly, with estimates of the hydrology and sediment yields being at the same time step.

Dissolved fraction

Dissolved inorganic nitrogen or soluble phosphorus nutrient load (LDN) is largely associated with surface washoff from different source areas in a sub-catchment (Mills *et al*, 1985). It is estimated as the product of the surface runoff depth from source area (j), its area (A_j) and the average dissolved concentration of that nutrient in surface runoff from that land use (β_j):

$$LDN \quad = \quad \sum_j \{ \beta_j . A_j . \text{Surface Runoff}_j \}$$

This equation may be extended to include a load from baseflow, particularly where these is considerable nutrient input directly to the surface water resource, such as with human settlements and livestock grazing areas. This load may be estimated as the product of the baseflow depth, the sub-catchment area and the observed average dissolved concentration in baseflow from that sub-catchment where this is available. Alternatively, an area weighted average of the typical average dissolved baseflow concentration of that nutrient (α_j) for each land use may be used. This results in the following loading function:

$$LDN = \sum_j \{ \alpha_j A_j \text{ Baseflow} \} + \sum_j \{ \beta_j A_j \text{ Surface Runoff}_j \}$$

Table 4.G.1 presents typical ranges of values for α and β associated with different land uses in South Africa, based on a synthesis of values from Pegram et al (1999), Novotny and Olem (1994), Mills et al (1985), together with a number of South African studies.

Table 4.G.1 Nutrient loading concentrations (mg/ℓ) for rural land uses.

Land use type	Nitrogen		Phosphorus	
	baseflow (α)	surface (β)	baseflow (α)	surface (β)
Undisturbed	0.01 - 0.03		0.005 - 0.02	
- grassland		0.1 - 0.5		0.01 - 0.03
- woodland		0.05 - 0.15		0.05 - 0.02
Livestock	0.05 - 0.1		0.01 - 0.03	
- extensive grazing		0.5 - 1.5		0.02 - 0.1
- intensive pasture		3.0		0.05 - 0.3
Crops	0.05 - 0.5		0.01 - 0.02	
- fallow		2.5		0.1
- active		1.5 - 3		0.1 - 0.3
Forestry	0.01 - 0.02	0.1 - 1	0.005 - 0.01	0.01 - 0.03
Settlements[1]				
- rural traditional	0.1 - 1	0.5 - 4	0.02 - 0.05	0.05 - 0.2
- informal	1 - 5	2 - 20[2]	0.05 - 0.5	0.05 - 1

[1] Urban areas have not been included in this loading function, because they are addressed below.
[2] A large portion (20% - 70%) of the dissolved nitrogen from informal settlements is ammonia.

Solid phase organic nitrogen and particulate phosphorus nutrient load (LSN) is associated with sediment yield. The solid phase nutrient concentration in eroded soil is generally larger than in-situ, because the lighter organic matter and clay particles with which nutrients are associated are more readily eroded than heavier sand and silt. This process is referred to as enrichment, and is represented in loading functions by an average nutrient enrichment ratio (en). Enrichment ratios are event-specific, ranging from about 1 for large storms that erode all particles to about 3 for small storm events, with an typical long-term average value of about 2 (Mills *et al*, 1985).

Solid phase

The solid phase nutrient loading function is thus the product of the enrichment ratio, the mass concentration of the solid phase nutrient in the soil (γ_j) associated with source area (j) and the sediment yield (S_j).

$$LSN = (en) \sum_j \{ \gamma_j S_j \}$$

The solid phase nutrient concentration (γ_j) in the soil should be based on local measurement, where possible. This may be based on sampling of the in-situ soil or existing local soil surveys, or alternatively through sampling of sediment deposited in fields or drainage channels. If sediment samples are used, this already reflects the nutrient enrichment and the enrichment ratio is set to 1.

Where local observation is not possible, general soil surveys may be used. Organic nitrogen concentrations may be estimated at about 5% of the organic matter, while particulate phosphorus is 44% of the P_2O_5 concentration in soils. Typical nitrogen content in soils is 500mg/kg to 2000mg/kg, while typical phosphorus content is between 250mg/kg and 1000mg/kg.

The equations presented above may be used to estimate monthly or annual nutrient loads from different land use related source areas. A distinction can be made between source areas with the same land use, but different natural characteristics (eg. soils), by specifying them differently in sediment yield and/or hydrological modelling.

LOADING FUNCTIONS IN THE AMATOLE SYSTEM

Objective of this Assessment
Nutrient loading functions were used for the Amatole System Analysis, to estimate the phosphorus load from different land use types as input to a monthly river-reservoir model. This enabled the identification of those land uses that were causing eutrophication problems in Laing and Bridle Drift dams, as well as the prediction of the impacts of future land use changes in the catchment. As such, it assisted the evaluation and prioritisation of non-point source management needs, as well as the planning of future water resource development options in the Amatole system.

Application
The analysis was done for ten land use types in 18 sub-catchments throughout the Amatole system. The System Analysis monthly flow sequences were used to drive the loading functions, because the results needed to be consistent with the system analysis. This hydrology had been separated into surface runoff and baseflow using the WQT model. The surface runoff was further disaggregated between the land use types, based on relationships derived from their SCS curve numbers. The USLE was applied for sediment yields, and these were used together with the disaggregated hydrology to determine phosphorus loads, which were input to the river-reservoir model. All parameters were derived using literature values, but were modified slightly to match observed system response. Pathogen loading functions were also applied.

Key Results
The analysis indicated that the sub-catchments with rural, informal or urban settlements contributed the greatest phosphorus load, and that about 80% of this load stemmed from these settlements. Crop production accounted for the remaining load and was dominant in the sub-catchments with few settlements.

Limitations
Although the analysis identified the major contributing sources, it is not able to distinguish between production and delivery processes, or the relevant land use activities associated with these land uses. Therefore, while it can predict the impact of future development and may be used for prioritisation of sources, it cannot assist in the selection of management interventions to mitigate these impacts. The increased complexity of the model also requires more time than the simpler scoping techniques, but less than the detailed process models (section 4.I). Selection of loading function coefficients also requires an analyst with an understanding of non-point source processes and impacts.

References
Pegram, GC (1999) “Models which disaggregate catchment processes” in *Development of a non-point source assessment guide: Test case studies*. G Quibell (ed), WRC Report No. 696/2/01, Pretoria.

If only total nutrient load estimates are required for rural agricultural modelling, only the solid phase fraction needs to be estimated (McElroy *et al*, 1976). This is not recommended for modelling rural and informal settlements, where the dissolved fraction is relatively high.

Dissolved and solid phase nutrient loads can be combined to provide total nutrient loads. Loading functions do not attempt to describe the adsorption-desorption dynamics between the dissolved and solid phases. This requires complex distributed phase simulation, which may be done using the models presented in Section 4.I. However, it may be estimated that available (adsorbed) phosphorus ranges from 5% to 10% of the particulate phosphorus, while the available (adsorbed) nitrogen ranges from 3% to 8% of the solid phase nitrogen.

Organic Matter The loading function for organic matter is similar to the solid phase nutrient equation, consisting of an organic matter enrichment ration, the organic matter concentration in the soil, and the sediment yield from a source area (McElroy *et al*, 1976). The organic concentration in the soil should be obtained from local sampling, where possible, otherwise the approach used for estimating nutrient concentration should be used. The typical range in organic matter content of soils is between 1% and 5%. The organic matter enrichment ratio varies from 1 to 5, with higher values being associated with sandy soils.

Pathogens Although pathogen impacts are associated with concentrations, and loading functions are more suited to estimating load, loading functions may be used to provide estimates of non-point pathogen yields from livestock grazing and informal settlements. Similar processes govern pathogen mobilisation and delivery and sediment yield. Therefore, loading functions of the type used for solid phase nutrients may be used for pathogens. A representation of the pathogen load (LP) is based on the product of the *E.coli* mass concentration in the sediment and the sediment yield. There is no literature available on pathogen concentrations in soil and the associated enrichment process, so the enrichment ratio approach is not used.

$$LP = \sum_j \{ \eta_j . S_j \}$$

Table 4.G.2 Typical order of magnitude of *E.coli* loading concentrations.

Land use type	*E.coli*	
	baseflow (α) (MPN/100ml)	sediment (η) (MPN x 10^6/kg)
Undisturbed	0	10^{-2} - 10^{-1}
Other land use	0	10^{-1} - 1
Livestock - extensive grazing - intensive pasture	 10 - 10^2 10^2	 1 - 10 10
Settlements[1] - rural traditional - informal	 10^2 - 10^3 10^3 - 10^4	 10 - 10^2 10^2 - 10^3

It should be noted that this indicates the delivery of pathogens to the surface water as an average over a month, and the corresponding concentrations are, therefore, an average. Furthermore, it does not address the issue of pathogen die-off during delivery to and transport within the surface water. This approach should, therefore, only be interpreted as providing an indication of the relative importance of different source area contributions to pathogen contamination, rather than as a detailed pathogen modelling technique, which would be presented in Section 4.I.

The pathogen loading function may be extended to reflect the direct contamination from animal and human use of rivers, by adding a baseflow load contribution, as with the dissolved nutrient loading function. Table 4.G.2 presents general ranges in E.coli concentrations in baseflow and sediment yield for various land uses.

Other Loading Functions

McElroy *et al* (1976) and Mills *et al* (1985) propose a number of similar loading functions for other water quality concerns in rural catchments. Although these have not been applied in South Africa, they potentially provide useful non-point source assessment techniques for screening level evaluation.

Pesticides

The solid phase loading function form may be used for estimation of insoluble pesticide loading from large catchments (McElroy *et al*, 1976), based on general data about average soil pesticide concentrations. However, this is not particularly accurate and does not reflect the importance and temporal variation of pesticide application.

Mills *et al* (1985: pg 191) present a relatively simple pesticide runoff model that treats pesticide as a distributed phase substance and performs a mass balance in the surface centimetre of soil. It takes account of pesticide application and decay rates, and uses a simple partition coefficient to estimate the dissolved versus adsorbed portion of pesticide in the surface centimetre of soil. The dissolved and adsorbed fractions are then distributed into the surface runoff and sediment yield for a particular storm event as estimated using the daily SCS curve number and USLE approaches discussed above. This model is not presented here, as it is more detailed than the other loading functions.

Metals

McElroy *et al* (1976) propose two methods of estimating heavy metal loadings. The first is similar to the solid phase nutrient loading function, assuming that most metals from rural areas are strongly bound to the soil matrix, and are either naturally occurring or are applied in metal-based pesticides. McElroy *et al* (1976) present typical metal concentrations in soils throughout the USA, but South African data would be required to apply this approach. It is assumed that no metal enrichment occurs.

The second method is used to estimate total heavy metal or radiation loads (LM), usually from mines or mine dumps. The approach is to add the contributions from a number of sources (j), for which average concentrations (Cj) and discharge (Qj) are known. This approach may be simplified if a number (n_j) of sources with similar characteristics can be grouped. This is intended as a high level screening tool to focus further analysis.

$$LM = \sum_j \{ n_j Q_j C_j \}$$

Acid mine drainage

A similar approach has been used for estimating the acid loads associated with sulphate discharge from heavily-mined areas. It is based on the total number of sources (N), the distribution and the associated acid loading factors for active underground mines, active surface mines, inactive underground mines and inactive surface mines, and the neutralisation capacity (alkalinity) of the receiving surface waters (McElroy *et al*, 1976). The loading function was developed for the distribution of mines in the Monongahela River in the USA, and the load index values translate this for other distributions.

$$LA = N [Ka (I_{au} + I_{as} + I_{iu} + I_{is}) - Kb.Q_r.C_{alk}]$$

where: Ka and Kb — acid generation and alkalinity neutralisation rates, with mean values of 130kg/day and 0.15kg/day, respectively.
I_{au}, I_{as}, I_{iu}, I_{is} — load index values (McElroy *et al*, 1976; pg 143).
Q_r — average annual runoff depth in the catchment (cm/year).
C_{alk} — concentration of average background alkalinity (mg/l).

Salinity from irrigation

The salt loading function for return flow is based on the steady state condition where salts applied through irrigation in any period are assumed to be returned in drainage during that period (Mills *et al*, 1985). Return flow salt concentrations are thus the irrigated salt concentration scaled by the ratio between the quantity of irrigation water applied and the quantity returned. The estimation of return flow is based on estimates of the efficiency of the irrigation system, the crop evapotranspiration, precipitation and the irrigation supply. The impact of a number of irrigation areas on the surface water resources is then a mass balance of the salt load in the river and the decreasing volume.

Background Contributions

Background loadings are those that would have occurred under pristine land use conditions, with limited impacts from humans. Their estimation is important for the prioritisation of non-point sources, particularly in terms of their potential manageability. Background conditions may be estimated using any of the above techniques, but applying them for the natural undisturbed land use conditions. This is particularly applicable to sediment, nutrients and organic matter, for which a large portion of the load may be from background contributions. However, this approach is also relevant for the loadings of pathogens and metals.

An alternative approach is to use iso-pollutant maps or regional estimates of background conditions. The development of this type of information is currently being attempted for the definition of the quality component of the ecological Reserve, under the National Water Act. The approach is based on the definition of ecoregions for which natural quality conditions are to be estimated. Once this has been done, it would be possible to combine the concentration estimate with the WRSM90 streamflow estimates to get a preliminary estimate of the background load in a quaternary sub-catchment.

This stream- to- source approach does not provide a direct indication of the relative contribution from different sources. These may be estimated as an equivalent unit area contribution (i.e. total load divided by catchment area) times the area of each “source”. Alternatively, the estimated load may be disaggregated between “source areas” with different natural vegetation types and natural physical characteristics, based on relative areal loading rates calculated by using simple load estimation techniques applied to natural conditions (Sections 4.F and 4.G).

Urban Potency Factors

Non-point source contamination from urban areas differs from rural areas due to the high percentage of impervious areas (i.e. roofs, streets, etc) and hardened pervious surfaces (i.e. pathways, open areas, etc). This results in increased surface runoff and washoff of accumulated contaminants. Urban loading functions assume that the impact from urban pervious surfaces is relatively insignificant, and thus they focus on impervious surfaces (see the Background discussion on potency factors). They are most appropriate in formal residential, commercial and industrial areas, but could potentially be applied to the more dense informal areas, if parameters are developed. Mills *et al* (1985) propose annual and event (continuous) loading approaches, both of which are presented below.

Annual loading

For the annual urban loading function, the load (LU_j) from a particular urban land use (j) is the product of the area (A_j), a concentration factor (α_j) in $kg.ha^{-1}.cm^{-1}$ of rain, a population density function (F_j), street cleaning factor (γ_i) and the annual precipitation (P) in cm. The total urban load is then the sum over all the land uses (source areas).

$$LU = \sum_j \{ A_j \alpha_j F_j \gamma_j \} P$$

The population density function for formal residential areas is $0.142+0.134\,(PD)^{0.54}$, with PD in people per hectare (i.e. ranging from 0.8 to 2.5 at typical densities) while it is 1.0 for commercial and industrial land use. The street cleaning factor is 0.2 times the cleaning interval (in days). Average concentration factors for different formal urban land uses are presented in Table 4.G.3, from Mills *et al* (1985). Unfortunately, equivalent values have not been developed for informal settlements in South Africa.

Table 4.G.3 Contaminant concentration factors for annual urban loading.

Land use type	BOD_5	SS	PO_4	N
Residential	0.35	7.2	0.015	0.058
Commercial	1.41	9.8	0.033	0.131
Industrial	0.53	12.9	0.031	0.122
Other developed	0.05	1.2	0.004	0.027

Surface runoff

The event loading functions, which may be used to provide continuous daily loading time series, are based on accumulation and washoff of sediment, with adsorbed contaminants. Total daily surface runoff (Q) is needed to estimate sediment washoff. This may be calculated according to the urban SCS curve number approach, or a simple depression storage model that distinguishes between impervious and pervious surfaces. The latter calculates runoff (Q) as a runoff coefficient (cr_i or cr_p) times the excess precipitation (P) after the depression storage (DS_i or DS_p) has been filled:

$$Q = cr_i\,(P - DS_i) + cr_p\,(P - DS_p)$$

A mass balance is performed on the depression storage, which is increased through evaporation. The maximum depression storage is typically 1.5mm and 6mm for impervious and pervious areas, respectively. The runoff coefficient is typically 0.9 for impervious areas and 0.15 for pervious areas. Alternatively an area weighted average may be used in the above equation.

Sediment

Daily sediment accumulation is assumed to be proportional to the street curb length per unit area (Cl_j) and an accumulation rate (z_j) for each urban land use (j). McElroy *et al* (1976) present various methods for estimating curb-length (i.e. typically twice the street length), the most reliable of which is measurement of aerial maps or plans. Typical curb-lengths in South Africa range from about 0.15km/ha in suburban areas with population densities of around 25 people per hectare, to 0.3km/ha for densely populated areas with more than 150 people per hectare. Commercial and industrial areas typically have curb-lengths of about 0.25km/ha. Typical sediment accumulation rates are presented in Table 4.G.4, based on Mills *et al* (1985: pg 226). This approach is commonly used to estimate the non-point source impact from highways.

Table 4.G.4 Typical urban sediment accumulation rates and potency factors.

	Residential	Commercial	Industrial	Roads
Sediment accum. ($kg.km^{-1}.d^{-1}$)	48 - 66	69	127	69
BOD_5 (mg/kg)	9200	8300	7500	2300
Kjeldahl nitrogen (mg/kg)	1700	1100	1400	160
Nitrate (mg/kg)	50	500	60	80
Phosphate (mg/kg)	900	800	1200	600
Cadmium (mg/kg)	3.0	4.2	4.0	
Chromium (mg/kg)	192	225	288	80
Copper (mg/kg)	93	133	128	120
Iron (mg/kg)	20 600	23 300	21 800	
Lead (mg/kg)	1430	3440	2780	12 000
Manganese (mg/kg)	392	397	490	
Nickel (mg/kg)	28	48	41	190
Zinc (mg/kg)	350	520	368	1500
E.coli ($MPNx10^6$/kg)	16	6	4	1

The total accumulated sediment on each land use (j) at the end of a day (X_j) is equal to the total at the beginning of the day (X_{oj}), plus the daily accumulation, but minus any sediment washoff (Y_j) or removal through street cleaning on that day. Street cleaning is based on an efficiency (e) associated with the cleaning technique, and typically ranges from 10% of sediment for hand sweeping and up to 40% for mechanical sweepers. This results in the following mass balance loading equation:

$$X_j = X_{oj} + Cl_j.z_j - Y_j - e.X_{oj}$$

The percentage of accumulated sediment that is washed off during any day is assumed to be exponentially related to the daily surface runoff (Q_j) during that day, which has been empirically observed to be:

$$Y_j = [\ 1 - \exp(-1.8\ Q_j)\ ]\ X_{oj}$$

Contaminants and potency factors

Urban contaminant loadings from each land use are calculated using potency factors (c_j) on the sediment yield (Y_j). This equation is used for both dissolved and solid phase contaminants, because the assumption is that these are all washed off the impervious surfaces together. The total load (LU) of a contaminant from an urban catchment is the sum of the unit loads from the individual land uses in the area times their areas (A_j).

$$LU = \sum_j \{\ A_j\ c_j\ Y_j\ \}$$

Table 4.G.4 presents typical North American potency factors, derived from Mills *et al* (1985) and Novotny and Olem (1994). These potency factors are used in many of the process models described in Sections 4.H and 4.I.

ESTIMATING LEAD WASHOFF FROM PIETERMARITZBURG

Objective of this Assessment

A sediment and lead accumulation and washoff analysis using potency factors, was conducted on central Pietermaritzburg, in order to evaluate the approach under South African conditions and to develop a method to produce long-term lead washoff from the urban area to evaluate the potential severity of this problem. This was conducted as part of the evaluation assessment for the Mgeni Catchment Management Plan.

Application

Runoff volumes and lead concentrations had been observed at the stormwater outflow from central Pietermaritzburg. The event-based urban loading function approach was applied to a single 3mm runoff storm event. There had been 4 days of accumulation after a previous large storm which was assumed to have "cleaned" the surfaces. The area is 50% residential, 40% commercial and 10% industrial, with an average curb length of 0.25km/ha. There was no information about street sweeping in the area.

Key Results

The storm was estimated to have washed 30% of the accumulated material, which was equivalent to 22kg/ha of sediment and 52g/ha of lead. This was equivalent to a sediment concentration of 733 mg/ℓ and an associated lead concentration of 1.7 mg/ℓ. The average sampled concentrations were 244mg/ℓ for suspended solids and 0.57mg/l for lead, which are about one third of the simulated values, but with similar solid:lead ratios. However, observed suspended solid loads typically underestimate sediment yields, averaged storm samples often underestimate loads, and no sweeping was assumed. Therefore, the results were realistic and illustrate the potential usefulness of the potency factor approach in estimating urban loading, particularly as there is no calibration required.

Limitations

Potency factors are a simplified representation of the production and delivery processes governing urban washoff. They assume that contaminant washoff is proportional to sediment washoff, which may not be appropriate for substances that are predominantly in the dissolved phase. However, simple management practices may be evaluated, so potency factors may be used for preliminary selection assessment.

References

NSI (1996) *Pollution Sources.* Mgeni Catchment Management Plan. DWAF Report WQ U200/00/0913. Pretoria.

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4H. SIMPLE PROCESS MODELS

Background

Simple process models use simplified deterministic representations of the processes governing non-point source production and delivery. They simplify the representation of interactions between hydrology, sediment yield and contaminant loads, but require the development of computer code to represent the more refined process, temporal and/or spatial detail. These models usually consist of separate hydrological, sediment and water quality modules that are simulated in a sequential manner, starting with the hydrology followed by the sediment transport and finishing with pollutant transport, because pollutant and sediment fluxes are dependent on the water flows. However, this increased complexity generally implies greater data requirements.

Simple process models are usually oriented towards either urban or rural land use, because the important processes governing non-point source impacts differ considerably. However, some of these models can simulate non-point source impacts from mixed catchments, because they have urban and rural modules. Many of these models estimate contaminant washoff using potency factors (see Section 4.G).

☞ WHAT ARE SIMPLE PROCESS MODELS

Assessment Aims
Estimate continuous time series of non-point source contamination, under current and/or future conditions, and to understand the causes of these impacts, top support evaluation and prioritisation, and to a lesser extent selection and assessment.

Approach
Simplified deterministic representation of the processes and interactions governing hydrological, sediment and contaminant washoff, using sequential modules within computer models.

Characteristics
Various models are available to model the various non-point source concerns in urban and/or rural catchments. They may be transferable through the use of physically-based parameters, but usually benefit from calibration where local data are available.

Requirements
Extensive time series data for model input, calibration and verification. Use under similar conditions to assist with parameter selection, and analyst's experience. These models are time intensive, and should only be used where adequate resources are available.

Limitations
These models simplify the representation of processes governing non-point source impacts and cannot differentiate between the activities causing impacts from a particular non-point source. Furthermore, the parameters may not have physical meaning and thus need to be calibrated.

A number of operational computer models have been developed over the past three decades. To be operational, a model should have a documented user manual and background theory, should be supported by the developer or an institution, and should have been applied and verified (Donigan and Huber, 1991).

Simplified process models often have fairly complex hydrological process simulations, but are described with this group if they simplify sediment and/or contaminant washoff processes. This section provides an overview of the simple process models that have been applied in South Africa, and thus have relevant case studies as well as some level of local expertise. Only a brief evaluation of the models is provided, with an indication of appropriate case studies. Table 4.H.1 summarises the important characteristics of these models, particularly in terms of:

- the land use simulated,
- the water quality concerns simulated,
- whether water quality data are required for calibration or verification,
- whether South African specific parameters are available and have been tested,
- whether future scenarios can be simulated; and
- whether best management practices (BMPs) can be evaluated.

Table 4.H.1 Summary of model characteristics.

Model	Land use[1]		Quality[2]						Data needs		Future scenario	BMP
	U	R	SS	N	P	S	M	O	WQ	SA		
STORM	✔		✔	✔	✔					✔	✔	✔
SWMM	✔		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
ACRU-NPS	✔		✔	✔			✔			✔	✔	✔
HSPF	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
PEXPM	✔			✔						✔	✔	✔
PEM		✔	✔	✔					✔	✔		
DISA		✔				✔				✔	✔	✔
WQT	✔	✔				✔			✔	✔	✔	

[1] Land use may be urban (U) and/or rural (R)

[2] Quality constituents include sediment (SS), nutrients (N), pathogens (P), salinity (S), metals (M) and others (O) including toxic organics.

[3] The data needs are evaluated in terms of the requirement of water quality needs for calibration (WQ) and the availability of South African specific parameters (SA)

Generic Sediment Yield Estimation Techniques

Simple process models are generally based on fairly detailed hydrological simulation, an empirical sediment washoff module and potency factors for other contaminants. Detailed descriptions of the various hydrological modelling approaches are not provided in this non-point source document, while the potency factor approach was outlined in Section 4.G. Sediment yield simulation in simplified process models are generally based on the following approaches, some of which have been outlined in section 4.G:

USLE The Universal Soil Loss Equation estimates annual soil loss per unit area (X), based on factors representing the rainfall erosivity (R), the soil erodibility (K), the topography and drainage density (LS), the land use cover (C) and management practice (P).

$$X = R.K.LS.C.P$$

The USLE is the most widely used empirical sediment yield model for pervious areas, and has been extensively used in South Africa. The basic equation has been updated in the Revised USLE (Renard et al, 1991), which has improved the estimation of the erodibility and slope-length factors. The Modified USLE (Williams and Berndt, 1977) allows the simulation of sediment yield for different events, by replacing the rainfall erosivity factor by a surface runoff factor, and is thus suited to continuous sediment modelling. Lorentz and Schulze (1995) provide a thorough overview of the application of the USLE, RUSLE and MUSLE in South Africa. Thus, process models that are based on the USLE and its extensions do have parameters available for South African conditions.

Negev model

The Negev sediment generation model (Negev, 1967) simulates generation and transport of sediment from rural areas. The fine soil particles (silt and clay) produced by raindrop impact during a time period (A_t) are a function of the land cover fraction during the growing season (COV), a soil property factor (K_N), and the precipitation during the time period (P_t) to a power (RER):

$$A_t \quad = \quad (1 - COV) \, . \, K_N \, . \, (P_t)^{RER}$$

These particles are available for transport if surface runoff ($ROSB_t$) occurs during the time period, otherwise they accumulate in the reservoir of fine particles ($SRES_t$) which is available for subsequent periods. The delivery of particles (SER_t) is estimated as a function of these variables, a transport factor (KSER) and a power factor (SR):

$$SER_t \quad = \quad KSER \, . \, SER_{t-I} \, . \, (ROS_t)^{SR}$$

General parameters for this model have not been developed, and its application requires calibration against extensive data. Furthermore, it has only been used in a limited number of case studies as part of HSPF in South Africa, which reduces its general applicability for sediment modelling.

Sartor model

Sediment washoff from impervious urban areas may be described by the empirical model developed by Sartor and Boyd (1972). This is based on a first-order particle removal approach, which integrates to:

$$P_t \quad = \quad P_o \, [\, 1 - \exp(-k_u.r.t) \,]$$

P_t is the mass of solids removed during time (t), P_o is the mass of accumulated solids at the start of the event, k_u is the washoff coefficient related to the street surface characteristics and r is the rainfall intensity. This approach is widely used in urban non-point source models, and is the basis of the urban model described in Section 4.G. The physical basis of this approach makes it applicable for formal urban areas in South Africa, although further research is required to verify the accumulation and washoff rates that are proposed for North American applications.

STORM

Storage, Treatment, Overflow, Runoff Model is a lumped parameter continuous simulation model, which was designed for the US Army Corps of Engineers (HEC, 1977), primarily for application to small urban watersheds. The hydrologic model is based on the SCS curve number approach or the rational method, with unit hydrograph methods to produce hourly runoff. Particulate matter is accumulated on impervious areas at a constant rate and washoff is based on Sartor's model. Soil loss from pervious areas is computed by the USLE, with a delivery ratio. BOD, orthophosphate, nitrogen and total coliforms are assumed to be transported with particulate matter, so potency factors are multiplied by the sediment loads.

STORM also simulates the delivery process associated with the storm water drainage system (without routing or decay), and allows the representation of 100% treatment or storage, particularly for combined sewer systems. It therefore supports the selection of certain management interventions for urban storm water washoff. Unfortunately, there is no freely available operational micro-computer version and it has not been applied in South Africa. Nevertheless, it does provide a useful approach for quick evaluation of the impacts of urban non-point source washoff.

SWMM

Storm Water Management Model is an urban runoff simulation model designed for the US EPA (Huber and Dickenson, 1988), which provides high resolution (i.e. minutes) continuous or event-based simulation of complex storm water systems. Either sewered and unsewered areas can be described, with simple non-linear reservoir or detailed distributed hydrological modelling of areas flowing into a sewer collection point and sophisticated hydraulic simulation of drainage networks. The rainfall-runoff process is based on a nonlinear reservoir approach. The model allows simulation of backwater effects, surcharging and looped sewers, as well as groundwater infiltration.

The USLE is used to estimate soil loss from pervious areas, while Sartor's sediment accumulation and washoff model is used for impervious areas. Most constituents can be modelled, with loads being derived using potency factors on the sediment or a statistical rating curve approach related to a power function of the flow. Routing and first order decay may be simulated during delivery, as may the effect of various storm water storage and treatment devices. In summary, SWMM is a useful urban stormwater model that may be used to evaluate the quality of washoff from formal urban areas, as well as to support the selection of storm water delivery management interventions.

During 1999 the Cape Metropolitan Council accepted SWMM as the model of choice for Cape Town's urban river management initiatives, and its water quantity implementation was being tested at the time of writing. Unfortunately, at the time of writing no comprehensive test of water quality modules was in the offing.

ACRU-NPS

ACRU was originally developed as a detailed process hydrological and water quality model for predominantly rural catchments in South Africa (see Section 4.I). Recently, Schmitz and Villiers (1997) have extended ARCU to use within-day synthetic rainfall distributions to enable the development of runoff hydrographs from urban areas. The possibility for sub-daily simulation of solids, nutrients and metal loads from urban areas has been developed, and is called ACRU-NPS. It also allows the simulation of single storm events, following the original SCS Curve Number approach.

The urban component is based on the accumulation and washoff from pervious surfaces and impervious surfaces, using the equations from SWMM. This model has been applied to the Palmiet catchment in Durban (see case study below), using parameters derived from the Pinetown catchment monitored by Simpson (1986), to which the model was applied for eleven storm events. Thus ACRU-NPS provides a South African model for estimating non-point source washoff from urban areas, either alone or as part of a mixed catchment assessment with the rural components of ACRU.

EXPORT LOADS FROM THE PALMIET CATCHMENT (ACRU-NPS)

Objective of this Assessment
To estimate the daily catchment export of a number of constituents, in order to evaluate the modelling approach for a mixed land use catchment. Although this was primarily a research application, it provides storm-related information of the export load associated with particular storm events, which may be used to prioritise time periods requiring management attention and to predict the impact of land use changes on catchment export.

Application
The ACRU-NPS model was applied to the 20.3 km^2 Palmiet River catchment, for daily simulation of a number of water quality constitutents, over a period of two years. The catchment has 11.6 km^2 residential, 4.6 km^2 open space, 2.4 km^2 industrial and 1.7 km^2 commercial areas, from which COD, nitrogen, suspended solids and various metals were simulated.

Key Results
Total catchment export values were presented in kg/ha/day for ten selected storm events. A reasonable correlation was obtained between simulated and observed values, except for nitrogen and chromium.

Limitations
The application does not provide a breakdown of the contributions from different land use types, although it may be possible to apply the model seperately to smaller more homogeneous areas, as with the general ACRU model. It may be used to simulate the storm pollutograph when applied to a largely impervious urban catchment with detailed rainfall data, as was done for the Pinetown catchment (presented in the same report). As with all urban models, selection of appropriate accumulation rates is critical to the simulation, which requires an experienced analyst and/or detailed information for calibration.

References
Schmitz, PMU and G du T de Villiers (1997) *The development of an urban component of the ACRU model*. WRC Report No 424/1/97. Pretoria.

HSPF

Hydrological Simulation Program-Fortran was developed by Hydrocomp (Bricknell *et al*, 1993) as a comprehensive package for hydrological and water quality simulation in urban and/or rural catchments. It is a lumped parameter continuous simulation model, adapted from the Stanford Watershed Model IV that can be used to simulate both catchment hydrology and streamflow. Channel routing is based on the kinematic wave approximation. HSPF models sediment yield from pervious areas using Negev's model, while Sartor's model is used for impervious surfaces.

Two alternative approaches can be employed in HSPF to estimate contaminant loads: either via potency factors (described here) or via detailed adsorption-desorption algorithms (described in Section 4.I). Potency factor contaminant load simulation in HSPF (Donigan & Crawford, 1976) is typically used for urban catchments. Washoff of other contaminants is simulated using potency factors on sediment yield. HSPF is a comprehensive model and has extensive data needs, both for input as well as for calibration. Many of the parameters are not physically based, and thus the model needs to be calibrated with local data, which limits its use in data poor situations.

Nevertheless, HSPF provides a tool for evaluating the impacts of non-point source washoff in predominantly urban catchments, particularly where instream transport must be considered. It is also viable in rural (agricultural) catchments, but in this situation the potency factor approach makes it more appropriate for adsorbed contaminants. However, when it is used in its more detailed form (originally known as HSPF-ARM - see Section 4.I) for rural catchments, HSPF can be a powerful non-point source simulation model.

NUTRIENT LOADING IN THE BERG CATCHMENT (HSPF)

Objective of this Assessment
HSPF was applied to a range of smallish gauged catchments in the Berg River Basin to compare the reliability of its PO4 load predictions (via calibrated potency factors) against those of other simpler models, as well as the robustness of its parameters for transfer to ungauged areas.

Application
The model was run at a daily resolution,i.e. daily rainfall and evaporation data were used as input . Calibration of the hydrological, sediment and water quality parameters occurred at both daily and monthly resolution and against monthly flow-weighted infilled loads.

Key Results
The calibration of the hydrological parameters was relatively unsuccessful owing to a poor distribution of daily rainfall station locations. This made evaluation of the PO4 simulation not feasible. The impression was gained, however, that the calibration of the simpler water quality option in HSPF would follow relatively easily once the hydrological calibration was under control.

Limitations
Unless calibration parameters happen to be available already, this application appears to be mainly viable in situations with appropriate rainfall input data and suitable streamflow water quality information to allow detailed calibration.

References
Matji MP and Görgens AHM (1999) “A comparative study of phosphorous production simulation models in rural catchments of the Western and Eastern Cape”. Ninth SA Nat. Hyd. Symposium, Western Cape, 29-30 November, 1999.

PEXPM

This model has been specifically designed for application to informal urban areas in South Africa (Hughes and Van Ginkel, 1993). Runoff calculations are based on the SCS formulation, applied to pervious, connected and unconnected impervious areas. Phosphorus yield is based on a budgeting approach where daily inputs are specified according to a socio-economic survey of the area, and output is related to the relationship between rainfall and runoff and the quantity of phosphorus stored on the land surface. Phosphorus export is not related to sediment transport and does not provide estimates of dissolved phosphorus. It also requires a socio-economic survey of the settlements in the catchment. Unfortunately, the model has not been verified on any monitored catchments, even though it has been applied in South Africa, in Botshabelo and five settlements in the Buffalo River catchment.

PHOSPHORUS LOADS IN THE BUFFALO CATCHMENT (PEXPM)

Objective of this Assessment
To estimate the distribution of total phosphorus loads from five settlements in the Buffalo River catchment, in order to compare these to point sources and other catchment inputs to Laing and Bridal Drift Dams and, thereby, to prioritise management attention.

Application
The model was applied to three predominantly urban township settlements (Ilitha, Mdantsane and Zwelitsha), a rural village (Mlakalaka) and an informal settlement (Needs Camp). The phosphorus budget was calculated based on detailed socio-economic surveys of activities contributing to phosphorus accumulation on pervious and impervious surfaces in these settlements, inculding waste disposal, water supply and sanitation, livestock, crop production and informal economic activities. The washoff function for accumulated phosphorus was developed according to the rainfall pattern for the area.

Key Results
The model indicated that phosphorus is washed off by infrequent large rainfall events, and that phosphorus storage accumulates up to 400% of the average annual input. The median annual loading from these settlements was about 60% of the annual phosphorus input, and ranged from 18 kg/ha/a from Mdantsane up to 201 kg/ha/a from Need Camp. Unfortunately, there were no sampled data for calibration of the simulated results, and thus they should be treated with caution, particularly as they are an order of magnitude higher than the equivalent unit area loads presented in Tables 4.F.2 and 4.F.3 (see Section 4F).

Limitations
Although the accuracy of the phosphorus loading estimates for this model may be questioned, the approach provides valuable information about the relative phosphorus inputs and export from different settlements. This may be used in potential and hazard maps (see Section 4E), and enables the identification and prioritisation of the particular activities contributing to phosphorus production within settlements.

References
Van Ginkel, CE, J O'Keeffe, DA Hughes, JR Herold and PJ Ashton (1996) *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.* WRC Report No 405/2/96. Pretoria

PEM The Phosphorus Export Model (Weddepohl and Meyer, 1992) was developed in South Africa to simulate monthly soluble and particulate phosphorus export from non-point sources in predominantly rural catchments. It uses estimates of surface runoff from the Pitman model (WRSM90) and sediment yield from the USLE. The latter is modified to provide monthly yields based on monthly erosivity and a delivery ratio (similar to the approach outlined in Section 4.G).

Soluble and particulate phosphorus export is based on exponential relationships describing the proportion of the available phosphorus removed by surface runoff and sediment yield, respectively. These relationships must be calibrated for a catchment, using observed phosphorus and flow data. This restricts the use of the model in data-poor situations and cannot distinguish between different non-point source areas. It, therefore, cannot be used to predict future land use changes or the impact of management interventions. The approach adopted in PEM is equivalent to nonlinear loading function, which is calibrated to catchment conditions. It has been applied to a variety of catchments in South Africa.

PHOSPHORUS LOADING IN THE MGENI CATCHMENT (PEM)

Objective of this Assessment

To estimate monthly time series of phosphorus export from two predominantly rural sub-catchments (gauging stations U2H012; U2H013) upstream of impoundments on the Mgeni River, as input to a simple reservoir eutrophication model (REM).

Application

The two Upper Mgeni catchments involved were respectively 119 km^2 and 438 km^2 ,with primary land use of forestry and beef cattle production. PEM was calibrated against four years of monthly P loads which had been constituted from grab sample-based infilled daily P concentrations and observed daily flows. Infilling, by the FLUX package (Section 4D), followed a stratified sampling procedure.

Key Results

For the one Mgeni catchment a good correspondence between observed and simulated P loads was achieved, but in the case of the other catchment the goodness-of-fit of the simulated values was relatively poor. The authors ascribed this unsatisfactory result to poor sampling of the observed flows during the FLUX application, which in turn yielded unrepresentative P concentrations during infilling. The authors make it clear that application of PEM was relatively easy, but that PEM tended to over-estimate P loads during the low flow season.

Limitations

The model has to be calibrated against observed nutrient and streamflow data, and thus can only be applied to monitored catchments, or those with similar characteristics to a catchment where the model has been calibrated. No distinction is made between land use types, nor production and delivery processes, which restricts its use to scoping or coarse evaluation assessments.

References

Weddepohl, JP and DH Meyer (1992) *Utilisation of models to simulate phosphorus loads in southern African catchments*, WRC Report # 197/1/92, Pretoria.

DISA

The Daily Irrigation and SAlinity (DISA) model is a daily time step conceptual model of salt balances and flows in an irrigation scheme. The model is configured on the basis of soil texture class details, is of the capacity-limiting soil-moisture-budgeting variety (as opposed to the soil moisture tension-based variety) and portrays alluvial aquifers as one-dimensional Du Puit situations. Effective soil depths and alluvial hydraulic conductivities are set by calibration against observed streamflow salinities. DISA allows a wide variation of irrigation practices and provides the user with extensive control over efficiencies and losses. It is menu-driven and allows the evaluation of various irrigation management approaches, as well as the planning of irrigation scheme development or extension. Its primary use is to optimise the operation of irrigation systems to minimise salinity impacts on receiving surface water resources.

SALINITY IRRIGATION RETURN FLOWS IN THE BREEDE RIVER

Objective of this Assessment

This study covered both the evaluation and prioritisation assessment levels in an examination of what the salinisation impact of planned irrigation in the Middle Breede River Basin might be and what effect various management options would have.

Application

The system was configured into about sixty modelling cells according to five primary soil textural classes, including distinction between alluvial and terrace aquifer types, and for a typical hydro-meteorological data set of five years. All canals, pumps, pipelines, balancing and irrigation storage dams and intermittent artificial drainage that make up the irrigation system were volumetrically modelled, including salinity patterns in all conduits and storages. Different levels of future irrigation extensions were super-imposed in the various regions of the system and the extent of salinisation was observed. Some of the management options included increased freshening releases from the Greater Brandvlei supply dam, as well as salinity-intercepting drains which dump the return flows in the main river channel below the most downstream point in the system.

Key Results

The assessment showed clearly that, given an interim yield surplus in Brandvlei Dam, increased freshening releases could be used as a “holding” operation for a further few years while planning continued to determine the engineering feasibility of other more permanent options. However, in salinity terms, consideration of certain hard options relating to higher level canals with a single upstream intake may be inevitable.

Limitations

The model requires an external assessment of regional groundwater flow patterns that may affect the alluvial zone dynamics. Relatively detailed soil and alluvial mapping as well as irrigation system details are prerequisites for appropriate configuration, as are observed downstream streamflows and salinities.

References

Görgens, AHM, H Beuster, A Greyling and SF Forster (1991) “Application of the DISA hydrosalinity model to irrigation water supply planning in the Breede River” *Proceedings of the 5th National Hydrological Symposium,* Stellenbosch.

WQT AND NACL

WQT (Allen and Herold, 1988) is a deterministic monthly time step hydrosalinity system simulation model. The catchment washoff module simulates the accumulation and washoff of soluble solids from pervious and impervious surfaces, as well as groundwater storage and discharge, through a process of partitioning of observed or simulated streamflows (i.e. no rainfall data are used). Growth in the production of salts can also be represented. An irrigation module takes account of multiple cropping, irrigation efficiency and sub-surface storage. WQT can be linked with the system analysis Water Resources Planning Model to evaluate reservoir system operation.

NACL (Herold, 1981) is a deterministic daily time step catchment salinity simulation model. Hydrology is simulated using the Pitman model (daily version of WRSM90), while salinity is simulated as accumulation and washoff from impervious and pervious surfaces.

SALINITY LOADS IN THE UPPER/MIDDLE VAAL CATCHMENT

Objective of this Assessment
The Upper and Middle Vaal sub-catchments of the Vaal Basin provide water to the industrial heartland of the RSA. Increasing salinity due to multiple return flow re-use, as well as atmospheric deposition from thermal power stations and washoff from urbanisation, threaten the future fitness-for-use of this river system. A multi-reservoir system model at monthly resolution was configured for the whole Vaal Basin to optimise the planning and operating rules of the system. A number of salinity management options comprising blending with freshening releases from Vaal Dam, the system's main dam, were evaluated.

Application
As many of the Vaal Barrage and certain other Middle Vaal catchments are relatively small and, therefore, have short response times, the monthly resolution of the system model and WQT is unsuitable for their simulation. For this purpose, the NACL daily model was used to develop understanding of these catchments, to fill in grab sample salinity values and to provide reasonable estimates of certain salinity parameters and model configuration requirements for WQT. WQT was calibrated for a range of gauged catchments in the Upper/Middle Vaal and the salinity parameters imported into the Water Resources Planning Model for the evaluations described above.

Key Results
The calibrations were on the whole satisfactory and the system model applications yielded clear results about the benefits of different blending options.

Limitations
The model's salinity parameters do not have direct physical meaning and flow-weighted monthly salinities/loads are required for their calibration. Calibration is a process that requires a fair degree of "feel" for the model's responses and is not straight-forward.

References
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4I. DETAILED PROCESS MODELS

Background

The detailed process models attempt to describe the physical processes and interactions governing non-point source production and delivery. Like the simple process model, they are usually based on hydrological, sediment and contaminant models, but they incorporate detailed processes, such as adsorption-desorption, decay and plant uptake, into the simulation of contaminant movement and transformation in soil and water. These contaminant processes are integrated with relatively complex hydrological and sediment models.

Unfortunately, these models tend to be very data intensive and as such are limited to areas for which there has been intensive data collection. The uncertainty of *a-priori* parameter estimates can lead to highly inaccurate output estimates in unmonitored catchments where calibration and verification are not possible. However, the model parameters often have physical interpretations and can be linked to observed catchment characteristics. The requirements of these models are not usually warranted in urban situations, so detailed process models are generally oriented towards rural and agricultural land uses.

☞ WHAT ARE DETAILED PROCESS MODELS?

Assessment Aims
Simulate event-based or continuous time series of non-point source impacts, to support the evaluation and prioritisation of sources and associated activities, as well as the selection of management interventions to mitigate these impacts.

Approach
Detailed deterministic representation of the processes governing sediment and contaminant mobilisation, transport and transformation in soil and water, using sophisticated computer models.

Characteristics
Various models typically simulating a sediment, nutrient and toxic organic production and delivery from predominantly rural sources. They are often designed to evaluate the effectiveness of alternative management interventions.

Requirements
Intensive data for model input and calibration, as well as significant time, resources and analyst experience for application.

Limitations
These models can provide the most accurate estimates of non-point source impacts, but only where adequate resources and data are available. Where these are not adequate, the results may be less reliable than the simplest assessment techniques.

A number of operational computer models have been developed over the past three decades that fall in this category (Donigian and Huber, 1991). The key criteria is that these models do not simulate contaminant washoff using potency factors, as do most of the simplified models. This section provides a brief overview of the detailed process models that have been applied in South Africa, together with an indication of relevant case studies. Table 4.I.1 summarises the important characteristics of these models, in terms of:

- the land use simulated,
- the water quality concerns simulated,
- whether water quality data are required for calibration or verification,
- whether South African specific parameters are available and have been tested,
- whether future scenarios can be simulated; and
- whether best management practices (BMPs) can be evaluated.

Table 4.I.1 Summary of model characteristics.

Model	Land use[1]		Quality[2]						Data needs		Future scenario	BMP
	U	R	SS	N	P	S	M	O	WQ	SA		
WITQUAL	✔		✔	✔	✔	✔	✔		✔	✔	✔	✔
ACRU		✔	✔	✔	✔					✔	✔	✔
HSPF-ARM		✔	✔	✔	✔	✔	✔	✔	✔		✔	✔
CREAMS		✔	✔	✔				✔				✔✔[4]
ANSWERS		✔	✔	✔					✔			✔✔
SWRRB		✔	✔	✔				✔				✔✔
AGNPS		✔	✔	✔								✔✔
PRZM		✔	✔					✔				✔✔
SHEE												

1 Land use may be urban (U) and/or rural (R)
2 Quality constituents include sediment (SS), nutrients (N), pathogens (P), salinity (S), metals (M) and others (O) including pesticides.
3 The data needs are evaluated in terms of water quality needs for calibration (WQ) and the availability of South African specific parameters (SA).
4 The models with ✔✔ for BMP were specifically designed to test management interventions.

WITQUAL

WITSKM (Coleman and Stephenson, 1993) is a physically-based, variable time step, distributed continuous hydrological simulation model, using the Green-Ampt infiltration and kinematic overland flow equations, particularly for urban catchments. The catchment is split into sub-catchments which can be further sub-divided into cells which homogeneous characteristics. Runoff from these is connected to a neighbouring cell or to the storm water drainage system. The latter allows the evaluation of delivery management treatment and storage structures.

WITQUAL (Coleman and Simpson, 1996) represents the quality component of the model, which is driven by the hydrology from WITSKM. Sediment washoff is simulated separately by raindrop detachment on pervious surfaces and by accumulation and washoff from impervious surfaces, and is transported according to the carrying capacity of the surface flow. The partitioning of contaminants between the dissolved and adsorbed phase is calculated during a storm event, which leads to the estimation of the contaminant washoff dissolved in surface runoff and adsorbed to particulate matter. Decay of accumulated contaminant on the soil surface or during delivery is also simulated. This allows the effect of storm water detention facilities to be evaluated. The small time-steps used in these models require significant input data. However, where this is available, WITQUAL

provides a detailed urban simulation model that has been developed specifically for South African conditions and has been tested under conditions in peri-urban settlements (see the Shembe case study below).

WASHOFF FROM THE SHEMBE CATCHMENT (WITQUAL)

Objective of this Assessment
To simulate storm event washoff from a primarily informal settlement catchment. Although this was primarily a research exercise, it provides the basis for detailed evaluation of the response of various parts of the catchment to different storm events, distinguishing between the accumulation and washoff of contaminants.

Application
The WITQUAL model was applied to the 5.6 km² Shembe catchment, simulating suspended solids, particulate and soluble phosphorus and TDS. The catchment area is 35% informal settlement, 25% rural settlement, 11% low cost residential housing, 5% commercial and 24% unsettled. The catchment was discretised into 4 overland flow modules and 8 channels, as the basis for detailed rainfall runoff simulation. The model required calibration of hydrological parameters, as well as the solids detachment parameters, the phosphorus fraction in solids, and the phosphorus partition coefficient.

Key Results
The model provided reasonable simulation results, although it tended to overestimate the peak suspended solids and particulate phosphorus concentrations, and underestimate the soluble phosphorus and TDS concentrations at the beginning of a storm event.

Limitations
The model requires detailed rainfall records and observed runoff and quality data for calibration, either in the catchment or for a similar catchment. Although land use types are not distinguished, the discretisation of the catchment may be done to represent relatively homogeneous areas. The model provides detailed information on the physical processes governing contaminant production and delivery, and thus provides the basis for detailed evaluation and prioritisation assessments.

References
Coleman, TJ and DE Simpson (1996) *Adaptation and calibration of an urban runoff quality model.* WRC Report No. 299/1/96. Pretoria.

ACRU

ACRU is a daily time-step continuous quasi-distributed parameter simulation model developed for predominantly rural catchments in Southern Africa (Smithers and Schulze, 1995). It uses an adaption of the SCS curve number approach, in which available soil water storage depth replaces the curve number. It performs a detailed soil moisture budget, as would be expected from an agriculturally oriented model, and allows the simulation of streamflow with hydrograph routing. It also allows the simulation of runoff from connected and unconnected impervious surfaces in urban areas.

SEDIMENT LOADS IN THE MGENI CATCHMENT (ACRU)

Objective of this Assessment
To simulate sub-catchment sediment yield in the Mgeni River catchment, which also provided the basis for phosphorus and pathogen simulations. This information was used for prioritising areas for sediment management, as part of the Mgeni Catchment Management Plan (MCMP), distinguishing between sediment production (erosion) and delivery (yield).

Application
The ACRU sediment module was applied to the 4 079 km² Mgeni River catchment upstream of Inanda Dam. Daily streamflow and sediment yield was simulated from 137 sub-catchments over a 34-year period. This was based on an evaluation of soil loss potential for 65 256 grid cells of about 6 ha each, which was then averaged for each sub-catchment. The soil loss potential for these grids provided the bassis for a sediment potential map, which was also used for the MCMP.

Key Results
Simulated mean annual sediment yield ranged from 20 kg/ha to over 6 000 kg/ha, with the highest yields from the rural settlement areas on highly erodible soils and steep slopes in the Valley of a Thousand Hills. These values corresponded well to long-term impoundment sedimentation studies in the catchment. Interestingly, it was noted that the greatest yields were associated with single flood events with low recurrence intervals. Simulated sediment yields compared favourably with detailed sampling calculations. However, the phosphorus and pathogen simulations were not as good.

Limitations
The model distinguishes between sediment production and delivery, but provides estimates of sediment yield, rather than suspended solids, and will therefore tend to be higher in the long term. It also does not explicitly differentiate between land use types for the sediment yield, but this can be addressed by the sub-catchment disaggregation and analysis of the erosion potential maps. Certain agricultural management interventions can be tested through the RUSLE parameters, and thus the model provides the basis for evaluation, prioritisation and even selection assessments. However, the complexity of the model implies that experienced analysts should be used for application.

References
Kienzle, SW, SA Lorentz and RE Schulze (1997) *Hydrology and Water Quality of the Mgeni Catchment.* WRC Report TT 87/97. Pretoria.
Ninham Shand (1996) *Pollution Sources.* Mgeni Catchment Management Plan. DWAF Report WQM U200/00/0913

Sediment yield is estimated using the Modified and Revised USLE. Routines for the estimation of phosphorus and pathogen export from predominantly rural areas have been developed (Kienzle et al, 1997). Adsorbed and dissolved phosphorus concentrations in the top 10mm of soil are modelled using an adsorption process. Any inputs are added to the available store, less any washoff. During a rainfall event, the dissolved and adsorbed fractions are recalculated and the resulting concentrations are applied to the surface runoff and sediment yield to estimate phosphorus washoff. A similar approach was developed for *E.coli* loading, but at present has not been validated. Recently, an urban washoff model (ACRU-NPS) has been developed (see Section 4.H). Therefore, ACRU provides a detailed non-point source simulation model that may be applied in rural and/or urban catchments.

HSPF The hydrological and simple process modelling in HSPF was described in Section 4.H. HSPF-ARM (Donigan and Davis, 1978) performs detailed simulation of contaminant production, delivery and transport, particularly for nutrient and pesticide washoff from rural-agricultural catchments. It uses an adsorption-desorption equation to simulate the transport and partition of contaminants, and represents the volatilization, oxidation, photolysis and biodegradation of contaminants during delivery and transport, based on first-order reactions. This is a very detailed and comprehensive model of the catchment hydrological and water quality processes, which required extensive data input and calibration. The number of possible parameters implies the need for experienced analysts with an understanding of both the model and the study catchment. Unfortunately, HSPF-ARM has not been applied in South Africa using the full possibilities for nutrient or pesticide modelling, even though it has been widely used internationally. However, the hydrological components of HSPF have been applied thoughout South Africa.

CREAMS The Chemicals Runoff and Erosion from Agricultural Management Systems model (Knisel, 1980) was developed by the US Department of Agriculture to analyse best management practices. It was designed as a field scale model that simulates hydrology, sediment yield, nutrients and pesticides. It does not specifically require calibration, but this improves the simulation. Surface runoff can be estimated by the SCS curve number approach for daily data or the Green-Ampt infiltration equation for hourly data. The hydrological component has been applied to rural catchments (Mulder and Kelbe, 1991).

Sediment is modelled using the Modified USLE. Dissolved and adsorbed nutrient and pesticide concentrations are associated with surface runoff and sediment yield. The partitioning of these contaminants between the soluble and solid phase is performed using a simplified isotherm model. Biological transformation (eg. nitrification) and plant uptake of nutrients can also be simulated. The evaluation of agricultural practices is enabled in the model, such as foliar spraying, incorporation of pesticides and tillage. CREAMS is quite data-intensive and was designed to be applied to fairly homogeneous field size catchments of less than 100ha. As such, it is similar to individual source models (Section 4.J) and is not really appropriate for most large catchment applications. The SWRRB and AGNPS catchment scale models have been developed based on the CREAMS modelling routines. Unfortulately, the water quality components of CREAMS have not been applied in South Africa.

Other Models The preceding models have all been applied and verified for conditions in South Africa. However, a number of other operational models exist, which may also support non-point source assessment. Many of these were developed specifically to test and select management interventions in agricultural catchments:

ANSWERS The Areal Non-point Source Watershed Environment Response Simulation is primarily an event-oriented agricultural simulation model using the distributed parameter concept (Beasley and Huggins, 1981). The catchment is represented by uniform square (about 1-4 hectare) elements, whose hydrologic response is computed by explicit backward solution of the continuity equation. Infiltration is based on Holtan's equation, while sediment detachment is based on a modification of the USLE. Sediment detachment, transport and deposition is simulated within each cell, with the cell yield being transferred to the next cell. Nutrients are modelled using correlation relationships between chemical concentrations, sediment yield and runoff. The distributed nature of the model allows evaluation of sediment control measures to be presented spatially within a catchment. ANSWERS's event-based and data-intensive nature limits its applicability to well-monitored catchments.

SWRRB and PRS Simulator for Water Resources in Rural Basins (Arnold et al, 1990) is a continuous hydrologic simulation model, that was developed from CREAMS to provide a simulation model for large catchments. It uses a modification of the SCS curve number approach for daily runoff simulation, with soil moisture being used to determine the curve number, instead of antecedent precipitation. Sediment loss is based on the Modified USLE, while the CREAMS routines are used for nutrient and pesticide washoff. The Pesticide Runoff Simulator is based on SWRRB and was designed to simulate pesticide adsorption and runoff from small agricultural water sheds. It performs detailed modelling of pesticide application, transformation and transport, and can test pesticide management practices.

AGNPS Agricultural Non-point Source Pollution model was developed by the US Department of Agriculture (Young et al, 1986) for simulating continuous or event-based sediment and nutrient washoff, primarily for testing agricultural management practices. It is a distributed model which is based on the unit hydrograph and Modified USLE approaches, with routing of pollutants from the top to the outlet of the watershed. Nutrient concentrations are simulated for the soluble and adsorbed phases, using a similar approach to CREAMS, with relationships between chemical concentration, sediment yield and runoff.

PRZM The Pesticide Root Zone Model was designed particularly to simulate pesticides in the unsaturated zone (Carsel et al, 1984), but provides information about pesticide yield in the dissolved and adsorbed phase. The hydrology is based on the SCS curve number approach and sediment yield on the USLE, while the fate of applied pesticide is simulated in detail, taking account of pesticide uptake by plants, surface runoff, erosion, decay, volatilisation, foliar washoff, advection, dispersion and retardation.

MIKE-SHE MIKE-SHE is an advanced version of the *Systeme Hydrologique Européen* model (Abbott *et al*., 1986) developed in the early eighties by collaboration among French, British and Danish modellers. This model integrates the unsaturated and saturated zones of the soil together with the overland flow into a complete dynamic system with interaction among most components. The model operates on a grid basis using finite difference schemes. Selected water quality processes have been added to this configuration. Locally, Prof Denis Hughes of the Institute of Water Research of Rhodes University has researched the implementation of the water quantity part of MIKE-SHE under Southern African data availability conditions. His findings do not sketch a favourable picture in terms of the viability of local applicability of this model. At the time of writing, his report to the WRC was not yet available.

References

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Smithers, Jeff and Roland Schulze (1995) *ACRU Agrohydrological Modelling System: User Manual*. WRC Report TT70/95. Pretoria.

Young *et al* (1986) *Agricultural Non-point Source Pollution Model: A Watershed Analysis Tool*, Agricultural Research Service, US Dept. of Agriculture, Morris, MN.

4J. SINGLE-SOURCE MODELS

Background

Most of the non-point source assessment techniques discussed in Sections 4.C to 4.I have been oriented towards analysis of multiple source areas at a catchment scale. Single source models represent the processes and activities governing production and delivery of contaminants from a single source area, with the aim of evaluating the effectiveness of alternative management interventions. This information is used to support the selection of best management practices for that source area.

Single source models may be applied to site-specific conditions, for the management of a particular source as part of the water use licensing requirements in a sensitive catchment, or under generic conditions, to support the selection of best management practices as regulations for a controlled activity. The types of source areas that are most appropriate for this type of modelling are:

- agricultural (crop) fields, including land management practices;
- concentrated sources, such as confined animal facilities, mines and dumps, and waste disposal sites; and
- settlement and urban areas, including sanitation and storm water systems.

☞ WHAT ARE SINGLE-SOURCE MODELS?

Assessment Aims
Evaluation of non-point source production and delivery from single source areas, together with the effectiveness of management interventions, to support the selection of best management practices.

Approach
Represent the processes and activities governing the non-point source impacts from either generic or site-specific source areas, allowing them to be changed to reflect the implementation of management interventions, based on conceptual knowledge and/or empirical data.

Characteristics
Specific techniques used for urban and settlement areas, concentrated sources and agricultural (crop) fields, with parameters reflecting physical source characteristics.

Requirements
Detailed description of the source characteristics and understanding of the processes and activities governing non-point source impacts.

Limitations
By definition, these techniques do not address the effects in the receiving surface water resource, and are only as good as the understanding of the processes governing non-point source production and delivery.

Three approaches may be used to analyse these source types, namely field scale simulation, concentrated source loading and delivery management evaluation.

Field Scale Simulation

These models simulate the processes governing production and delivery within a source area, and usually incorporate options that represent management practices. Field scale simulation is typically performed on agricultural fields, rather than on urban areas.

The most common approach is to use one of the catchment scale process models, that were specifically developed to evaluate management interventions, but to apply it to a single homogeneous source area. An advantage of these models is that selected management practices can be easily incorporated into the catchment version of the model to evaluate the effect in the receiving surface water resources. The models that are particularly appropriate for the evaluation of management practices, associated with the specified contaminant washoff from agricultural fields, are (see Section 4.I):

- CREAMS, for combined sediment, nutrient and pesticide washoff;
- AGNPS, for sediment and nutrient washoff;
- ANSWERS, for sediment erosion;
- SWRRB, for detailed evaluation of nutrient washoff from fertilizer application;
- PRS and PRZM, for detailed evaluation of pesticide washoff.

Concentrated Source Loading

The evaluation of non-point source impacts from concentrated sources should always be performed at a single source area scale and then input to catchment models as “point sources”. This is because concentrated sources are typically required to implement management systems, and the characteristics of the concentrated source and condition of the management system determine the severity of its non-point source impact.

Most concentrated sources pose a greater threat of groundwater contamination than to surface water resources. However, the following concentrated sources may require non-point source analysis, either to determine their potential impact, to evaluate the need for management systems or to select appropriate management practices:

- Mines, including the working areas and discard dumps;
- Confined animal facilities, including feedlots, dairies and piggeries, with their effluent detention ponds and irrigation fields; and
- Industrial and domestic waste disposal sites, including municipal land fills, sludge disposal and irrigated effluent fields.

Each of these sources have different waste (contaminant) types, processes governing its production and delivery and viable management interventions. Therefore, techniques used for their assessment should differ considerably, and should be developed specifically to reflect the key elements that should be evaluated.

These techniques may involve simple processing of observed data to understand the non-point source impacts. Alternatively, detailed models may be developed to reflect the individual processes governing these impacts. Ninham Shand (1996) illustrates the application of source-specific models to evaluate the non-point source impacts from various concentrated sources for the Mgeni Catchment Management Plan, such as a feedlot, wastewater works sludge irrigation and pesticide application to a crop field. Unfortunately, particular techniques cannot be described in this section, due to the diversity of concentrated sources, lack of clear methodologies for their assessment, and the dearth of South African applications.

Delivery Management Evaluation

A variety of models have been proposed to evaluate structural management practices in the delivery process associated with a particular (single) non-point source area, and to support the design of these structures. Structural management practices are discrete structures, and as such, require the collection of non-point source runoff into a conduit, i.e. they are pseudo-point sources. This is generally the situation in storm water systems, and thus these techniques tend to be oriented towards urban areas. They support the selection of management practices and provide valuable information on their effectiveness as input to catchment scale analysis. The approaches may be:

- conceptual, where the physical consequences of the intervention are represented, or
- empirical, where the observed impacts of actual interventions are monitored and represented as an efficiency factor.

However, most delivery management evaluation techniques are a combination of conceptual relationships supported by empirical parameters. Campbell *et al* (1996) reviewed a number of structural practices/systems for intercepting and treating urban runoff. They present relationships describing the functioning of these systems, and the range of observed treatment efficiencies. These systems were grouped as:

- Pond systems, including wet-dry ponds, stabilisation ponds, urban lakes, oxidation ditches and balancing dams;
- Filtration and vegetated infiltration systems;
- Chemical treatment, including disinfection and phosphate precipitation; and
- Constructed wetlands.

These relationships and efficiencies were incorporated into a model for the evaluation of urban structural management systems (Coleman, 1996). This model has a simple loading routine for estimating contaminant washoff loads from urban areas, but detailed routines for estimating the attenuation, assimilation and discharge of this load from the management system. The model has been calibrated and verified for South African conditions, including peri-urban informal settlements.

The models described in this section are closely related to the heuristics presented in Section 4.K, although these provide some guidance on the design of these systems.

References

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Coleman, TJ (1996) *Expert system for the design of stormwater management systems for urban runoff*. First Draft Report for WRC Project No K5/598. Pretoria.

Ninham Shand (1996) *Pollution Sources*. Mgeni Catchment Management Plan. DWAF Report WQM U200/00/0913. Pretoria

4K. HEURISTICS

Background

For non-point source assessment, heuristics are defined as rule-based or expert systems that identify the main processes and activities governing the production and delivery of contaminants from source areas and indicate the effectiveness of alternative management practices. In other words, they are the qualitative equivalent to the single source models presented in Section 4.J.

Heuristics are typically developed through empirical observation and experience with actual physical systems or research prototypes. As such, they are generally based on reliable data, but unfortunately these results are often contradictory, due to site-specific variations. The skill in using heuristics is to know which results are most applicable in a particular context. Thus, as with most non-point source assessment techniques, the application of heuristics require experienced analysts with an understanding of both the literature values and the site-specific conditions under which they must be applied.

☞ WHAT ARE HEURISTICS?

Assessment Aims
Identify the key processes and activities causing impacts from a particular source area and indicate the probable effectiveness of alternative management practices.

Approach
Rule-based or expert opinion, based on empirical observation or experience with existing systems or research prototypes.

Characteristics
Provide information about the causes of non-point source impacts from urban and rural land uses, and synthesise data on the efficiencies of different management practices.

Requirements
Literature or experience on source areas and management practices with similar characteristics to the application.

Limitations
They do not represent the site-specific conditions and thus their accuracy is entirely dependant upon the analyst's knowledge and previous experience.

Although heuristics on the effectiveness of management practices may be integrated into rule-based expert systems, they are usually presented in tabular form, indicating the advantages and disadvantages of different alternatives.

Urban Management Practices

There is considerable international literature on the effectiveness and performance of structural management practices for urban runoff control. The following table is on such heuristics from Schueler et al (1992).

Regional, Site-Specific, and Maintenance Considerations for Structural Practices to Control Sediments in Storm Water Runoff (Schueler et al., 1992)

BMP Option	Size of Drainage Area	Site Requirements	Regional Restrictions	Maintenance Burdens	Longevity
Infiltration basins	Moderate to large	Deep permeable soils	Arid and cold regions	High	Low
Infiltration trenches	Moderate	Same as for infiltration basins			
Vegetated filter strips	Small	Low-density areas with low slopes	Arid and cold regions	Low	Low if poorly maintained
Grassed swales	Small	Low-density areas with <15% slope	Arid and cold regions	Low	High if maintained
Porous pavement	Small	Deep permeable soils, low slopes, and restricted traffic	Arid and cold regions or high wind erosion rates	High	Low
Concrete grid pavement	Small	Same as for porous pavement		Moderate to high	High
Filtration basins and sand filters	Widely applicable	Widely applicable	Arid and cold regions	Moderate	Low to moderate
Water quality inlets	Small	Impervious catchments	Few restrictions	Cleaned twice a year	High
Extended detention ponds	Moderate to large	Deep soils	Few restrictions	Dry ponds have relatively high burdens	High
Wet ponds	Moderate to large	Deep soils	Arid regions	Low	High
Constructed storm water wetlands	Moderate to large	Poorly drained soils, space may be limiting	Arid regions	Annual harvesting of vegetation	High

References

Schueler, TR, PA Kumble and MA Heraty (1992) *A current assessment of Urban Best Management Practices. Techniques for reducing non-point source pollution in the Coastal Zone*. Technical Guidance Manual. US Environmental Protection Agency. Washington DC.

PART 5 : THE WAY FORWARD

5A. FRAMEWORK FOR NON-POINT SOURCE MANAGEMENT

Introduction

An investigation into framework for non-point source management was conducted as part of this project. It proposed that the future development and implementation of non-point source management by DWAF is conducted in two sequential phases, namely *strategy formulation* and *strategy implementation*, as outlined below. The rationale for this is that:

- non-point source input to the national water resource strategy (NWRS) is urgently required, supported by a series of procedures and guides for non-point source management;
- the water use authorisation management system (WARMS) urgently requires licence application guides for its further development; and
- the actual implementation of non-point source management (including the development and consultation of management measures) is a lengthy process which should not delay the above tasks.

Formulating the Strategy

This phase should consist of three main components. These should be conducted concurrently, due to the requirement for significant integration and feedback between the strategies, procedures and guides. This is an urgent component of the water law implementation.

National non-point source strategy as part of the NWRS

The establishment of the national water resource strategy (NWRS) provides an invaluable opportunity to formulate a national non-point source strategy (NNPSS). This would set out DWAF's intentions for non-point source management in South Africa over the next five years and the requirements of water management institutions, sectors and stakeholders.

It is assumed that a point source management strategy will also be developed, either as part of this NNPSS process or with significant communication and integration around the approach. The needs and focus of the NNPSS differs from a point source strategy in the emphasis on co-operative governance and non-statutory persuasive approaches, even though the general approaches should be similar.

The NNPSS should focus on the following important tasks:

- Identifying the requirements, content and form of the NWRS, and the implications for the NNPSS.
- Identify the requirements of the water resource classification system and determination of resource quality objectives, in terms of non-point source management.
- Developing the relationship between the NNPSS and other components of the NWRS, particularly the resource protection, point source management and water pricing strategies.

- Revising and refining the preliminary management framework for non-point source management.
- Exploring which non-point source management approaches are appropriate under different conditions, including persuasion, regulation, pricing and co-operative governance.
- Detailing the considerations for adopting alternative statutory measures for non-point source control, including general authorisations, regulations, water use licensing and directives.
- Fostering and implementing co-operative governance arrangements.
- Developing regional considerations for non-point source management.
- Specifying the requirement for a non-point source management strategy within a water management area as part of every catchment management strategy.

This final point is possibly the most crucial element of the NNPSS. In particular, it should explore the relationship between the catchment non-point source strategy and other statutory and non-statutory non-point source management measures implemented at a water management area (WMA) or catchment level. Furthermore, it should outline a procedure for developing and implementing a catchment non-point source management strategy as part of the catchment management strategy (CMS).

Procedural guides

The NNPSS must be supported by the development of procedures and guides for the promulgation of statutory non-point source management measures, as well as the implementation of non-statutory non-point source management approaches. These procedural guides should primarily be targeted at water quality management personnel in DWAF and catchment management agencies. However, they should also be relevant for all stakeholders, particularly non-point source sector representatives and staff in other organs of state that may be involved in the development and implementation of non-point source management.

Statutory procedural guides should be developed for:

- *Regulations* on a national or WMA level.
- *General authorisations* at a national, WMA or catchment scale.
- Declaring non-point sources as *controlled activities*, *waste disposal* or *waste discharge* requiring *water use licences*, either as a national/regional licence or catchment-based compulsory licences requirement.
- Requiring non-point source conditions on water use authorisations (general authorisation or water use licence) other than those defined above (i.e. not non-point source specific).
- Formulating and issuing a *directive* for a particular site, and possibly implementing action and recovering costs.

Non-statutory procedural guides should be developed for:

- *Persuasive* approaches to encourage collaboration with non-point source sectors to develop management approaches that may be incorporated into statutory measures or catchment management strategies.
- *Co-operative governance*, particularly to guide and facilitate the fostering of collaborative partnerships with other organs of state responsible for or involved in non-point source related sectors.
- *Water use pricing*, outlining the way in which the pricing strategy may be used to encourage adoption of proactive non-point source management approaches.

The framework outlined in the NNPSS would indicate when each of these procedural guides is appropriate and should be used.

Licence application guides

The generic registration, licensing and water use charging processes have been outlined in the *Business Process Models* as part of the WARMS, and these do not need to be duplicated. However, these models need to be interpreted from the non-point source perspective, in order to identify the elements that are important for non-point source management

This analysis should inform the development of *licence application guides* for non-point source related water use authorisation, as support to the WARMS. These guides should:

- specify the information that is required to support the non-point source versions of the business process models, particularly for registration, licence application, appeal, review, water use charging, billing, and monitoring and evaluation; and
- provide guidance on how to obtain this information, including relevant data sources and the types or character of assessment techniques that may be useful, possibly by sector (as outlined in this Guide).

Implementing the Strategy

The implementation phase should follow on from the strategy formulation phase, and consists of two main components. These components should be conducted concurrently over a period of two to three years, in order to allow adequate stakeholder consultation and sectoral involvement.

Strategic implementation plan

An implementation plan should be developed, which outlines the priority non-point source sectors (and activities), target outputs and activities, responsibilities and time-frame for implementing the NNPSS. The details of these requirements will become clear during the strategy formulation phase.

Sectoral engagement

It is absolutely critical to the success of non-point source management that the strategies, procedures and guides (developed during the first phase) be applied to and evaluated for the highest priority non-point source sectors, possibly in critical WMAs. The dual objectives of this implementation should be:

- to implement non-point source management in accordance with the NNPSS, and
- to test and refine the strategy, procedures and guides.

This implementation should be done in collaboration with the relevant institutions, sectors and stakeholders, and will require an extensive and extended consultation and participation process. The sectoral implementation should be designed to address the lessons learned from past water quality management experience:

- The non-point source management approach should be as simple and as streamlined as possible.
- Ensure that the intention of the management approach is clear to polluters.
- Match management approaches to the non-point source character (i.e. source/sector-specific).
- Site-specific management should only be adopted where absolutely necessary.
- Reflect the “cradle-to-grave” philosophy of environmental management.

A significant effort should be placed on mobilising the priority non-point source sectors and ensure their involvement, collaboration and possible financial support. This mobilisation should be started early, and thus requires attention during the strategy formulation phase.

5B. RESEARCH RECOMMENDATIONS

Non-point Source Assessment

Given the growing importance of non-point sources in the total contaminant loading of South Africa's rivers and streams - an inevitable hazard of the need to develop the country - the formalisation of current individual research and conceptual efforts in this field into a National Programme is recommended. Such a Non-point Source Research and Development Programme should be the output from a strategic research planning process, perhaps facilitated by the WRC for this purpose. Such a programme should cover research themes, technology transfer themes, capacity building themes and management policy development themes.

The primary focus areas of this Programme relevant to non-point source assessments can be expected to include the following:

(i) Establishing a limited set of representative (in non-point source terms) catchments monitored for the purposes of the Programme for a period of, say, five years, including, as far as possible, existing DWAF monitoring points.

(ii) Using the representative catchments for problem-tree analyses of the non-point source causative chain, followed by conceptual development of management frameworks and protocols for each representative causative chain.

(iii) Non-point source-related modelling: The following topics appear to have received inadequate attention in South Africa:

- rule-based *vs* simulation approaches
- optimality of scale and resolution with respect to inadequate water quality, rainfall and land-use data
- low-cost sampling procedures supported by modelling
- building non-point source simulation capability in current South African models such as ACRU and WRYM
- deepening local experience in the application of USA models with international standing, particularly SWMM and HSPF
- non-point source impacts on groundwater

(iv) Development of non-point source load "potential" mapping procedures using the latest national land-use mapping and GIS-based integration procedures.