South African Water Quality Management Series

PROCEDURES TO ASSESS EFFLUENT DISCHARGE IMPACTS

Department of Water Affairs and Forestry

Water Research Commission
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Foreword

South Africa is mostly a semi-arid country with scarce water resources. In order to help balance our scarce water supply with increasing water demands it is imperative that water is re-used as much as possible. The South African Water Act therefore made it mandatory that effluents must be treated to acceptable standards and returned to the water course from which the water was originally obtained. The Department of Water Affairs and Forestry, as the custodian of South Africa's water resources, has been implementing these requirements stipulated in the Water Act since the early 1950s through a uniform effluent standards approach. Continued deterioration of water quality in some parts of South Africa has lead the Department to adopt a more comprehensive approach towards controlling the impacts of effluents on the quality of the receiving water bodies. One of the key concepts embodied in this approach is that the capacity of water bodies to assimilate waste is a limited national resource which must be managed in a sustainable way.

Since the Department published its comprehensive approach to effluent control in 1991, it became obvious that the necessary management tools and information to support its implementation had to be developed. Because the receiving water quality objectives approach takes many factors into account there was the danger that its application in practice could lack consistency. The need to formalise the assessment of the impact of effluent discharge on the receiving water bodies, prompted the Water Research Commission and the Department to jointly initiate a project which culminated in the production of this manual of practice, which is relevant to South African conditions.

In this document the procedures are described which must be followed to assess the impacts of effluent discharges on the quality, and therefore the fitness for use, of the receiving water bodies. These assessments will be used to decide whether or not an application to discharge an effluent will be granted or not, and, if it is granted, what the requirements should be that the discharger must comply to. It therefore forms one of the corner stones of the Department's current approach to the management of effluent discharges.

In some respects, the procedures described in this document represent major departures from past water quality management policies and practices. To name only a few, from now on the following is required:

- An application to discharge an effluent must demonstrate that all reasonable efforts have been made to, first of all prevent waste, and secondly to minimise it. Only thereafter will minimum quality standards for effluents, or standards based on receiving water quality, whichever are the strictest, be considered. It is only under exceptional circumstances that exemptions to the above requirements will be considered.

- The Department shall insist that the process of assessment and decision-taking concerning applications to discharge an effluent is open and transparent and promotes accountability. It is from now on required that interested and affected parties are appropriately notified of such applications; that they are effectively involved in the assessment and decision-taking processes; that they have adequate access to the relevant information; and that a record of the assessment and the final decisions are kept for public scrutiny.

This document is primarily aimed at all those who have to dispose of effluents, and are therefore required to comply to the requirements of the Water Act, and to the water quality practitioners in the Department and provincial and local authorities, who as a team are jointly responsible for the protection of South Africa's water resources. However, because it also documents, in some detail, current water quality management policies and practices in South Africa it should also be a useful source of information for academic and research institutions, non-government organisations and members of civil society who are concerned about water quality.

The Department recognises that the policies, procedures and practices described in this document are still evolving. Some of them may change quite substantially in the course of the comprehensive review of the Water Act that I recently announced. I therefore wish to use this opportunity to invite anyone who wants to contribute to further development of water quality management policies and practice in South Africa to comment on the procedures described in this document, and the policies underlying them. Please send your comments and/or proposals to The Director: Water Quality Management, Department of Water Affairs and Forestry, Private Bag X313, Pretoria 0001. Fax. No. (012) 323-0321.

Kader Asmal

Professor Kader Asmal
Minister of Water Affairs and Forestry

June, 1995

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Acknowledgements

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The Steering Committee responsible for this project consisted of the following persons:

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Quick reference guide

A very brief overview of what the manual is about; where the major parts are located and what they cover

Quick Reference Guide

The manual consists of the three main parts shown below. This guide contains a short one page outline of each part; highlighting the **scope** and intended **audience** of each, and including an abbreviated table of **contents**. This guide also introduces the **roadmap**; a graphical overview of the effluent discharge investigation.

Water quality management

Effluent discharge investigation

Supporting information

Water quality management

A description of water quality management policies and principles, emphasising effluent discharge management . . . . Page 1

What is this part of the manual about?

This part of the manual discusses the approaches adopted by the Department of Water Affairs and Forestry to the management of water quality. It describes the context of water quality management within which the effluent discharge investigation and the procedures involved in applying for permission to discharge an effluent take place.

Who should read this part of the manual?

This part is particularly useful for **water quality managers** and those who need to have a broad understanding of the policies and strategies adopted by the DWAF. It is also useful for **potential dischargers** who need an overview of the procedures involved in applying for a discharge permit.

Summary of main sections

Effluent discharge investigation

A description of the tasks associated with an effluent discharge investigation, highlighting key issues .... Page 27

What is this part of the manual about?

This part of the manual provides:

- A description of the tasks to be undertaken to complete an effluent discharge investigation
- Criteria for decision-making and guidance on the types of procedures or methods that can be used in the investigation.

Who should read this part of the manual?

This part is useful for those **managing** an effluent discharge investigation, to help ensure that all the aspects are carried out. It provides the **consultant** with guidance on specialist topics and procedures, and the potential **effluent discharger** with an understanding of the scope and depth of the information required by the Department of Water Affairs and Forestry.

Summary of main sections

☞ *The roadmap to the effluent discharge investigation is described at the end of this Quick Reference Guide (a fold-out copy is also printed at the back of the manual).*

☞ *An overview of the effluent discharge investigation appears on pages 29 to 36.*

Supporting information

Appendices - with glossary, abbreviations, list of models, report guidelines, legislation, additional literature - and index . . . . **Page 195**

What is this part of the manual about?

This part of the manual contains supporting documentation in the form of appendices that provide:

- A **glossary** of important terms
- An **index** to important terms in the manual
- Guidelines for writing effluent discharge investigation **reports** which will accompany the effluent discharge applications
- Additional **literature** references, **acknowledgements abbreviations**
- References to applicable **legislation**
- Further details on certain **topics** mentioned in the text.

Who should read this part of the manual?

This part of the manual should be read by those who:

- Need to understand a term (see the **glossary**)
- Want to find references to a particular term (see the **index**)
- Want more information on items referred to in the main text.

Summary of appendices

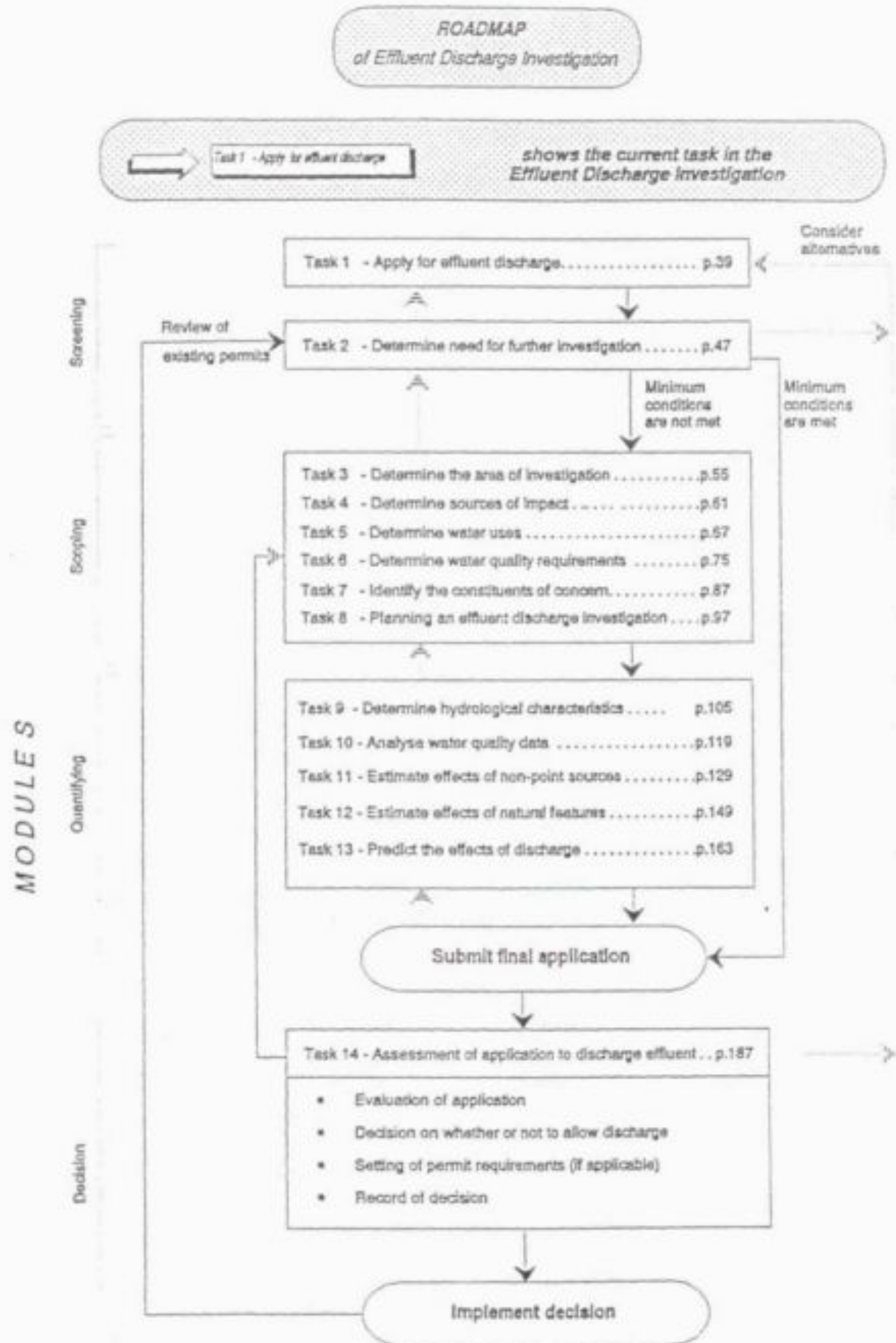

Figure 1 Roadmap for the Effluent Discharge Investigation

Use of the "roadmap"

The "**roadmap**" shown opposite provides a "quick and easy" method for navigating the second part of the manual; the description of the **effluent discharge investigation**. It combines a summary table of contents with a graphic view of the basic sequence and relationship between tasks in the investigation.

The left-hand side of the roadmap shows the various **modules** into which the investigation is divided. The modules in the procedure are further subdivided into one, or more, **tasks** (shown in square boxes on the roadmap). The start of each new module and task in the manual is preceded by a **coloured title page.**

The roadmap appears at the start of each **task** in the effluent discharge section of the manual, with that particular task being highlighted on the diagram (see the example in the shaded box just below the top of the roadmap).

Water quality management

A description of water quality management policies and principles, emphasising effluent discharge management

Water Quality Management in South Africa

☞ This part of the manual discusses the approaches adopted by the Department of Water Affairs and Forestry to the management of water quality. It provides a context against which to understand the effluent discharge investigation, and its relationship to other environmental management tools.

☞ This part is particularly useful for **water quality managers** and those who need to have a broad understanding of the polices and strategies adopted by the Department.

WATER QUALITY MANAGEMENT:
A. Principles and Policies of Water Quality Management

A. Principles and Policies of Water Quality Management

A.1 Roles and role players in water management

custodianship

In South Africa, the state is the custodian of water resources. The Department of Water Affairs and Forestry (DWAF) is the primary agency responsible for water resources management. With respect to water quality its mission is to ensure the fitness of South Africa's surface water, groundwater and coastal marine resources, for water uses and for the protection of the natural aquatic environment, on a sustainable basis (DWAF, 1986).

other participants

The DWAF has adopted a participatory management approach to water quality management. In practice this means that the responsibility for water resources management is shared among central, provincial and local government departments, private sector organisations, community based organisations and non-governmental organisations concerning themselves with water resources management. Water users and effluent dischargers are also involved in the process of developing and implementing management plans. As a result of their increasing environmental awareness, the general public is taking an active role in matters concerning the environment. As a result of the dynamic political situation in South Africa at the time this version of the manual was produced, the exact roles and responsibilities of the various role players have not been defined. Despite that, the DWAF accepts that in future **broad consultation** must play a crucial role in water quality management and endeavours to involve the appropriate role players in the process.

role of the DWAF

In executing its mandate with respect to water resources management the DWAF finds itself at the intersection of many different, and often conflicting, interests. One of its key roles is to reconcile, integrate and co-ordinate these diverse interests within the framework of sustainable and equitable utilisation of South Africa's water resources. Its role requires the DWAF to **formulate clear water quality goals**, to develop **flexible strategies** to achieve these goals, and to **ensure the implementation** of the resulting actions plans. The DWAF, in its role as custodian of South Africa's water resources, also has to audit the effectiveness of water quality management efforts undertaken by other role players.

A.2 Water quality management policies, approaches and practices

A.2.1 Prerequisites

The following prerequisites form the basis of water quality management policies and practices in South Africa.

- Because water is such a scarce resource, **effluent has to be returned and re-used** in order to help balance water supply with the demand for water. Water quality at pristine, unaffected levels therefore cannot be maintained and some **changes in water quality** is accepted as being inevitable.

- Waste disposal to air or soil (for example, effluent irrigation, dumping mining wastes, or gaseous emissions) impacts on the quality of surface and groundwater. Therefore, waste disposal has to be evaluated holistically and the best practical environmental option has to be selected.

- Economic development should not take place at the expense of the environment, nor place excessive demands on the natural resource base. Sustainable economic development which is in balance with environmental protection and sustainable resource use is encouraged. The weight being given to the economic and social benefits associated with an operation discharging an effluent will, however, depend on other factors such as the available assimilative capacity of the receiving water body and the hazardous nature of the effluent. In the justification for an effluent to be discharged, the weigh of economic and social benefits will be less if either the assimilative capacity of the receiving water body has been, or is close to being, exceeded and/or if the effluent contains constituents which are considered to be hazardous for water uses or the aquatic environment.

- **Participation of the public**, including those impacting on water quality and water users, is vital in the process of formulating water quality management goals and management strategies.

- The basic **geographic unit of water quality management is the catchment**. Catchment management must integrate land use effects with physical characteristics of the catchment and with external factors, such as economics, to plan and control water quality. Many of these factors have boundaries that are different from catchment boundaries. Therefore, successful water quality management relies on integration of these diverse factors into a holistic management system.

A.2.2 Precautionary approach

definition and application

The DWAF has adopted a precautionary approach to water quality management in which active measures are taken to avert or minimise potential risk of undesirable impacts on the environment. Therefore, when developments are proposed, it is required that probable impacts on the health of people and the resource must be predicted, as well as the environmental and economic benefits. This precautionary approach is applied in all the water resource decisions made by the DWAF.

implications

This approach has some important implications:

- **Avoiding potential risks** to the environment and human health by preventing, where possible, the introduction of harmful, or potentially harmful, constituents, into the environment. This is done even in the absence of scientific proof that such introductions will cause harm.

- Minimising risk to the environment by "erring on the safe side" in all the decision-making steps involved in water pollution control

- The **conservation of resources** is encouraged to reduce the need to develop new resources such as energy, water and minerals.

The precautionary approach adopted by the DWAF will, and is meant to, result in activities, limits, or standards which are more stringent than what is required just to meet minimum requirements for maintaining the fitness of water for the protection of the natural aquatic environment and for water uses.

A.2.3 Receiving Water Quality Objectives approach (RWQO)

definition

The **Receiving Water Quality Objectives approach** focuses on the quality of the receiving water, instead of the quality of the emissions from a source, in decisions concerning pollution control (DWAF, 1991). It requires that sources, both point and diffuse, are controlled to achieve the desired quality in the receiving water. The desired quality of the receiving water is stated in the form of a receiving water quality objective.

assimilative capacity

Assimilative capacity refers to the concept that water bodies can tolerate the input of some wastes without the quality of the water deteriorating to the point that the water uses are adversely affected. Water is an effective solvent and natural water bodies serve as excellent means of transport of dissolved and suspended material. A water body, therefore, provides many mechanisms to modify, move, or otherwise transform material discharged into it. An additional consideration is that the quality of water, unaffected by discharges from human activity, is sometimes far better than what is required for most water uses. Wastes can often be discharged into such water bodies with little or no effect on the water uses.

Assimilative capacity for a constituent differs in fundamental ways, depending on whether the constituent can be considered conservative or non-conservative:

- **Conservative** constituents are not lost due to chemical reactions or biochemical degradations. Such constituents may include, for example, total dissolved solids and chlorides. Conservative constituents accumulate along the length of a water body in the direction of motion, so that amounts added at the most upstream point are still present at the most downstream point. Concentrations of conservative constituents can be reduced only by dilution with water with a lower concentration.

- **Non-conservative constituents**, on the other hand, decay with time due to such mechanisms as chemical reactions, bacterial degradation, radioactive decay, or settling of particulates out of the water column. Many constituents exhibit non-conservative behaviour, including oxidisable organic matter, nutrients, volatile chemicals and bacteria. The amount of a non-conservative constituent decreases with time and/or distance from the point of input.

A.2.4 Decision-making hierarchy for setting effluent requirements

In line with its precautionary approach, the DWAF has adopted a decision-making hierarchy for considering any application for the discharge of an effluent to a receiving water body. This hierarchy is depicted in **Figure 2** below and described in the subsequent text.

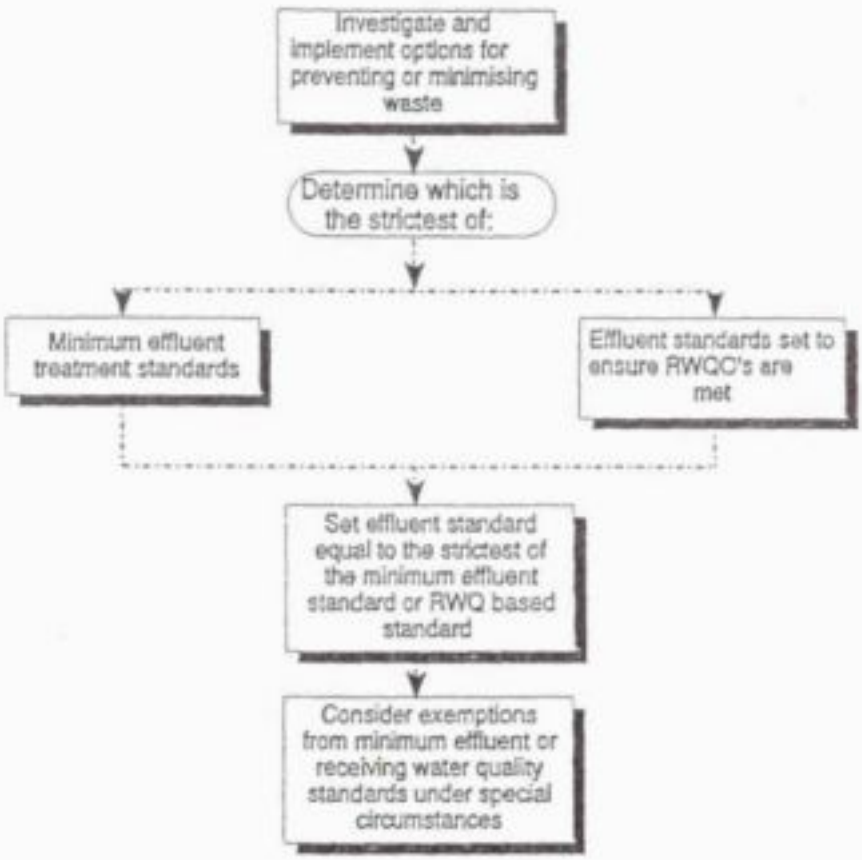

Figure 2 Decision-making hierarchy for considering applications to discharge effluent

- First of all, options for **preventing and minimising waste** through source reduction, recycling, detoxification and neutralisation of wastes must be thoroughly investigated. Caution should be taken that, in this process, one is truly avoiding or minimising waste and not simply shifting it from one environmental medium to another, for example, from water to land, or from water to air.

- If, after all the practical options to prevent and or minimise waste have been exhausted, there is still waste or an effluent, **it will be required to meet whichever is the strictest of minimum effluent standards** or **receiving water quality based effluent standards**.

  Appropriate **minimum effluent standards** are currently being investigated. The current General or Special Effluent Standards will in the interim be used as minimum standards. *(See Appendix G for a list of the existing standards).*

The effect of the treated effluent on the receiving water's fitness for the protection of the natural aquatic environment and for water uses will be assessed against the desired **receiving water quality**. Effluent standards required to meet the desired receiving water quality are derived on the basis of an **effluent discharge investigation**. **Such receiving water quality based standards may sometimes be stricter than minimum effluent standards.**

- **Exemptions** from minimum effluent or receiving water quality based standards will be considered under special circumstances, and as a last resort, but will require sufficient justification on technological, economic and socio-political grounds. Such exemptions may not always be granted, may in most cases be temporary, and almost certainly will be withheld if the effluent discharge investigation shows that the receiving water's fitness for the protection of the natural aquatic environment and for water uses will be significantly reduced.

A.3 Point source management

The DWAF has developed a number of tools, or standardised procedures, to support its range of water quality management activities. The most important of these tools with respect to the control of point source impacts are:

- The setting of water quality **objectives**
- Conducting **investigations to assess the impacts** of effluent discharges
- Granting **permits** to discharge effluent.

effluent discharge permits

An important instrument used in the control of point source impacts is the **effluent discharge permit**. These permits are issued by the DWAF and are subject to review and possible amendment, whether explicitly stated in an individual permit or not.

exemption permits

An **exemption permit** is a particular type of effluent discharge permit. At present, in terms of Section 21 of the Water Act (Act 54 of 1956), effluent is required both to be purified to prescribed standards and to be returned to the source of origin (the point of abstraction of the intake water. *(Refer to Appendix H for the text of this portion of the Act)*. Exemption permits, subject to requirements specified by the Minister of DWAF, **may** be granted to operations that **cannot** fulfil both the requirements of Section 21.

discharge to sewage works

Operations that return their discharge to a municipal sewage treatment works are generally excluded from the requirement to obtain an exemption permit. However, under Section 21.2 of the Water Act exceptions may be made, particularly in cases where the discharge from a particular operation creates recognised problems for the treatment works. In these cases, the DWAF requires the same process to be followed in applying for an exemption permit as is the case for effluent discharged directly to public water.

other sources of impact

The effluent discharge investigation process described in this manual is primarily aimed at point source management and does not deal specifically with the DWAF's approach to managing other sources of impact on water quality (for example, diffuse discharges from urban stormwater runoff). However, there are similarities among all these approaches and they are dependent on each other. For example, sites giving rise to both point and diffuse sources of impact on water quality will be considered as a "single source" and analysed accordingly under the DWAF's **total waste management** approach. Therefore many of the procedures described in this manual can also be used for investigating the impacts of other sources of impact on water quality.

A.4 Receiving water quality objectives

An important step in any management process, which consist of developing plans, organising, controlling and evaluating success, is the process of stating specific **receiving water quality objectives** for each system or sub-system. A receiving water quality objective is a quantitative statement of the quality in a water body that must be maintained.

A.4.1 Setting of water quality objectives

selection process

In setting water quality objectives for a water body, such as a stream reach or part of a reservoir, the DWAF invokes a complex process. **Figure 3** shows a graphic interpretation of some of the elements of that process. Setting appropriate objectives is an iterative process which seeks a balance between the requirements of the different water uses, the general public, and other interested and affected parties. The process takes account of the various environmental, technological, economic, political and social factors which affect the use of the water and the quality of the water in the water body.

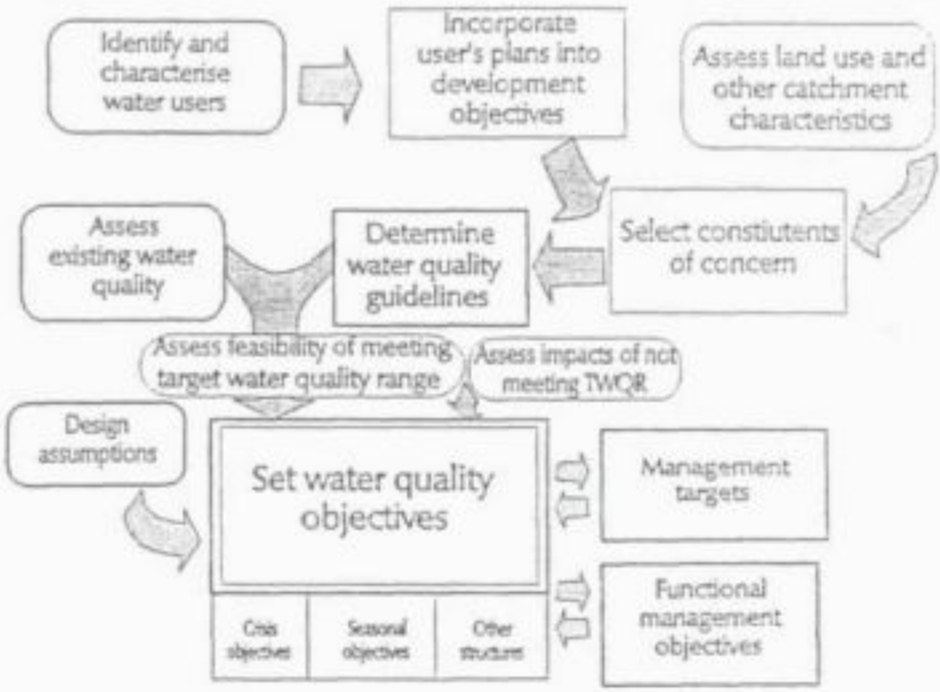

Figure 3 The setting of water quality objectives

development objectives

The initial steps determine which are the water users and what their desires for water quality, both now and in the future, are. Since most users are not familiar with the technical aspects of water quality, their desires are often expressed in terms of goals or plans for development. These **development objectives** must then be interpreted in terms of water quality through the involvement of representatives of the DWAF. For example, a development objective may be to attract eco-tourists. The water quality requirements derived from this development objective may be that the aesthetic features of the water body is maintained at high standards and that adequate supplies of water that can be treated to potable standards are available. Each of these in turn has to be made more specific before they could be considered to be objectives.

constituents of concern

Water quality constituents of concern are selected by considering the development objectives and the water quality constituents for which the impacted water uses are likely to be sensitive as well as information on land use and other catchment characteristics. Constituents of concern are measurable quantities, such as the concentration of sodium in a river, or an index of biological diversity, which in a particular case would best characterise the fitness of water for the protection of the natural aquatic environment and for water uses.

target water quality range

For each water quality constituent of concern a range of water quality can be defined over which there would be no impairment of a particular water use or of the natural aquatic environment. This range is defined as the **Target Water Quality Range.** The *South African Water Quality Guidelines* (DWAF, 1993, 1995) specifies the Target Water Quality Ranges for most recognised water uses for a large number of water quality constituents. The

Target Water Quality Range is described more fully in *Task 6, Determine water quality requirements.*

Water quality objectives can be set so they fall either within or outside the Target Water Quality Range. This means the water quality objective can be within, or worse than the Target Water Quality Range. The initial point of departure for setting the objective is to either set it equal to the existing water quality, or set it equal to the limit of the Target Water Quality Range, whichever is better water quality. The water quality objective may, after consideration of all the factors mentioned above, eventually be set at a value worse than the Target Water Quality Range. It is then the duty of the DWAF, and all concerned, to continue looking for ways to improve water quality and to review the objectives from time to time so that the water quality objective can eventually be set within the Target Water Quality Range.

factors affecting actual values of water quality objectives

The **receiving water quality objective** (RWQO) is the statement of the quality in a water body that must be maintained. The process of determining an appropriate numerical value to set as an objective uses the Target Water Quality Range, and other values, as one of its important inputs. It is a complex and evolving process that includes consideration of issues such as the following:

- The DWAF's water quality management policies and principles
- Natural phenomena such as geochemical characteristics of drainage basins, droughts, and floods
- Current quality of the receiving water compared to the Target Water Quality Range
- Sensitivity of downstream users to changes in water quality for the constituents of concern
- Available technology for dischargers to improve the effluent quality and for downstream users to mitigate the effects of deteriorating water quality
- Economic implications for dischargers to treat the effluent to more stringent levels and for downstream users as a consequence of deteriorating or improving water quality
- Options for, and feasibility of, providing alternative water supply or compensation for affected users.

Because the factors that affect water quality and the users change with time, water quality objectives set at any particular time have to be reviewed from time to time.

A.4.2 Elements of water quality objectives

Water quality objectives have the same characteristics as general management objectives, i.e. they must be specific and documented with respect to the following:

- What has to be achieved (the water quality objective must be stated in such a way that whether or not it is achieved can be measured)
- Where they apply
- When they begin and for how long they will apply
- Who is accountable for setting the objective, ensuring that it is achieved and monitoring whether it is complied with (usually the DWAF)
- Key assumptions underlying the setting of water quality objectives, for example, under what conditions would objectives **not** be met
- What the contingency plans are for periods or circumstances under which objectives would not be met.

A water quality objective is often stated as a maximum value not to be exceeded, but other ways of stating objectives may also be used. It can be stated to apply at all times or different values can be set to apply at different times (seasons) or conditions (low flow, high flow).

management targets

Because water quality objectives are often stated as maximum values not to be exceeded, the actual water quality would be approaching the objective only during extreme events such as droughts, industrial accidents, etc. For day to day management purposes **management targets**, which are designed to measure management performance under normal conditions, are used.

examples of management targets

For example, if an objective is set to maintain a concentration that never exceeds 30 mg/ℓ, a management target could state that the median of measured values must be less than 10 mg/ℓ.

other kinds of objectives

Additional objectives can also be identified. For example, a **crisis objective** can be developed for drought conditions. **Seasonal water quality objectives** can also be set, for example, for those cases where user requirements vary between seasons.

A.4.3 Functional management objectives

activities to help achieve objectives

Water quality objectives and **functional management objectives** must be clearly distinguished. Water quality objectives are specific numeric limits set for water quality constituents of concern. In contrast, functional management objectives describe, and set standards for, the management activities that need to be executed to achieve the water quality objectives. Functional management objectives could be set for activities such as granting permits for point source control or for launching education programmes to promote non-point source control.

use of water quality objectives in point source control

In the point source control process, water quality objectives are used to set appropriate limits for an effluent discharge. The results of the effluent discharge investigation will be used to help select appropriate concentration and quantity limits that will maintain the water quality objectives under appropriate design assumptions.

if no water quality objectives are in place?

The DWAF's approach to developing water quality objectives is to set these for all catchments. This is done by means of catchment investigations, the end results of which are water resource management plans, including water quality objectives, for each catchment. These catchment management plans are being developed systematically for each catchment in South Africa but it will of necessity take a long time to have one for each catchment. Therefore, those who wish to discharge effluent into water bodies in catchments that have not yet had water quality objectives set, will be responsible for developing the information necessary for the DWAF to set objectives. This may require that two separate, parallel studies have to be conducted - one to investigate the effect of the proposed discharge on the receiving water, and another to collect the information and conduct the public meetings necessary to set water quality objectives.

A.5 Water quality management and the Water Act

revision of the Water Act

Major new developments in water quality management policy and implementation took place since the previous major revision of the Water Act in 1984. There may seem to be some uncertainty and ambiguity about the interpretation of the Water Act with respect to the DWAF's mandate to implement its present water quality management policies and practices. However, experience has been that the DWAF's mandate to control impacts on water quality and manage water in terms of the Water Act as it currently stands is sufficiently wide to provide the required legal backing for its actions. Because the DWAF's current policies and practices have not specifically been incorporated in the Water Act it is often a cumbersome process to apply the legislation where that is required. It is for this and for other reasons that the Minister of Water Affairs and Forestry has recently announced that the Water Act will be comprehensively reviewed and updated. During the review process those sections of the Act dealing with water quality management will be comprehensively revised in order to streamline the effective implementation of the legislation. Any uncertainty or ambiguity there may be in the current Act with respect to the DWAF's mandate to implement its water quality management policies will also dealt with.

The DWAF's water quality management policies and practices as described in this manual, are already being fully implemented. They are considered to be backed by both the current Water Act but will be more specifically included in the forthcoming revision of the Water Act.

REFERENCES

Policies and Principles of Water Quality Management

DWAF, 1986. *Management of the water resources of the Republic of South Africa.* Department of Water Affairs and Forestry, Pretoria, South Africa. 459 pp.

DWAF, 1991. *Water quality management policies and strategies in South Africa.* Department of Water Affairs and Forestry, Pretoria, South Africa. 38 pp.

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WATER QUALITY MANAGEMENT:
B. Management of Effluent Discharges

B. Management of Effluent Discharges

B.1 The role of effluent discharge investigations

The effluent discharge investigation is one of the water quality management tools the DWAF uses for management of point source effluent. It obtains and records specific information about an effluent discharge and its impact on the receiving water and the water users. These investigations form an important part of implementing the RWQO approach because it provides much of the information on which decisions to allow or deny an effluent discharge is based. Effluent discharge investigations must provide sufficient, relevant data for the DWAF to determine whether or not an effluent discharge will be allowed. The data will also be used to determine requirements that the discharger and the effluent must meet. Decisions will be based on the DWAF's policies for water quality management.

An effluent discharge investigation assists with three important management functions, i.e.:

- A **planning** function that evaluates the risks, costs and benefits associated with an effluent being discharged
- An **information** function that provides information to all the participants to help make the trade-offs implicit in a complex management function
- A **control** function that establishes limits on effluent that can be discharged.

This manual identifies the issues to be considered when carrying out an effluent discharge investigation and outlines procedures for conducting the investigation.

B.2 Initiating the investigation

There are several ways in which the circumstances or potential problems that might require an effluent discharge investigation can be identified. A "problem" is defined, in this case, as any activity or occurrence that has a potentially negative effect on the quality of a water body. Some examples of ways to initiate these investigations are given below.

B.2.1 Application for an exemption

who must apply

In terms of the Water Act - Act 54 of 1956 (in particular, Section 21(1), *refer to Appendix H for the text*) - any user of water that:

- Does not return the used water (effluent) to the point of abstraction and/or
- Discharges an effluent that fails to meet the requirements of the appropriate effluent standard (*Appendix G lists the existing effluent standards*)

must apply to the DWAF for an exemption. Any new application for exemption will always require an investigation.

B.2.2 Re-evaluate existing exemptions

circumstances change

Exemptions from standard permit requirements have been granted to many dischargers over the years. Many of these exemptions will remain in force as long as the circumstances under which they were issued remain unchanged.

expiry date

Some permits are subject to an expiry date. When the conditions, under which an exemption was granted, change, including the exemption reaching its expiry date, it will be re-evaluated. In many of these evaluations, an effluent discharge investigation will be required. In future, all exemption permits will only be valid for a specific period, for example, 5 years.

process changes

If dischargers are planning to alter their processes, or affect the resulting discharge in some other way, the DWAF should be approached with a revised application for effluent discharge. Discussions between such dischargers and the DWAF will be held to determine whether or not an effluent discharge investigation will be necessary.

other factors

There are likely to be other cases, for example, increasing development in a catchment, which indicate an exemption needs to be re-evaluated. The DWAF has the legal right to require such re-evaluations.

B.2.3 Identification of receiving water quality problems

Real or perceived concerns, for example, a fish kill or a perception that the receiving water quality is unacceptable as a result of an effluent discharge, can lead to the identification of a water quality problem. Additional work may be required to pinpoint the cause of the problem, but if the contamination can be traced to one or more point sources, an effluent discharge investigation may be warranted.

relationship with integrated catchment management studies

It is the intention of the DWAF to complete catchment studies on a systematic basis for every catchment in the country. Effluent discharge investigations can be required as part of an integrated catchment management study. For those investigations conducted as part of a larger basin study, dischargers are responsible for providing the information relating to their own discharge.

For effluent discharge investigations conducted **before** a catchment study has been completed, the dischargers must assemble all the information needed for a decision by the DWAF. For those investigations conducted **after** a catchment study has been completed, much of the relevant information on catchment characteristics, other sources of impact on water quality affecting downstream users, etc., will be available.

B.3 Waste disposal to public water: A privilege

discharge is not a right

Disposal of waste into a public stream is considered by the DWAF to be a privilege that can be granted to a facility that complies with specified requirements and acts responsibly. It is not a right given to every effluent producer. A potential discharger must, therefore, provide justification for being allowed the privilege of using a public water course for waste disposal. Before the DWAF will allow waste to be disposed of into the water environment it will require the discharger to demonstrate that all feasible efforts have been made to avoid, reduce, recycle, detoxify and neutralise waste.

allowable loads

Allowing a potential discharger to dispose of effluent into the water environment, i.e. the allocation of a specific waste load, is a crucial part of water quality management. Basing an allowable waste load on an effluent's effect on the receiving water quality may in certain cases require the DWAF to impose stricter standards where minimum treatment standards do not maintain acceptable water quality. On the other hand, it also allows the DWAF to balance the competing requirements of users, resource protection, the needs of the environment, and economic, social and technological constraints by allowing relaxations of a minimum effluent standard under certain circumstances. However, it must be realised that the weight being given to economic, social and technological considerations will be less in cases where either the assimilative capacity of the receiving water body has been, or is close to being, exceeded and/or if the effluent contains constituents which are considered to be hazardous for water uses or the natural aquatic environment.

The DWAF has the final authority on whether or not a particular effluent discharge will be allowed and what the requirements will be for it to take place.

B.4 Compatibility of effluent discharge investigations with the Integrated Environmental Management approach

Integrated Environmental Management (IEM) is a process developed under the auspices of the Department of Environment Affairs. It is designed "to ensure that the environmental consequences of development proposals are understood and adequately considered in the planning process" (DEA, 1992).

IEM principles

Relevant principles underpinning IEM are that there must be:

- Informed decision-making
- Accountability for information on which decisions are taken
- Accountability for decisions taken
- An open, participatory approach in the planning of proposals
- Consultation with interested and affected parties
- Due consideration of alternative options
- An attempt to mitigate negative impacts and enhance positive aspects of proposals

- An attempt to ensure that the "social costs" of development proposals (those costs borne by society, rather than the developers) be outweighed by the "social benefits" (benefits to society as a result of the actions of the developers)
- Democratic regard for individual rights and obligations
- Compliance with these principles during all stages of the planning, implementation and decommissioning of proposals (that is, from cradle to grave)
- The opportunity for public and specialist input in the decision-making process.

common philosophy

Effluent discharge investigations follow from the same fundamental philosophy as the IEM process. In short, the process of planning for development should be transparent, multi-disciplinary, and holistic. A transparent process implies that the procedures followed are open to public participation and that the path followed to decision-making is documented and can easily be examined. The investigation is required to be multi-disciplinary because environmental relationships are so complex that they extend beyond any single discipline. The issues of environmental and resource protection are so broad and interrelated that a holistic view is necessary to recognise all the effects of planned actions and to balance the benefits and costs.

The IEM process stems from the conviction that the principles underlying sustainable development should direct the planning of proposals, rather than being considerations to be addressed once the proposal has been "planned." Effluent discharge management also relies on addressing potential concerns during the planning process. Both processes require the assessment of alternative options at an early stage in the planning process.

Table 1 Similarities between the Integrated Environmental Management process and Effluent Discharge Investigations

The following element in IEM is included (at least broadly) in -	the following element in Effluent Discharge Investigations
Classification of proposal	Screening module
Initial assessment	Screening module
No formal assessment	Minimum requirements are met
Impact assessment	Scoping, Quantifying, and Reporting Modules
Review	Assessment of application
Conditions of approval	Assessment of application
Implement proposal	Assessment of application

REFERENCES

Management of Effluent Discharges

DEA, 1992. *The Integrated Environmental Management Procedure*. Guideline Documents 1-6, Department of Environment Affairs, Pretoria, South Africa.

Effluent discharge investigation

A description of the tasks associated with an effluent discharge investigation, highlighting key issues

Overview of the Effluent Discharge Investigation

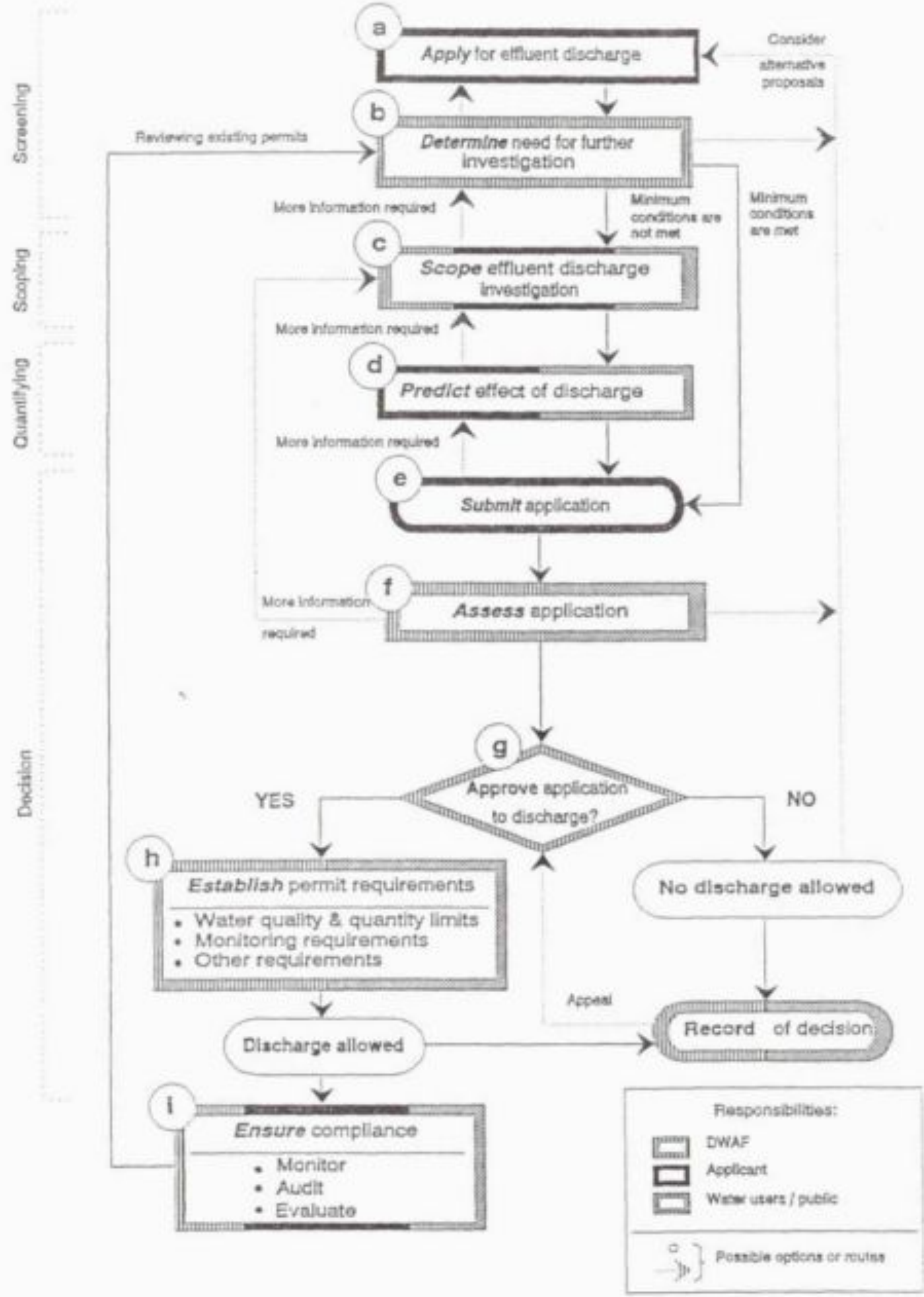


Figure 4 Outline of the Effluent Discharge Investigation process

Overview of the Effluent Discharge Investigation

purpose

This section provides an overview of the **effluent discharge investigation** process. Subsequent sections describe the procedures involved in it in more detail.

outline of process

Figure 4 opposite is a flow diagram that shows the activities in the process. The diagram also indicates **who** is responsible for each activity. The relative emphasis on any activity in the process may vary from one application to the next, according to the specific circumstances. The process is both iterative and interactive; it makes provision for reassessing a prior decision after gathering additional information. Therefore, arrows are often shown in two directions, going down to the next task and optionally up to the previous task.

Discussions and negotiations between the DWAF, those applying for permits and other interested and affected parties take place whenever required. The process often begins with a consultation between the discharger and the DWAF.

Provision is also made in the process for review of existing permits. The permitting procedure is also subject to review and will be updated from time to time as a result of policy or structural changes.

a. Apply for effluent discharge

consultation

The first step in the investigation process is a discussion between the proposed discharger and the DWAF. The discussion covers the issues involved in the discharge. It provides an opportunity for the DWAF to obtain preliminary information about the application and for the discharger to understand the DWAF's requirements. At this stage the applicant should identify key interested and affected parties and start to consult with them.

transparency

The DWAF, from now on, is allowing interested and affected parties access to information concerning effluent discharges it has issued or plans to issue permits for. The information contained in the application for an exemption permit and in any effluent discharge investigation will, on request, be made available to interested and affected parties. The only exception would be where such information contains confidential business information. However, these exceptions will have to be very strongly motivated because the DWAF believes that in most cases the relevant information can be presented in such a way that it does not compromise the confidentiality of business information.

The DWAF also believes that in future it will adopt what is currently becoming international practice namely to move towards a more transparent process for the involvement of interested and affected parties. The easiest way to do that is to require that an applicant for a permit to discharge effluent must announce it in the local press. Such an announcement will have to state the name and address of the applicant, the water body into which the effluent is to be disposed if allowed, the relevant characteristics of the effluent and the possible impacts it may have. The DWAF may also consider publishing a monthly list of applications received. It is important that effluent dischargers are aware of these trends and prepare for their implementation.

justification

In order for the request for permission to discharge an effluent to be considered, the applicant should **justify** the need for the discharge by the following:

- Specifying the need for the operation
- Justifying the disposal of an effluent with a given quality after having exhausted the options for preventing or minimising waste
- Showing why, if any other alternatives for dealing with waste have been identified, one particular option has been proposed.

scope of alternatives

During the investigation process, the need to consider alternative applications may be identified by the DWAF, the applicant or the other parties involved. Alternatives can involve any aspect that affects water quality, including treatment processes, disposal routes, provision of alternative supplies for downstream water users, etc.

Refer to the Screening Module, Task 1: Apply for effluent discharge, for more detail.

b. Determine need for further investigation

purpose of screening

The purpose of this step is to determine whether or not an applicant can meet certain minimum requirements set by the DWAF and the interested and affected parties. If so, a permit can be issued without further investigations having to be done. If not, additional information must be provided through an **effluent discharge investigation** at a level of detail that will be determined in discussions between the discharger, the DWAF and the other parties involved.

minimum requirements

The applicable minimum requirements will be determined through discussion between the DWAF, the discharger and the interested and affected parties. These minimum requirements include limits on the quality and quantity of effluent, as well as requirements for monitoring programmes, disclosure of information concerning the discharge and its impacts, and "good operating practices".

minimum requirements met

A preliminary investigation by the discharger is needed to show that the discharge meets the minimum requirements and that the receiving water's fitness for the protection of the natural aquatic environment and for water uses will be maintained. Based on this, the DWAF will be able to make a decision as to whether or not to issue a permit. No further investigation will be needed.

minimum requirements not met

If an applicant fails to meet the minimum requirements or if the impacts on the fitness for the protection of the natural aquatic environment and for water uses of the receiving water are unacceptable or uncertain, then two options exist. The applicant can suggest alternatives which do meet the DWAF's minimum requirements or a more **detailed effluent discharge investigation** can be carried out. This decision on the required course of action should be agreed to by the DWAF, the applicant and the other parties involved.

responsibility for investigation

The DWAF, the applicant or the other parties involved may require that the detailed effluent discharge investigation be carried out by external consultants. If an external consultant is required, the onus is on the applicant to appoint consultants who are competent to carry out the investigation and who are acceptable to the DWAF and the other parties involved. The applicant must also pay for the services of such consultants.

Refer to the Screening Module, Task 2: Determine need for further investigation, for more detail.

c. Determine the scope of the detailed effluent discharge investigation

Once it has been decided that an effluent discharge investigation has to be done, the first step is to determine the extent of the investigation and the appropriate approach. The scope may vary considerably according to the circumstances. The activities associated with scoping the investigation are:

- Determine the area of investigation
- Determine sources of impact on water quality
- Determine water uses
- Determine water quality requirements
- Identify the constituents of concern
- Plan an effluent discharge investigation
- Refine the list of interested and affected parties to be involved in the process.

The Scoping Module (Tasks 3 to 8) describes in detail the activities involved.

d. Predict the effects of discharge on water quality

It is necessary to predict and quantify the effect of the discharge on the receiving water body so that appropriate water quality limits, and other requirements, for the effluent discharge can be specified. The activities associated with quantifying the effects of the discharge are:

- Determine hydrological characteristics
- Analyse water quality data
- Estimate effects of non-point sources
- Estimate effects of natural features
- Predict the effects of discharge on water quality.

The Quantifying Module (Tasks 9 to 13) describes in detail the activities involved.

e. Submit application

The detailed effluent discharge investigation must be described in a report which covers the above issues. The report format is described in Appendix C.

f. Assessment of an application to discharge

purpose

The purpose of the assessment is to ensure that:

- Sufficient information is provided to enable the DWAF and the other parties involved to evaluate the impacts of the effluent discharge and make a decision regarding the issuing of an exemption permit
- Sufficient consultation with interested and affected parties has taken place
- The effluent discharge investigation report has addressed all the relevant issues in sufficient detail.

peer review

The DWAF will, if necessary, ask for **peer review** by other specialists of technical aspects of the investigation to ensure the objectivity of the report.

g. Approve application to discharge?

The decision as to whether or not to approve an application to discharge will be made by the DWAF. The **justification** supplied by the applicant will be considered, as well as the results of any additional investigation that has been undertaken and the views of the interested and affected parties. If the DWAF decides **not** to issue the permit, based on the application under review, other alternatives might be suggested and required to be investigated.

record of decision

If the application to discharge has been refused, notification, in writing, will be given to the applicant. In all cases, whether or not an application is approved, and a record of decision will be kept and made available to interested and affected parties on request.

The Decision Module (Task 14) describes the issues involved in determining whether or not to approve an application to discharge an effluent.

h. Establish permit requirements

Establishing permit requirements involves the integration and weighing of all the information that has been received in order to determine the requirements which an effluent discharge will have to comply with.

requirements

Before a permit is granted, a number of **requirements**, to which the future permit holder will have to comply, will be specified by the DWAF. These requirements address aspects such as:

- Detailed effluent standards
- Plant operation and maintenance requirements
- Monitoring requirements
- Reporting requirements.

The DWAF has developed some standard requirements, based on industry type and discharge methods, that are often included in permits. Most permits contain a mixture of standard and site- or case-specific requirements.

expiry dates

Permits are currently issued with expiry dates. The period for which a permit will be valid will generally not exceed 5 years and will depend on issues such as:

- Uncertainty in the information on which decisions were based
- Time required by a discharger to implement major changes in the operations
- Changes in the capacity of the receiving water body to assimilate waste, for example, as a result of the development of water resources or land use changes in a catchment.

The Decision Module (Task 14) describes the issues involved in establishing the appropriate permit requirements.

i. Ensure compliance and reassessment

After the permit has been issued, a number of activities are needed to ensure that the requirements set out in the permit are complied with. These activities are maintained for the lifetime of the permit.

monitoring

The discharger has to monitor the effluent and the receiving water body. Monitoring includes the sampling, analysis and reporting. Specifications for sampling and analysis are included as part of the permit requirements, which also specify that reports of the results are to be provided to the DWAF and, possibly, other parties as well, at regular intervals.

auditing

Auditing is the process whereby the DWAF ensures that a permit holder is complying with all permit requirements and that the permit requirements provide sufficient protection to the quality of the receiving water body. This is done by means of:

- Analysis of a permit holder's monitoring results
- Regular site visits to check compliance
- Independent sampling of the permit holder's discharge and the receiving water body by the DWAF
- Follow-up of complaints received from the public.

The DWAF will make the results of such auditing available to interested and affected parties.

Non-compliance with permit requirements is usually dealt with by persuading the permit holder to address the problem, as it is the DWAF's policy to first try to solve the problems by achieving co-operation from the permit holder before resorting to confrontation. However, the DWAF has the right and the duty, in terms of the Water Act, to prosecute offenders.

evaluation

Exemption permits are reassessed from time to time, in the light of ongoing changes or developments, to ensure that:

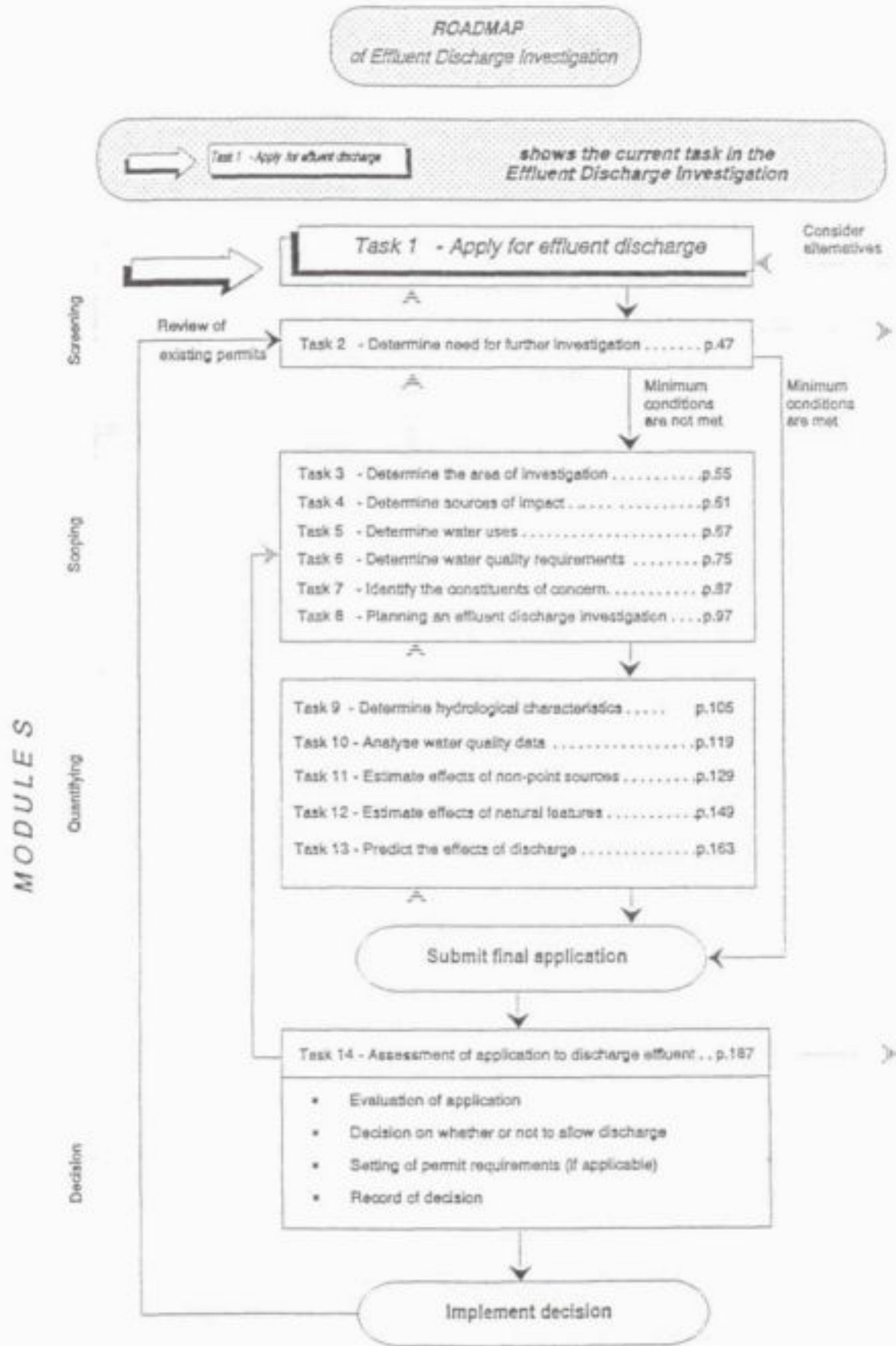
- Effluent discharge investigations were comprehensive and accurate
- Criteria by which decisions were made were adequate and still reflect DWAF's policies
- Monitoring programmes are providing sufficient information to assess impacts
- Permit requirements are sufficient to control impacts and continue to meet water quality objectives.

The issues involved in ensuring compliance to permit requirements are described in more detail in Task 14.

EFFLUENT DISCHARGE INVESTIGATION

SCREENING MODULE

TASK 1:
Apply for Effluent Discharge


ROADMAP
of Effluent Discharge Investigation
Task 1 - Apply for effluent discharge
shows the current task in the Effluent Discharge Investigation
Task 1 - Apply for effluent discharge
Consider alternatives
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Minimum conditions are not met
Minimum conditions are met
Scoping
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Task 7 - Identify the constituents of concern. p.87
Task 8 - Planning an effluent discharge investigation p.97
Quantifying
Task 9 - Determine hydrological characteristics p.105
Task 10 - Analyse water quality data p.119
Task 11 - Estimate effects of non-point sources p.129
Task 12 - Estimate effects of natural features p.149
Task 13 - Predict the effects of discharge p.163
Submit final application
Decision
Task 14 - Assessment of application to discharge effluent . . p.187
Evaluation of application
Decision on whether or not to allow discharge
Setting of permit requirements (if applicable)
Record of decision
Implement decision

TASK 1:
Apply for Effluent Discharge

☞ The objective of **applying for effluent discharge** is for the discharger to obtain the privilege of using some of the assimilative capacity in the receiving water for the disposal of waste. It allows the DWAF, as well as other interested and affected parties, to obtain information they require to decide whether or not the application can be approved or whether there is a need for further investigation.

☞ During the **preliminary investigation**, the applicant must gather information on the activity producing the effluent, as well as the effluent itself and relevant information on the surrounding catchment. The aplicant should also identify interested and affected parties and notify them as to the invesitgation.

☞ In the application, **justification** must be provided for:

- The need for the discharge in terms of the development's significance for sustainable development
- The necessity of producing an effluent containing waste.

☞ During the screening of the application, the DWAF ensures that the applicant has taken all feasible actions to firstly **prevent** and secondly **minimise waste**.

☞ During this process, the need to consider **alternatives** may be identified by the DWAF, the applicant or any of the interested and affected parties.

1.1 Consultation interviews with the DWAF and others

> ☞ Consultation interviews between the applicant, the DWAF and the interested and affected parties early in the process can provide:
> - Information for the DWAF and the other parties involved on the likely effects of the discharge
> - Guidance for the discharger on DWAF's water quality management policy and practice, its information requirements, and the possible concerns of the other parties involved.

While consultation interviews between the applicant, the DWAF and the interested and affected parties before an application for an exemption permit is formally submitted is not explicitly required by law, it provides substantial benefits to all parties. The DWAF requires certain information of all dischargers and has generic requirements for many types of discharges. Discussion of those requirements before much effort is spent on developing information will enable the discharger to focus the investigation on the information required by the DWAF. By identifying and involving the interested and affected parties at an early stage, their concerns, if any, can be established and be dealt with from the start of the process.

1.2 Submit preliminary information

> ☞ The applicant must supply at least the following information for the preliminary investigation:
> - Location of the activity
> - Type and scale of the activity
> - Nature of the effluent
> - Water users in the catchment
> - Sensitivity of the catchment
> - Water quality status of the catchment
> - Who the interested and affected parties are and what their concerns are.

The DWAF requires certain information from the discharger. A brief outline of the type and scope of this information is outlined below.

project life cycle In an application to discharge an effluent, the preliminary information supplied must include a description of the impact of the facility on the receiving water body throughout its entire life cycle, i.e. during construction, operation, decommissioning and after closure.

Minimise waste. During the screening of the application, the DWAF has to ensure that the discharger has taken all feasible actions to prevent and minimise waste.

level of detail

If a detailed investigation is needed, then the preliminary information will form the basis for additional information gathering in the rest of the investigation. In many ways, this initial task is a smaller-scale version of a more detailed investigation.

The applicant is responsible for obtaining all the information required for the preliminary investigation.

location of the activity

The location of the facility and the points where effluent is (or will be) discharged must be clearly identified in the context of the surrounding catchment.

nature of the effluent

The following aspects of the effluent must be characterised:

- The type and expected concentrations or levels of various physical, chemical, biological or other constituents
- The raw materials used and the process(es) that produce the discharge
- Known or likely changes in the quality of the receiving water that will be caused by the discharge
- Possible impact on the downstream users as a result of the likely changes in water quality.

type and scale of the activity

Information about factors that could contribute to or mitigate water quality effects should be supplied. These factors include:

- Physical size of the facility
- Volume of the discharge
- Expected variation in the volume of discharge
- Material and product storage practices
- Possible risk of accidental spillages and the precautions that have been taken to contain these
- Possible risk of non-point sources and/or stormwater and the precautions that have been taken to prevent these.

water uses

Water uses that could be affected by the discharge must be identified.

sensitivity of the catchment

Highly sensitive catchments are ones with:

- Rare or endangered species of plants or animals and unique ecosystems that could be affected by the discharge
- Economically important water uses with very stringent water quality requirements

- **Historical conflicts** over water use or water quality issues
- **Other issues** related to environmental protection, human health, technology application, economic effects, legal restrictions, etc.

Any links between the catchment in which the activity is located and other catchments should be noted. Examples are: water transfer schemes between catchments, or rivers that cross or form international boundaries.

interested and affected parties

A list of interested and affected parties containing details of contact persons (addresses, telephone and fax numbers) and their concerns must be provided.

water quality status of the catchment

A statement of the water quality status of a catchment must provide a summary of past, existing and projected future water quality in the catchment. The status is evaluated in terms of the existing water quality compared to ideal water quality required by existing and projected water uses.

Extensive monitoring is not required during the preliminary investigation, but some measurements may be required if no data are available.

legal requirements

The discharger must demonstrate that other legal requirements have been satisfied. Among the issues likely to be relevant are:

- The right to abstract water
- Other permits which may be required
- Location of the point of discharge compared to the point of abstraction
- Quality of the effluent compared to general and special effluent standards.

1.3 Provide justification for discharge

☞ The applicant must justify the need for the discharge in terms of:

- Its contribution to sustainable development
- The quantity and quality of the effluent being produced
- Any alternative(s) proposed

justification

The applicant should **justify** the need for the discharge by the following:

- Specifying the benefits derived from an existing operation, or to be derived from a proposed operation, in terms of its contribution to sustainable development.

  This must be done both in economic and in social terms. It should address issues such as creation of jobs (both direct and indirect), vital services being provided, foreign exchange being generated etc. The weight being given to the economic and social benefits associated with an operation discharging an effluent will, however, depend on other factors such as the available assimilative capacity of the receiving water body and the hazardous nature of the effluent. If the assimilative capacity of the receiving water body has been, or is close to being, exceeded and the effluent contains constituents which are considered to be hazardous for water uses or the aquatic environment, then permission to discharge an effluent may be withheld even if there are major social and economic benefits to be derived from the operation wanting to discharge such an effluent.

- Justifying the quantity, quality and disposal method of the final effluent.

- Showing why, if other and better alternatives have been identified, one particular option has been selected.

The justification must be presented in such a way that the DWAF's decision-making hierarchy, as set out in Section A.2.4, can be applied.

1.4 Consider alternatives

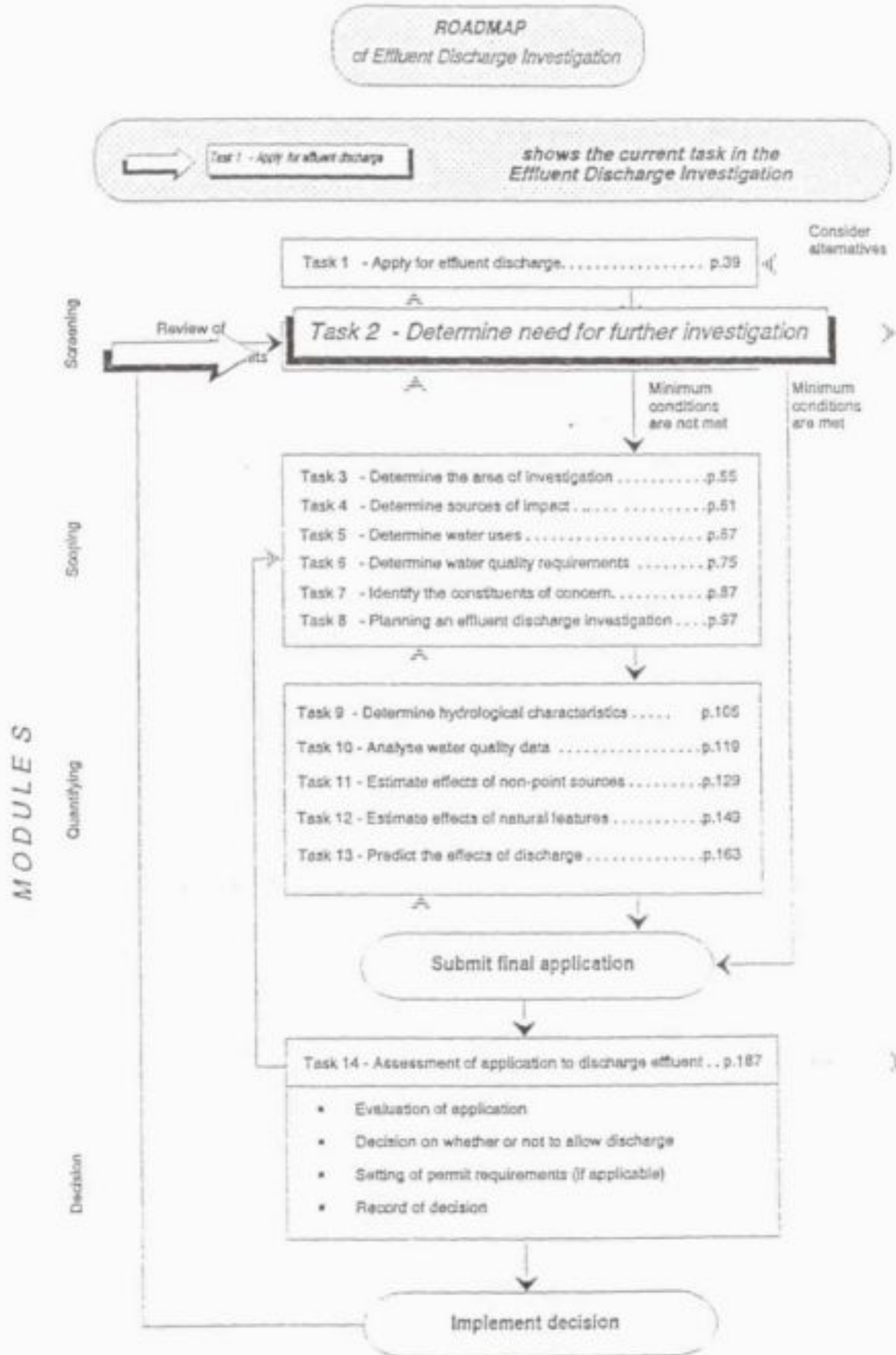
scope of alternatives

The need to consider alternatives may be identified by the DWAF or the applicant. Alternatives can involve any aspect that affects water quality, including alternative industrial processes, other treatment processes, disposal routes, provision of alternative supplies for downstream water users, etc.

adoption of alternatives

Adoption of one, or several, of the alternatives may necessitate further investigation to assess the effects of these alternatives on receiving water quality. The alternatives to be assessed will often determine the scenarios that must be included in a detailed effluent discharge investigation.

TASK 2:
Determine Need for Further Investigation


ROADMAP
of Effluent Discharge Investigation
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shows the current task in the Effluent Discharge Investigation
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Task 10 - Analyse water quality data p.119
Task 11 - Estimate effects of non-point sources.........p.129
Task 12 - Estimate effects of natural features...........p.143
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Decision
Task 14 - Assessment of application to discharge effluent .. p.187
Evaluation of application
Decision on whether or not to allow discharge
Setting of permit requirements (if applicable)
Record of decision
Implement decision

TASK 2:
Determine Need for Further Investigation

☞ The objective of **determining the need for further investigation** is to establish if sufficient information is available to decide whether:

- Permission to discharge can be given or not

  or
- More information is needed before such a decision can be taken.

☞ In some very simple situations, it may be possible to make a decision about discharging the effluent, based on information contained in the application. The Screening Module provides for that situation. An opportunity for the involvement of interested and affected parties in evaluating applications that have passed this preliminary step without further investigation, is provided during *Task 14, Assessment of an Application to Discharge an Effluent.*

2.1 Decide whether additional investigation is needed

> ☞ Additional investigation will be needed if the important issues cannot be resolved with the available information. The additional information needed can range from "none" to that requiring extensive investigation.

responsibility for information

A decision to require more detailed investigation will be taken by the DWAF, based on information supplied by the discharger in the application to discharge effluent and the concerns, if any, of interested and affected parties.

no hard & fast rules

Many factors will be relevant to particular situations and all will have to be integrated and considered by the DWAF. There can be no "hard and fast" rules for the decision about whether or not further investigation is required, as there are likely to be special considerations and local requirements that make each case unique. Nonetheless, the criteria listed below can be used to help determine the important technical issues involved in the decision about the discharge and to decide whether or not further investigation is warranted.

sensitive catchment?

The sensitivity of the catchment can be defined in terms of the:

- Tolerance of the water users for changes in water quality which may result from the effluent discharge
- Extent of the economic impact on affected water users
- Uniqueness, conservation value and conservation status of the natural aquatic environment that could be affected.

impact on the receiving water?

Effluent from an industry with a large volume of waste, or a poorly-run small industry, could both have large impacts on water quality of the receiving water. Thus the size of the industry is not a direct indication of its potential impact on the receiving water. The assimilative capacity of the receiving water is also an important aspect. A receiving water with a small assimilative capacity could be substantially affected by an effluent that would cause little change if discharged to a water body with a large assimilative capacity.

toxic substances?

Toxic substances in the discharge imply the need for additional investigation. The DWAF is developing an approach to control toxic effluent. Until specific guidelines are available, every discharge which contains potentially toxic substances will be subject to effluent investigations.

exceed minimum standards?

If a discharge does not comply with the general and special (minimum) effluent standards, the reasons and effects of the non-compliance must be determined. Minimum standards can include limits on the quality and quantity of the effluent. Effluent that does not meet minimum standards is likely to require further investigation.

economic considerations?

Economic and financial implications, both for the discharger and water users must often be considered in the preliminary phases. If these impacts could be significant it probably requires further investigation.

baseline information available for the catchment?

Much of the required information would be readily available for catchments for which catchment studies have recently been completed. If no catchment studies were done before or, if substantial changes have occurred since a previous catchment study, additional investigation will probably be needed.

case- or site-specific factors?

Case- or site-specific factors, for example:

- Local and/or regional development plans
- Risk and impacts of spillages and accidents on the site or facility from which the effluent is discharged
- Risk and impacts of non-point sources of impact on water quality from the site or facility on both the surface and groundwater quality, must be considered.

2.2 The next steps

additional information required

Once the situation has been assessed, and if the need for further investigation to gather additional information has been identified, the next step will be to determine the scope, or terms of reference, for the detailed investigation.

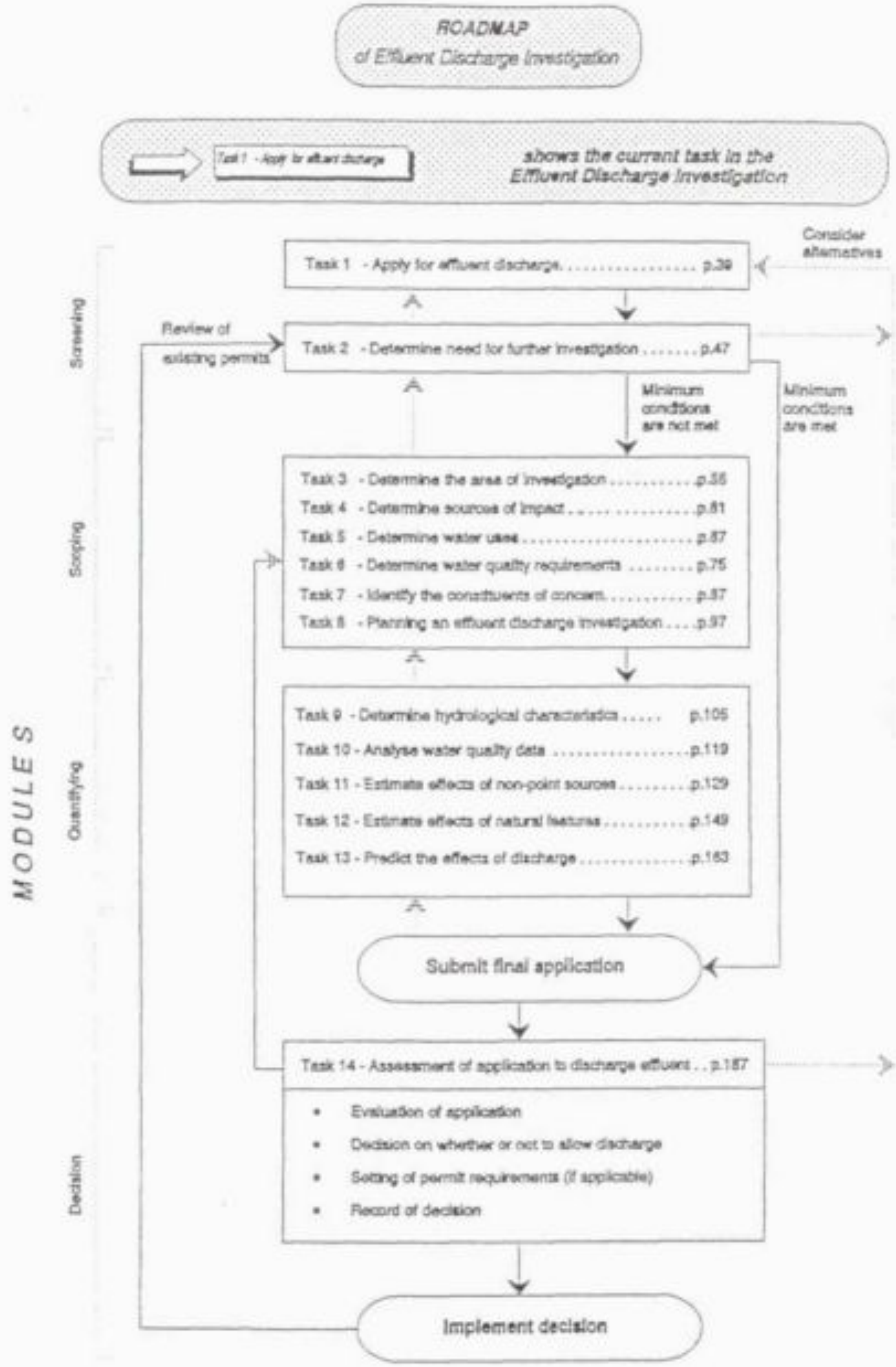
The DWAF, the applicant or the other parties involved may require that the detailed effluent discharge investigation be carried out by external consultants. If an external consultant is required, the onus is on the applicant to ensure that the consultants appointed are competent to carry out the investigation and that they are acceptable to the DWAF and to the interested and affected parties. The applicant is required to pay for their services.

no further investigation

If further investigation is not required, the next step for the discharger is a formal submission of the information required in the form of an application to discharge an effluent. The application and the information it contains will be assessed by the DWAF and other interested and affected parties. Based on the outcome of such an assessment the DWAF will decide whether or not to issue a permit and if so what the permit requirements will be.

EFFLUENT DISCHARGE INVESTIGATION

SCOPING MODULE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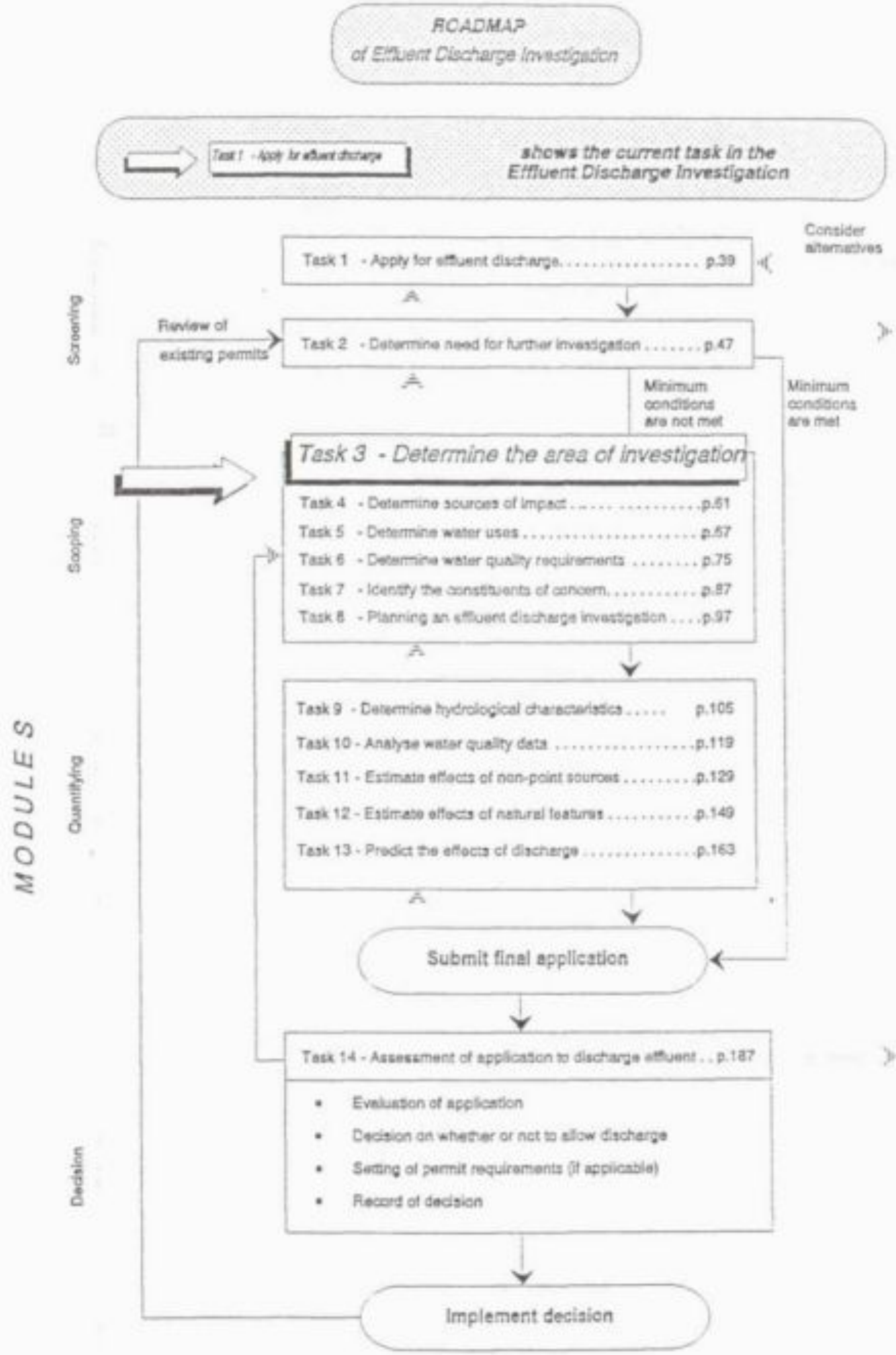
TASK 3:
Determine the Area of Investigation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TASK 3:
Determine the Area of Investigation

☞ Practicality dictates that an effluent discharge investigation must have limits. Determining the geographic area to be considered in an effluent discharge investigation has to balance the availability of resources, including time and money, with the potential scale of impacts on water quality likely to be caused by discharging an effluent.

☞ The downstream limit to the geographic area to be considered in an effluent discharge investigation should include all the users that are affected by the proposed discharge. The extent of the area affected by the discharge may not be obvious from the beginning of the investigation, therefore, an iterative process will be required to ensure that the area of the investigation can be extended, or retracted, if necessary.

3.1 Selection of the area boundaries

overall perspective

The geographic area to be considered in an effluent discharge investigation must be defined in such a way as to ensure that:

- Any future changes in upstream water quality
- The requirements of water users and other interested and affected parties downstream of the likely impacts of the discharge

are taken into account.

choices of limits

The choice of the **upstream limit** will typically be determined by consideration of inputs to the receiving water. The choice of the **downstream limit** will typically be determined by how far downstream water users and other interested and affected parties are likely to be impacted by the discharge.

Factors that will influence the choice of limits of the area of investigation include:

- Other sources of contamination from natural and human activities which contain constituents of concern that:
  - Are present in the effluent being investigated
  - Affect the same water uses
- The location and type of water users
- Dilution by tributaries
- Water quality objectives
- The concerns of other interested and affected parties.

flexibility of limits

The initial geographical limits of the effluent discharge investigation cannot be fixed at the beginning of the investigation. Even after the initial scope has been determined, these limits should not be considered to be rigid. Important information could still become available during the investigation that might influence the choice of the boundaries of the area of investigation.

Determining the area of investigation is an iterative process, that is, previous decisions are reviewed in the light of additional data. The scope should be as wide as possible at the initial stages and, as more information becomes available, narrowed down to focus on the area that will be crucial in the final decision making.

3.2 Upstream limit of the area of investigation

headwaters

The upstream limit of the area of investigation is a point where conditions in the water body (for example, water quality, hydrology and hydraulics) can be considered to be unimpacted by the discharge under consideration. The water quality at this point will be called the **headwaters quality** and the conditions will be called the **headwaters conditions**.

Ideally, the headwaters conditions should be described and, apart from the known or predicted variation, be a fixed quantity for the purpose of the investigation. Headwater conditions can seldom be assumed to be static, therefore, several scenarios of headwaters conditions may have to be considered for the purpose of the investigation.

criteria for upstream limit

The ideal requirements for an upstream limit for the purpose of characterising headwater conditions are as follows:

- It should be possible to **describe** the water quality and the factors that affect it, such as hydrology or hydraulics, at this position. Therefore, there must be sufficient data on these conditions at the headwaters point.

- The variation in the water quality, hydrology and/or hydraulics, at this point should be **predictable**. In other words, it should be possible to identify the sources of the variation and to predict the resultant water quality, hydrology or hydraulic conditions.

3.3 Downstream limit of the area of investigation

initial estimate of downstream limit

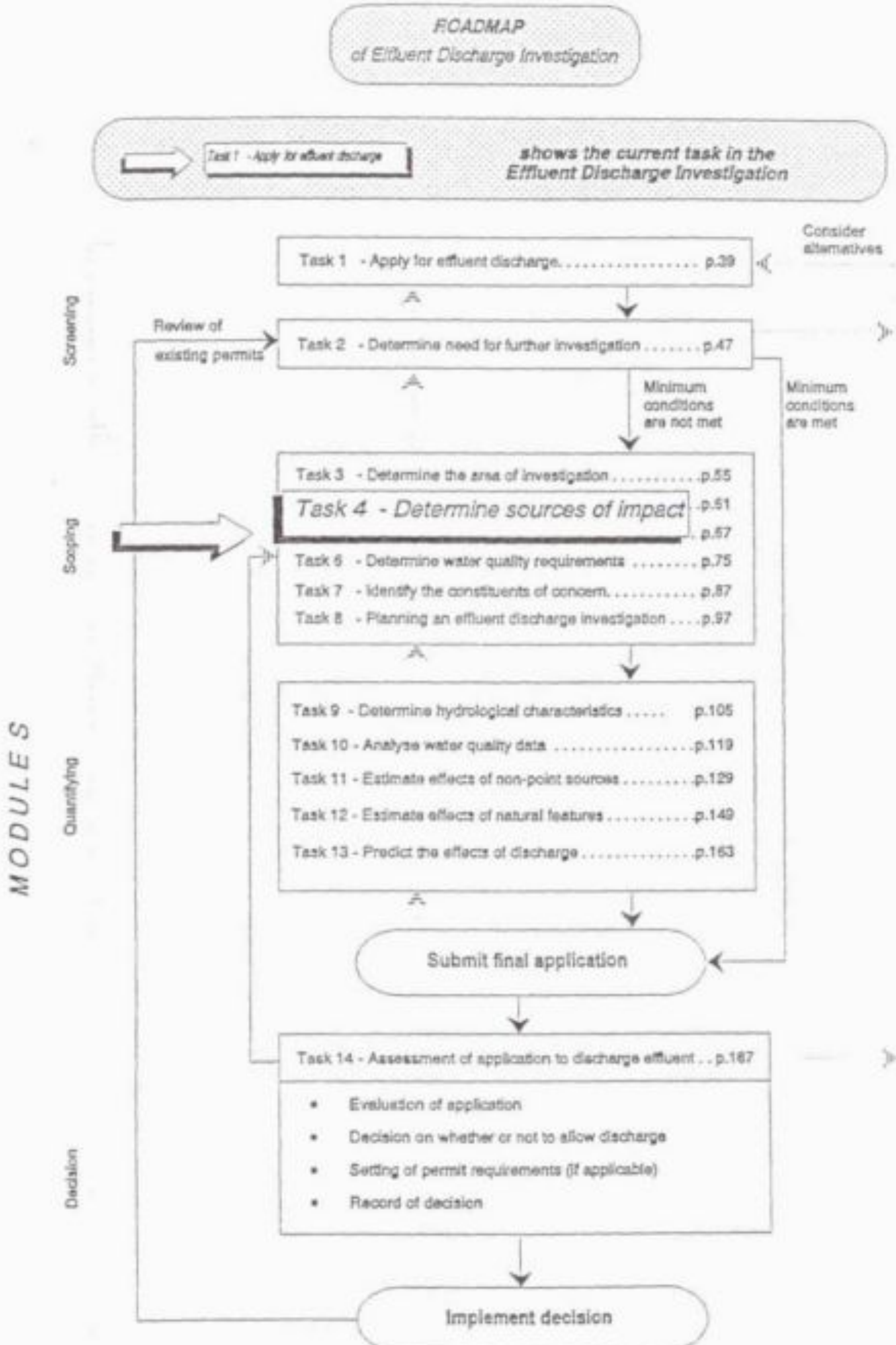
The downstream limit of the effluent discharge investigation must be selected such that the impact on and concerns of users and other interested parties downstream from the proposed discharge can be assessed. During the first iteration of the scoping phase, the whole catchment or the widest possible area of investigation should be considered so that a synoptic investigation of all users and other interested and affected parties can be made.

final estimate

The final downstream limit will be selected by considering, among others, the following factors:

- The location of sensitive users that are likely to be impacted by the discharge
- The distance, from the point of discharge, at which the impact of the discharge is still expected to be notable
- Other factors which can mask or confound the impacts from the effluent discharge being considered, for example, other discharges which may cause similar impacts or tributaries which may reduce impacts.

TASK 4:
Determine Sources of Impact on Water Quality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TASK 4:
Determine Sources of Impact on Water Quality

☞ This task consists of identifying the man-made sources and natural features in the area of investigation that could affect the quality of the water body receiving the effluent discharge. These sources and natural features are characterised in terms of the magnitude of their effects on water quality and the options to control these effects.

☞ The permit requirements for an effluent discharge are set by taking into account the effects of man-made sources and natural features on the water quality properties or constituents of concern. The volume and quality of the effluent allowed to be discharged will depend to a large extent on the effects of these sources of impact on water quality.

4.1 Definition of sources of impact on water quality

The following definitions related to impacts on water quality are used in this manual:

- An **impact on water quality** refers to any alteration of the physical, chemical or biological properties of water. Such impacts can:
  - Cause the fitness of water for the protection of the natural aquatic environment and for water uses to improve or to deteriorate
  - Be caused by man or by the natural features of the basin in which a water body is situated.

  This definition of what entails a water quality impact means that any source, whether it is man-made or a natural feature, or whether not it adversely affects the fitness of water for the protection of the natural aquatic environment and for water uses, would be defined as a source of impact.

  It is also important to understand that a specific impact can improve the fitness of water for one purpose while at the same time cause it to deteriorate for another. For example, an inter basin transfer of low salinity water to a naturally saline receiving river system will improve the fitness of the receiving water body for, say irrigation purposes, while at the same time such an impact may cause the health of the natural aquatic environment, which was adapted to a saline environment, to deteriorate.

- Typical **sources of impact** on water quality are:
  - Isolated incidents, e.g. accidental spillage of contaminanst from stationary or mobile sources
  - Point source discharges, e.g. from waste-water treatment plants or other industrial facilities
  - Transfer of water from one river basin to another
  - Diffuse or non-point sources, e.g. runoff from land used for different purposes, atmospheric deposition, etc.
  - The natural features of a river basin, i.e. constituents, energy or effects picked up by water from its contact with the earth's surface, apart from any human activity.

- In the context of the above definitions, a **water quality constituent of concern** can be any constituent, energy or effect which does, or potentially can, adversely affect the fitness of water for the protection of the natural aquatic environment and for water uses.

4.2 Procedure to identify sources of impact on water quality

The different sources of impact on water quality for the constituents of concern must be identified and their respective effects on the quality of a receiving water body must be quantified. This will help to put the effects on water quality of the effluent discharge being investigated into the appropriate perspective.

Figure 5 gives an overview of the procedure used to identify sources which are likely to impact on water quality in water bodies receiving an effluent. The steps are described below.

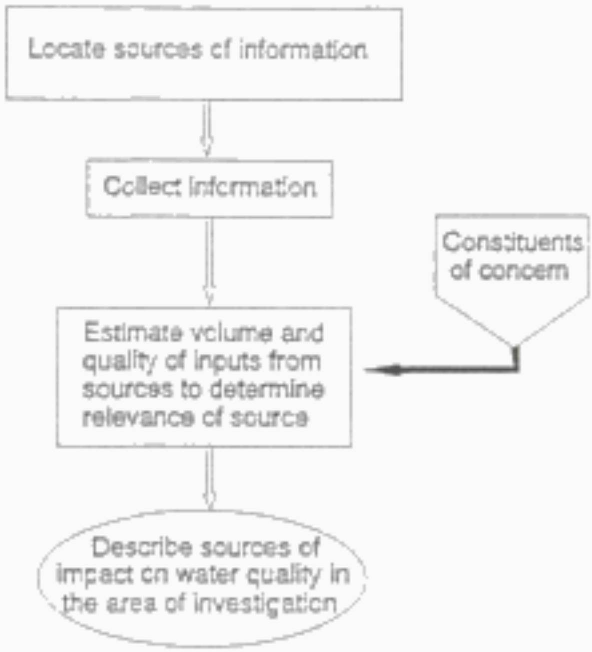


Figure 5 Identify sources of impact on water quality in the area of investigation

4.3 Locate sources of information

The first step is to locate the information sources. Some examples of information sources are:

- Record of permits issued by the DWAF
- Local authorities, for example, municipalities
- Industries
- The public
- Conservation organisations
- Physical inspection of the area of investigation
- Use of historical data to make an assessment of spacial and temporal changes in water quality in the receiving water body.

4.4 Identify and describe sources of impact on water quality

> ☞ Using all available sources of information, identify all possible sources of impact on the quality of the receiving water body in the area of investigation.

other sections of this manual that apply to this task

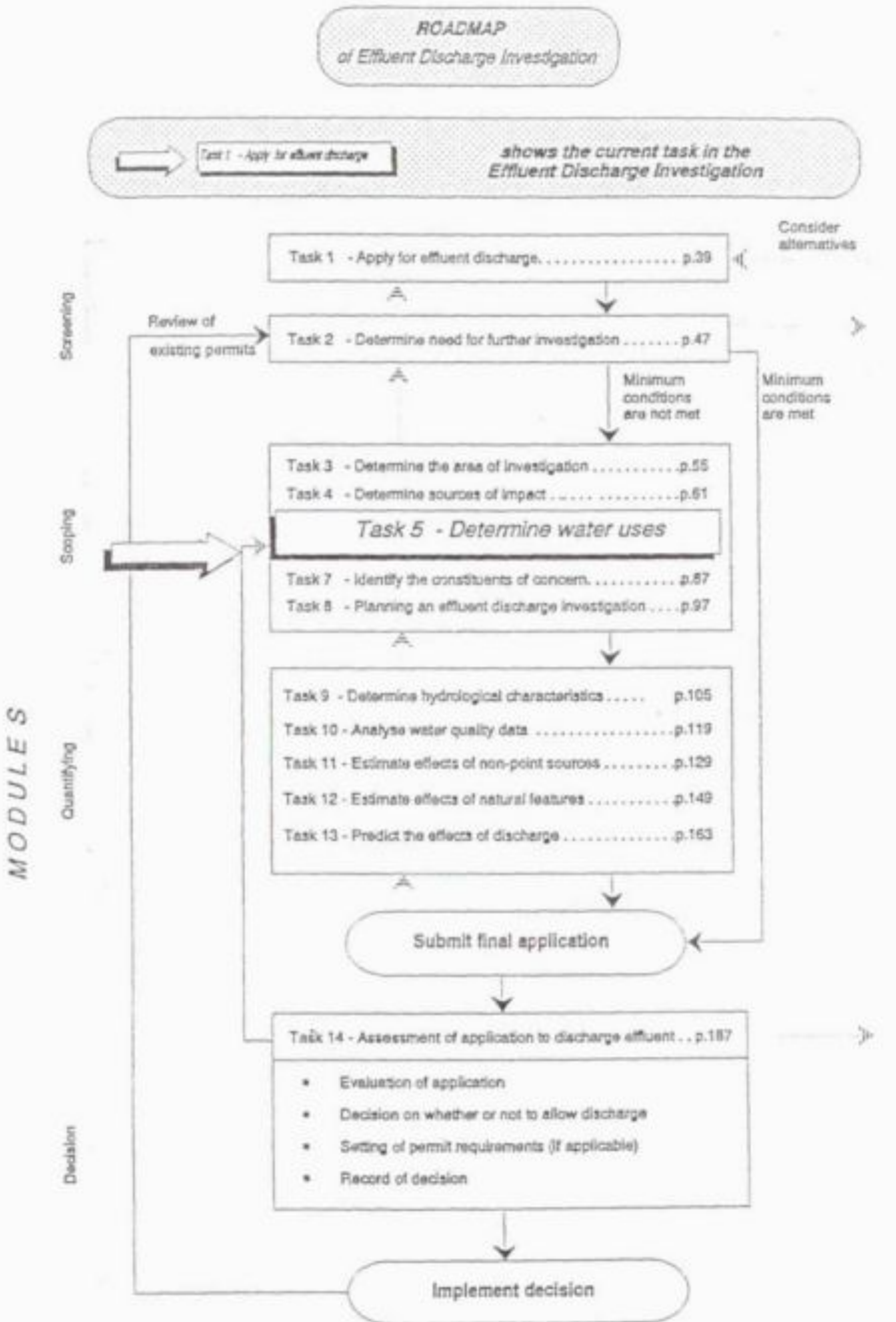
Tasks 11 and 12 that describe water quality effects resulting from natural features and from non-point sources provide information on the kinds of impacts one might expect from those sources.

what the descriptions include

Describe the sources that impact on water quality in the area of investigation, in terms of:

- Where they are located
- The properties and characteristics of their discharge or impact
- The range over which the properties and characteristics varies
- Any other factors which affect the impact of these sources and/or the spatial or temporal distribution of such impacts (e.g. industries such as fruit canners which operate only during certain seasons or fluctuations in the gold price which may affect, over longer cycles, the scale of mining operations, etc.)
- The significance of the source by comparing its impact on the quality of the receiving water body with that of the effluent discharge being investigated
- The options available and constraints for controlling the undesirable impacts and enhancing the desirable impacts of these sources on water quality of the receiving water body.

TASK 5:
Determine Water Uses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TASK 5:
Determine Water Uses

☞ The objectives of this task are to:

- Gather information on water users and the natural aquatic environment
- Determine which water users and aspects of the natural aquatic environment are most likely to be affected by the discharge so that their water quality requirements can be determined.

☞ Water quality is not an intrinsic property of water, it can only be described in the context of what the water is or will be used for.

☞ The water users and the natural aquatic environment should be characterised in sufficient detail so that their unique water quality requirements can be determined.

5.1 Who uses water in the area

responsibility

The discharger collects information on the water users and the natural aquatic environment in the affected catchment. The DWAF will ensure that all significant users and the features of the natural aquatic environment have been taken into account.

A flow diagram showing the steps involved in this task, as well as its links to other tasks in this module, is given in **Figure 6**.

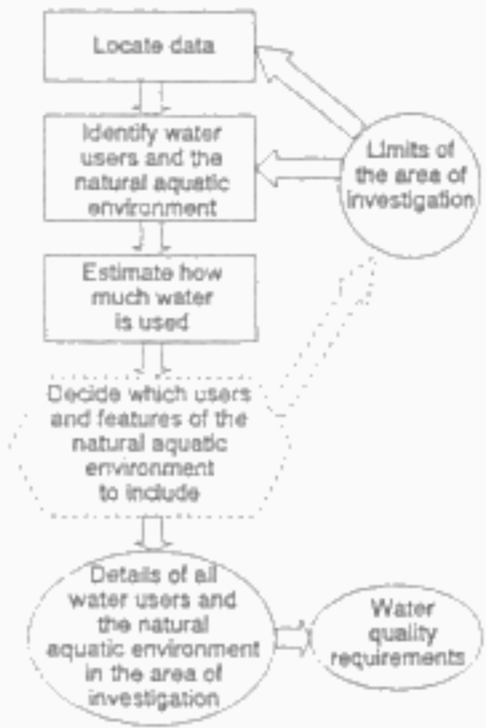


Figure 6 Flow diagram for "Determine water uses and the natural aquatic environment in the area of investigation"

water users

There are water users in all sectors of the economy. Water uses can be classified according to four main categories, namely:

- Agricultural
- Domestic
- Industrial
- Recreational

These major classifications can be sub-divided as follows:

▪ Agricultural	▫ Irrigation, according to crop and soil type ▫ Stock watering ▫ Aquaculture
▪ Domestic	▫ Drinking water, water used for washing and cleaning, gardening, etc.
▪ Industrial	▫ Industries have a wide range of processes each with different water uses e.g. direct consumption in the product, cooling water, washing water etc.
▪ Recreational	▫ Primary contact - e.g. swimming - where the entire body is expected to be submerged ▫ Secondary contact - e.g. boating, water-skiing - where full body submersion is not expected ▫ Fishing ▫ Aesthetics (no direct water use)

Protection of the health of the natural aquatic environment, although it is not a water use but rather a part of the water resource itself, also needs to be characterised in terms of its water quality requirements.

water quality requirements

Each water use as well as the need to protect the health of the natural aquatic environment has certain **water quality requirements** which can be assessed in terms of particular water quality constituents. The requirements for different users vary substantially within each sector. Agricultural water quality requirements depend on the crop, soil and irrigation practices employed; different industrial processes each have different requirements; water quality requirements for the protection of the health of the natural aquatic environment vary depending on the habitat, the sensitivity of the organisms, the occurrence of rare and endangered species and other, site-specific, considerations such as the conservation status and conservation importance of the ecosystem. *See Task 6 for a description of determining water quality requirements.*

5.2 Locate sources of data on water use

A number of sources of data can be accessed for information. Among them are:

- DWAF records
- Local authorities
- Industries
- Municipalities
- Irrigation boards

- The public
- Conservation groups
- Field studies.

The degree to which the data are accessible varies according to the data source. For initial estimates, DWAF records will often be sufficient.

5.3 Determine location of water users

> ☞ In this step the physical location of water users and features of the natural aquatic environment within the area of investigation are described.

level of detail

The amount of time and effort spent in extracting, analysing and correlating data from different sources will depend on the point that has been reached in selecting the scope of the investigation. In the first iteration, which takes a wide view with little detail, broad categories of users will be sufficient, as long as the most sensitive users are represented. Later iterations may require more attention to identifying specific needs of water us rs, for example, crops grown on specific soil types.

5.4 How much water is used?

> ☞ Each water user must be associated with a volume of water consumed and the in-stream flow requirements of the natural aquatic environment need to be determined.

The estimate of the volume used may be based on actual recorded values (for example, from municipal records), from estimated average figures supplied in the literature, or estimated by other indirect measures. In determining the scope, the objective is to estimate the relative volumes of water used. That estimate, in turn, is used to provide input to assess the importance of the uses. Exact figures are not essential for the initial estimates. Data should be as accurate as possible within the time and other constraints of this initial phase. More detailed data on some water uses or the natural aquatic environment will be needed during subsequent phases to determine the water quality requirements.

It is equally important to estimate the in-stream flow requirements of maintaining healthy the natural aquatic environment in order to balance these needs with that of water users.

5.5 Which users should be included?

initial selection

In the first iteration of scoping, where the entire catchment might have been identified as the study area, **all users** as well as **all the features of the natural aquatic environment** must be included.

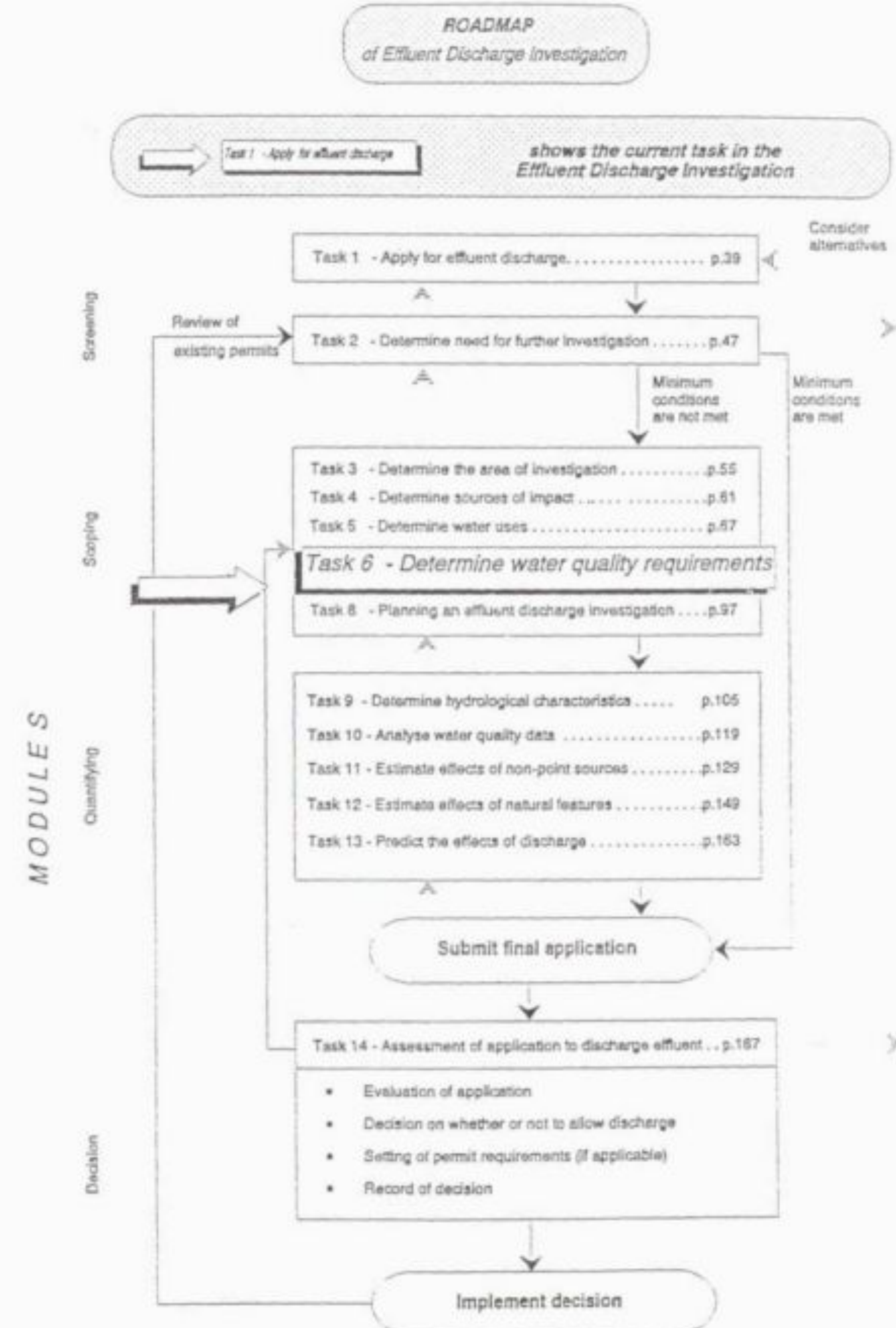
omission of some uses

In later iterations, some water users and the natural aquatic environment or components of ecosystems in the study area may be omitted on the basis of the following criteria:

- They are upstream of the discharge and do not have an effect on and is not affected by the downstream water quality
- Some may be insensitive to all the components of the discharge.

Neither water users nor the natural aquatic environment or components should be omitted if there is uncertainty about their roles or likely economic importance and status in the study area.

TASK 6:
Determine Water Quality Requirements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TASK 6:
Determine Water Quality Requirements

☞ Water quality requirements must be described for the water users and for the protection of the natural aquatic environment downstream of the proposed discharge for each of the constituents of concern. These descriptions should contain at least the Target Water Quality Range, as specified in the South African Water Quality Guidelines, and the effects on water uses and the natural aquatic environment, of water quality which is outside the Target Water Quality Range.

6.1 How are water quality requirements determined?

what is water quality

The term **water quality** is used to describe the physical, chemical, biological and aesthetic properties of water which determine its fitness for the protection of the natural aquatic environment and for water uses. Many of these properties are controlled or influenced by constituents which are either dissolved or suspended in water.

fitness of water

Note that statements of water quality in the form of statistics on the concentrations or levels of water quality constituents do not say anything about how **desirable or acceptable** it is for water to have the properties listed. Therefore, in addition to such statements, one also needs to make a judgement about how desirable or acceptable water of such a quality would be for a particular purpose before its fitness can be determined.

what water quality is required

For the assessment of water quality it is necessary that each of the water uses and the natural aquatic environment be characterised in terms of its water quality requirements. Such characterisation involves establishing:

- For what purpose and how water is used
- How much water is used
- What are the typical water quality related problems being experienced by each water use
- Which are the key water quality constituents for that use, i.e. those that are directly or indirectly associated with typical water quality problems
- What norms or yardsticks would one use to measure the impacts of water quality on the use
- What the target water quality range is for the key constituents for that use
- What are the effects on the use of the water quality that is outside of the target water quality range.

The process to characterise and determine the water quality requirements for protecting the health of the natural aquatic environment must be undertaken in a similar way to the one used to characterise the water uses.

no effect range

For each water quality constituent there is a **no effect range**, which is the range of concentrations or levels at which the presence of that constituent would have no known or anticipated adverse effect on the fitness of water for the protection of the natural aquatic environment and for water uses. These ranges were determined by assuming long-term continuous use (life-long exposure) and incorporate a margin of safety.

Target Water Quality Range

The Department of Water Affairs and Forestry has, as a matter of policy, decided to strive to maintain the quality of South Africa's water resources such that it remains within the no effect range. Therefore, in the South African Water Quality Guidelines the no effect range is referred to as the **Target Water Quality Range** (TWQR). It is included, and highlighted as such, in the water quality criteria provided for each constituent in the South African Water Quality Guidelines. The word "target" emphasises that this is the water quality the DWAF strives to maintain in terms of its duty to maintain the fitness of South Africa's water resources on a sustained basis.

The **Target Water Quality Range** must be specified for each of the key constituents for each water use and for the protection of the the natural aquatic environment.

water quality objectives already set

The DWAF is developing receiving water quality objectives for all catchments on a systematic basis. Dischargers wishing to discharge into those stream reaches or other water bodies for which water quality objectives have already been set, would need only to verify that all constituents of concern in the effluent to be discharged had been included in the objectives.

If receiving water quality objectives have previously been set, the task of determining water quality requirements will have already been completed.

water quality objectives not previously set

Those dischargers wishing to discharge into stream reaches or other water bodies for which water quality objectives have not yet been set for the constituents of concern in the effluent would follow the steps shown in Figure 7 below. This process would involve determining the water quality requirements, for each key constituent, of water uses and the natural aquatic environment which are likely to be impacted by the effluent discharge.

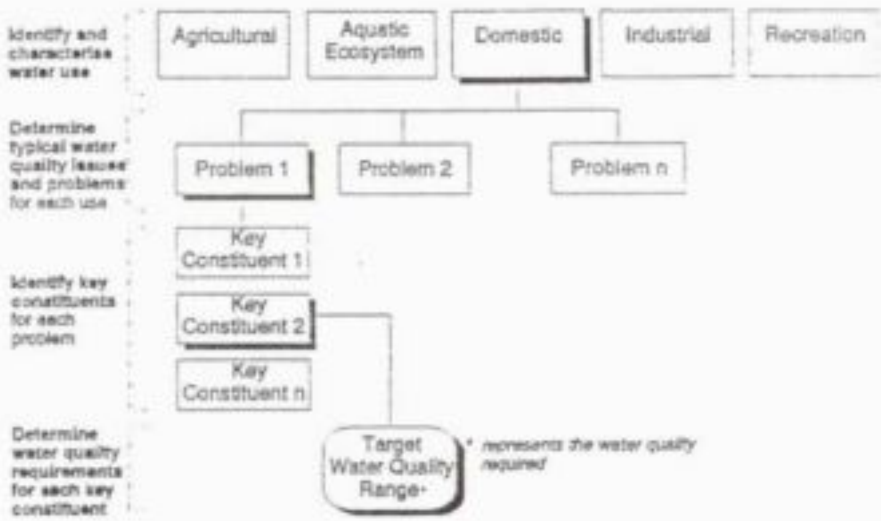

Figure 7 Flow diagram indicating the steps involved in determining water quality requirements

6.2 Water quality guidelines

6.2.1 South African Water Quality Guidelines

The DWAF has developed, and maintains, the South African Water Quality Guidelines which is its primary source of information and decision support on the water quality requirements of a variety of water uses and for protecting the health of the natural aquatic environment (DWAF, 1993).

definition of a water quality guideline

A **water quality guideline** is a set of information provided for a specific water quality constituent. It consists of the water quality criteria, including the target water quality range, for that constituent, together with other supporting information such as the occurrence of the constituent in the natural aquatic environment, the norms used to assess its effects on water uses, how these effects may be mitigated, possible treatment options, etc.

applicability of guidelines

The South African Water Quality Guidelines consists of the guidelines for domestic, recreational, industrial and agricultural water uses as well as guidelines for the protection and maintenance of the health of the natural aquatic environment.

These guidelines are now in the process of being expanded by developing guidelines for more constituents and by developing guidelines for protection of the health of the natural aquatic environment. Similar guidelines for the coastal marine environment and for estuaries are also being developed (DWAF, 1995, in prep.).

The primary basis for determining water quality requirements is the South African Water Quality Guidelines, described above. These should be used unless there are specific reasons why they are not applicable, as described below. Where necessary the information in the South African Water Quality Guidelines should be supplemented with information from other local and international sources or guidelines.

site-specific guidelines

Some cases will require the development of site-specific guidelines. For example, guidelines may not be available for a specific constituent of concern. Generic guidelines may not be appropriate for local conditions in the study. Knowledge of local conditions is essential to develop site-specific guidelines from generic guidelines.

In those cases where it is necessary to develop site-specific guidelines, those involved in effluent discharge investigations must follow the same process that was used for the development of the South African Water Quality Guidelines and which is described in the Guidelines.

updating of guidelines

The South African Water Quality Guidelines are updated and expanded from time to time. Therefore, those involved in effluent discharge investigations in which water quality requirements need to be determined should confirm that they are using the most current version of the South African Water Quality Guidelines.

6.2.2 Other water quality guidelines

There are some combinations of water uses and water quality constituents of concern for which the South African Water Quality Guidelines do not contain the information needed for determining water quality requirements. In such cases it may be necessary for those involved in effluent discharge investigations to consult other sources of local and international water quality guidelines.

- **Local information**

  Local sources of information which can be used to supplement the South African Water Quality Guidelines include:

  Summarised Water Quality Criteria (Kempster *et al.*, 1980)
  South African Bureau of Standards: Specification for water for domestic supplies (SABS, 1984)
  Water quality fitness for use rating curves for domestic water (Kempster and Van Vliet, 1985)
  Proposed aesthetic/physical and inorganic drinking-water criteria for the Republic of South Africa (Kempster and Smith, 1985)
  Water quality criteria in South Africa (Aucamp & Vivier, 1990)
  The effect of water quality variables on riverine ecosystems: A review (Dallas and Day, 1993)

- **International information**

  International sources of information which can be used to supplement the South African Water Quality Guidelines include:

  Australian Water Resources Council: "A compilation of Australian Water Quality Criteria" (Hart, 1974)
  United States Environmental Protection Agency: "Health effects criteria for marine recreational waters" (Cabelli, 1984)
  World Health Organization: "Guidelines for Drinking Water Quality" (WHO, 1984)
  United States Environmental Protection Agency: "Quality Criteria for Water: 1986" (USEPA, 1986)
  Canadian Council of Resource and Environment: "Canadian Water Quality Guidelines (Canadian Guidelines, 1987)

6.3 Graphic presentation of information

graphic presentations

At a particular location, the combination of water users, measured water quality, and water quality guidelines forms a complex picture that describes the water's existing fitness for the protection of the natural aquatic environment and for water uses. **Graphic presentations** are used as tools to integrate and display this information.

Graphic presentations are used to summarise information required for setting or revising **water quality objectives**. They are also useful tools, on their own, for communicating with water users. Graphic presentations do not document particular decisions; rather, they are used by water quality managers to help in their decision making.

examples of graphic presentations

Figure 8 shows a version of a graphic presentation of how water quality varies over time compared to the water quality requirements of a single user at a single point in the river. This type of presentation is useful for a water quality manager who needs to assess if there are any trends in water quality over time and to see how these will impact on the water user. The "concentration" line may need clarification and/or enhancement in some cases. It will often show measured data, but the data may be transformed to show statistics such as weekly averages, monthly maximums, etc. The location of the measuring point for which the information is displayed is also important. The ideal point is just upstream of the user, but this information may not always be available.

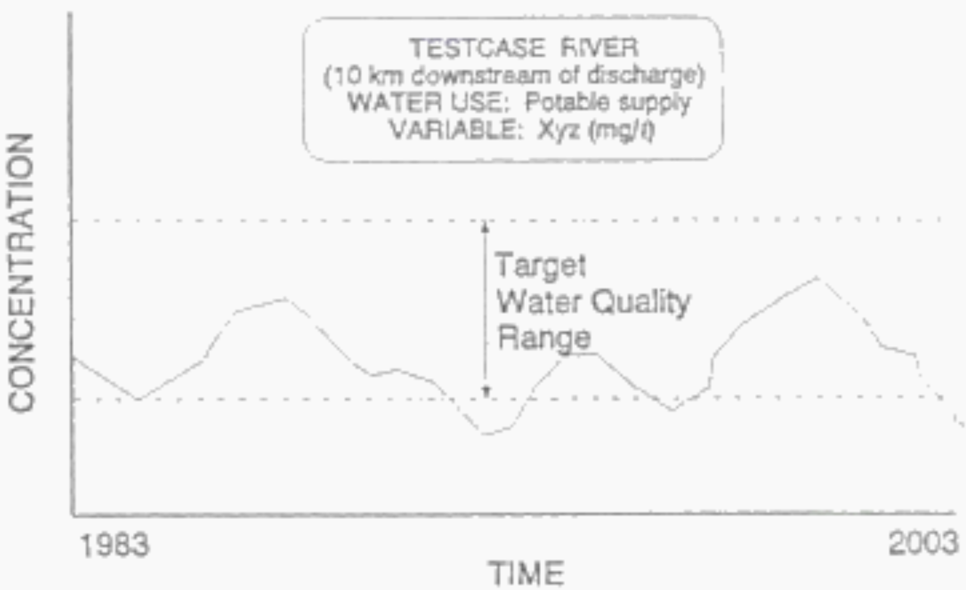

Figure 8 An example of a graphic display of a time series of measured or predicted water quality compared to requirements of a single user, at a single location in a river

Figure 9 shows another graphic presentation of water quality over the length of a river and compared to the requirements of different water users. This way of presenting information is useful for giving an overall picture of the existing water quality in relation to all users in a reach. Note that where a user has a single abstraction point (such as the potable supply point shown in the figure), the target water quality range is linked to a point. Where a user has multiple or diffuse abstraction points (such as the irrigation use), that target water quality range applies over the length of river where abstraction occurs.

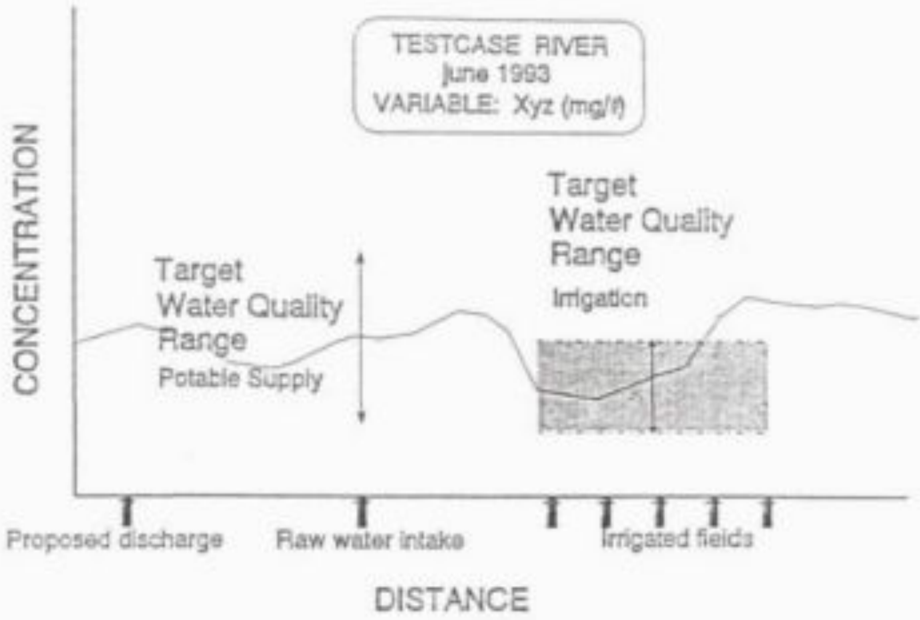

Figure 9 A graphic presentation of measured and predicted water quality along the length of a river compared to the requirements of water users

As in the single use case, the "concentration" line will need clarification and/or enhancement. It may show data as measured for different purposes but will more often represent summarised or transformations of measured data, such as weekly averages, monthly maximums, etc.

In both the above graphic presentations, only a single guideline range, i.e. the target water quality range has been shown for each user. In practice, other ranges can also be shown, for example, the range of water quality which would be considered to be tolerable or unacceptable.

The effects of the discharge can be "superimposed" on the existing water quality in the graphic presentation to show what its likely impact would be on the resultant water quality.

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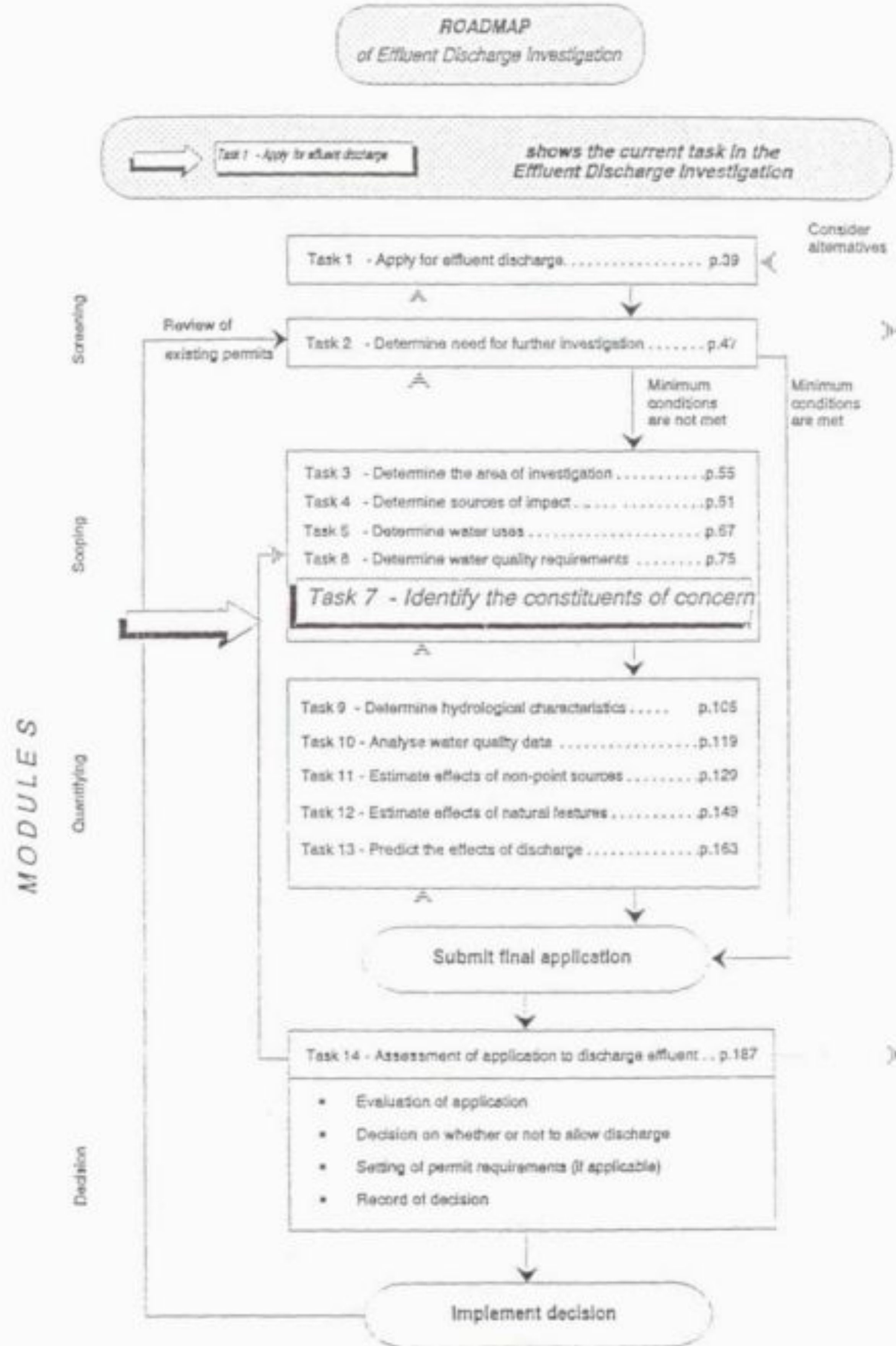
TASK 7:
Identify the Constituents of Concern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TASK 7:
Identify the Constituents of Concern

☞ Time and resource limitations means that it is not possible to investigate the effects of all the possible constituents which may occur in an effluent on water uses and on the health of the natural aquatic environment. Therefore, one needs to identify the constituents in the effluent that are of concern to water users and for the protection of the natural aquatic environment in order to focus the effluent discharge investigation on these.

☞ To be able to identify the constituents of concern, the water uses likely to be affected must be characterised and the possible effects of changes in water quality on these users must be determined.

☞ The extent to which water quality can affect a specific water use can often only be assessed by considering these effects at a detailed process level.

7.1 The effects of water quality on water uses and the natural aquatic environment

In order to identify water quality constituents of concern it is necessary to understand how water quality affects the water uses and the natural aquatic environment likely to the impacted by an effluent discharge.

The South African Water Quality Guidelines is the principle source of information which the DWAF uses to assess the effects of water quality on water uses and the aquatic environment.

In these Guidelines the different water uses and sub-uses are characterised from the perspective of the typical water quality problems they experience as well as their water quality requirements. Each water quality constituent for which guidelines are provided is also briefly described in terms of its occurrence in the water environment, typical sources of impact on water quality, its interactions with other constituents, how it is measured, how data should be interpreted, what the options are for removing it from the water and what its effects are on water uses.

The DWAF requires that the South African Water Quality Guidelines are used in the process of identifying water quality constituents of concern for the purpose of effluent discharge investigations. These guidelines should, however, not be considered as the only source of information. Other sources containing much more detailed information, for example Hem (1989) and Thomann and Mueller (1987), should also be used.

7.2 Identify the water quality constituents of concern in the effluent

The following steps will help with the identification of which water quality constituents occurring in an effluent would be of concern to downstream users. The identification of constituents of concern is an iterative process so one must be prepared to go through these steps more than once. Each of these steps are described in greater detail in the ensuing sections:

- Do a preliminary selection of constituents in the effluent for analysis and determine their likely concentration ranges (*see Section 7.3*)
- Determine the concentration range of the same constituents in the water body that will be receiving the effluent (*see Section 7.4*)
- Determine the hydrological characteristics of the receiving water (*see Section 7.5*)
- Combine the effluent and receiving water in realistic proportions, to determine the likely changes in the concentration of various constituents in

the receiving water that would result from discharging the effluent (*see Section 7.6*)

- Compare the likely changes in water quality for each constituent with the water quality requirements of downstream water users and for the maintenance of the health of the natural aquatic environment to determine which constituents would be of concern (*see Section 7.7*).

7.3 Make the initial selection of constituents of concern

By considering the key water quality constituents from a water user perspective and what occurs in the effluent, possible constituents of concern should be selected from the following groups:

- Constituents in the effluent discharge itself
- Constituents in other existing discharges to the receiving water
- Constituents derived from the catchment geology.

The key water quality constituents will fall into one of the following groups:

- Physical properties - pH, conductivity, suspended solids
- Major cations - Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+
- Major anions - OH^-, CO_3^{2-}, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, PO_4^{3-}
- Heavy metals - Fe, Mn, Al, Zn, Cu, Ni, Cr, Co, Pb, Se
- Other inorganic constituents - B, Si, F
- Organic constituents
- "Whole effluent toxicity" - should be considered as a possible constituent of concern for complex effluents.

If determining the range of concentrations of the potential constituents of concern in the effluent to be discharged is not a straightforward procedure, the flow chart in **Figure 10** should be used for guidance. The procedure is simple, though long, but will help ensure that potential constituents of concern are not omitted.

whole effluent toxicity

If the constituents in an effluent are too numerous and varied to identify and analyse cost-effectively (i.e. complex effluents), tests should be conducted on the effluent, separately and combined with the receiving water, to determine its toxicity to a variety of aquatic organisms. This measurement is referred to as "whole effluent toxicity".

Figure 10 Flow diagram showing the procedure to determine the composition and variability of effluent quality

7.4 Determine the concentration ranges of the constituents in the receiving water

Use existing data or data collected during the preliminary investigation, to define the current concentration ranges for the possible constituents of concern in the receiving water.

Concentrations of the potential constituents of concern are likely to change over an annual cycle, therefore, information on their concentrations at least at the end of the dry season and mid-way through the wet season will provide a rough first estimate of the maximum spread in concentrations.

7.5 Determine the hydrological characteristics of the receiving water

This step is addressed in considerable detail in the *Task 8. Determine Hydrological Characteristics*. Information must be obtained about the range of flows that are likely to be observed in the receiving water. The low flows are especially important because they represent the situations in a receiving water body when its assimilative capacity for waste is at its lowest.

CONSTITUENT OF CONCERN :

PLAN	
POINT	km
Upstream	
E	0
Downstream	
Direction of flow	

UPSTREAM (U/S)

	MAX CONC	MIN CONC	MAX FLOW	MIN FLOW
BEFORE RAINS				
DURING RAINS				

EFFLUENT (E)

	MAX CONC	MAX FLOW
EFFLUENT		

EXPECTED DOWNSTREAM (DS) CONCENTRATIONS (mg/ℓ)

(MAXIMUM EFFLUENT DISCHARGE RATE AND CONSTITUENT CONCENTRATION COMBINED WITH DIFFERENT SCENARIOS OF UPSTREAM CONDITIONS)

		MAX FLOW	MIN FLOW
BEFORE RAINS	MAX CONC		
	MIN CONC		
DURING RAINS	MAX CONC		
	MIN CONC		

ARE USERS AFFECTED (CONCERNED) BY THE CONCENTRATION RANGES FOR THIS CONSTITUENT

WATER USE	SUB-USE	PRESENT √/x	CONSTITUENT OF CONCERN?			
			YES	ACCEPTABLE RANGE	NO	?[1]
DOMESTIC						
RECREATION						
INDUSTRY						
AGRICULTURE						
NATURAL ENVIRONMENT						
MANAGEMENT	LONG TERM TRENDS					
	RWQO COMPLIANCE					
	PERMIT REQUIREMENTS					

NOTES :
- Mark the position of downstream water USERS on the schematic plan and indicate their distance in kilometres (km) from the E[ffluent]

1. ? indicates further investigation is needed

Figure 11 Form to assist in selecting constituents of concern

7.6 Determine quality of the receiving water downstream of the effluent discharge

If the quality of the receiving water has been analysed at various times of the year, the form shown in **Figure 11** can be used (one sheet per constituent) for calculating the range of quality expected downstream of the discharge. This form can also be used by water resource managers to help select constituents for monitoring of longer-term trends.

7.7 Select the constituents of concern

identify water users

The water users will have been identified earlier in the investigation (*see Task 5, Determine Water Uses*). Their location or abstraction points should be indicated on the schematic plan on the form shown in **Figure 11** to show the distance downstream from the effluent discharge and their relationships to other discharges or tributaries of the water course.

effects on users

The location of abstraction points of other users will be taken into consideration in determining the quality of the future supply available to each user. For example, the concentrations of non-conservative constituents may drop with distance from the point of effluent discharge and major discharges or tributaries joining the water course may change the quality of the future supply according to their own composition.

The lower section of the form lists the water uses and sub-uses present and requires an answer to the question "Are users affected (concerned) by concentrations of this constituent?" The question:

- May have an obvious answer
- May require site-specific investigation to provide an answer.

In the case of an obvious answer, YES or NO would be indicated and an acceptable concentration range given in the case of a YES. Preliminary investigation may provide the answer in the second case or the question may be deferred for further investigation and indicated in the column headed "?".

initial list of constituents of concern

The form in **Figure 11** would thus be completed for each constituent, which would become a constituent of concern whenever the YES or the "?" was indicated in the lower part of the form. All such completed sheets taken together would provide the initial list of the constituents of concern.

Further investigation might be needed in the course of the effluent discharge investigation. This may require, for example:

- Modelling of the fate of non-conservative constituents
- Consideration of synergistic effects
- Consideration of the possibility of solublisation of certain constituents from the sediment.

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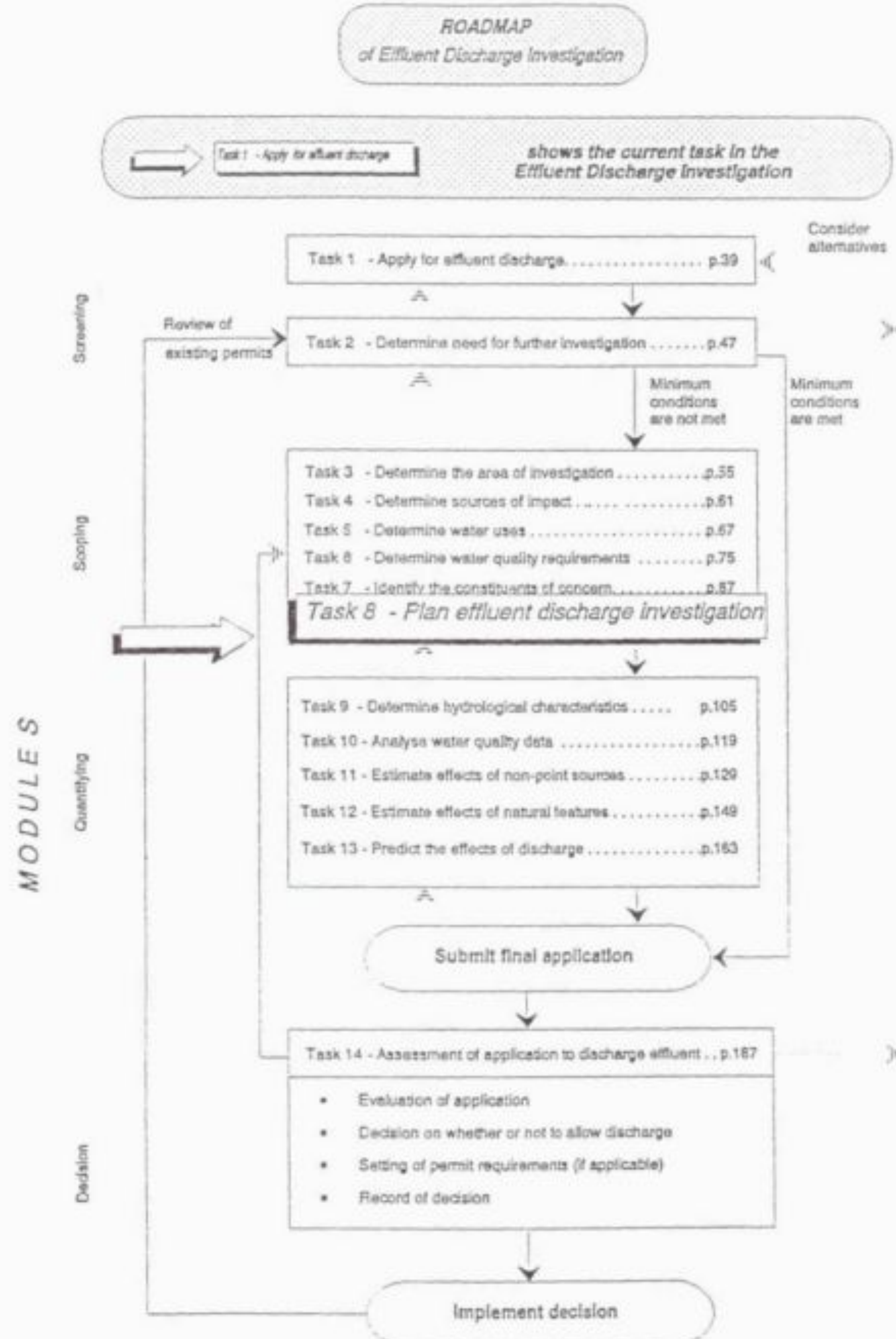
TASK 8:
Planning an Effluent Discharge Investigation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TASK 8:
Planning an Effluent Discharge Investigation

☞ This task deals with the planning requirements of an effluent discharge investigation.

☞ The steps described here should be used as a checklist to ensure that important details are not overlooked.

8.1 Important steps

The scoping module is concluded by planning the detailed investigation of the impacts of the proposed effluent discharge on the receiving water.

☞ There are four important aspects which must be resolved to ensure that such an investigation is done cost-effectively:

- A steering committee consisting of representatives of the DWAF, the discharger(s) and interested and affected parties needs to be constituted.
- The scope of the investigation and the terms of reference for specific tasks need to be determined.
- The time over which the investigation has to be completed need to be determined.
- The financial requirements for completing the investigation and how these costs will be shared amongst the different parties involved, need to be determined.

8.2 Constitute a steering committee

role of the steering committee

In order to ensure that the interests of all the parties involved in a discharge investigation are effectively dealt with and that these are taken into account throughout the execution of a project it is strongly recommended that a steering committee is constituted. The role of the steering committee is to define the terms of reference for the investigation, to monitor progress and to evaluate the findings. In addition to the discharger, the steering committee should also include representatives from DWAF and interested and affected parties.

DWAF representatives

It is important that the appropriate staff from the DWAF is represented on the steering committee. These representatives must have the mandate to interpret policy and make decisions on behalf of the department.

other government organisations

In some cases the decision taking process on whether or not to allow an effluent discharge requires that other government or provincial organisations be involved. It is important that these organisations are identified and asked to be represented on the steering committee. Organisations to be considered are:

- Department of Health
- Department of Environment Affairs and Tourism
- Provincial nature conservation agencies
- Local authorities and organisations involved in water supply and sanitation.

public involvement

DWAF seeks to involve the public as far as practically possible in decisions regarding water quality management. Inclusion of interested and affected parties in effluent discharge investigations and the associated decision-making process can greatly affect the scope of the investigation. The involvement of interested and affected parties, particularly if it is done too late or as an after thought, can substantially increase the time and cost required to complete an investigation. At least the following groups should be consulted for possible involvement in the steering committee overseeing an effluent discharge investigation:

- Water users in the area of investigation
- Representatives of environmental conservation groups in the area
- Any discharger(s) who are in the area of investigation and who may or do impact water quality in the same way that the applicant is likely to do.

8.3 Determine the scope and detailed terms of reference

preliminary investigation

It is possible that an initial investigation may be carried out at a superficial level to determine the major issues that should later be dealt with in detail. The preliminary investigation should be based on the information submitted in the application to discharge, as described in *Task 1, Apply for effluent discharge*. For those cases, all the tasks in the Scoping and Quantifying Modules would be addressed, but using only available information and relying on sensitivity analysis. Conservative (worst case) estimates and assumptions would be used, where needed, to ensure that any possible unacceptable effect is identified.

subsequent investigation

A second stage of the investigation could be conducted when the preliminary investigation indicates that an effect might be unacceptable. The second stage would generally have more emphasis on quantifying a specific part of the identified problem. Information from the initial analysis would be used to allocate resources to the detailed investigations.

catchment study in place

The existence of a completed catchment study or a survey of the catchment in which the point source is located will greatly expedite the initial scoping exercise.

amount of available data

The amount and reliability of available data will greatly affect the scope of the investigation, particularly in terms of the time required and the final cost. If sufficient information on the background and effluent quality is available, the time required to complete an investigation may be limited. If little data are available and a sensitivity analysis indicates that the allowable discharge requirements might be quite different as result of unquantified factors, data collection to define those factors should be initiated.

future development

Decisions must be made regarding the time frame to be addressed in the investigation. Projections of future development should be made in this procedure. Criteria for selecting an appropriate time frame include the:

- Expected duration of the discharge
- Rate of change predicted
- Magnitude of the changes predicted
- Amount of information available on expected changes.

time frames

For rapid or major changes, the time frames addressed in the investigation should include short- to medium-term scenarios of 5 to 15 years. The uncertainty of predictions associated with scenarios is so large that special precautions should be taken when using these for setting effluent discharge limits. It would be more feasible to establish discharge requirements based on short-term scenarios and to re-evaluate those requirements from time to time.

Develop work plan

A work plan that describes the tasks included in the effluent discharge investigation, the time required to complete each task, the resources required in terms of manpower and equipment and the task scheduling will provide a framework for the steering committee to evaluate the progress of the investigation and to ensure that all the relevant tasks have been included.

8.4 Determine time over which the investigation is to be completed

effect of data collection on time required

An assessment of the amount of information available and the amount of data that must be collected would provide an estimate of the amount of time required to collect the additional data. When determining the amount of effort and time to put into data collection both the magnitude and importance or seriousness of the possible impacts must be considered.

Conversely, where a serious situation already exists and some immediate solution is required, less time for data collection may be available. In that case, great care is needed in planning data collection efforts, to ensure they are as efficient as possible. A longer term data collection programme should be considered to provide data to re-evaluate any crisis decisions that were made.

Data collection should extend over a period long enough to cover the important time periods. For example, low flow often provides the worst case conditions that must be protected against. Data collection should cover those periods.

long-term cycles

Consideration must be given to long-term cycles that affect the amount of water available. Rainfall is variable and meterological variation produces periods of less-than-average rainfall. Those conditions must be taken into account, although it is impractical to wait for the one-in-a-100-year low flow event so that its effects can be measured. Annual rainfall variation can be deduced from historical data in the area of investigation, or in nearby areas.

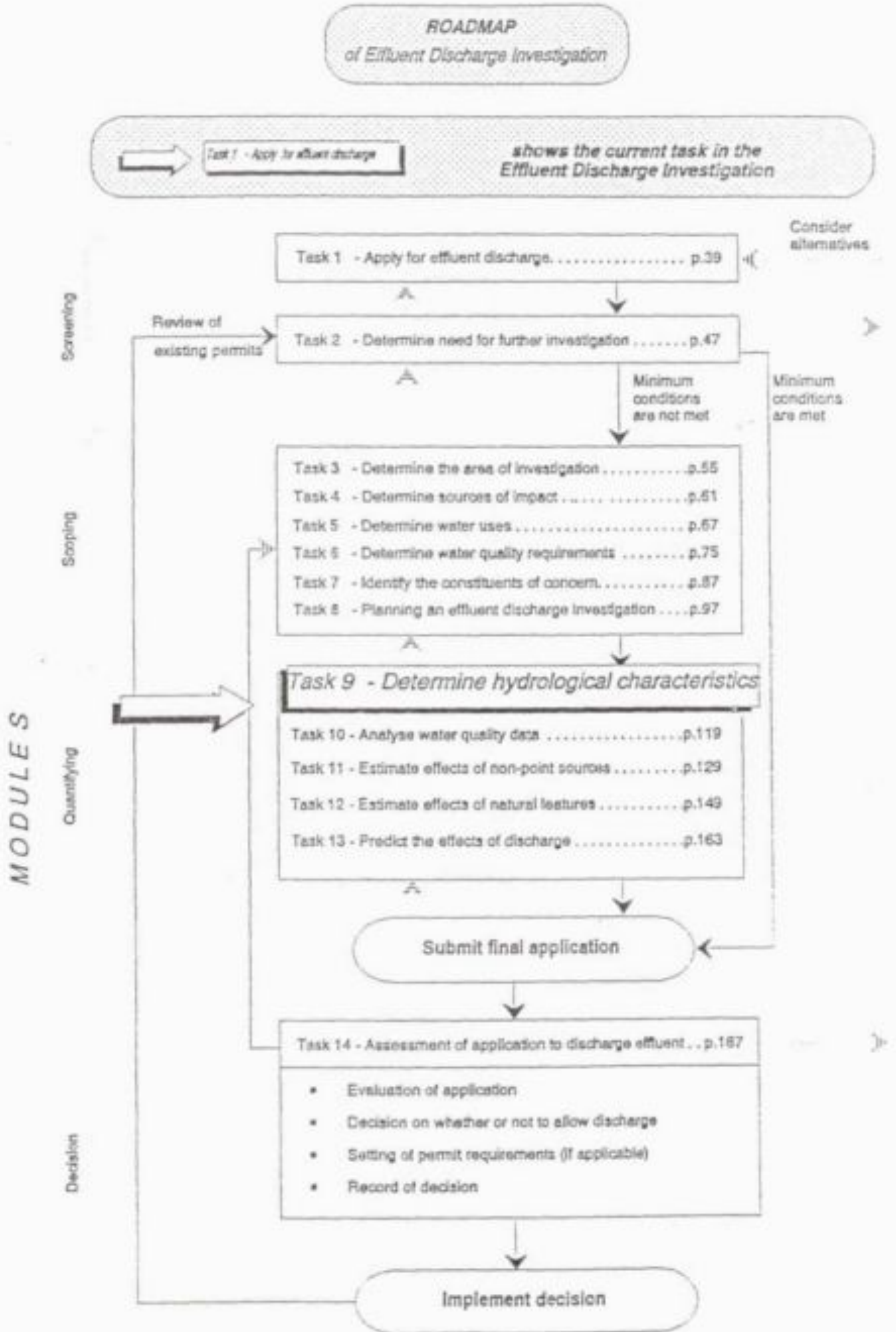
8.5 Financing the investigation

The DWAF, the applicant or the other parties involved may require that the detailed effluent discharge investigation be carried out by external consultants. If an external consultant is required, the onus is on the applicant to ensure that the consultants appointed are competent to carry out the investigation and to pay for their services.

EFFLUENT DISCHARGE INVESTIGATION

QUANTIFYING MODULE

TASK 9:
Determine Hydrological Characteristics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TASK 9:
Determine Hydrological Characteristics

☞ The purpose of this task is to describe the hydrological characteristics of the receiving water. It must describe both seasonal and longer-term variations in the hydrological characteristics of the receiving water.

☞ The hydrological characteristics of the receiving water is one of the most important determinants of its assimilative capacity. It is therefore important that it is done thoroughly, comprehensively, and with sufficient attention to low flow conditions.

9.1 Determine hydrological characteristics

> ☞ A key issue in the effluent discharge investigation is the interaction between the hydrological characteristics of the receiving water and the effluent. Of the many hydrological characteristics one could investigate, it is important to determine which ones are most closely related to the potential impacts of the effluent discharge and to focus attention on these.

When selecting the hydrological characteristics to be included as part of the discharge investigation it is important to carefully consider the water quality requirements as well as the water use patterns of the water users and the in-stream flow requirements of the aquatic environment. The hydrological characteristics that should be considered in the discharge investigation should be derived from these needs and requirements.

For example, the impacts of water quality on a water resource's fitness for the protection of the natural aquatic environment and for water uses are in some cases related to the ambient concentrations of particular constituents at the point of use or abstraction. In other cases the impacts depend more on the mass load of a particular constituent entering a water body over a period of time rather than on its ambient concentration at any particular time. In many cases impacts are related to both the ambient concentrations of constituents in the receiving water as well as on the mass load of a constituent entering the water body over time.

In those cases where the impact of an effluent is primarily related to the ambient concentration of one or more constituents in the receiving water body, hydrological characteristics which will allow ambient concentrations to be determined, should be selected, for example, daily flows. In those cases where the impact of an effluent is primarily related to the load of constituents, appropriate hydrological characteristics such as total annual runoff and water retention time, should be selected. The selection of appropriate hydrological characteristics is very case- and site-specific and depends on the nature of the impact the effluent may have on specific water quality requirements and on water use patterns of water users. It is of critical importance that the appropriate hydrological characteristics be selected and approved by everyone involved before data analysis and modelling starts.

9.2 Streamflow characteristics

9.2.1 Classification of streams

classification of natural streams

Natural streams can be divided into three general classes, each having a characteristic type of runoff depending upon the physical characteristics and climatic conditions of the catchment, namely:

- Ephemeral
- Intermittent
- Perennial

The above classification applies often only to a section or reach of a stream and not necessarily to the entire drainage system.

ephemeral

Ephemeral streams carry only surface runoff and hence flow only during and immediately after periods of precipitation. They sometimes have no permanent or well-defined channels but follow depressions in the natural contour of the ground surface. The drainage basin is either impervious or the groundwater table is always below the bed of the ephemeral stream. In the more arid parts of South Africa there are many drainage basins, some having large areas, in which the stream channels are always above the water table and therefore carry only surface runoff.

intermittent

Intermittent streams, in general, flow during wet seasons and are dry during dry seasons. The groundwater table lies above the bed of the stream during the wet season but drops below the bed during dry seasons. Hence the flow is derived principally from surface runoff but during wet seasons receives a base flow contribution from groundwater.

perennial

Perennial rivers flow at all times. In such rivers even during the most severe droughts, the groundwater table never drops below the bed of the river and therefore maintains a continuous base flow. Many rivers on the eastern and southern parts of South Africa as well as the major river systems in the central and western parts of the country are perennial.

urban streams

Streams draining urban areas can typically have flows made up of effluent discharges or leakage from water supply pipes, or general discharges of the water after use by domestic and industrial users. Depending on how regular the flow in these streams are, they can have hydrological characteristics similar to any of the above three stream categories.

9.2.2 Statistical summaries of stream flow characteristics

annual characteristics

The mean annual runoff (MAR) gives an indication of the average total annual water discharged through a river. For skewed distributions, the median is often preferred to the mean as an estimate of "average" conditions.

Measures of variability such as the standard deviation, coefficient of variation and coefficient of skewness can give an indication of the range of flows and the probability of occurrence of high or low flows. The lowest and highest annual streamflows are also useful as an indication of the range of flows to be expected.

monthly characteristics

The seasonal index indicates, by means of a coefficient, the extent of the month-by-month fluctuation. It is the difference between the maximum and minimum month where months are plotted as the cumulative departure of mean calendar month flow from mean monthly flow (expressed as % MAR).

daily characteristics

In terms of the effluent discharge investigation, the daily or continuous flow characteristics are typically the most important. Flow-duration information, where the flow equalled or exceeded is plotted against time, is a useful tool for discharge investigations.

low flow frequency

Also useful is low flow frequency information for various durations or statistical measures of daily low flows, for example, the 5 percentile of average daily flow, the $_7Q_{10}$ (the 7-day average flow with a recurrence interval of 10 years) and others.

limitations

One must be cautious about using only statistical summaries of hydrological characteristics in effluent discharge investigations. In many cases it may be better to simulate the impact of effluent on the receiving water body by using the complete record of a particular hydrological characteristic, for example, daily flows and then to extract statistical summaries of the simulated effects for assessment purposes.

9.3 Determine sources of streamflow data and information

9.3.1 Streamflow data recorded by the DWAF

> ☞ If there is a suitable gauging station close to the site, the data can be requested from the DWAF in a specified media format.

flow data

Streamflow data are collected by the DWAF at numerous streamflow gauges throughout the country. The resulting information is stored in electronic data files. The streamflow data bank forms part of the Hydrological Information Systems (HIS) under the control of the DWAF. These data can be requested from the DWAF, who supplies the data on specified media, for example, on computer disk. The data file contains the flow rate averaged for 24 hours and the date of that flow.

data from dams

The Directorate of Hydrology of the DWAF also uses data from state-owned dams to provide streamflow information. A water balance is produced in which the inflow to the dam, the spillages from the dam and the releases to the users, for domestic, irrigation or compensation are taken into account. Also taken into account is the rainfall on the dam surface and the evaporation from the free surface.

location of gauging stations

DWA Hydrological publication No 12 (DWA, undated) contains lists of river, reservoir, evaporation and rainfall gauging stations. The river gauging stations are referenced by station number, river, place, latitude and longitude, catchment area, period of record and classification, according to accuracy of measurement. For the dams, additional details are given. The numbering system shown in these tables has recently been updated (McDonald, 1989). Information on whether there are streamflow gauges close to a specific site can be obtained from this publication.

9.3.2 Published streamflow data from the DWAF

> ☞ The DWAF has published monthly flow records and other details from each gauge and reservoir under its jurisdiction in various hydrographic surveys.

types of data

Monthly flow records are published in a set of documents, namely:
- Hydrographic Survey Publication No 8, (DWA, 1964)
- Hydrological Information Publication No 10 (DWA, 1978)
- Hydrological Information Publication No 11 (DWA, 1978).

These documents give look-up tables identifying each of the gauges and for each gauge, list station details, year, annual runoff, monthly runoff, number of days of observed flow and any periods when there were no observations or the gauge was exceeded. For reservoirs, the monthly inflow (nett inflow) and the inflow plus precipitation on the water surface (gross inflow) is given. Periods of no record are also given.

access to data

The Hydrological Information Publications are freely available in libraries throughout the country. DWA Publication No 12 (DWA, undated), or the reference tables in the front of the flow publication, can be used to select the gauge. Records can then be extracted from the publications.

limitations of the data

The published data contain monthly flow records only, which are often not as useful for effluent discharge evaluation as the daily records. The publications contain data only to 1970 and will no longer be updated. Additional information can be requested from the DWAF.

9.3.3 Observations at the site

local observations

Some information can be obtained from site inspection and other local data collection programmes. This may include data and information on:
- Seasonality of the river
- Flow rates in the months of the year
- Lowest flows observed
  - When during the year
  - Which year the lowest
- Cessation of flows
  - Length of cessation
  - When during the year
  - Which years

Unless local observers have recorded their information and have correlated their observations with other detailed records, the credibility of the observations will suffer. However, the locally obtained site information can often be used for enhancement and verification of other information.

9.3.4 Problems in the use of recorded streamflow data

☞ The ideal would be to have, at the site in question, a long unbroken record of flow in an undeveloped catchment. This ideal is almost never obtained: thus the existing data and information have to be adjusted and used to maximum effect.

effect of changes in the catchment

Most hydrological data are in the form of historical records, however long unbroken records are the exception rather than the norm. The existing records reflect the effect of any changes to the catchment that had an impact on streamflow. The changes can have marked impact on the streamflow record. For example, dams have a major impact on the low flow characteristics of streams. Catchment changes can include afforestation, urbanisation, construction of infrastructure such as dams and irrigated agriculture. The data therefore may not represent a stationary record. Catchment changes are also likely to continue and possibly intensify in the future. The historical record may not allow the user to make predictions of future changes which may well incorporate different land uses, land cover, or other factors that have not occurred in the past.

The consequence of a non-stationary record is that the effect of the changes must be identified and removed, since most statistical analysis procedures assume the underlying process does not change with time.

sparsely distributed gauges

Streamflow gauges in South Africa are situated relatively far apart and, due to the large area, the coverage of the whole country is sparse. Therefore, streamflow data for a specific site is not often available. It is thus unlikely that the monitoring points maintained by the DWAF will coincide with the ideal location for an effluent discharge evaluation.

9.3.5 Other hydrological information

> ☞ Other hydrological information is available from the following sources:
> - WR90 study: "Surface Water Resources of South Africa"
> - Catchment studies
> - Systems analysis studies

WR90 study description

In 1982, the University of the Witwatersrand published a comprehensive survey of water resources in South Africa (Middleton *et al.*, 1982). In order to update this information, the Water Research Commission, in 1990, commissioned a new study of the surface water resources of South Africa (Midgley *et al.*, 1994). In this study, a mathematical model for simulating monthly runoff, WRSM90, was calibrated against some 400 flow gauges. Historical land use and land cover information was used in the calibration process. Monthly flow files at the quaternary catchment boundaries (some 3 000 records) for the 70-year period 1920-1990 will be available in the study documentation. These documents are freely available. Information on flow is also available on computer diskette. A serious limitation of this type of information is that it does not adequately deal with low flow information which is often of primary concern in effluent discharge investigations.

catchment studies

A number of integrated catchment studies have been commissioned by the DWAF over the last 10 years. Surface water resources modelling is done as part of the study and monthly flow information is produced using mathematical models at numerous key points in each basin. A list of basins already studied and to be studied is maintained by the DWAF. Flow records can be accessed on computer compatible media.

systems analyses

The DWAF have over the last five years commissioned a number of systems analyses for the major water supply systems, for example, Vaal River, Orange River, Western Cape, Amatole, etc. Hydrology is an integral part of the systems analysis and monthly virgin flows have been produced using mathematical modelling at a large number of selected sites within the catchment. In addition, stochastic flows have been generated from the monthly flow record at these sites, for input into the reservoir models. A list of the systems analysis already done and underway is maintained by DWAF. Flow records generated for these studies can be accessed on computer compatible media.

9.4 Mathematical streamflow models

> ☞ Because problems are encountered with existing streamflow data, especially those of site location and influence of catchment changes, the discharger will often need to generate streamflow information for the particular site, using a mathematical model *(also see Task 14, Determine effects of discharge on water quality.)*

model time-step selection

It is likely that the discharger would wish to generate flows on a daily time-step. Modelling at this level of detail, however, can be time-consuming and extremely costly due to the large amount of input data required. It may be useful to model at a monthly time-step initially, to obtain some of the streamflow characteristics and then to model selectively at a daily time-step to verify the answers.

daily models

There are a number of daily models used in South Africa, among which are the daily Pitman model, the Stanford Watershed model (HSPF), the ACRU model, WITSKM, CREAMS and others. These models are detailed in Appendix F. The DWAF is also in process of developing a daily model which may in future be available for simulating daily flows.

monthly models

The most well-known of the monthly models used in South Africa is the Pitman model (recently upgraded into modular form and now termed WRSM90). The model is described in Appendix F.

9.5 Analyse data to characterise streamflow

> ☞ The discharger must use the hydrological data to simulate the effects of the effluent on water quality. There are two factors which will affect the concentration in the river:
> - The **total mass** that the discharger will release to the river over a given period of time
> - **The rate of discharge.**

use of the data

The discharger has to create a file of daily or monthly flows, for a period of time. This file may be a historic record, a simulated flow record or may be a data file patched with modelled values. The discharger then has to assess the size, nature and complexity of the problem. The streamflow characteristics described above should be of use in this assessment.
A number of calculation techniques are described below.

annual and monthly characteristics

The mean (or median) annual runoff will give an idea of the average annual flow. The standard deviation will give an idea of the variation about the mean. The seasonal index will give an indication of the variations throughout the year and may be the first indication of extreme variation in the annual cycle. It is also possible to construct, from the monthly flow volumes, curves showing the percentage exceedence by month. This gives an idea of the frequency with which monthly flows are equalled or exceeded. These characteristics can be calculated from the daily information and/or from the monthly flow volumes.

An indication of the **low flows** within each month and how these vary year by year is, in many cases, a key issue in evaluating the effect of an effluent discharge.

low flow characteristics

Low flows can only be calculated from daily data. However, these are not always available and there are techniques to obtain an idea of the frequency of daily flows from monthly data. Any number of low flow statistics can be calculated from a daily record, for example, the lowest one-day flow on record, the lowest 7-days flow on record, the cumulative *x*-day flow with a frequency of recurrence of *y* years, the 5th percentile and others. Some of these techniques and the flows obtained are described by Harris and Middleton (1993).

A number of overseas countries use a statistically defined low flow to set the limit at which the effluent may be discharged - the "design flow" concept. For example, some states in the USA use the $_7Q_{10}$, that is the lowest flow over 7 consecutive days with a 1:10-year recurrence interval.

In South Africa, the wide variation in low flow characteristics in different areas makes the selection of a single, predefined design flow impractical. The concept of assessing the effects of an effluent discharge at some selected low flow remain valid, even if it is done on a case- or site-specific basis.

flow duration curves

It is possible to create a flow duration curve from daily flow records, i.e. a curve that shows, on the vertical axis, the flow rate equalled or exceeded and on the horizontal axis, the time for which this flow is equalled or exceeded. From the duration curve, the discharger will be able to ascertain the duration of time in any month that a particular streamflow occurs. A technique to construct duration curves based on monthly data, given a monthly flow record, has been described by Pitman (1993).

simulating discharges

It may be useful for the discharger to simulate the effects of the proposed discharge on the river system. This simulation can be conducted by generating the relevant flow in the river and adding to those the effluent discharge. At relevant downstream points, the effect of the discharge on concentration can be determined, taking cognisance of the abstractions and accretions that will occur downstream of the site. It is possible to simulate a continuous release, or a set release when the river flow exceeds a certain flow rate.

The calculations described above are all based on observed records or on simulated records (based on observations). The risk that the future streamflow in the river system will be lower than that observed or modelled has to be considered in the assessment of an effluent discharge.

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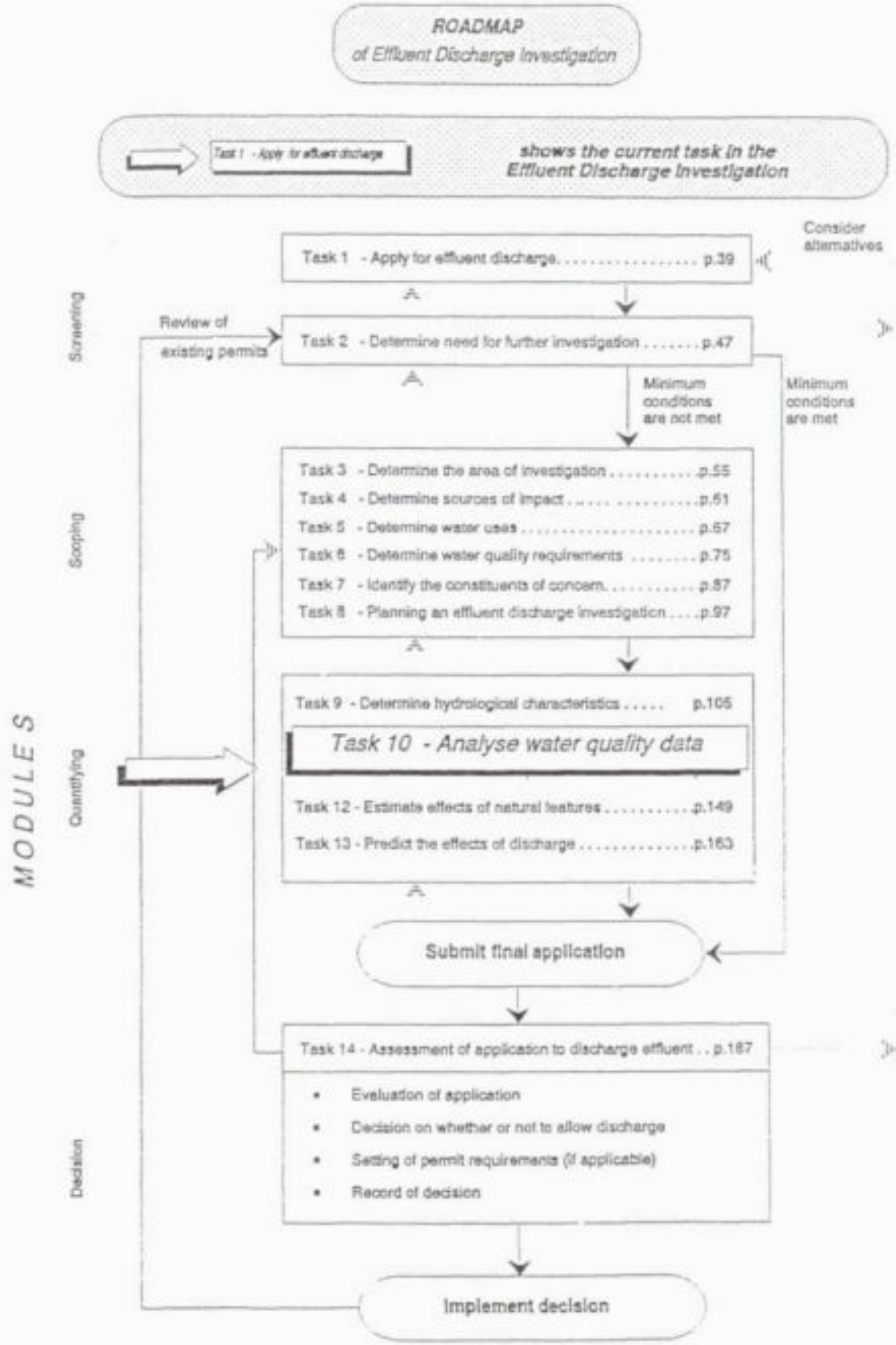
TASK 10:
Analyse Water Quality Data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TASK 10:
Analyse Water Quality Data

☞ This task describes the water quality data analysis that needs to be performed to assess the impacts of an effluent discharge on the receiving water.

☞ The purpose of describing both the existing water quality and how it will be changed by the proposed effluent discharge is to provide the information required to assess the effect of the proposed discharge. These descriptions should be detailed enough for the DWAF and the other participants in the decision making process to decide whether or not to allow the effluent to be discharged and if allowed, what requirements to specify.

☞ It is necessary to analyse water quality both upstream and downstream of the potential discharge. Upstream water quality describes the environment into which the effluent will be discharged; downstream water quality describes how the effluent will be changing that water quality.

10.1 Data analysis framework

variability of water quality

The concentrations of water quality constituents usually vary over wide ranges. Some of the variation can be explained but there is often a large component of that variation which is purely random. To emphasise this variability, water quality constituents are often referred to as 'water quality variables'. Because water quality is such a variable property, statistical methods must be used to describe water quality and the changes to it.

framework for analysis

The description of the receiving water quality should be developed within a framework that includes:

- Analysis of water quality changes over time, i.e. those changes observed in the past and those expected in the future
- Identification of the dominant processes that affect the water quality constituents of concern
- Conceptual modelling of the processes that control water quality
- Identification of the critical periods during which the water quality changes likely to be caused by the effluent discharge are most likely to affect downstream water users.

10.2 Sources of water quality data

> ☞ Data on water quality and flow are available to the public from the Directorate of Hydrology of the DWAF. For some investigations, where data are limited, or not available, **data collection** may have to be initiated.

quality of data collection

The quality of any data analysis performed depends directly on the quality of the data collection programme. For those effluent discharge investigations in areas where the water quality monitoring programme has been carefully attended to, data analysis is likely to be straightforward and conclusive. However, in areas where little or no data have been collected in the past, the evaluation must depend on data collected over a very short period. Major issues relating to short-term sample collection are highlighted in this section, but the analyst should be aware of the need to tailor the sample collection activities to the information needs. Short-term, intensive data collection can provide some of the information needed to describe site-specific processes that affect water quality. Long-term data collection efforts are needed to provide the information needed to assess large scale changes in water quality.

10.2.1 Using existing data records

Directorate of Hydrology data

A very large database of flow and water quality has been constructed by the DWAF. Water quality and flow constituents are reported on either a weekly, bi-weekly, or monthly basis. The data are available to the public from the Directorate of Hydrology. A list of the data available for each site, has been published in a two-volume set entitled Water Quality Data Inventory (Swart *et al.*, 1991), available from the DWAF.

The DWAF collects water samples on either a weekly, bi-weekly, or monthly basis. Analysis of the samples is typically for sodium, magnesium, calcium, fluoride, chloride, sulphate, potassium, silica, ammonium, orthophosphate, nitrate plus nitrite, total alkalinity, pH, electrical conductivity and total dissolved solids. The DWAF has routinely collected samples and analysed samples at gauging weirs since the early 1970s. Several improvements have been made in the programme over the years, so the analyst should expect some step changes in the data that may not be correlated to any changes in the catchment.

other sources of data

Additional data collection has been carried out by dischargers and by the Regional Offices of the DWAF as part of their effluent auditing programmes. Many of these data are related to existing permits and are available from the DWAF for the proposed effluent discharge investigation. As usual, any data collected and/or analysed by different agencies or laboratories should be compared for systematic differences produced by differences in sampling techniques or analysis procedures.

10.2.2 Collecting new data

need for additional data

Data collection may have to be initiated because no data exist, or because additional data are necessary to describe water quality constituents adequately. If water quality models are developed in the process of the study, additional data will almost surely be needed; routine data collection seldom, if ever, provides sufficient data for modelling purposes.

no data available

If no data at all are available for a reach proposed for effluent discharge, the initial sampling and analysis should be extensive. The steps involved in setting up a water quality monitoring programme are described in Appendix D. Components of the effluent and other sources of contamination should be considered when selecting constituents to monitor.

model requirements

Each constituent of concern is likely to require different models and, therefore, different data collection efforts. Many references are available on proper sampling techniques, including internal DWAF reports (Rossouw and Badenhorst, 1987). The US Environmental Protection Agency has published technical guidance specifically for sample collection programmes for the allocation of waste loads (USEPA, 1985, and Mills *et al.*, 1986).

10.3 Investigate data characteristics

☞ Data record attributes that complicate the evaluation of water quality conditions can be divided into two groups:

- Data limitations (for example, missing values)
- Statistical characteristics (for example, seasonality).

10.3.1 Data limitations

common data limitations

Data limitations often complicate the evaluation of water quality. Common data limitations include:

- Missing values
- Changes in sampling frequency
- Changes in sampling location
- Changes in analysis procedures
- Multiple observations within one sampling period
- Uncertainty in the measurement procedures
- Censoring the measurement signals (values less than the limit of detection)
- Small sample size
- Outliers.

Techniques exist to account for some of these limitations and should be used. Major errors can occur when data limitations exist, but are not recognised.

changes in sampling programme

Changes in the sampling programme are common causes for this situation. Often changes in sampling location or analytical procedures are not documented as part of the database. Any step change observed in a data record should be investigated in terms of sampling programme changes before assuming real water quality changes.

inappropriate sampling procedures

An additional limitation can result from inappropriate sample collection procedures. Contamination of sample bottles, improperly calibrated instruments, or many other mistakes can affect the accuracy of data.

non-representative samples

The collection of non-representative samples is a special case of data error. For major solute constituents, some degree of homogeneity within a water body is common. However, for minor constituents, such as orthophosphate, which may be associated with suspended material, single grab samples may be very poor representations of the whole stream (Hem, 1985).

10.3.2 Statistical characteristics

> ☞ Statistical characteristics are affected by the natural variation of water quality in the environment and by variation in the sampling programme itself. Four common statistical characteristics are:
> - Distribution shape
> - Seasonality
> - Homogeneity of the variance
> - Serial correlation.
>
> While these characteristics do not cause computational problems, they may violate assumptions underlying statistical methods chosen to analyse the data. This can result in false conclusions about the behaviour of water quality in the environment.

distribution shape

Distribution shape is often assessed by graphical methods or by distribution testing procedures. A graphical method is shown in **Figure 12**, which is a plot of the frequency distribution of the observed data. A normal distribution, with the mean and standard deviation calculated from the observed data, is also plotted. The figure shows that the normal distribution is a poor fit to the observed data.

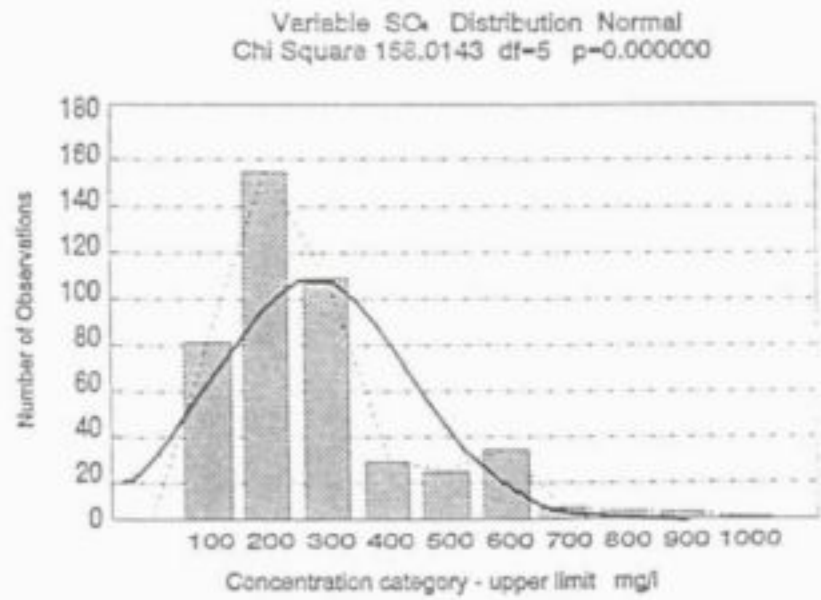

Figure 12 Frequency histogram of observed data shown with a normal distribution with the mean and standard deviation calculated from the data

goodness of fit tests

Statistical tests to evaluate the goodness of fit to an assumed distribution are available. Some of the common tests are the Chi-Square, the Kolmogorov-Smirnov and the Durbin-Watson statistic (Gilbert, 1987). If a Chi-Square test is done for the normal distribution and the underlying distribution is, in fact, normal, the Chi-Square value tends to approach the degrees of freedom. **Figure 12** shows the results of the Chi-Square test on a data set that is obviously not normally distributed. The software that was used to do the test displays the probability as 0.000000 that the result of the Chi-Square test would have occurred by chance if the underlying distribution had, in fact, been normal. This means that the probability is less than 1×10^{-6} that the result of the Chi-Square would have occurred if a normal population was sampled. The results of the statistical test confirm the visual interpretation, namely that the particular data set is not normally distributed.

tails of distributions

Minor deviations from theoretical distributions can often be neglected, but the analyst must be aware that the greatest deviations are often in the tails of the distribution, that is, the number and magnitude of extreme events. The tails are often the most critical in terms of hypothesis tests. For very sensitive decisions, one may wish to compare the results of hypothesis tests that assume a normal distribution with the results of tests of rank order statistics. If the same hypothesis is accepted or rejected, one can confidently proceed. If the results are different, additional analysis or more sampling may be required.

additional literature on data analysis

Gilbert (1987) provides a detailed discussion of statistical analysis procedures for environmental constituents and uses many water quality examples. Ward *et al.* (1990), discusses many issues associated with water quality data analysis, particularly for data collected in routine monitoring programmes. Harris *et al.* (1992) discuss analysis of water quality data using examples from South African monitoring programmes.

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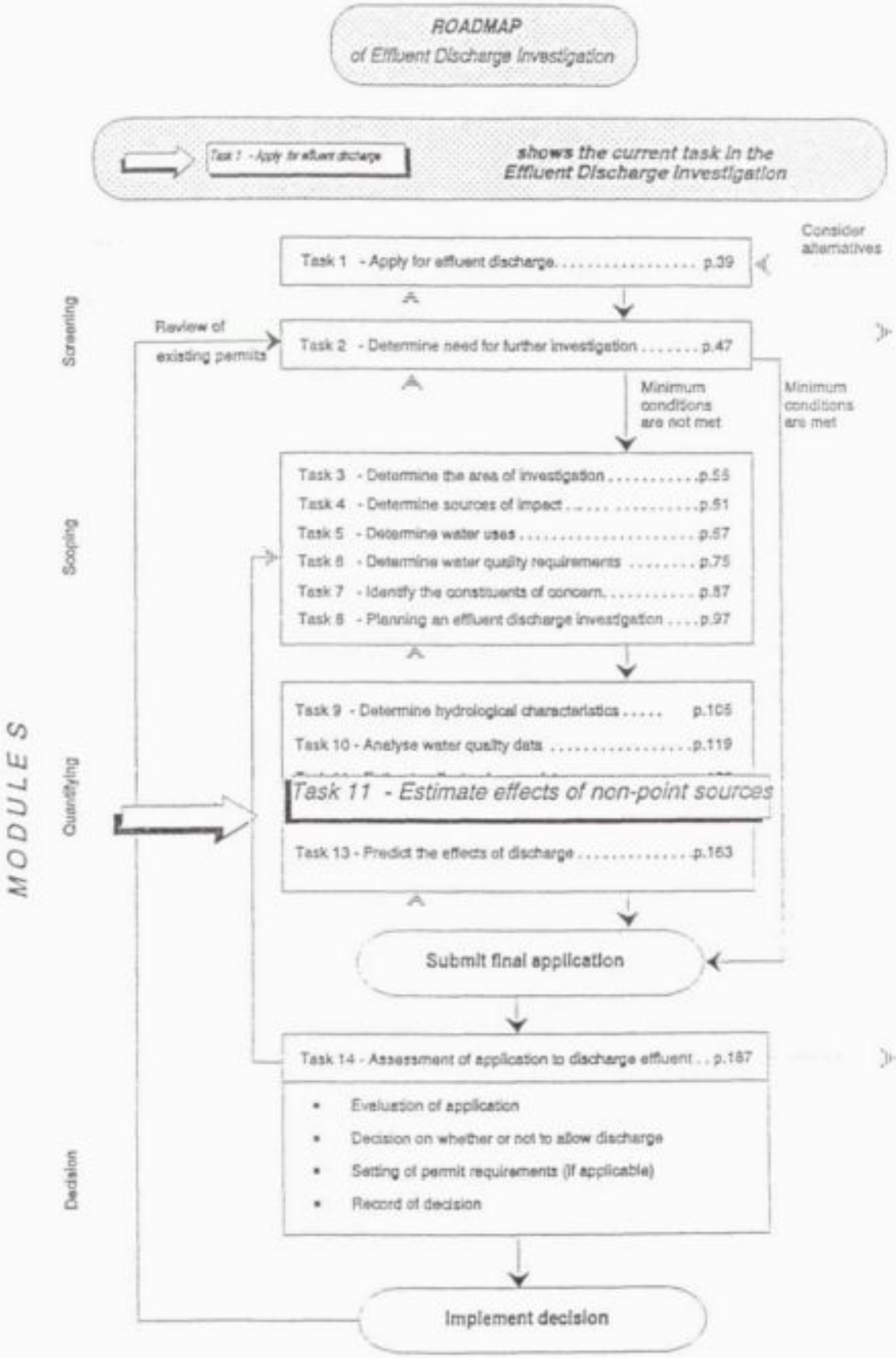
TASK 11:
Estimate Effects of Non-point Sources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TASK 11:
Estimate Effects of Non-point Sources

☞ Non-point sources may, in some catchments, have a greater impact on water quality than point sources. It is therefore important to be able to quantify the impacts of non-point sources on water quality.

☞ Non-point sources which impact on water quality can result from any activity which produces constituents that enter the receiving water body in an intermittent and/or diffuse manner. Non-point sources typically arise during wet weather events which causes surface washoff of constituent. Because waste can accumulate in catchments during dry weather periods a time lag may exist between when a constituent is released from its source and its appearance in a receiving water body.

11.1 Determine categories of non-point sources impact on water quality

☞ Non-point sources impact on water quality can be broadly classified in terms of the following land uses and practises, each of which result in distinct kinds of sources with their associated range of constituents:

- Formal and informal urban development
- Commercial and subsistence agriculture
- Silviculture
- Mining and exploration
- Aquaculture
- Industry.

Land disturbance and atmospheric deposition may further contribute to the load generated by these land use classes.

11.1.1 Formal and informal urban development

types of urban areas

Urban development encompasses residential (formal and informal) areas, commercial centres, industrial development, roads and parking lots, parks and green zones and waste disposal sites. Impacts on water quality are generated in urban areas from many different combinations of land use.

urban sources of impact on water quality

Urban sources which impact on water quality include erosion of exposed soil surfaces, litter, wear on vehicle tyres and brakes, decay of vegetation, application of fertilisers and pesticides on gardens, vehicle washing, swimming pool backwash water, animal waste, sewer blockages and overflows, industrial spillages etc. Atmospheric deposition is an important contributor to non-point sources in urban areas. Airborne constituents mainly originate from vehicle exhausts, burning of fossil fuels, windblown dust, incineration of waste, etc.

urban loads

The typical ranges of loads exported from urban environments are shown in **Table 2**. The elevated **lead** content of urban runoff is linked to the use of fuels containing lead additives. The origin of **zinc** in urban runoff is linked to the widespread use of galvanised steel items (roofs, gutters, handrails etc.). **Microbiological** contaminants in urban stormwater are also of concern, especially from informal settlements and from urban developments with poorly maintained sanitation systems.

Table 2 Unit export loads[1] (kg/ha.yr) from urban catchments

Constituent	North American cities				RSA	
	Parks and green zones	Residential	Commercial	Industrial	Commercial[2]	Residential[3]
BOD	1.12	34	90	34	49	-
Suspended solids	11.2	390	360	672	309	198.0
Total nitrogen	0.22	9.0	11.2	7.8	7.54	3.90
Total phosphorus	0.04	1.6	3.4	2.2	1.33	0.58
COD	-	-	-	-	312	-
Cadmium	0.002	0.013	0.016	0.024	-	-
Chromium	0.003	0.026	0.028	0.044	0.09	-
Copper	0.007	0.045	0.049	0.077	0.11	-
Mercury	0.006	0.038	0.043	0.065	-	-
Nickel	0.004	0.029	0.032	0.030	-	-
Lead	0.022	0.157	0.174	0.269	0.74	-
Zinc	0.081	0.570	0.630	0.980	2.09	-
Iron	-	-	-	-	10.6	-
Manganese	-	-	-	-	0.26	-

(1) A unit export load reflects the mobilisation from a unit surface area during an average hydrological year (kg/ha.yr).
(2) Simpson *et al.*, 1980
(3) Simpson and Hemens, 1978

11.1.2 Commercial and subsistence agriculture

agricultural sources of impact on water quality

Agricultural activities, which can contribute to non-point sources impacting on water quality, include:

- Irrigation and irrigation return flow
- Cultivation of crops using row cropping or non-row cropping practises
- Land application of municipal/industrial sludge
- Livestock rearing
- Feedlots and associated stockpiling of animal waste and animal feed processing.

agricultural constituents

The major constituents, impacting on water quality, associated with crop cultivation include sediment, nitrogen, phosphorus, organic debris, pesticides and dissolved salts.

agricultural constituent mobilisation

The mobilisation of constituents from irrigated or dryland cultivation of crops depends on numerous biophysical factors including:

- Land tillage practises (contour ploughing, etc.)
- Fertiliser type and application
- Soil characteristics
- Rainfall patterns
- Land slope and topography
- Crop type and maturity.

export from cultivated lands

The export of constituents to the edge of cultivated lands has been extensively researched and can be quantified. The transport of mobilised constituents across virgin land and buffer strips is not well understood and is still the subject of investigation. Little information is available on the mobility of pesticides into natural water bodies.

pesticide export

The export of pesticides from cultivated lands is dictated by the transported sediment and pesticide interactions. **Table 3** gives an indication of the reported export of pesticides from cultivated lands.

Table 3 Typical pesticide application and export to the water environment

Pesticide	Crop	Application rate (kg/ha.yr)	Export rate (kg/ha.yr)
Atrazine	Corn (S)	3.36	0.54
Dieldrin	Corn (I)	5.60	0.039
Picloxam	Grass (F)	2.8	0.00006
Propachlor	Corn (S)	6.7	0.156
Toxaphene	Cotton (F)	10.1	0.097
Trifluralin	Cotton (I)	1.1	0.0019

S Surface application
F Foliar application
I Incorporated

fertilisers as sources of impact on water quality

Many different synthetic fertilisers are applied in South Africa depending on the soil status, crop type, crop maturity, etc. The typical fertiliser application rates vary significantly. On the Eastern Transvaal Highveld for example, the following rates are applied:

Nitrogen : 40 - 60 kgN/ha.yr
Phosphorus : 10 - 12 kgP/ha.yr
Potassium : 6 kgK/ha.yr

Synthetic fertilisers may contain a number of other inorganic constituents, apart from the major plant nutrients including magnesium, calcium, sulphate, chloride, zinc, copper, manganese, iron and boron (Bornman, 1989).

A nitrogen and phosphorus mass balance conducted on the Midmar Dam catchment concluded that only a small fraction of the applied fertiliser is exported. **Table 4** lists the application and export of nutrients from this catchment.

Table 4 Application and export of nutrients from the Midmar Dam catchment[1]

Plant nutrient	Fertiliser application (kg/ha.yr)	Catchment export (kg/ha.yr)
Nitrogen	10.9	1.44
Phosphorus	4.9	0.10

1. Hemens *et al.*, 1977

feedlot constituents whcih impact on water quality

Intensive animal feedlot farming generates large amounts of waste in a relatively small area. The potential impacts on water quality associated with feedlot farming can be appreciated by consideration of the annual waste load generated by a single animal, as shown in **Table 5**. The typical constituents associated with intensive feedlot farming include organic matter, nitrogen compounds, phosphorus compounds, dissolved salts and suspended solids.

Table 5 Estimated total waste production by farming animals[1]

Animal type	Wet manure (kg/yr)	Manure constituents		
		Nitrogen (kg/yr)	Phosphorus (kg/yr)	Potassium (kg/yr)
Dairy cattle	14900	61	10	49
Beef cattle	6700	31	9	19
Pigs	1400	9.4	2.2	3.2
Sheep	660	7.3	1.7	5.0
Laying hens	39	0.5	0.2	0.2
Broilers	26	0.4	0.1	0.1

1. USDA, 1979

erosion

The export of sediment from catchments as a result of erosion caused by commercial and subsistence agriculture practises is one of the most serious land and water resource problems faced in South Africa.

Large parts of South Africa are characterised by steep topography, long slope lengths and shallow eroded or erodible soils. Rooseboom (1978, 1992) calculated sediment production from large catchments to be as high as 100 $t/km^2.yr$. It is estimated that more than 120 million tonnes of sediment enters South African river systems annually.

11.1.3 Silviculture

silviculture constituents which impact on water quality

Silviculture, or cultivated forestry, disturbs the natural vegetation and land cover, resulting in the release of mainly sediment, plant nutrients (nitrogen, potassium, phosphorus), organic debris and pesticides. Most of the constituents exported from forestry lands are associated with sediment. This stresses the importance of soil erosion and sediment management in silviculture. The unit export rates for silviculture are, however, low compared to the other major land uses.

sediment export

Sediment export is an important impact of silviculture on the water environment and can be attributed to the following processes:

- Forestry development commonly takes place in high rainfall mountainous areas which are characterised by steep slopes. Exposure of steep slopes during land clearing and logging operations results in accelerated soil erosion.

- Construction of access roads typically involves cuttings and earth fills. This will make further soil available for erosion and export to the natural streams.

- Forestry activities may impinge on the natural stream banks and may cause local bank instability, thus creating a further source of sediment.

11.1.4 Industry

types of industries

Industrial operations generate the widest range of non-point sources, which can impact on water quality, of all land use classes. The major wet industrial operations in South Africa include power generation, textile manufacturing, paper and pulp production, iron and steel, synthetic fuels, mineral beneficiation and abattoirs.

industrial sources of impact on water quality

Non-point sources of impact on water quality from large industrial operations can originate from:

- Atmospheric emissions
- Waste dumps
- Raw material stockpiles
- Processing/manufacturing plants
- Product stockpiles.

identifying industrial impacts

Identification of the waterborne constituents which may emanate from an industrial operation, requires investigation into the specific industry. It must be appreciated that non-point sources of impact on water quality may emanate from any industrial site and non-point sources are not restricted to the major wet industries. An industrial operation which is considered "dry", in the conventional meaning of the term, may cause an impact on water quality if a raw material, waste material or product is exposed to precipitation and runoff. Non-point source impacts from industrial sites are not restricted to surface runoff, but may take place via a groundwater/seepage pathway.

11.1.5 Mining

mining sources of impact on water quality

The non-point sources of impact on water quality generated from mining are associated with:

- Dewatering of underground and opencast workings
- Waste rock discard and tailings dumps
- Mineral processing and beneficiation plants
- Mineral product stockpiles
- Mining infrastructure including offices, workshops, accommodation, haul roads, etc.

mining constituents of concern

The constituents of specific concern in the mining and beneficiation of gold, platinum, base metals and coal are summarised in **Table 6**.

Table 6 Constituents of concern in the mining industry

Constituent	Mining operations			
	Gold	Platinum	Base metals	Coal
Dissolved salts	•	○	•	•
Acidity	•	-	○	•
Sulphate	•	-	○	•
Chloride	○	-	-	-
Calcium	○	-	-	○
Magnesium	-	-	-	○
Sodium	○	-	-	-
Nitrate	○	○	-	-
Ammonia	-	○	-	-
Cyanide	•	-	-	-
Iron	○	-	○	○
Manganese	○	-	○	○
Aluminium	○	-	○	○
Heavy metals	○	○	•	○
Arsenic	○	-	-	-

• = constituent of primary importance
○ = periodic consideration necessary
\- = seldom problematic

causes of mining impacts

Mining and exploration generate or expose large reserves of material which can potentially impact on water quality. A relatively small fraction of the potential is typically realised, depending on the mining techniques, waste disposal, remediation and rehabilitation practises employed on a specific mine. Piles of waste rock and uneconomic ore generated during mining activities accelerate the oxidation of host rock and mineralised ores, by increasing their exposure to air and water. Water quality problems can be expected to occur in the vicinity of both active mines and abandoned prospecting sites. These water quality problems could include enrichment of surface waters with ions leached from the parent rock and tailings material, as well as possible acidity problems.

11.1.6 Aquaculture

aquaculture constituents of concern

Aquaculture involves intensive farming with aquatic organisms at high population density. The impact on the downstream receiving water body depends on the farming practises (side-stream or in-stream), type of organisms, feed pattern and feed materials. Constituents released from aquaculture operations may include organic residues, suspended solids, microbiological organisms and ammonia.

11.1.7 Atmospheric deposition

Atmospheric deposition is an ubiquitous phenomenon. Although the original sources of atmospheric constituents are usually difficult to trace, they are associated with all land uses, ranging from urban to rural areas. Emissions from power generation, industry and the mining sector can be very high (Els, 1990; Grobler *et al.*, 1992). Although recorded atmospheric deposition rates are high, it must be kept in mind that only a small fraction of the deposited material is typically exported from the catchment. Numerous measurements have been taken of atmospheric deposition rates, as listed in **Table 7** for a range of land uses.

Table 7 Atmospheric deposition of constituents (kg/ha.yr) for various South African land uses

Constituent	Urban: Pinetown[1]	Residential: Durban[2]	Rural: Midmar Dam[3]	Industrial: Transvaal Highveld[4]
Suspended solids	317	215	-	-
Total dissolved solids	193	-	-	-
Sulphate	-	-	-	36
Nitrogen (total)	9.3	22.9	9.8	-
Phosphorus (total)	0.65	0.52	0.35	-
COD	215	-	-	-
Copper	0.12	-	-	-
Lead	0.57	-	-	-
Zinc	0.84	-	-	-
Chromium	0.23	-	-	-

(1) Simpson, 1991
(2) Simpson and Hemens, 1978
(3) Hemens *et al.*, 1977
(4) Bosman, 1991

Vehicle exhaust gases are important contributors to atmospheric sources of impact on water quality, especially in urban areas, as reflected in **Table 8**.

Table 8 Constituent release from vehicles using leaded petrol[1]

Constituent	Deposition rate (mg/axle-km)
BOD	1.5
Nitrogen	0.11
Phosphorus	0.41
Copper	0.08
Chromium	0.06
Lead	7.88
Nickel	0.11
Zinc	1.0

1. Ahmed and Schiller *et al.*, 1981

11.1.8 Construction

Construction of infrastructure, buildings and services typically results in the exposure and disturbance of land. The export of sediment from such sites can be as high as 100 t/ha.yr depending on the soil type, topography, construction techniques, erosion control measures, etc. Sediment acts as the carrier for a range of constituents including plant nutrients, metals, organic compounds, etc.

11.2 Identify mechanisms of non-point source mobilisation

pollution pathways

Non-point source pathways should be described within the framework of the natural hydrological and geohydrological processes. The natural components of the hydrological and geohydrological cycle, including precipitation, runoff, infiltration, interflow, percolation and groundwater discharge, act as pathways for the movement of constituents from non-point source origins. **Figure 13** is a schematic description of these flow routes.

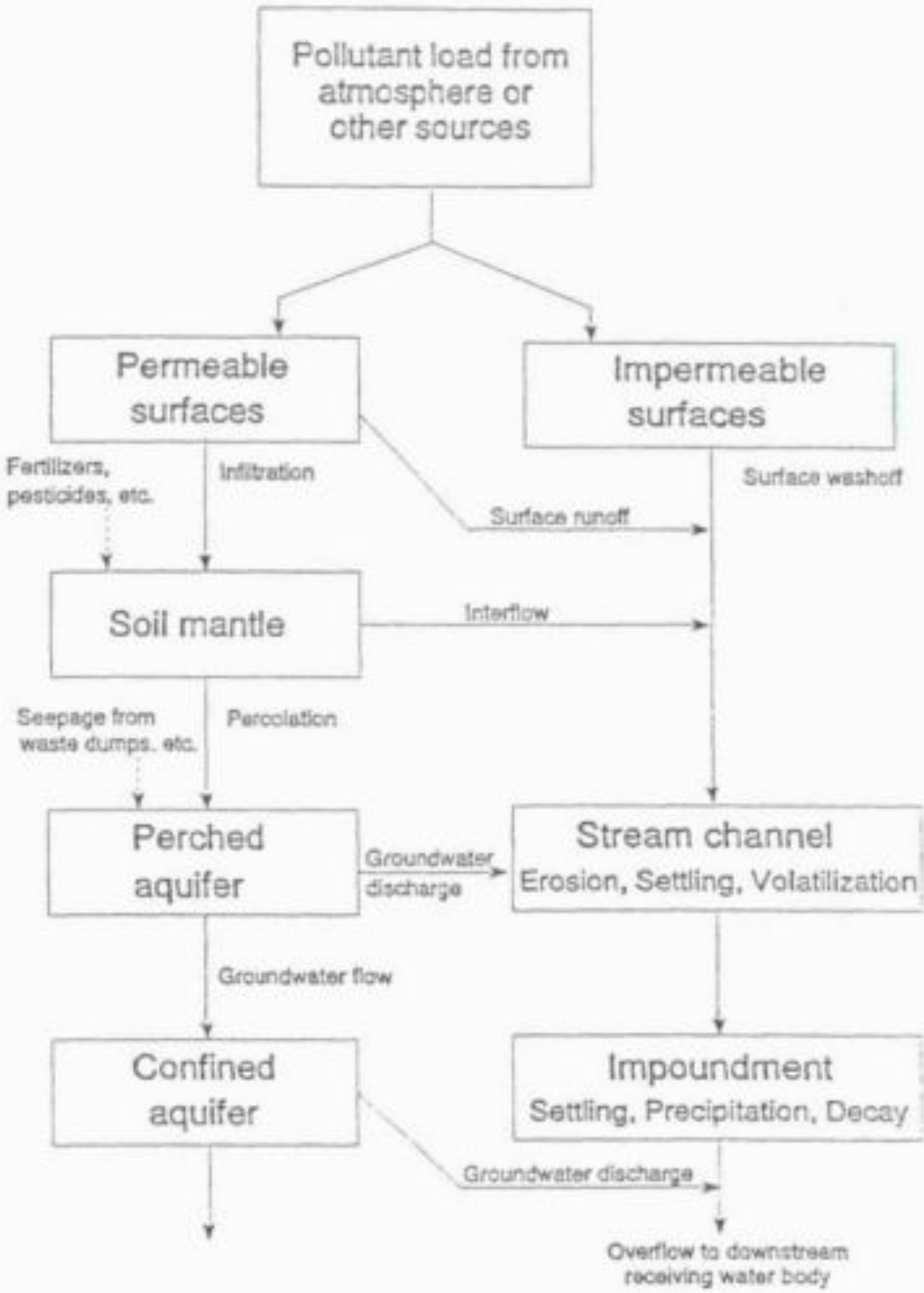

Figure 13 Hydrological and geohydrological flow routes contributing to comovement of constituents from non-point sources

Accurate description of the mechanisms of non-point source mobilisation depends on an understanding of the impact of different land uses on the hydrological/geohydrological pathways.

major transport mechanisms

The background water quality in a stream impacted by non-point source will depend on the relative load contribution from the following four main transport mechanisms:

- **Scrubbing** of airborne constituents, which remain in solution or in suspension in surface runoff
- **Surface washoff** from permeable and impermeable surfaces transports constituents in dissolved, adsorbed and particulate forms
- **Interflow** via the unsaturated soil mantle, that transports constituents in a colloidal and dissolved form
- **Groundwater** discharge from perched and deep aquifers that transports dissolved constituents.

seasonality of transport mechanisms

Groundwater discharge typically determines the background water quality during dry weather periods. Atmospheric scrubbing, surface runoff and interflow determine background water quality during and immediately after wet weather events.

11.3 Effects of land use on runoff

factors affecting pathways

In general the progression of land use from rural to agricultural to urban results in the following impacts on these pathways:

- Increased surface runoff and decreased base flow
- Increased storm peak flow
- Increased runoff volumes and decreased groundwater recharge
- Increased number of days with zero base flow
- Shorter duration of runoff events.

effects of land use

Land use and, particularly, misuse causes a rapid increase in sediment yields. However, the larger the size of the catchment, the greater is the so-called "averaging effect". The effects of various catchment land use activities on sediment yield are as follows:

- Where intensive agriculture is practised or where the vegetation is removed from a catchment surface, the "natural" sediment yield potential increases dramatically, often by a factor of 10 or more.

- Activities such as forestry can lead to increased sediment yields, particularly during planting and logging operations.

- Changes in patterns of land use can also lead to accelerated rates of soil loss through erosion.

- Very intensive construction activities can cause sediment loss rates in small areas which are equivalent to rates as high as 100 000 t/km^2.yr, whilst gravel roads generally appear to lose about 10 000 tonnes of soil/km^2.yr.

- Ploughed lands usually have potential sediment yields of several thousands of tonnes/km^2.yr, whereas sediment losses from grazed lands are approximately one order of magnitude less.

- Sediment yields from virgin (indigenous) forests can be as low as a few tonnes/km^2.yr. However, clearing of forests for agricultural land use or periodic logging causes a dramatic increase in soil loss each year.

It is important to note that the figures presented above are only generalised values. In those cases where the potential sediment yield could influence critical decisions about a particular activity or land use, more detailed investigations should be undertaken before decisions are taken.

11.4 Identify non-point source impact patterns

patterns

The patterns, i.e. how much and when, by which non-point source derived constituents end up in a receiving water body has important water quality effects. These patterns are the result of a complex interplay between the many natural and man-made processes that:
- Generate, or enhance the generation of constituents
- Mobilise and transport constituents.

These patterns differ markedly for different kinds of constituents such as particulates (e.g. sediment) and for dissolved constituents (e.g. TDS). These patterns depend on :
- The size and duration of individual runoff events
- The runoff history preceding a particular runoff event
- Longer term cycles such as seasonal cycles and drought and wet cycles.

transport of particulates

Particulates include sediment and a wide range of compounds adsorbed/attached to sediment including metals, organics, inorganic salts, etc. The detachment and transport of particulates are dependent on an available source and on the erosion energy associated with the rainfall. The graph in **Figure 14** shows a generalised pattern of flow and concentration for a storm event and the resultant load produced for particulates. The concentration of particulates in surface runoff is typically high during the initial phase of a storm (due to the availability of transportable sediments) and the concentration remains high until passage of the peak flow (due to the erosional power associated with high flow). The particulate concentration then typically drops during the receding leg of the hydrograph.

particulate loads

The cumulative load of particulates for a specific catchment will be dependent on the presence of sediment traps, such as impoundments and wetlands. Enrichment of the content of sediment may take place during the transport process, due to the selective removal of larger sediment particles through settling. This can be ascribed to the fact that smaller sediment particles have a relatively high content of constituents (nitrogen, phosphorus, metals, etc.), due to a high reactive surface to mass ratio.

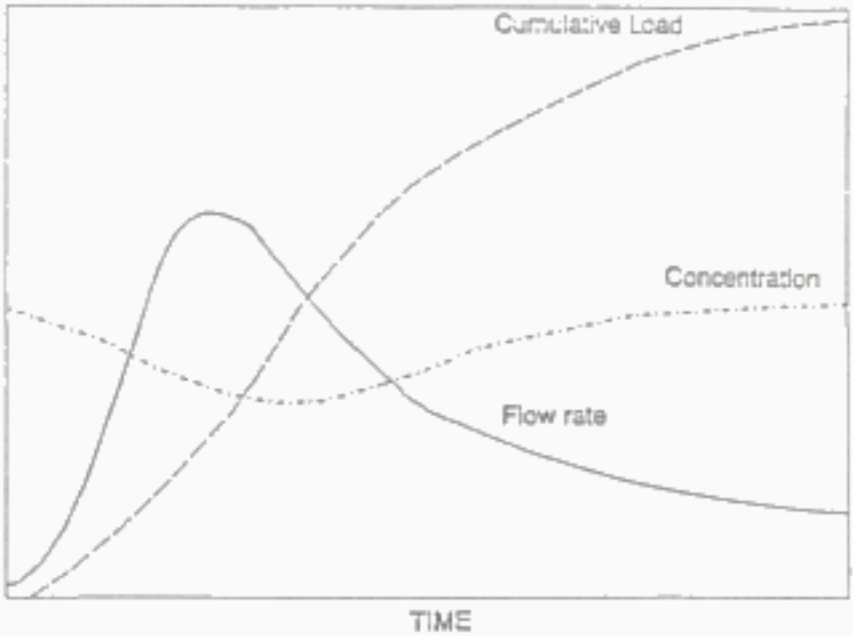

Figure 14 Particulate mobilisation pattern

transport of soluble constituents

The transport of soluble constituents is dictated by the availability of a specific constituent and the dissolution kinetics associated with the constituent. The rate at which a soluble constituent becomes available may, therefore, be dependant on the available contact time between runoff and the source of the impact. This contact time is typically inversely proportional to flow, resulting in lower concentrations at the hydrograph peak. **Figure 15** shows a generalised relationship between flow, dissolved concentration and resultant load.

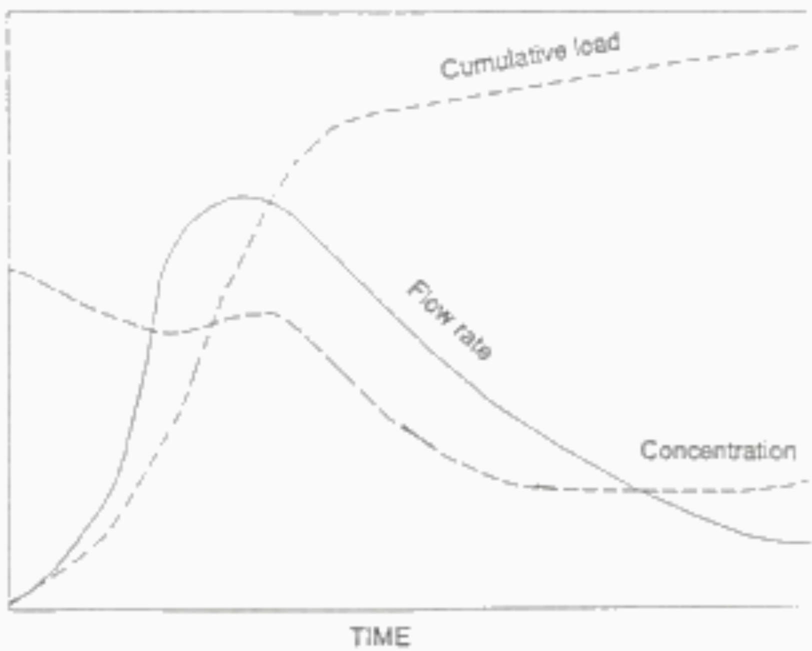

Figure 15 Soluble constituent mobilisation pattern

11.5 Model non-point source impacts

modelling framework

A number of deterministic and empirical modelling approaches can be applied to the quantitative description of non-point source impacts on water quality A general approach to water quality modelling is presented elsewhere *(refer to Task 13, Predict the effects of a discharge on water quality)*. Modelling of non-point source impacts should be conducted within the following framework:

- Adequate description of all the non-point source constituent transport paths including surface washoff, interflow, atmospheric deposition and groundwater discharge should be included.
- Conceptual modelling of a non-point source impact may indicate that one or two pathways are dominant. Modelling should then concentrate on these pathways.
- Modelling should preferably take place in a time continuum, even if export mainly takes place during storm events. Simulation of single storm events tends to be inadequate in the description of dry weather processes.
- Modelling should incorporate changes in physicochemical and biological processes taking place in the receiving water body. Certain constituents, such as organics, may have an indirect impact on the receiving water body in the form of depression of DO levels.

deterministic models

Deterministic non-point source models are usually constructed on the basis of a reliable hydrological model. Sophisticated models are available which incorporate all the possible constituent mobilisation, transport and transformation processes indicated in **Figure 13**.

surface washoff modelling

The **surface washoff** of constituents is typically the dominant pathway during wet weather events. The modelling of surface washoff is typically conducted using the following expression:

$$\frac{dP}{dt} = A(t) - KRP$$

where P = constituent surface concentration (M/L^2)
$A(t)$ = constituent generation rate on the catchment surface ($M/L^2.T$)
K = washoff constant
R = runoff ($L^3/L^2.T$)

It can be seen that the constituent generation A(t) on the surface is modelled as a time-dependent process, which typically approaches some asymptotic value. The washoff process is considered to be proportional to the storm intensity (R) and to the available source (P). This general approach can be refined for particulate and soluble constituents respectively. Empirical approaches can also be adopted in the modelling of non-point source mobilisation.

flow and load modelling

One of the classical equations relating non-point source load to flow is:

$$L = xQ^{y}$$

where L = constituent load (M/T)
Q = flow (L^3/T)
x,y = empirical constants

The application of such an empirical approach is demonstrated in **Figure 16** for sodium. It has been shown that the classical equation for non-point source loads may be refined to achieved better local application (Meyer and Harris, 1991).

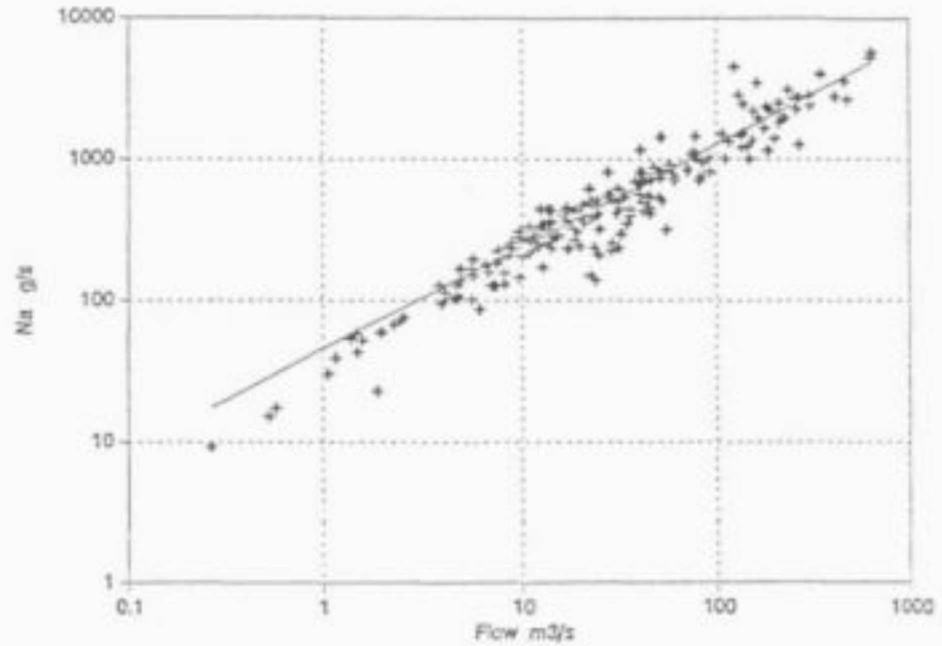

Figure 16 Empirical approach for modelling non-point source loads

An analysis of load is often useful when evaluating effects integrated over a long time and a large area, such as inflow to a dam or seepage from a tailings dam. Total load is also important for conservative constituents that can accumulate to undesirable levels.

flow and concentration modelling

While the above approach can be useful in evaluating total load, it should not be used to predict concentration. If the load shown on the vertical axis is calculated from measurements of concentrations and instantaneous flow, then the flow term appears on both axes. The correlation is, therefore, spurious and cannot be used for prediction of concentrations. A plot of instantaneous flow against measured concentration is more useful for estimating the change in concentration associated with flow. The relationship of flow with concentration is usually worse than that of flow and load. **Figure 17** shows the sodium concentration plotted against flow for the same data set shown in **Figure 16.**

The analysis should focus on concentration if the effects over a short time are predominant. This is often the case for effluent discharged to channels with flowing water. Water uses that involve abstraction of water from a channel are dependent on concentrations.

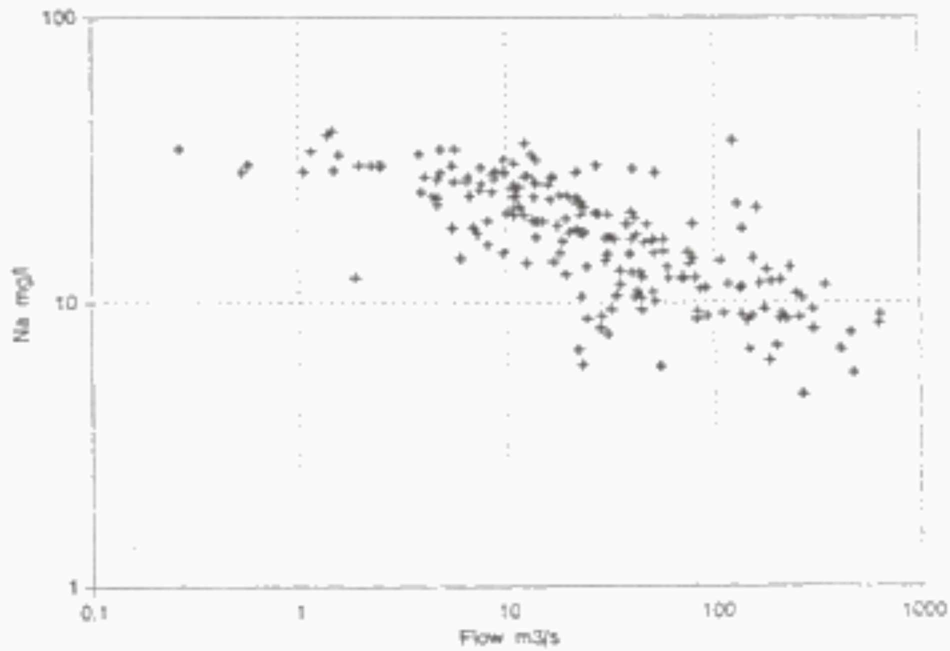

Figure 17 Sodium concentration as a function of flow rate for the same data set shown in Figure 16

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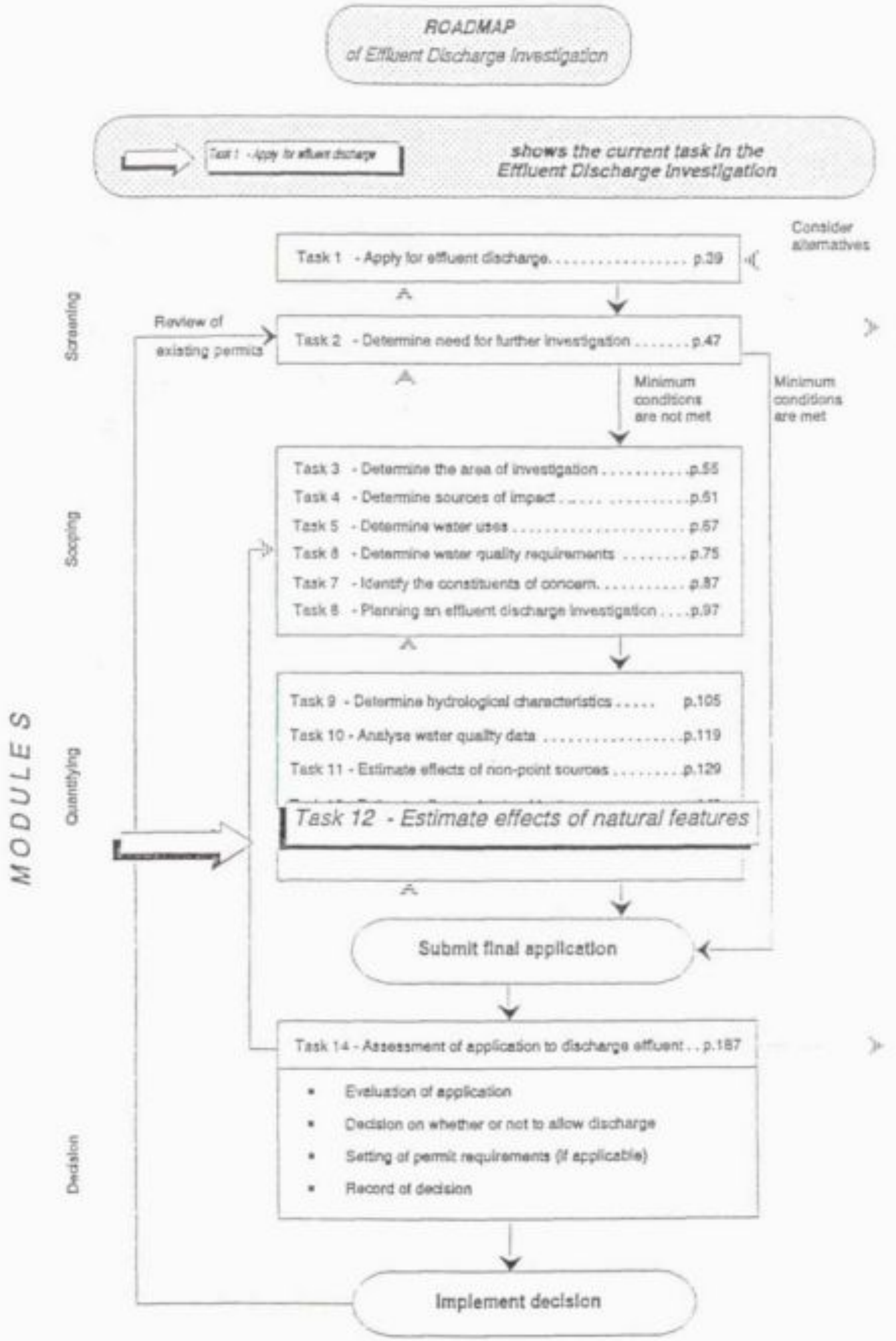
TASK 12:
Estimate Effects of Natural Features


ROADMAP
of Effluent Discharge Investigation
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shows the current task in the Effluent Discharge Investigation
Consider alternatives
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Minimum conditions are not met
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Decision
Evaluation of application
Decision on whether or not to allow discharge
Setting of permit requirements (if applicable)
Record of decision
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TASK 12:
Estimate Effects of Natural Features

☞ The purpose of estimating the effects of natural features on water quality is to be able to determine the background water quality of the receiving water body on which both point and non-point sources will be impacting.

☞ It is necessary to understand how catchment characteristics, individually and in combination, influence the quality of waters draining them. Following this understanding, one can assess the extent to which human activities have changed the background water quality. Against this background, the implications of water quality changes caused by a proposed effluent discharge can be evaluated.

12.1 Describe the effects of topography on catchment water

> ☞ The **primary** influence of topography on water quality in a catchment is expressed through the influence of topography on climate, in particular through the timing and quantity of rainfall received in different portions of the catchment. The **secondary** effects of topography are then expressed through features, such as slope steepness, on the patterns of runoff received by separate river systems in subcatchments within larger catchments.

effect of steep slopes

Areas with steeper slopes are expected to have the greatest runoff potential with relatively low rates of infiltration, particularly where total rainfall or rainfall intensities are high (Moon and Dardis, 1988). Extensive areas of steep slopes can trap orographic rainfalls and cast rain shadows on those areas of a catchment that may be shielded from prevailing rain-bearing winds by these higher slopes. Areas of steep slopes tend to contribute larger quantities of suspended sediments, salts and nutrients to receiving rivers (Rooseboom *et al*., 1992). Agricultural activities conducted on areas with intermediate (8 - 15 %) and steep (> 15 %) slopes can lead to a dramatic increase (ranging from two- to ten-fold) in erosion potential, which increases with increasing rainfall intensity (Rooseboom *et al*., 1992). Similar effects are caused by construction activities and the development of high-density urban areas (Grobler *et al*., 1987).

impacts of steep slopes

Impacts of steep slopes cannot easily be quantified or predicted. This is because a variety of factors are involved, including:

- Slope
- Soil type, depth and physical structure
- Type and degree of vegetation cover
- Intensity and duration of rainfall events.

Therefore, normally only qualitative predictions can be made in terms of increased runoff potential or sediment production potential.

effect of shallow slopes

Landscape slopes which are less than 8 % tend to have a much smaller runoff potential, with correspondingly greater infiltration (Moon and Dardis, 1988). Provided that the vegetation cover remains intact, they will only contribute significant quantities of suspended sediments and dissolved salts to nearby rivers via surface flow when rainfalls are very heavy. Instead, the increased infiltration of rainfall will retain sediments on the catchment surface and transfer dissolved salts downwards into the groundwater. Where these areas are ploughed for agriculture, with concomitant additions of fertilizers and biocides, this process can result in a decrease in fitness for use of the groundwater as the concentrations of salts and agrochemicals increases.

12.2 Describe the effects of climate on catchment water

> ☞ Climatic features control almost all aspects of the hydrological cycle and therefore regulate the quantity of water present within a river catchment and its seasonal distribution. The complex interactions between temperature, rainfall and evaporation affect the quantity and quality of water passing through the catchments. The primary effect of climatic characteristics on water quality is usually expressed through the effects of rainfall seasonality on the timing and duration of river flows.

rainfall erosivity calculation

A very important feature of rainfall is the **intensity of rainfall** during a defined time interval. High intensity rainfalls possess an enormous erosive potential. This is generated by the kinetic energy of the rain drops striking the earth's surface and accentuated by rapid surface runoff. An estimate of rainfall erosivity in a particular region can be obtained using the EI_{30} parameter, as described by Smithen and Schulze (1982) and Moon and Dardis (1988). This dimensionless index represents the product of the total kinetic energy of a storm and the maximum rainfall intensity measured during a 30 minute period. The kinetic energy is calculated as follows:

$$E = 11.9 + \log_{10} I$$

where E = kinetic energy, and
I = rainfall intensity (mm/h).

The resulting **erosivity values** can be plotted in the form of contour plots demarcating areas of high and low erosivity. The erosivity values recorded in South Africa normally range from less than 50 to over 500 (Smithen and Schulze, 1982). When the greatest values of the EI_{30} index (> 500) are centred over densely populated areas, particularly where the natural vegetation has been removed from the catchment surface, these areas are vulnerable to high rates of soil erosion.

effects of rainfall

High rainfalls, often experienced as discrete storm events, result in sudden increases in runoff. In turn, these cause rapid changes in river levels. Where the volume of river flow exceeds the channel capacity, the river overtops its banks and floods surrounding areas. Where rain storms are experienced, considerable quantities of topsoil may be eroded from exposed surfaces and lead to a dramatic increase in the loads of suspended sediment carried in the rivers. Conversely, the progressive decline in rainfall from the wetter to the drier months results in declining river flows with lower suspended sediment loads.

The **quantity of rainfall** received within a catchment and its **distribution in time** are the primary factors that influence the quantity of water that enters surface streams and rivers.

effects of temperature

Temperature is a function of latitude, cloud cover (precipitation), time of day and local topography. Topography has a major influence on air temperatures, resulting in a decrease of approximately 0.5°C for every 100 m increase in altitude. Water temperatures - and changes in water temperature - are the primary regulating mechanisms for most biological and chemical processes in streams and rivers. High or low water temperatures exert considerable influence on water quality through their regulatory effects on processes such as:

- Solubility of oxygen (and other gases)
- Changes in chemical equilibria
- Changed rates of photosynthesis, respiration, nitrification, denitrification, etc.

effects of evaporation

Evaporation is one of the most important mechanisms whereby water is lost from rivers, streams and impoundments. Evaporative water losses from a system are accompanied by a corresponding increase in the concentration of dissolved salts. Nett evaporation, or annual moisture deficit - rainfall minus evaporation - often has a geographical distribution pattern over a catchment that is correlated to the distribution of Symons Pan evaporation rates. Nett evaporation rates are usually least in those regions where rainfalls are highest.

moisture deficits

High annual moisture deficits indicate that the indigenous vegetation must be adapted for survival under periods of drought stress. In addition to the effects on indigenous vegetation, high values for the annual moisture deficit also create serious stress for irrigated crops most of which thrive in more humid regions. The high moisture deficit values also indicate the scale and duration of additional water requirements needed to ensure that crops survive the dry months.

effects of floods

Very high flows or flood events can scour out considerable quantities of material from the river bed and result in changes to the channel form. As flows decline after such extreme events, suspended material is deposited on the river bed and accumulates to fill depressions and cavities.

effects of low flow

During the drier months, river flows decline gradually to very low levels, often a small fraction of the average flows recorded during the wetter months. This decrease in flow, combined with relatively high rates of evaporation, causes an increase in the concentration of dissolved salts present in the lower reaches of the river. Progressive and longitudinal increases in dissolved salts have an adverse effect on all water users and on the ecological functioning of the ecosystem.

iron and manganese in surface water runoff

In higher rainfall areas, increased rates of chemical weathering promote the formation of iron-rich clays and the development of distinct layers of iron-rich material or "iron-pans". These layers trap infiltrating rainfall and accelerate chemical weathering processes. Water emanating from these regions can contain elevated concentrations of iron, manganese and other ions that have been weathered out of the host rock and overlying soils. Normally, where there has been no marked disturbance of the soil structure, the concentrations of iron and manganese in surface runoff are very low, usually of the order of 0.2 to 0.5 mg/ℓ. However, where these soils have been disturbed the manganese and iron values can rise sharply, for example, concentrations of over 1 mg/ℓ (Ashton *et al.*, 1992) have been reported.

12.3 Describe the effects of geology on catchment water

☞ The major geological impacts on water quality are associated with:

- The hydraulic effects caused by changes in river gradient
- Material of different sizes and hardness in the river bed
- Localised increases in turbidity caused by fine particles and clay minerals in suspension.

☞ Overall, it can be concluded that direct geological contributions to the water chemistry of any particular river system are relatively small. Contributions to the ionic content of surface waters are seldom more than a few milligrams per litre of each of the major ions. They are usually masked by the much larger (10 - 100 fold) contributions derived from overlying soils.

☞ The exception are some localised areas, in which significant direct geological effect on water quality occurs. It is usually the result of increased solubility of salts which can be enhanced by man-made activities such as mining and certain agricultural practises.

12.3.1 Types of weathering

weathering processes

All rocks weather slowly as a result of mechanical and chemical weathering, undergoing a cyclical process of breakdown, transport and transformation into a new geological unit or rock type. Typically, weathered rocks are easily eroded within decades, while unweathered or unaltered rocks are eroded very slowly over centuries. During weathering processes, rock particles - in the form of clay, silt, sand, gravel and dissolved materials, are transported by wind and water to new locations, generally at lower elevations, and deposited in layers.

effects of human activities

Except for river beds, rock formations are seldom so extensively exposed that they contribute significant quantities of chemical ions directly to a waterbody. The exception to this rule occurs where human activities have exposed rock formations, for example in mining activities, the construction of roadways and certain agricultural practises. In these situations, the normally slow weathering processes are accelerated and these geological units can contribute greater quantities of chemical ions to a water body.

In those cases where specific mineralised deposits of a metal ore are exposed, weathering processes are greatly accelerated. The combined effects of mechanical and chemical weathering can then rapidly leach out the metal ions into nearby water bodies. Where mines have been developed on economically viable mineral deposits, a number of additional impacts on water quality can be expected *(for more details, refer to Task 11.2.4, Mining)*.

12.3.2 Effects on surface water quality

contribution of salts and ions

Only order-of-magnitude estimates can be given for the potential contribution of chemical salts and ions from each geological unit to through-flowing river water. These estimates are based on professional judgement as to the erodability and solubility of the different component minerals within each lithological unit. Clearly, the **quantities** of salts and ions which will leach or dissolve out of a particular rock formation will also be time-dependent. The contribution of salts and ions to a water body from a specific rock formation is dependent on:

- The degree of weathering
- The type of minerals exposed
- The proximity to a stream or river in the local landscape
- Local climatic characteristics.

For example, where a particular rock type forms a low relief feature and is located away from a riverbed in a low rainfall region, it is unlikely to contribute significantly to water quality in the river.

mineral types

The harder, more resistant, rocks form noticeable steep-sided hills along valleys whilst the softer clays, shale, sandstone and carbonate rocks are more easily eroded, often undercutting the harder rocks. The softer rocks contribute to increased turbidity levels in the water, whilst the harder rocks contribute larger boulders and stones to the river bed. Again, the parent rock material contributes traces (<0.1 mg/ℓ) of silica, aluminium and iron, together with very low concentrations of (<1.0 mg/ℓ) magnesium, calcium, potassium and carbonate, to water quality in the rivers.

ion solubility

The **cations**: sodium, potassium, calcium and magnesium; as well as the **anions**: chloride, fluoride, sulphate, carbonate and phosphate, are all very soluble in water at normal temperatures and can be readily removed from existing weathered rocks and soils. Cations and anions will continuously dissolve in a water body until certain maximum levels of the dissolved components are reached. These maximum levels are determined by thermodynamic constants called "solubility products". If there are components present in the water that readily bind to the mineral's dissolved components then the former will further increase the amount leached from the original mineral. Once dissolved, they can either remain in solution or they can also interact with each other to form other insoluble precipitates.

metal ions

Where the chemical conditions of the water are suitable, metal ions may remain in solution, often at relatively high concentrations. In soft (acidic) waters metal ions often bind to naturally-occurring organic compounds such as fulvic and humic acids to form organo-metallic complexes which usually remain in solution. Where the alkalinity of the water is high, the metal ions tend to bind readily to carbonate ions to form soluble as well as insoluble metal carbonates.

12.3.3 Effects on groundwater quality

aquifer characteristics

Geological formations form the host or aquifer matrix and are therefore an extremely important physical factor affecting both the occurrence and quality of groundwater resources. The different geological formations within a particular catchment are often dominated by crystalline lithological units with little or no primary porosity. In these areas, groundwater is confined mainly to secondary structural features such as faults and dykes. Recent Quaternary alluvial deposits are usually scarce in South Africa and, when present, usually make up a very small percentage of the total catchment area, providing the only sites of primary aquifers.

groundwater quality

The quality of the groundwater present within each geological unit reflects the combined effects of climatic processes and the weathering of the parent rock material. In each case, groundwater slowly accumulates the different ions and salts that have been leached or dissolved out from the surrounding rocks. This process is enhanced or accelerated where chemical weathering processes predominate. The presence of carbonic and humic acids in the rain water as it percolates through the overlying soil and downwards through cracks and fissures in the rock material also enhances this process. If there is relatively little through-flow of water, the concentrations of dissolved ions and salts eventually reaches an equilibrium state, determined by the relative solubility of the various chemical components in the parent rock. The presence of mineralised zones in the parent rock material can lead to a gradual enrichment of the groundwater with specific ions such as arsenic, fluoride, nickel, copper and iron. If the concentrations of these ions reach high levels, they can lead to water quality problems for different water users.

12.4 Describe the effects of soils on catchment water

☞ The effect of each soil type on water quality within a particular river system should be evaluated on the basis of:

- The type and extent of material present
- Special characteristics of nutrient or salt content
- The form and variety of terrain types contained within the soil type
- The type and extent of any erosion
- The suitability of the soil type for agriculture.

☞ Normally, the direct contribution of ions and salts to solution from geological formations is one hundred times less than that from overlying soils and vegetation. Overall, the contributions from soils to water quality issues in any catchment are determined largely by the extent to which human activities have altered the indigenous vegetation cover, particularly through intensive agricultural practices.

soil types and forms

Soils are formed as a result of mechanical and chemical weathering processes *(refer to Section 12.3.1)*, plus contributions of organic matter from decomposing plant and animal remains. All these processes are, in turn, controlled by the climatic zone in which each soil type is located. The variability of soil types reflects the interacting effects of underlying geological features, terrain form and climate. There is also a considerable range of soil forms within each soil type; each soil form corresponds to differences in altitude, slope, parent material, local micro- and macro-climate features and land use.

soil characteristics

A range of different soil structures and characteristics can be found within each soil unit in any particular catchment. These differences are due to minor difference in terrain, underlying geological features and climatic characteristics (Moon and Dardis, 1988). Despite the range of differences within each soil unit, each unit possesses definite functional or structural similarities which characterise the soil type. The clay content and the cation exchange capacity of soils control most of the physical and chemical mechanisms whereby soils contribute ions and salts to groundwater and surface waters.

12.4.1 Effects of rainfall on soil formation

high rainfall

In warm, humid and wet landscapes, particularly those with greater than 800 mm of rainfall per annum, climatic processes dominate soil formation. Chemical weathering processes give rise to extensive deposits of secondary clay minerals and these give rise to the deep, oxidised, red, brown, black and yellow soils. In areas where both chemical and mechanical weathering processes are equally important, the soils are still coloured by secondary clay minerals but also contain a higher proportion of sand. In valley bottoms and at the base of hills, escarpments and steep slopes, the escarpment, transported alluvial and colluvial materials form higher proportions of the soils.

intermediate rainfall

In intermediate rainfall areas (annual rainfalls less than 800 mm), the soils are generally neutral to slightly alkaline, shallow and sandy. Where rainfalls decline further, the soils become progressively more sandy and contain greater quantities of salts. In arid areas, rainfalls are low and evaporation rates are high. Mechanical weathering processes dominate in these areas, causing the fragmentation of primary minerals such as quartz into smaller fragments. Soils are often shallower and geological materials (for example, sands and gravels) dominate the formation of soil types on unstable landscapes.

In higher elevation, cooler regions, mechanical weathering processes increase in importance as the rainfall declines whilst chemical weathering processes decrease in importance as determinants of soil formation. Here the soils contain variable proportions of sand and clay, derived primarily from weathering of the underlying geological formations. Transported materials are less important as soil constituents (Moon and Dardis, 1988).

irregular rainfall

Where rainfalls are scarce or irregular, salts are not easily removed from the soils and collect in troughs in the undulating landscape, often forming thin crusts of relatively impermeable material. This crust is often composed of carbonate and/or sulphate salts of calcium and magnesium.

12.4.2 Effects of flow on soil movement

soil transportation

In addition to the primary weathering processes which control soil formation, soluble soil constituents are leached out by horizontal or vertical water flows. Different types of soil components may also be moved physically to another portion of the system. Soil and geological material are transported by water, either as a solution which contains soluble salts and free ions, or as a suspension of clay, humus, silt, sand and gravel particles. During transportation the eroded materials are mixed and sorted and are gradually deposited. Erosion and deposition processes are highly significant in the formation of most soil types, particularly where water is the dominant erosional mechanism. Wind erosion processes only contribute significantly to soil formation in the drier western regions of South Africa where annual rainfalls are very low and variable.

soil erodability

The amount of soil removed depends on the steepness and length of slope, the erosivity of the rainfalls, the erodability of the soil and the type and degree of vegetation cover. The relative erodability of different soil types is often approximated as a direct function of the fine sand content. A low sand content (and high clay content) is usually indicative of relatively low erodability and *vice versa*. On gentle slopes, the surface soils are usually freely drained and can have a high potential for arable agriculture. Erosion rates are accelerated where road cuttings have been incised or where forestry activities have taken place.

12.4.3 Effects of sediment removal

factors affecting sediment yield

The presence of suspended sediment in surface waters can have a significant adverse impact on the ecological processes within such a water body and on the uses to which the water may be put. Therefore, it is important to estimate the sediment yield potential of the catchment of interest. A number of different constituents are important in determining sediment yields from a catchment. These include:

- Land use patterns
- Soil types
- Geomorphology
- Geology
- Vegetation cover
- Rainfall intensity.

catchment sediment yield

In the case of most catchments located in the wetter regions of South Africa, land use patterns and rainfall intensity appear to be the most important determinants of sediment yields. The soil map of a study catchment provides the primary basis for delineating areas of different sediment yield potential in the catchment.

sediment yield map

A generalised sediment yield map of Southern Africa has been developed and updated by Rooseboom *et al.* (1992). The maximum sediment yield which has been estimated for intensively cultivated areas (and overgrazed areas) in South Africa is 3 000 t/km^2.yr for one of the Caledon River subcatchments (Rooseboom *et al.*, 1992). However, this is an exceptionally high value and the sediment yield potential of most catchments is more frequently in the range of 50 - 500 t/km^2.yr.

12.5 Describe the effects of vegetation on catchment water

> ☞ Vegetation is one of the primary biophysical factors which influence water resources in non-urban areas. Different vegetation types produce varying densities of ground cover and require various levels of water utilisation; these, in turn, influence the quantity, quality and timing of runoff.

vegetation types

Acocks (1988) has described 70 vegetation (veld) types which cover South Africa. A veld type is a unit of vegetation whose range of variation is small enough to allow the same agricultural potential throughout. This concept allows wide potential variation, but this is limited to the relative importance of members of typical groups of species which occur throughout the unit. These veld types and their relative occurrence are directly related to climate and topography. In turn, these are usually strongly correlated in a catchment.

effect of vegetation changes

Throughout South Africa, the historical natural vegetation cover has been dramatically altered and reduced, with important consequences for water resources. The general trend has been towards a reduction in natural ground cover (the density of plant material above the soil surface, which influences interception of rainfall and impedance of runoff). A reduction in ground cover reduces infiltration - the extent to which rainfall penetrates the soil - and increases the amount of rainwater that does not infiltrate the soil but contributes to water course flow volumes via lateral surface movement.

influences on runoff

Vegetation influences runoff in four main ways:

- Interception of precipitation to reduce runoff
- Impedance of runoff by soil surface litter
- Enhanced water losses through evapotranspiration
- Increasing infiltration by opening up the surface layers of the soil.

effect on water quality

Generally, vegetation serves to retard runoff and increase infiltration, thereby decreasing concentration time, attenuating flood peaks and increasing the period of flow. This has a direct impact on water quality as it reduces soil erosion and sediment loads. However, intensive cultivation such as afforestation can reduce flow significantly (Chunnett, Fourie and Partners, 1987) due to increased evapotranspiration losses of water. In its natural state the vegetation would have released runoff at a rate that would be determined by rainfall, slope and soil type. This has largely been modified by land use practices, where the natural vegetation cover has been replaced by a cultivated crop. Where the vegetation cover has been removed, far greater quantities of salts and sediment are delivered to nearby rivers via surface runoff. This can be accelerated, for example where grassland in a high elevation catchment is burnt off to stimulate new growth for grazing. In these circumstances, large quantities of salts and oxidised organic matter can be washed into the rivers.

effects of reed invasion

The common indigenous reeds *Phragmites australis* and *P. mauritianus* have the potential to form dense stands, or reedbeds, in a wide variety of habitats. The development of reedbeds is a natural process and need not indicate adverse ecological conditions in any given area. However, reedbeds can expand to such an extent that they inhibit other biota and river processes. They are then considered to be encroaching. *Phragmites* reedbeds have caused encroachment problems in many Southern African rivers, particularly those that are seasonal or have been regulated. Hydrology is the primary control factor of these reedbeds. This control is exerted primarily through the size, frequency and duration of flooding and the length of the dry period. Impoundments attenuate all but the largest flood events, reducing the flooding regime downstream and facilitating reedbed encroachment.

effects of alien vegetation

Riverine and forest edge habitats are particularly susceptible to invasion by alien plants. In riparian habitats, many invasive species are abundant and are known to proliferate to the extent that they can completely choke water courses. The presence of alien plant species can have a number of implications for water quality in rivers. Some alien species are relatively unobtrusive, whilst others are termed aggressive invaders that are capable of transforming large tracts into virtual wastelands as far as production potential is concerned. They can also cause severe blockage of drainage lines, influence runoff and impact on water quality. Species such as *Eichhornia crassipes*, *Pistia stratiotes* and *Salvinia molesta* are known to take over the habitat of indigenous species, out-competing the latter and to cause anaerobic conditions in the water underlying the dense mats that form.

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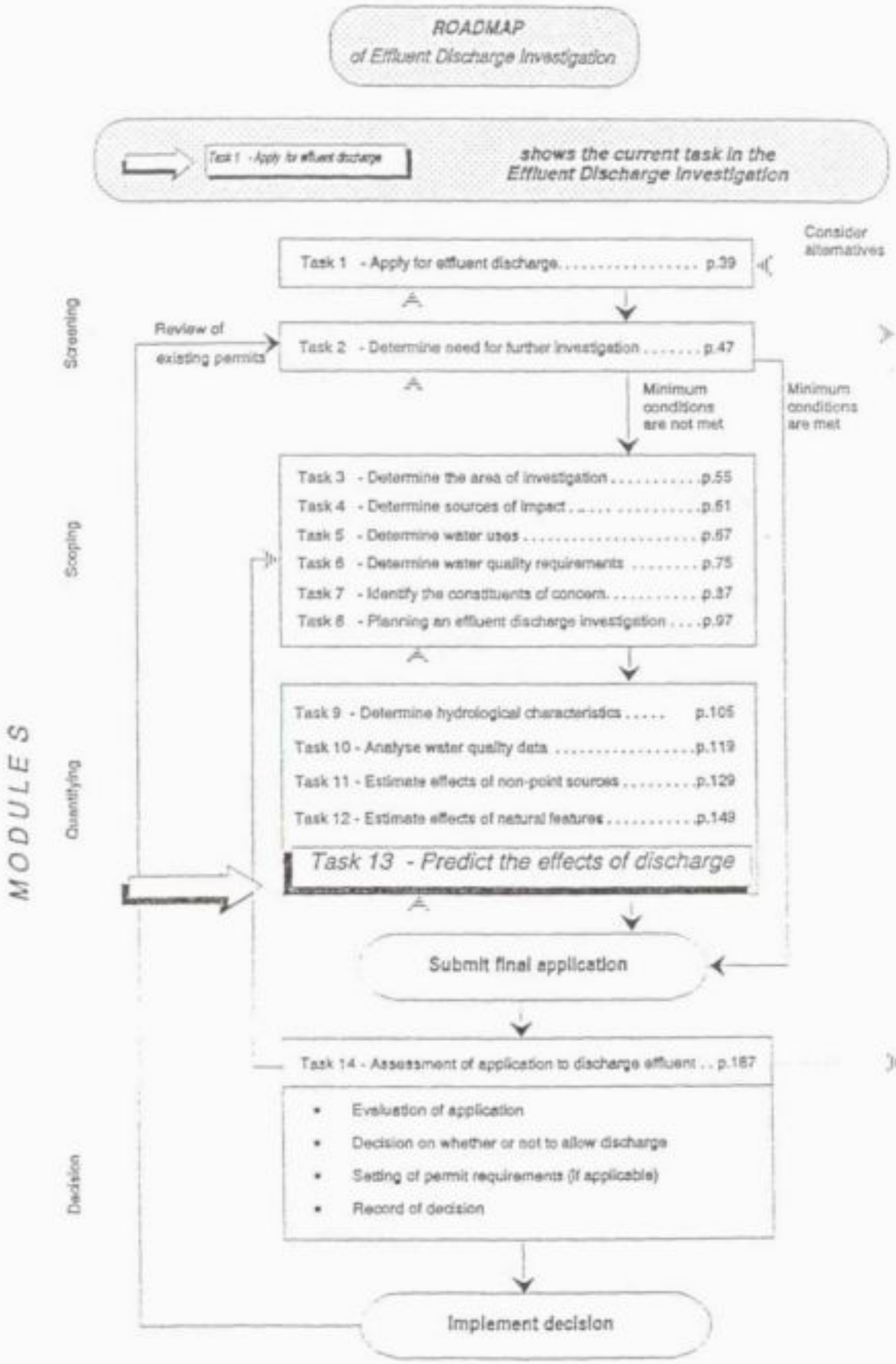
TASK 13:
Predicting the Effects of a Discharge on Water Quality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TASK 13: Predicting the Effects of a Discharge on Water Quality

☞ In order to evaluate an application to discharge an effluent, it is necessary to predict the possible effects that a discharge will have on the quality of the receiving water. In the case of existing discharges, both predicted and observed effects should be used to understand the cause-effect relationship between the discharge and the quality of the receiving water.

13.1 Introduction

☞ Mathematical models are used to predict the effects of effluent discharges on water quality. Models allow:

- A better understanding of the mechanisms and interactions that produce water quality behaviour
- A rational basis for making water quality control decisions provided that there is an appreciation of the limits of the use and roles of such models.

While mathematical models are useful for assessing the impacts of effluent discharges on water quality, there also needs to be an appreciation of the limits of the use and roles of models. The modeller needs to be able to communicate the results of a modelling exercise in terms that a decision maker can understand and which will allow rational decision to be made (Crockett *et al.*, 1989). In particular, both parties need to have at least an appreciation of the model assumptions and simplifications, as well as causes - and levels - of uncertainty of the model predictions. Models, whether existing or developed, should always be used and evaluated on a sound scientific basis (Beck, 1987).

This task contains two main sections: a discussion on important issues in modelling the effect of a discharge on receiving water quality; followed by an outline of a typical modelling procedure. There is also a short section discussing uncertainty and a summary reference to a detailed listing and descriptions of models appearing in Appendix F.

13.2 Selecting models to predict the effect of an effluent discharge on receiving water quality

☞ When selecting a model, the modeller may have to consider interactions in different types of **water systems** in order to fully assess the effects of discharges. A clear and unambiguous statement of the **goals and objectives** of the investigation will expedite the choice of either **existing** models, or the development of **new, site-specific** models.

☞ The modeller should also consider the:

- **Water quality constituents** that need to be modelled
- **Level of complexity** at which a constituent is simulated
- Minimum **time period** of interest
- Importance of **uncertainty** in the output from the model
- **Data requirements** of the model.

13.2.1 Determine the goals and objectives

goals and objectives

A clear and unambiguous statement of the **goals and objectives** of the investigation will expedite the choice of the model. The goal of determining the long-term average effect of a discharge on a receiving water body, is different to that of determining the effect of the discharge during extreme events, for example, a drought. Different models may possibly be selected to simulate the effects of the discharge depending on which objective is selected. Appendix F also contains information on the **Use of Output** of the listed models. This information will be useful in considering whether a certain model will be appropriate in terms of the stated goals and objectives.

13.2.2 Select the constituents to be modelled

factors affecting constituent selection

The constituents that should be included in the impact assessment modelling will be determined by factors such as the user requirements in the area under investigation, as well as the composition of the discharge(s). The modeller should consider both the constituents of concern *(refer to Task 7, Identify the constituents of concern)* and the processes which are important to the investigation.

constituents and processes

The water quality constituents that can be simulated by a model are dependent on the processes that are simulated in its structure. A conceptual diagram of a model is useful in understanding how a model accounts for various processes *(refer to Section 13.3.2)*. The documentation that accompanies a model should contain some form of conceptual diagram, or a description of the processes and constituents that the model simulates. The models in Appendix F are classified into water quality and hydrological models. **Water quality** models simulate water quality constituents, whereas **hydrological** models focus on the amount of water in a system. Further information is supplied on the water quality constituents and processes that each model simulates, under the headings **Description**, **Input** and **Output**.

13.2.3 Identify the type of system to be modelled

system types

The selection of the appropriate model will be dictated by the type of system(s) that is required to be simulated. One classification of the types of systems for which water quality and/or hydrological models are available is:

- Streams and rivers
- Reservoirs
- Estuaries
- Surface runoff
- Groundwater.

The models in Appendix F have been presented according to the above classification, namely streams/reservoirs, surface runoff and groundwater.

integrated system

This manual focuses primarily on effluent discharges into streams and rivers. However, because all the above-mentioned systems could interact, the modeller may have to consider these interactions in order to fully assess the effects of discharges. Some models integrate different systems, for example, the output from a surface runoff simulation becomes the input to a stream water quality simulation. Depending on the **goals and objectives**, the modeller may choose such an integrated model, or opt to develop a "linking program" that integrates two or more models.

water body characteristics

The characteristics of the water body - and linked systems - that is to be modelled are important. For example, are there point sources and/or non-point sources; abstractions and/or seepage to groundwater; what is the role of hydraulics; etc. It is also important to decide what assumptions can be made regarding mixing in the system because, for example, in many stream simulation models, complete mixing is assumed along the lateral and vertical axes.

13.2.4 Determine the dynamics of the system

period of impact

The modeller should decide what the minimum time period of interest is. If the goal of the investigation is to determine long-term average impacts, a **steady-state** model will be appropriate *(refer to Section 13.3.4)*. However, if the goal is to assess short-term impacts, a **dynamic** model will be needed. The brief descriptions of the models listed in Appendix F provide information on which are dynamic models.

13.2.5 Select the appropriate model complexity

factors affecting model complexity

There are many levels of complexity at which water quality is simulated in models. For example, the fate of non-conservative constituents are much more difficult to simulate as compared to conservative constituents. The level of complexity with which a constituent is simulated should also be determined by the goals and objectives of the investigation. The appropriate level of complexity *(refer to Section 13.3.5)* also depends on the amount, quality and nature of the field data available for calibration and verification *(refer to Section 13.3.7)*. It is inappropriate to choose a very complex model, if it is not possible to meet the model's data requirements.

13.2.6 Make provision for uncertainty

importance of uncertainty

The modeller should consider the importance of uncertainty in the output from the model in the light of the model's goals and objectives. In some cases, an average concentration is sufficient to indicate a general trend in water quality, resulting from a discharge. In such cases deterministic models are appropriate. In other cases it may be very important to assess the risk associated with the output from the model and a stochastic model may be more appropriate. Some predominantly deterministic models have a facility to analyse the uncertainty surrounding output as a result of uncertainty in parameter values. The modeller should find out how a model takes uncertainty into account, if at all, and decide whether it is sufficient to meet the goals and objectives. Uncertainty is discussed further in *Section 13.4*.

13.2.7 Other considerations for model selection

- **Availability**: is the model available in the public domain, or else, where is it available and what are the costs?

- **Documentation**: is the model structure, processes and all aspects well documented?

- **Support**: is expert support available locally or internationally and what are the costs of such support?

- **User friendliness**: the ease with which a model can be used is a major factor in determining the time and cost involved in an investigation.

Appendix F lists the names of the developers and vendors of the listed models and, where possible, the names of local experts that can be contacted for advice. Appendix F also contains a list of addresses where the developers and vendors can be contacted.

reliability

The reliability of a model can be related to the extent to which the model has been used in the past. It will be beneficial to scan the literature for case studies where the model has been applied, especially under conditions which are comparable to the conditions where it is to be applied. The more a model has been applied, the better the model has been validated, although no model can be said to have been completely validated *(refer to Section 13.3.10)*.

equipment needed

Computing equipment needed to run a model can be a limiting factor, although this is usually a lesser consideration.

13.2.8 Identify data requirements for a model

In choosing an appropriate model for an effluent discharge investigation, the modeller should always keep in mind the data requirements of the model. The type, as well as the amount and quality, of field data needed to calibrate and verify a model, should be considered. The input data needed to make predictions should also be considered. The data requirements of a model can describe the following parts of the system:

- The **initial state** (for example, headwaters conditions in a stream water quality model)
- The **disturbances** (for example, discharges into the stream)
- The **response** (for example, resulting water quality at certain locations along the stream).

In addition, the modeller will need estimates for **parameters** (for example, a range of possible growth rates, decay rates, settling rates, etc.) to enable first model runs before calibration.

uncertainty

The amount and quality of the above data will determine the success with which the model can be calibrated and verified. The modeller should also attempt to quantify the uncertainty associated with the predictions that the model will make. To do that, data regarding the uncertainty around the initial state of the system, input disturbances and parameter values will be needed. The uncertainty can be expressed in the form of statistics such as standard deviations and population variances.

data requirements

The type of model selected will strongly influence the minimum data requirements of the model. The degree of "lumping" of spatial and temporal variation will also determine the minimum data requirements, for example, a dynamic model will need a time series of data at various locations.

If the quality of the **input data** used for predictions is poor, it will lead to a poor model performance, even if the model has been adequately calibrated and verified.

13.2.9 Use an existing model or develop a new one

off-the-shelf models

There are many models available that deal with water-related problems. Most of these can be described as **off-the-shelf** models: the user need only supply input data to obtain model predictions. However, the calibration of these models and the interpretation of the results is not always simple, therefore, in many cases it is recommended that experts be consulted. Appendix F contains information on a number of models, many of which are well known and tested in South Africa. The choice of any particular model needs to be justified on the basis of site-specific conditions and the needs to be approved by the steering committee overseeing the investigation.

new model

In some cases it may be necessary to develop a new model to address a specific problem. All the steps outlined in the modelling procedure *(refer to Section 13.3)* should be followed in the development of any type of model. There could be various reasons why an off-the-shelf model would be inappropriate for an investigation. For example:

- In cases where a much simpler model than the available off-the-shelf models is required it is often more cost-effective to develop a site-specific model. Additional advantages are that the modeller has more flexibility and better control over the model structure, implementation and operation.
- If there is no single model that meets all the requirements, different models may have to be linked to simulate a system with different components. For example, a system where the output from a surface runoff is used as the input to a reservoir simulation model.
- There may also be cases where the type of processes, or the system to be modelled is of such a nature that no off-the-shelf model is appropriate. In such cases the modeller may opt to develop a new model for the specific situation. The model would be developed with specific goals and objectives in mind.

In general, decisions to develop new models should be carefully considered. More often than not the time and cost involved in developing even a simple model proved to be much more than originally estimated.

13.3 Outline of a typical modelling procedure

☞ A typical modelling procedure is divided into stages representing the periods **before** and **after** knowledge has been obtained of the behaviour of the system being modelled.

☞ The following are typical modelling steps:

- **Conceptualisation** - the spatial segregation of the water body into a number of segments and/or layers
- **Formulation** - choosing the relevant constituents and formulations for their interaction
- **Selection of model type and complexity** - approach and complexity must be appropriate to the goals and objectives
- **Model structure identification** - identify valid hypotheses or identify the need for better ones
- **Calibration** - the process of parameter estimation
- **Experimental design** - aims to ensure that collected field data are adequate to calibrate the model
- **Verification** - analysis of the discrepancy between model predictions and field measurements
- **Validation** - the process of testing the calibrated model against **independent** field data
- **Sensitivity analysis** - aims to establish the relative sensitivity of the model predictions to uncertainty in the model parameters and input data

steps in model development

This section briefly outlines a typical modelling procedure, depicted in **Figure 18**. The procedure is divided into two basic stages, which refer to the periods **before** (*a priori*) and **after** (*a posteriori*) knowledge has been obtained of the behaviour of the system being modelled. The steps in this modelling procedure are discussed in greater detail below. These steps will vary in importance and, possibly, sequence of execution, for different modelling applications. Beck (Orlob, 1983) presents a more detailed outline that further describes modelling concepts.

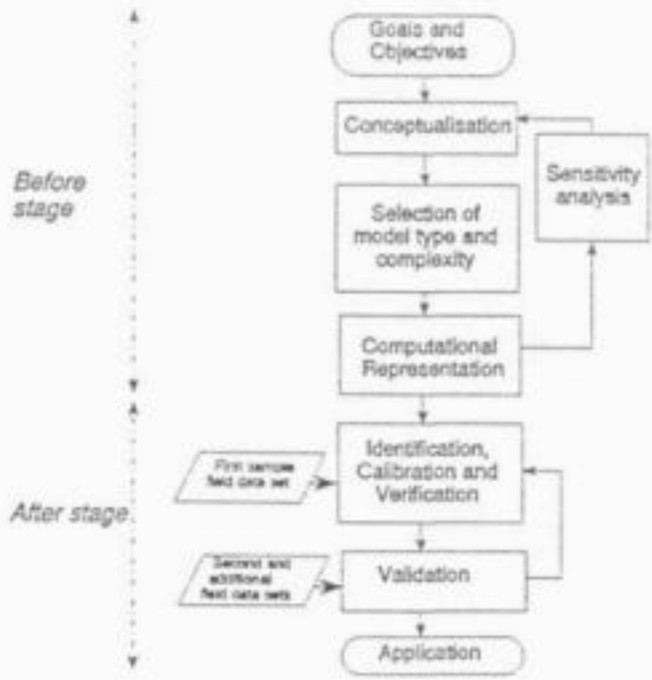

Figure 18 An outline of a typical modelling procedure

before stage

During the **before** stage assumptions about probable behaviour are used to construct the first model of the system. The **before** model is constructed using general knowledge and is not site-specific. These models can be used in initial investigations, making conservative assumptions about parameters and rate constants.

after stage

The **after** stage includes field data on the behaviour of the modelled system. Calibration of system parameters is undertaken so that the model simulates the real system more closely. With calibration, the model is made site-specific, because data from a particular system are used in the calibration process.

13.3.1 The purpose for which predictions will be used

goals and objectives

It is of critical importance to determine the exact purpose of and the way in which the predictions made with a model are going to be used in the assessment and decision-making process concerning a proposed effluent discharge. For example, the predicted information required may be the trend in the annual average response of a river system to patterns of population and industrial growth, whereas in another case it may be the probability of intermittent stream deoxygenation resulting from the diurnal variations of a particular sewage discharge. It is unlikely that the same model would be appropriate for meeting both these information requirements. It is equally important to understand how sensitive the decision-making process is for the predictions to be made. Some times other factors such as public perceptions or legal considerations may be of overriding importance. In such cases one should not invest too much time and effort in a modelling exercise.

13.3.2 Conceptualisation of the model

conceptualisation of processes

Conceptualisation involves:

- The possible spatial segregation of the water body into a number of segments and/or layers
- Decisions on how to represent the water quality constituents, for example, different species might be lumped together
- Assumptions about mixing regimes, complete mixing, plug flow, etc.

This step is part of the **before** stage, where "best guesses" - derived from previous experience, literature studies, etc. - are used to define the model structure. During the **after** phase these "guesses" will be reviewed and refined. The model conceptualisation is usually presented in the form of a diagram that shows the different state variables as boxes and the interacting processes between the state variables as arrows.

An example conceptual diagram from the QUAL2E model (Brown and Barnwell, 1987) is shown in **Figure 19** below.

Figure 19 Conceptual diagram of the QUAL2E model

13.3.3 Formulation of the model

variables and formulations

Following conceptualisation of the modelling problem comes model formulation. The relevant state variables and mathematical formulations for their interaction have to be chosen. The groups of quantities that play a role in the model and which have to be mathematically related to each other can be depicted as shown in **Figure 20**. These groups are, briefly, as follows

- **Unmeasured input disturbance** includes items such as the estimated yearly rate of phosphorus loading to a reservoir system from non-point sources.

- **Measured input disturbances** might comprise, for example, the recorded day-to-day variations of total biochemical oxygen demand (BOD), suspended solids and ammonia nitrogen concentrations in a treated sewage discharge to a river.

- **The process state variables** characterise the essential properties and behaviour of a process (or system) as functions of space and time.

- **Measured output variables** are measurements of some of the process state variables that are being simulated.

- **Model parameters** are, for instance, process rate constants such as the reaeration rate coefficient or chemical kinetic rate constants that appear in the equations of the system model. These parameters should be invariant, i.e. truly constant, but they often vary with respect to time and space. At the conceptualisation and formulation steps, the parameter's values are usually only known within a range.

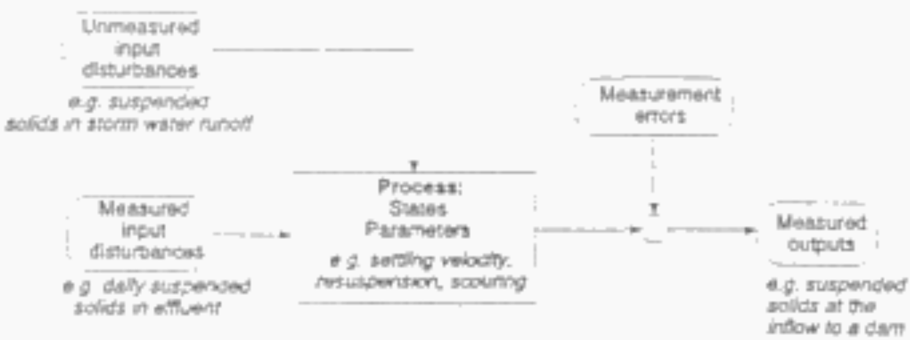

Figure 20 Definition of the system and variables

13.3.4 Selection of model type

classes of models

The type of model selected will depend on the goals and objectives. It is important that the model's basic approach and complexity be appropriate to the problem. Models can be classified in a number of ways, as described below.

distributed and lumped models

A **distributed parameter model** is one in which variations of all the quantities in **Figure 20** are considered to be continuous functions of time and space. However, prior experimental observations may indicate, for example, that horizontal gradients of dissolved material in a reservoir are not large enough to merit inclusion in the model. Thus, parts of the system description may be "lumped" together so that, for certain finite volumes of the water body, or within certain bounded spatial locations, water quality is assumed to be uniform and independent of position within the defined volume. A distributed-parameter model would be reduced by that assumption to a **lumped-parameter model.**

stochastic and deterministic models

A **stochastic model** accounts for stochastic input disturbances and random measurement errors (as shown in **Figure 20**). A **deterministic model** assumes that the future response of the system is completely determined by a knowledge of the present state and future measured inputs.

In a deterministic model the parameters are presented as exact numbers, whereas in stochastic models they are estimates stated in terms of statistical distributions.

Stochastic modelling is still a relatively new development in environmental chemistry (Jørgensen, 1991). The Department of Water Affairs and Forestry uses stochastic hydrological modelling extensively and developed both the expertise and computing capabilities for water quantity analysis, as well as an option to superimpose modelling the behaviour of conservative water quality constituents onto such a system analysis.

dynamic and steady state models

In a **steady state model**, the variables defining the system are not dependent on time, whereas in **dynamic models** they are. An example of a steady state model is one in which the average spatial variations in a river system are computed for an average time-invariant set of waste-water discharge, temperature and stream flow conditions. In steady state models the variables are only functions of space and not time.

Like the lumped-parameter model, the advantage of the steady state model is its potential for simplifying computational effort through the elimination of one of the independent variables - time - in the model relationships. Another important reason for choosing a steady state model is that the data requirements are much less than those for a dynamic model.

internally descriptive and black box models

These two model types represent two ends of a spectrum, rather than discrete categories. An **internally descriptive model,** is one in which the internal mechanisms of process behaviour are described. A **black box model** makes no explicit reference to how processes take place; it only deals with what is measurable, namely the inputs and outputs. Most models contains elements of both approaches.

An internally descriptive model relies on a deductive reasoning approach to predict the outputs - it utilises prior knowledge of known mechanisms to calculate the system's response to certain disturbances (i.e. a **before** approach).

For a black box model the response of the real system to input disturbances is recorded. This information is used to calibrate the model in such a way that it would give the same type of responses to such disturbances. The way in which the output is synthesised is of no importance, therefore the actual mechanisms inside the process box are not taken into account.

13.3.5 Complexity of models

knowledge and uncertainty

The selection of the complexity level of a model is a matter of balance. It is necessary to include the state variables and the essential processes. On the other hand, it is important not to make the model more complex than the data set can bear. The knowledge about processes and state variables, together with the data set, determine the model. If the knowledge is poor, the model will be unable to give many details and will have a high degree of uncertainty. With more detailed knowledge of the problem, a more detailed model with a low uncertainty can be constructed but always with larger data requirements.

excessive complexity

With modern computer technology, increasingly complex models are possible. Models can, however, become too complex - it is easy to add more state variables and equations, but much harder to obtain the data needed for calibration and validation of the model.

> With a given amount of data, the addition of new state variables or parameters beyond a certain model complexity only adds to unaccountable uncertainty (Jørgensen, 1991). As a general rule models should be as simple as they can be and not simpler.

literature on complexity

The literature of environmental modelling contains several methods applicable to the selection of model complexity. A comprehensive discussion is presented in Jørgensen (1988).

13.3.6 Model structure identification

hypothesis testing

Discriminating between various hypotheses that are, believed to be good approximations of the "real" system's behaviour or, otherwise, identifying the need for better hypotheses, is called **model structure identification**. This choice is made with the aid of *in situ* field data. The hypothesised structure that "best fits" the experimental data is chosen.

limits of model structure

The importance of model structure identification in the modelling procedure is partly related to the fact that water quality and ecological systems are not well defined. Therefore the "true" relationships between the system variables are unquantified. The "black-box" approach to modelling might thus be the only option to use in some cases.

13.3.7 Calibration of the model

purpose of calibration

Calibration is the process of obtaining estimates for the model's parameter values by using measured field data. Parameter values often cannot be measured directly - therefore the inputs and outputs which can be measured are used to deduce them. Model calibration is not, however, merely a question of finding the best estimates of parameters, but also quantifying the uncertainty surrounding these estimates. When the data are sparse, the calibration process is unlikely to be incisive. It can provide only a first filter of some uncertainty from the possible ranges of parameter values in literature (Hornberger and Spear, 1981). The sample of acceptable, candidate parameter values may then be used to generate a sample of predictions from the model (Fedra, 1983).

calibration procedures

An **informal** calibration procedure is shown in **Figure 21**. The modeller starts with some model structure and set of associated parameter values. The simulated model performance is then compared with the observed behaviour of the system under investigation. If the model is found to be inadequate in its characterisation of reality, the modeller adjusts some parameter values until the model output matches the observed data. There are more **formal** procedures available for model calibration (see Orlob, 1983). An algorithm can be employed that uses the measured outputs, predicted outputs and errors to formally adjust the parameter values of a model.

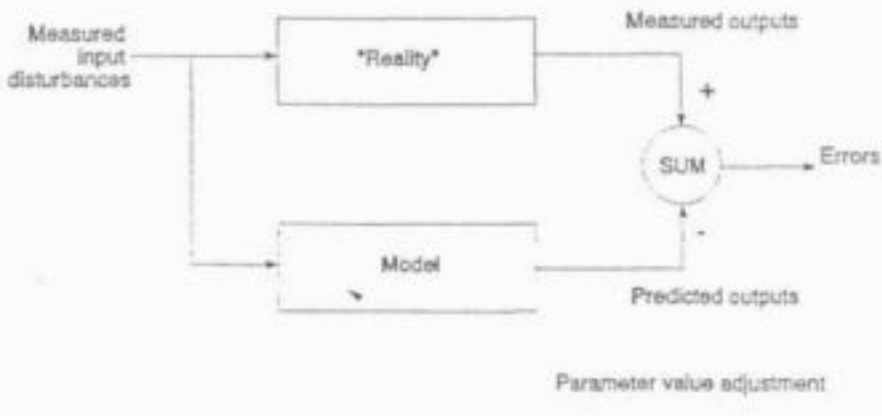

Figure 21 A rudimentary method of model calibration

> An exercise in accurate parameter estimation is of dubious value if the prior problem of model structure identification has not been satisfactorily resolved.

calibration of complex models

Jørgensen (1991) cautions that very complex models are more difficult to calibrate, because there are more parameters involved. Given the unavoidable uncertainty in measured field data, this leads to an increased level of uncertainty in the parameter values, up to a point where an increase in complexity leads to a decrease in information from the model.

13.3.8 Experimental design

factors affecting experimental design

The aim of the **experimental design** is to ensure that collected field data are adequate to calibrate the model. It includes considerations such as the sampling interval, the length of the experiment and the choice of constituents. The **before** model structure affects the choice of variables to be monitored. If, for instance, the model structure lumps the growth of various bacterial species together, there will be no need to monitor the various species separately. The experimental design for a modelling exercise should be directed towards ensuring that the chosen model will be calibrated properly.

literature on experimental design

Beck (Chapters 3 and 11 in Orlob, 1983) gives guidance on experimental designs for modelling, including algorithms for parameter estimation.

13.3.9 Verification of the model

purpose of verification

The process of **verification** is designed to control errors when deciding to accept or reject the model - as a whole - as a valid instrument of prediction. Verification entails an analysis of the discrepancy between modelled outputs and measured field data. Due to uncertainties in the model structure, input and output data and parameter values, it is reasonable to expect discrepancies between the model's output and field data. However, these discrepancies should be tolerable in terms of the original **goals and objectives**.

error assessment

To assess the "correctness" of model predictions, one should consider the following:

- The magnitude of the errors (i.e. the difference between model output and corresponding field data)
- The statistical properties of the errors.

Should the error sequences not conform to the desired properties, this suggests that the model does not characterise adequately all of the features of the observed behaviour. A strong correlation between variations in a given input and the variations in the model response errors of a given output, for example, may indicate that the model structure should be modified to accommodate additional significant relationships between those two variables. Analysis of the model performance along these lines, therefore, highlights the importance of model structure identification.

control of errors

The type of error that should be controlled is a type II error, i.e. the error of mistakenly accepting an invalid model (Burns *et al.*, 1990). There always remains a residual ambiguity in the representation and interpretation of past behaviour, normally referred to as a lack of **model identifiability** (Beck and Halfon, 1991). This means there will always be ambiguity in the future predictions made by models. Should the decision be taken to establish the causes of a lack of model identifiability, there are broadly two areas in which the search might be directed:

- Restructuring of the model

- Improved field monitoring programmes to improve the model calibration.

13.3.10 Validation of the model

purpose of validation

There is no guarantee that the model validity extends beyond the sample data set against which it has been calibrated. Validation is, then, the testing of the adequacy of the model against **independent** field data. This data are usually collected from different sites or if collected at the same site it must be for a different time period.

13.3.11 Sensitivity analysis

purpose of sensitivity analysis

The major goal of sensitivity analysis is to establish the relative sensitivity of the model predictions to uncertainty in the model parameters or in the input database. If the output is completely insensitive to a specific parameter, it means that it will be impossible to find a reliable estimate for that parameter during calibration. If the output is very sensitive to a specific parameter or certain input data, special effort should be taken to obtain a very good parameter estimate or reliable input data. Sensitivity analysis should be done both before and after the calibration step in the modelling procedure. Sensitivity analysis is an important part in the feedback loops to previous steps in the modelling procedure (see **Figure 18**).

"Before" sensitivity analysis

Sensitivity analysis can yield insight into the nature of the model and its suitability for calibration, even before experimental field data has been used. **"Before"** sensitivity analysis can establish the relative magnitudes of changes in the simulated model responses to changes in the model parameter values. It may lead to a restructuring of the model at the conceptualisation stage.

"After" sensitivity analysis

"After" sensitivity analysis examines the possible distribution of model responses, given the distributions of estimated parameter values. If the uncertainty in the parameter values leads to too much uncertainty in the model predictions, the feedback loop leads back to the conceptualisation step.

13.4 Uncertainty in modelling

☞ Error in model predictions can arise from sources such as:
- The model structure
- The uncertainty of parameter values
- Poor characterisation of the ranges of input values.

☞ The degree to which uncertainty is significant in terms of the goals and objectives of the modelling effort **must** be identified before attempting to account for the uncertainty in to the model's predictions. Procedures to identify and reduce uncertainty "correctly" are essentially part of a "trial and error" process.

significance of uncertainty

Beck (1991) places the issue of uncertainty in the context of **decision-making**. He states that the first issue to be resolved is the degree to which uncertainty is significant in terms of the **goals and objectives** of the modelling effort. The options are:
- The level of uncertainty is not significant, thus enabling the use of the model in an entirely deterministic fashion *(also refer to Section 13.3.4)*
- The level of uncertainty is significant and some account of the uncertainty associated with the model's predictions must be given.

Significance is not solely a function of the magnitudes of the prediction errors; a small amount of uncertainty in predicting contaminant levels close to a critical decision point may be more significant than a large uncertainty in predicting levels much lower - or much greater - than this critical level.

13.4.1 How can the source of uncertainty be quantified?

sources of uncertainty

Much of the uncertainty in a model derives from the lumping of ecological, spatial or temporal heterogeneity of behaviour into a single model parameter *(refer to Section 13.3.4)*. Error in predictions can arise from sources other than the model structure and uncertainty of parameter values. Erroneous assumptions about the pattern of variations in the input disturbances of the system could also contribute to error. An example is a well calibrated water quality model that fails to predict the observed DO levels in a stream, because of the input data does not adequately represent organic rich discharges upstream. The problem does not lie in the model's structure or calibration, but in the poor characterisation of the input loads.

use of literature values

If one assumes that the model error is simply reflected in uncertainty in the model parameters, an initial answer may be found in the literature. Upper and lower bounds on the feasible, or "likely", values of the model's parameters are often available and they may be used to delimit the uncertainty in the relevant parameter. Given enough data, the modeller can attempt to find an "optimum" value for a parameter through formal algorithms, together with a quantification of its error variance (Van Straaten, 1983).

13.4.2 How can the uncertainty be reduced?

limits to reducing uncertainty

Beck (1991) states that it is extremely difficult to quantify the uncertainty attached to the model structure and to prescribe procedures to identify and reduce it "correctly". This is essentially a "trial and error" process.

use of field data

In situ field data have to be used to calibrate the model and to establish whether the model is fit for making predictions (i.e. verification). Sufficient monitoring of the appropriate constituents, will ensure that the model identifiability is maximised, by minimising the uncertainty around the model parameter values.

increased number of mechanisms

One option is to increase the number of deterministic mechanisms described in the model. The effect is an increase in the number of parameter values that are needed and again an increased level of uncertainty. Therefore, a simpler model is often more effective, given the constraints of obtaining sufficient data for a more complex model. Part of the "art" of modelling is to determine and include only the significant processes so as to limit the level of complexity.

13.5 List of water quality related models

available models

Appendix F contains a list of available models that are related to water quality. Not all these models are directly applicable to modelling of an effluent discharge investigation, but all of them are related to water quality in some way. This list is **not** a complete one of **all** models which might be of use in effluent discharge assessment studies in South Africa. Details on other models are also presented in Appendix F. Modellers will do well to keep abreast of the latest developments in environmental modelling by reading the literature. A list of readings and useful references is presented in Appendix E.

Information given on the models in Appendix F includes:

- Name
- Description
- Input requirements
- Output options
- Databases accessed
- Vendor/developer/contact person(s).

model classifications

The models in Appendix F are classified into water quality and hydrological models. **Water quality** models are used to simulate water quality, whereas **hydrological** models focus on the amount of water in a system. Although this manual focuses on the investigation of effluent discharge impacts on water quality, the influence of hydrology is critical and must receive sufficient attention. Almost all water quality models have an integral hydrological component, whereas stand-alone hydrological models deal with specific problems regarding the amount of water, such as droughts or floods and the probability of such events. The models have been further classified according to the systems which they simulate:

- **I. Water quality** models
  - A. Streams/Reservoirs
  - B. Surface Runoff
  - C. Groundwater
  - D. Equilibrium Models

- **II. Hydrological** models
  - A. Surface Water
  - B. Groundwater
  - C. Integrated Surface and Groundwater Models

Equilibrium models (I.D) were classified differently because they focus on chemical processes in aquatic solutions in general, without reference to any hydrological system.

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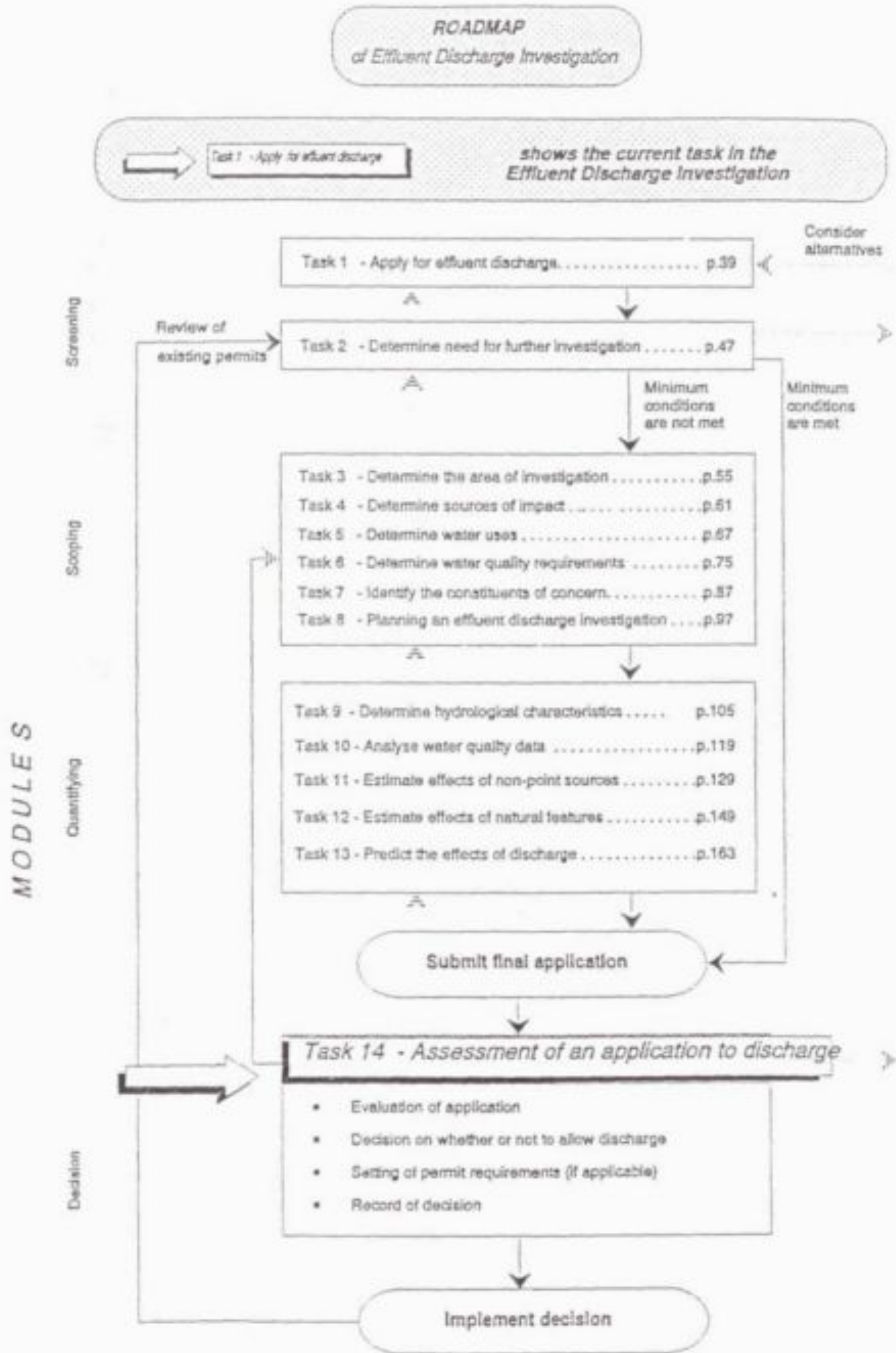
EFFLUENT DISCHARGE INVESTIGATION

DECISION MODULE

TASK 14:
Assessment of an Application to Discharge an Effluent


ROADMAP
of Effluent Discharge Investigation
Task 1 - Apply for effluent discharge
shows the current task in the Effluent Discharge Investigation
Consider alternatives
Task 1 - Apply for effluent discharge.................. p.39
Screening
Review of existing permits
Task 2 - Determine need for further investigation p.47
Minimum conditions are not met
Minimum conditions are met
Scoping
Task 3 - Determine the area of investigation p.55
Task 4 - Determine sources of impact p.61
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Task 10 - Analyse water quality data p.119
Task 11 - Estimate effects of non-point sources p.129
Task 12 - Estimate effects of natural features p.149
Task 13 - Predict the effects of discharge p.163
Submit final application
Task 14 - Assessment of an application to discharge
Decision
Evaluation of application
Decision on whether or not to allow discharge
Setting of permit requirements (if applicable)
Record of decision
Implement decision

TASK 14: Assessment of an Application to Discharge an Effluent

☞ The purpose of this task is for the DWAF and the other interested and affected parties to evaluate and assess the application to discharge an effluent in order to conclude whether or not the discharge should be allowed, and if allowed, what the permit requirements should be.

☞ This assessment should be based on the information contained in the application as well as the information collected during the effluent discharge investigation.

14.1 Assessment criteria

assessment of an application

The assessment of an application to discharge an effluent must be done within the context of the DWAF's water quality management policies and principles (*see Water Quality Management, Sections A and B*). In such an assessment, local site and case specific factors will be taken into account, particularly through the involvement of interested and affected parties in the assessment process.

As part of the assessment process the DWAF has to ensure that the applicant has:

- Provided sufficient information to enable the DWAF and the interested and affected parties involved in the assessment to reach a conclusion on the desirability of allowing the discharge
- Sufficiently and effectively involved the interested and affected parties in the effluent discharge investigation and the assessment of the application
- Completed an effluent discharge investigation which adequately addressed all the relevant issues.

The application to discharge an effluent and the information supporting it must specifically address the DWAF's decision-making hierarchy. For convenience this is repeated below in full and is also depicted in **Figure 22**.

- First of all, options for **preventing and minimising waste** through source reduction, recycling, detoxification and neutralisation of wastes must be thoroughly investigated. Caution should be taken that in this process, one is truly avoiding or minimising waste and not simply shifting it from one environmental medium to another, for example, from water to land or from water to air.

- If, after all the practical options to prevent and or minimise waste has been exhausted, there is still waste or an effluent **it will be required to meet whichever is the strictest of minimum effluent standards** or **receiving water quality based effluent standards**.

  Appropriate **minimum effluent standards** are currently being investigated. The current General or Special Effluent Standards will in the interim be used as minimum standards. *(See Appendix G for the existing standards.)*

  The effect of the treated effluent on the receiving water's fitness for the protection of the natural aquatic environment and for water uses will be assessed against desired **receiving water quality**. Effluent standards required to meet desired receiving water quality are derived on the basis of an **effluent discharge investigation**. **Such receiving water quality based standards may sometimes be stricter than minimum effluent standards**.

- **Exemptions** from minimum effluent or receiving water quality based standards will be considered under special circumstances and as a last resort, but will require sufficient justification on technological, economic and socio-political grounds. Such exemptions may not always be granted, may in most cases be temporary and almost certainly will be withheld if the point source investigation shows that the receiving water's fitness for the protection of the natural aquatic environment and for water uses will be significantly reduced. Such a justification must also be accompanied by a very specific action plan and milestones, tied to specific time scales, by means of which the discharger undertakes to improve its waste management practices to the extent that it will meet the DWAF's standard requirements. If an exemption permit is issued, such an action plan, including the milestones and time scales, will become part of the permit requirements and therefore becomes a binding contract between the discharger and the DWAF.

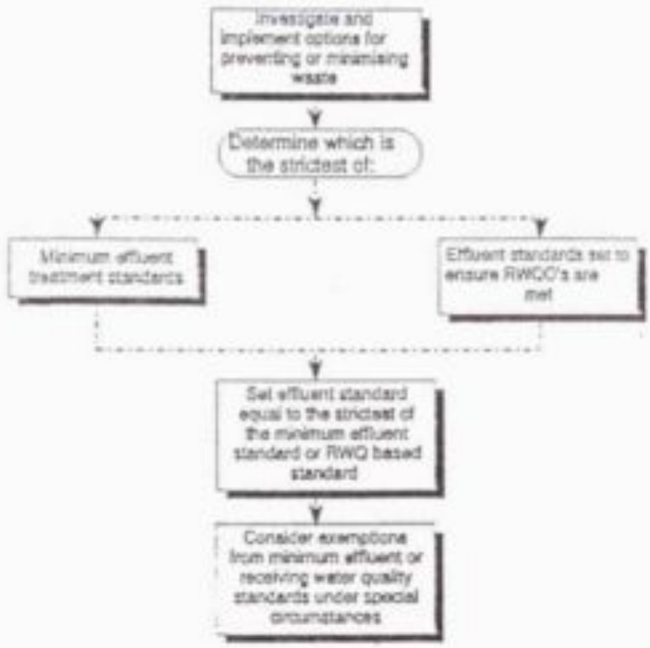

Figure 22 Decision-making hierarchy for considering applications to discharge effluent

14.2 Dealing with risk

factors affecting risk

The assessment and the eventual decision-making concerning an application to discharge an effluent has built into it the risk of making the wrong assessments and decisions. The main factors contributing to this risk are:

- Inadequate, incomplete or inaccurate information used in the assessment and decision-making process
- Unforeseen events, such as severe droughts, that were not taken into account in the assessment process
- Inadequate assessment and decision-making procedures.

Such assessment and/or decision-making errors can be grouped into two categories, namely:

- Being too strict - i.e. erroneously concluding an effluent would have an unacceptable impact and therefore deciding to refuse permission for it to be discharged
- Being too lenient - i.e. erroneously concluding that the impact of an effluent will be acceptable and therefore deciding to allow it to be discharged.

incomplete or inadequate information

Depending on how one deals with uncertainty, particularly in the face of incomplete or inadequate information, can obviously influence whether one is more likely to be too lenient or too strict. These two categories of errors are not independent of each other, in other words by trying to decreases the chances of making one kind of error one increases the chances of making the other kind. For example by minimising the chances of being too lenient one increases the chances of being too strict.

err on the safe side

In line with its precautionary approach to water quality management, the DWAF's policy is to rather err on the safe side. That means it would rather be too strict than being too lenient. This is achieved, inter alia, by making assumptions on the safe side or accepting worst case situations, particularly when dealing with incomplete and inadequate information, in the assessment and decision-making process.

14.3 Dealing with the consequences of failure

It must be recognised that in all assessment and decision-making concerning the management of the impact of effluent discharges there is a chance that circumstances can arise under which the effluent will have an unacceptable impact on the receiving water. Obvious cases are:
- Equipment and/or management failures at the facility generating the effluent
- Natural events such as extreme droughts which can result in very low of zero flows in the receiving water body lasting for exceptionally long periods.

It should be clearly understood that the applicant is responsible for dealing with the consequences of both eventualities. Plausible and specific continency plans for dealing with such eventualities must be provided by the applicant.

14.4 Conclusion of the assessment

The final outcome of the assessment of an application to discharge an effluent in a water body can be any one of the following conclusions:
- To allow the effluent to be discharged
- Not to allow the effluent to be discharged
- To require additional information or further investigation because the assessment is inconclusive.

14.4.1 Effluent discharge allowed

If the conclusion of an assessment of an application to discharge an effluent is that it should be allowed, then a specific administrative process within the DWAF is set in motion. The purpose of this process is to issue the appropriate permit to the discharger and to specify all the general and special case- or site-specific permit requirements.

The requirements specified in a permit belong to the following categories:

- **The period for which a permit is valid** must be specified. In cases where the discharger has undertaken an action plan to improve effluent quality this requirement is of particular importance because it allows the DWAF to revoke a permit if inadequate progress is made with respect to the previous undertakings to improve effluent quality. The expiry of a permit allows the DWAF and the other interested and affected parties the opportunity to reassess the effects of an effluent discharge on the receiving water body.

- **Requirements relating to effluent quality and quantity.** It is important to be very clear whether the limits set are maximum values (i.e. never to be exceeded) or average values. If they are averages it must be clear whether or not they are simply arithmetic averages or flow-weighted averages. In certain cases the DWAF may specify in-stream limits in the permit, however these are more difficult to administer than effluent limits.

- **Monitoring requirements,** for which the discharger is responsible, are specified in the permit for both effluent quality and quantity as well as for water quality in the receiving water body, both upstream and downstream of the discharge. Such monitoring provides the DWAF with information on whether or not the effluent meets the permit requirements as well as on the effects of the effluent on the quality of the receiving water body.

  Such monitoring is of critical importance in evaluating the performance of a discharger and for the purposes of reassessing the impacts of an effluent discharge. Therefore, careful consideration has to be given to designing a proper monitoring programme for each effluent discharge. Guidelines for designing such a monitoring programme are provided in Appendix D.

  The DWAF will also conduct its own monitoring, mainly to audit the results being submitted to it by the discharger.

- **Requirements related to good house keeping** are often included in permits. It has been found that the majority of failures to meet effluent quality and quantity requirements are related to poor house keeping in the facility generating the effluent which is discharged. For example it can be required that a comprehensive water management plan, including stormwater handling, for the facility is developed and maintained.

- **Requirements relating to the impacts on groundwater** and monitoring thereof.

Once a permit has been issued, another administrative process, namely to ensure compliance to permit requirements and continued evaluation of the effects of the discharge on the receiving water body is set in motion. It briefly involves the discharger regularly submitting information to the DWAF. The DWAF, through regular site visits, analysis of the information submitted to it, independent auditing and responding to concerns and complaints of the public or specific water users, makes sure that the effluent complies to the permit requirements.

14.4.2 Effluent discharge not allowed

In some cases the assessment of an application to discharge an effluent results in a decision not to allow an effluent to be discharged. In the majority of cases this leads to the applicant developing other options. These options then have to go through the whole process of investigation and assessment as described in this manual.

14.4.3 Results of the assessment inconclusive

This should be a rare outcome if all the interested and affected parties were effectively involved in the process of scoping and investigating the impacts of an effluent on a receiving water body. It should occur only if an unexpected issue emerges after the investigation of an effluent discharge has been completed. If such a situation occurs the additional information required or issues to be investigated should be specified and agreed to by the interested and affected parties involved. The whole process as described in this manual should then be repeated in order to reach a conclusion concerning whether or not the effluent discharge should be allowed.

14.4.4 Record of decision

If the application to discharge has been refused, notification, in writing, will be given to the applicant. In all cases, whether or not an application is approved, a record of decision will be kept and made available to interested and affected parties on request.

Supporting information

Appendices - with glossary, abbreviations, list of models, report guidelines, legislation, additional literature - and index

APPENDIX A:
Glossary

APPENDIX A:
Glossary

agricultural water use is water that is used for irrigation of crops, watering of livestock and maintenance of aquaculture.

assimilative capacity is the capacity of a water body to assimilate, through processes such as dilution, dispersion and chemical and biological degradation, waste disposed to a water body without water quality changing to the extent that the *fitness of water* for the protection of the *natural aquatic environment* and for *water uses*, is impaired.

biochemical oxygen demand (BOD) is the amount of dissolved oxygen required to meet the metabolic needs of aerobic organisms in water rich in organic matter.

case-specific - see *site-specific*

chemical oxygen demand (COD) is the amount of oxygen required to oxidise all the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant.

contact recreation refers to one of the categories used to describe *recreational water use*. It involves full-body water contact such as swimming and diving.

diffuse sources are distributed or dispersed sources of impact on water quality, resulting from surface run-off, infiltration or atmospheric deposition.

domestic water use is the use of water for drinking, washing, bathing, cooking etc.

effluent standard is a legally enforceable value or limit set for a *water quality constituent* in an effluent being discharged into a water body.

effluent discharge permits are legal documents specifying the limits, monitoring requirements and reporting schedules, as well as other requirements which are set when an effluent discharge is allowed. These permits are issued and administered by the Department of Water Affairs and Forestry.

exemption is a type of *effluent discharge permit*, issued in terms of Article 21 of the Water Act, which exempts a discharge from either (a) not discharging at the point of abstraction, and/or (b) not complying with the *General Effluent Standard* *fitness of water* is a judgement of the suitability of the quality of the water for one of the four recognised *water uses* and for protecting and maintaining the health of the *natural aquatic environment*.

General Effluent Standard is a set of *effluent standards*, published in terms of the Water Act which are applicable throughout South Africa. An effluent must comply to the whole set, unless an *exemption* relaxing one or more standards has been issued by the Department of Water Affairs and Forestry.

igneous rock is rock which was formed from the cooling of magma and which has not changed appreciably since its formation.

industrial water use is water that is used (with or without treatment) for various industrial processes.

intermediate contact recreation is one of the categories used to describe *recreational water use*. It includes activities with a high degree of water contact such as waterskiing and canoeing, as well as those involving relatively little water contact such as paddling or wading.

management actions include the functions of planning, organising, leading and controlling. They serve to implement *strategies*.

metamorphic rock is rock that has been greatly altered from its previous condition through the combined action of heat and pressure.

minimum effluent standards are limits for the concentrations of water quality constituents in an effluent, and are based on treatment technology.

mixing zone is a region in a receiving water body in the vicinity of the point of discharge of an effluent. It is characterized by incomplete mixing of the effluent with the water body.

natural aquatic environment is defined as the abiotic (physical and chemical) and biotic components, habitats and ecological processes contained within the outer edges of the riparian zones, in the case of rivers, or within fringing vegetation zones, in the case of reservoirs, lakes and wetlands. Terrestrial biota, which depend on the aquatic ecosystems for survival, are included in this definition but humans are not.

no effect range is that range of concentrations or levels for a *water quality constituent* at which the presence of that constituent would have no known or anticipated adverse effect on the *fitness of water* for the protection of the *natural aquatic environment* and for *water uses*. These ranges were determined by assuming long-term continuous use (life-long exposure) and incorporate a margin of safety.

non-contact recreation is one of the categories used to described *recreational water use*. No direct contact with water is involved, for example, picnicking or hiking. Scenic and aesthetic aspects are important features in this category.

non-point sources - see *diffuse sources*

norms are yardsticks by which changes in *fitness of water* can be measured (for example health effects, crop yield, biodiversity, etc.)

point sources are known discreet sources of impact on water quality from, for example, a pipe discharging an effluent from an industry. The volume and quality of the discharge can be directly measured and quantified.

receiving water quality objective - see *water quality objective*.

recreational water use is water that is used for:

- *contact* recreation (swimming, water skiing, windsurfing etc.); or
- *non-contact* recreation (boating, fishing, bird watching etc.)

Uses associated with aesthetic beauty are also included. Pools receiving continuous maintenance are not included.

site-specific refers to conditions that are unique or specific to a certain site, locality or case.

Special Effluent Standard is a set of *effluent standards*, published in terms of the Water Act (54 of 1956) which are applicable in certain catchments in South Africa.

target water quality range is a range of water quality which the Department of Water Affairs and Forestry has, as a matter of policy, decided to strive to maintain. It corresponds with the *no effect range*. Therefore, in the South African Water Quality Guidelines the *no effect range* is referred as the *target water quality range (TWQR)*.

water quality is used to describe the physical, chemical, biological and aesthetic properties of water which determine its fitness for the protection of the *natural aquatic environment* and for *water uses*.

water quality constituent is a term which is used generically in this manual and the South African Water Quality Guidelines for any of the properties of water and the substances suspended or dissolved in it.

Several other terms are also used in the international and local literature for the properties of water or for the substances dissolved or suspended in it, for example, water quality variable, characteristic, determinand, etc.

water quality criteria are defined in the South African Water Quality Guidelines as scientific and technical information provided for a particular water quality constituent in the form of numerical or narrative descriptions of its effects on the *fitness of water* for the protection of the *natural aquatic environment* and for *water uses*.

It is defined in different ways in the international literature, for example:

- *US EPA (1986)* a designated concentration of a constituent that, when not exceeded, will protect an organism, an organism community or a prescribed water use or quality with an adequate degree of safety.
- *Canada (1987)* scientific data evaluated to derive recommended limits for water uses.
- *Australia (1992)* scientific and technical information used to provide an objective means for judging the quality needed to maintain a particular environmental value (water use).

water quality guideline is a set of information provided for a specific *water quality constituent*. It consists of the *water quality criteria*, including the *target water quality range* for that constituent, together with other supporting information such as the occurrence of the constituent in the *natural aquatic environment*, the norms used to assess its effects on *water uses*, how these effects may be mitigated, possible treatment options, etc.

The South African Water Quality Guidelines consists of the guidelines for domestic, recreational, industrial and agricultural *water uses* as well as guidelines for the protection and maintenance of the health of the *natural aquatic environment*.

Water quality guidelines are also defined in the international literature as:

- *Canada (1987)* a numerical concentration or narrative statement recommended to support and maintain a designated water use
- *Australia (1992)* water quality guidelines translate the criteria into a form that can be used for management purposes
- *WHO (1984)* the level of a constituent that ensure aesthetically pleasing water and does not result in any significant risk to the health of the consumer.

water quality objective is a concentration or level, not to be exceeded, set for a specific *water quality constituent* in a defined water body, or portion or a water body, to ensure, with a given measure of reliability, its agreed fitness. This is an achievable value, determined by considering the water quality requirements of recognised *water users* and for the protection of the health of the *natural aquatic environment* as well as relevant physical, technological, economic and sociopolitical issues.

It is also defined internationally as:

- *Canada (1987)* a numerical concentration or narrative statement which has been established to support and maintain a designated *water use*.

water quality standard is a term used in international water quality literature which is defined as:

- *Canada (1987)* an objective that is recognised in enforceable environmental control laws of a level of government
- *Australia (1992)* what guidelines (perhaps further modified by social, political and/or economic considerations) become when compliance is mandated by law

- *US EPA (1986)* a standard connotes a legal entity for a particular reach of waterway or for an effluent.

water use can be one of the four uses of water recognised by the Water Act:

- domestic
- industrial
- agricultural
- recreational

water user is a person or group of persons which use water for a particular purpose.

APPENDIX B:
Abbreviations

APPENDIX B: Abbreviations

BAT	Best Available Technology
BATNEEC	Best Available Technology, Not Entailing Excessive Cost
BPEO	Best Practical Environmental Option
BPWQO	Best Practical Water Quality Option
DWAF	Department of Water Affairs and Forestry
EPA	Environmental Protection Agency (United States of America)
GIS	Geographical Information System
HRI	Hydrological Research Institute
IA	Impact Assessment
IEM	Integrated Environmental Management
POLMON	Pollution Monitoring Database
RSA	Republic of South Africa
SABS	South African Bureau of Standards

APPENDIX C: Guidelines for Effluent Discharge Investigation Reports

APPENDIX C:
Guidelines for Effluent Discharge Investigation Reports

C.1 Purpose and nature of these guidelines

The guidelines and report format presented below should be seen as a checklist against which a consultant can structure information obtained during the **effluent discharge investigation** clearly and logically. It is acknowledged that no checklist can be sufficiently comprehensive to cover all cases, but the outline should provide a minimum basis from which to work.

This report format is broadly based on that developed by the Department of Environment Affairs for report requirements for initial assessments and impact assessments (Department of Environment Affairs, 1992).

These guidelines do **not** attempt to provide guidance for report writing. Elements such as style, language and presentation also contribute to understanding and ease-of-use of the report, but fall outside the scope of this manual.

As the nature and requirements for effluent discharge investigations develop, these report guidelines could be modified to reflect such changes.

C.2 Focus of the report

The aim of the report should be to enable the decision-maker to make a waste load allocation decision. It is the responsibility of the discharger to provide sufficient information in a form that motivates the application. Key issues should be highlighted and distinguished from supporting information. The extent and detail of the information required in the report should be determined during the scoping of the investigation.

C.3 Summary of the report format

The following items should be included in a report:
- Cover page
- Executive summary
- Contents page
- Terms of reference
- Introduction
- Background information
- Details of the permit application and motivation
- Description of the process(es) producing the discharge
- Description of the area of investigation

- Water quality requirements
- Receiving water quality
- The effect of the discharge on the receiving water quality
- Monitoring systems design
- Information availability
- Conclusions and recommendations
- Definitions of technical terms
- References
- Personal communications
- Appendices.

C.4 Cover page

The cover page should provide relevant information about the discharger and the impact assessment:
- Type of application
- Name of concern
- Consultant(s) involved
- Address(es) and contact telephone and facsimile number(s)
- Report designation (draft/final) and reference
- Date of submission.

C.5 Executive summary

The executive summary should provide a brief but complete overview of the report, highlighting the main findings, key issues, conclusions and recommendations. It should provide executive managers with an insight into the key issues which have emerged from the investigation. This will enable them to evaluate the final waste load allocation decision.

C.6 Contents page

The contents page should show the main sections and sub-sections of the report and enable the reader to locate any topic of interest quickly.

C.7 Terms of reference

The exact requirements for the terms of reference will vary according to the discharge being assessed. This section should describe the conditions for consultants responsible for the investigation to carry out a sufficiently detailed study and address all the key issues.

C.8 Background information

The introduction should provide a background for the report, giving:
- The reason(s) the investigation has been undertaken
- A summary of the details of the proposed discharge, including any alternatives that are being investigated
- An outline of the report structure and content
- A brief description of the objectives of the investigation, and the approach adopted to meet those objectives.

C.9 Details of the permit application and motivation

This section should briefly outline the request that the discharger is making in respect of a proposed or existing discharge, together with the motivation for the discharge. This motivation should take cognisance of the DWAF policy. It could include items such as:

- Reasons for not meeting effluent discharge standards
- Consideration of precautionary measures and water reuse
- Economic justification for the discharge.

The application should include references to, and a summary of, previous applications and/or permits relating to the discharger. These could be both water usage and effluent discharge permits. If previous permits are required to be modified or extended, then the appropriate reasons must be clearly stated. Full details of all permits and previous applications should appear in the report appendices.

C.10 Description of the process(es) producing the discharge

This section should summarise information on the following:

- Raw materials used in the process
- Water-using processes, and their effect on water quality
- Water management procedures
- Sources of effluent
- Effluent treatment facilities
- Proposed, or actual, location and manner of discharge.

Details of the process, such as extensive analyses of raw materials, water circuit description, comprehensive water balance, and effluent discharge composition, should be included in the report appendices.

C.11 Description of the area of investigation

This section will contain background information on the catchment, so that the context of the investigation can be clearly seen. The following should be included:

- Description of the catchment in which the discharger is located
- Identification of the limits of the area of investigation (including the reasons for selection).

C.12 The effect of the discharge on the receiving water quality

C.12.1 Modelling

This section should provide details on how the impact(s) was modelled, with particular emphasis on the following:

- Description of scenarios modelled (flow conditions, upstream water quality, variables of interest)
- Model selection, description and implementation

- Summary of model results, with supporting details to included as report appendices.

C.12.2 Effect of the discharge

For each predicted effect, describe the following:

- The water users, or other affected parties
- The type and nature of the effect
- The significance of the effect (in terms of number and type of users affected, extent, duration, frequency, risk, etc.)
- The uncertainty involved in the prediction of the impact
- Any feasible mitigatory measures and their effects on reducing the impact.

C.13 Monitoring systems design

This section should provide information on the following:

- An outline of the design approach used
- A description of the proposed effluent compliance monitoring system, an
- A description of the proposed effluent discharge impact monitoring system.

C.14 Information availability

If information is incomplete or unavailable at the time of the investigation, this should be clearly stated, highlighting:

- Gaps in data records and information
- Implications of the above for the assessment process
- Recommendations for data collection programmes.

C.15 Conclusions and recommendations

This section should provide the decision maker with the following:

- A description of the key issues
- A summary of the anticipated impact(s) for each alternate option and the mitigatory actions associated with each
- Proposed loads in the discharge (variables, concentrations and associated flows)
- The risks and uncertainties associated with the proposed discharge
- A summary of the proposed monitoring programme(s)
- Any additional recommendations.

C.16 Definitions of technical terms

A glossary of terms relating to the investigation should be included as an appendix in the report.

C.17 References

All written material used in the development of the report, and as part of the effluent discharge investigation, should be fully listed (including any unpublished documentation).

C.18 Personal communications

In an effluent discharge investigation, verbal comments are often obtained from various interested and affected parties. These should be listed with name and date of communication. Full comments may be included in the appendices.

C.19 Appendices

Appendices should provide **support** for statements and conclusions appearing in the main body of the report, in order to ensure that the main report remains concise.

Appendices should also contain **background** documentation. The following are examples of appropriate contents of appendices:

- Copy of existing and, if appropriate, previous permit(s)
- Copy of the permit application
- Detailed model descriptions and model outputs
- Detailed calculations
- Full documentation of public meetings with users and user groups.

Examples of other documents that could be included are:

- Specialist reports
- Policy guidelines
- Locality maps
- Site maps and diagrams
- Glossary of terms relating to the investigation
- Any correspondence related to the investigation
- Details of personal communications
- Any legal documentation related to the investigation.

Any of the above documents could, if sufficiently large, be compiled as a separate document and referenced as such.

REFERENCES

Appendix C: Guidelines for Effluent Discharge Investigation Reports

Department of Environment Affairs, 1992. *The Integrated Environmental Management Procedure.* Documents 1 to 6, Pretoria, South Africa.

APPENDIX D:
Design of Permit-related Monitoring Systems

APPENDIX D: Design of Permit-related Monitoring Systems

D.1 Overview of the monitoring systems design process

Step 1: Identify information expectations

"Information expectations" refer to the manager's expectations of the results of the monitoring programme. The decisions which will be based on the information should be stated. The information users and the person(s) responsible for allocating the funds should contribute to discussions to determine these expectations. For permit-related monitoring, objectives are generally limited to:

- Determine compliance with permit conditions
- Estimate the impact of the discharge on the receiving water
- Audit the monitoring conducted by the dischargers themselves.

A complete statement of the objectives of the monitoring will provide a basis for an initial selection of variables for measurement. Subsequent steps in the design procedure rely on an accurate and precise understanding of the objectives for monitoring.

The product of this step is a statement of the objective of the monitoring programme. If more than one objective has been identified, the statement should also identify their priorities so that resource allocation can be optimised.

Step 2: Establish statistical design criteria

The information expectations identified for the monitoring programme should be stated as a **hypothesis** or as a **statistic** to be estimated, whichever is more appropriate. The statement of the hypothesis or statistics will help to identify the statistical procedures used.

A precise statement of the hypothesis is important, because there may be alternative statistical methods for testing the hypothesis. Hypothesis tests are associated with a significance level that specifies the probability that the hypothesis has been incorrectly rejected. Statistics, such as the median of observations, should be explicitly stated as well. Statistics are associated with a confidence interval. Confidence intervals are upper and lower limits that define an interval over which the "true value" of the statistic is contained with the specified confidence. Calculated estimates of statistics will often be compared with some constant value, e.g. the effluent standard or the receiving water quality objective, by the use of a hypothesis test.

The uncertainty in the results should be assessed relative to the amount of data collected. In general, increasing the number of samples will decrease the variance in the calculated statistic, however, monitoring is quite expensive. There is often a trade-off between cost and the desired precision for the statistic. A statement of the statistical criteria, including the desired precision in the form of significance levels or confidence interval widths, can improve decisions about the amount of data necessary.

The product of this step is a statement of the hypothesis to be tested or the parameter to be estimated. The significance level of the relevant test of the hypothesis or the acceptable confidence interval of the parameter should also be stated.

Step 3: Design of a monitoring network

The third step in the design of a water quality monitoring system consists of selecting the locations of sampling sites and determining the frequency of sampling.

The product of this step is a diagram, with accompanying text, that locates the sampling sites and a statement of the frequency of sampling for each variable at each site.

Step 4: Develop operating plans and procedures

The fourth step deals with the selection of sampling and laboratory procedures, storage and retrieval of the data, and data analysis procedures. Documentation of this step is essential to ensure that the plans and procedures are consistently maintained throughout the life of the monitoring programme. Only a consistent programme will provide the data necessary for determination of long-term changes in effluent quality or in its impact on receiving water.

The product of this step is a document that describes the sampling procedures and the analysis procedures to be used for each variable to be analysed and procedures for data storage, retrieval and analysis. Reference to standard methods can be used where they exist.

Step 5: Develop information reporting procedures

Information reporting procedures deal with the types, timing, and format of reports, distribution of the information and the evaluation of the monitoring system. Reporting is the step that ensures that the information developed in the sampling and analysis programme is transferred to water quality managers.

The product of this step is a document that describes the reporting formats, including the statistics to be reported, the time over which the data are to be analysed, the frequency of reports, and the person or office where the reports are to be submitted.

D.2 Effluent Compliance Monitoring

The DWAF's compliance monitoring policies and procedures are described in a DWAF document, the *Compliance Monitoring Manual* (DWAF, 1991), which is reviewed and revised regularly, to reflect the changes in the Department's policies. The stated objective of this document is to provide the participants in compliance monitoring activities with:

- An understanding of basic principles and their implementation
- Detailed guidance on procedures, responsibilities and time controls for compliance activities
- Explanations of the policies and procedures to answer questions asked by permit holders.

D.2.1 Identify information expectations

The most obvious use of permit-related water quality monitoring data is to produce information to determine whether or not a discharger complies with the terms of their permit. The information can be expected to provide decision support for that determination.

D.2.2 Establish statistical design criteria

The hypothesis most commonly associated with determining compliance is the one stated above, namely, some **statistic** (often the 95 percentile) of the measured concentrations is less than or equal to the effluent standard. The hypothesis test is to reject the hypothesis if the upper confidence limit of the calculated statistic is greater than the effluent standard.

The calculation procedure for the test is simply to determine the 95 percentile and its confidence limits. Percentiles are concentrations associated with a particular rank after all the observations have been ordered from lowest to highest. The 95 percentile is the concentration that has 95 % of the observations less than or equal to it.

Because percentiles are based only on the ranking of observations, not on the magnitudes themselves, the number of samples used to calculate percentiles is of critical importance. At least 20 observations are required to estimate a 95 percentile. In the case where only 20 observations are available, the 95 percentile would be equal to the largest observation.

Including confidence intervals in the hypothesis test complicates its calculation and increases the need for additional data collection. In the example used above, with 20 observations, the upper confidence limit could not be calculated. The DWAF has addressed this issue by developing the computer program, COMPLY, which uses the technique of repeated simulations of data sets similar to those observed. Statistics are calculated on the simulations to estimate upper confidence limits for a 95 percentile.

The COMPLY computer program does a coarse screening to compare the available data with the standard. If the standard requires the 95 percentile of a variable to be below a certain level, the program tests whether the whole confidence interval around the 95 percentile falls below the set standard level. If this is not the case, additional analysis is indicated and done by the Monte Carlo analysis method. The method does not assume any underlying distribution of the data and has the advantage that confidence intervals are calculated on the repeated simulations, so that fewer data points are needed. It should be noted that COMPLY could indicate that a violation has occurred, even if 95 % of the measured values fall below the standard. The reason for this is that the program repeatedly samples from the sample distribution of the observed data. The confidence intervals used for the comparison are based on calculation of 500 sets of 95 percentiles, rather than the single observed data set.

D.2.3 Design of a monitoring network

a. Location of monitoring points

No regulations specify a procedure to determine the location of compliance monitoring points. However, although rigid rules are not appropriate, the following guidelines should be used to select compliance monitoring points:

- The **quality** and **volume** at the monitoring point should be as representative as possible of the effluent that actually enters the water body.
- Compliance monitoring should be done at a point where the monitored stream consists **only** of the effluent of concern. It should not be diluted by any other stream, either natural or effluent.
- The location of compliance monitoring points should be determined in consultation with the effluent producer in such a way that :
  - It would be possible to get a satisfactory estimate of the actual volume of effluent being discharged
  - Sampling points would be accessible
  - Further improvement in effluent quality before the point entry into the water body would be taken into account. Vegetation or other natural effects could have a positive influence on effluent quality, and if such an effect is significant, it should be considered as "treatment" of the effluent. Note, however, that the dilution of the effluent by any natural or other effluent stream will not be considered as treatment.
- An exact description of the location of the compliance monitoring points, according to existing DWAF guidelines in the *Compliance Monitoring Manual* (DWAF, 1991), must be included in the permit conditions.

Flow gauging of sewage treatment works is often done at the intake with the assumption that the outflow of the works equals the inflow. However, there are losses due to sludge disposal, evaporation and/or infiltration (in the case of maturation ponds). These losses should be estimated and compared to the total volumes of raw sewage as well as the flow of the water body into which the effluent is discharged. These losses should be taken into account in an effluent discharge investigation.

During the term of a permit, the point of discharge may be moved, for example, due to maintenance work or other alterations. Also, in some cases, the final location may still be unknown at the time of issuing the permit, for example for investigations made during the proposal phase. The likely discharge points should all be described in the permit monitoring document together with the associated monitoring point for each. The discharger should then specify the location of the samples in the compliance monitoring report. If new monitoring points are added after a permit has been issued, the permit holder should use the existing guidelines to inform the DWAF of any changes in the location of monitoring points.

b. Monitoring variable selection

Two types of effluent variables affect the environment, namely water **quality** variables and water **quantity** variables. Both types are interrelated. The data on these variables should, therefore, be handled and stored to maintain the link between water quality and water quantity data that were taken on the same day, or within the same period of time.

- **Water quality variables**

  These can be physical, chemical or biological properties of the water. The *Compliance Monitoring Manual* (DWAF, 1991) describes some of the water quality variables that could be monitored and points out important considerations.

  It is impossible to monitor all variables that describe water quality, therefore, a limited number are chosen to be monitored. The variables of concern will be identified in accordance with the **Receiving Water Quality Objectives** approach, depending on the requirements of the recognised water users. The variables to be measured will be identified during the step to **determine information expectations**.

  The cost of sampling and analysis restricts the number of variables that can be monitored. It is possible to use a variable that is easier and quicker to measure, such as **electrical conductivity** or **turbidity** as an indication of characteristics that are more difficult to measure, such as the **total dissolved solids** or the **suspended solids** in a sample. Microbiological contamination is typically measured with **biological indicators species**, e.g. the number of *E. coli* is used as an indication of **faecal contamination** of water, although the organism is not likely to cause illness.

- **Water quantity variables**

  These are the variables that describe water quantity, e.g. **flow rates**.

c. Sampling frequency

A number of factors influence the choice of a sampling frequency, namely:

- The use that will be made of the information, for example, detect trends, monitor compliance, determine the source of pollution/toxicity, establish base line conditions, audit the monitoring programme of a discharger, determine the acceptability of permit conditions etc.
- The **statistical methods** used to analyse the data
- the **statistical characteristics** of the target water quality population
- **Economic and physical considerations** e.g. staff and equipment needed, the number of sampling sites and the ability of the laboratory to process the samples.

The number of samples taken should be enough to meet the stated information expectations. The minimum number of samples needed to meet the information expectations should be determined for each monitored variable. Some compromise is generally needed to incorporate the statistical requirements into a practical monitoring programme. The **information expectations** and the **statistical design criteria** will determine the **statistic(s)** that will be calculated from the data gathered during the monitoring programme.

Apart from economic and physical considerations, the **statistical methods** used to calculate the required **statistic**, and the **statistical characteristics** of the target water quality population, will determine the number of samples needed.

The **target population** is the complete entity that the **statistic** seeks to describe, for example, if the **target population** is the sodium concentration throughout a month, the **monthly mean** concentration is just an estimate of the "true" concentration for the month. The actual mean can never be established; it can only be estimated by sampling from the population - the more samples that are taken, the better the estimate that is obtained.

The **statistical characteristics** of the target population, such as the **underlying distribution** and the **variability**, determines when and how many samples should be taken. The variability and underlying distribution of the receiving water quality is usually determined from historical data, if available. This is necessary, because a multitude of unknown factors could have an effect on the receiving water quality and the only way to take these factors into account is by assuming that the characteristics observed in the past would be repeated in future.

Once the designer of the monitoring system has a knowledge of the **statistical characteristics** of the **receiving water quality population**, a sampling frequency can be calculated, taking these statistical characteristics into account, and using statistical methods.

The same principles apply for determining the sampling frequency of an **effluent compliance monitoring programme**. However, in this case, the variability would be largely attributable to human activities and would, therefore, be more predictable than in the case of monitoring the receiving water body.

The most important characteristics of effluent quality data to take into account when determining the sampling frequency are **cyclical variation** and **serial correlation** (see also Section D.6.2).

Cyclical variation in effluent can mainly be ascribed to human activities, and include **diurnal cycles and weekly cycles**. **Serial correlation** is the phenomenon observed when an individual data point repeats information contained in a previous data point. This happens when the sampling frequency is shorter than the effects created by the process being sampled. The nature of many effluent producing processes, where liquids move through buffer units, mixing takes place, etc., is to level out the effects of sudden changes in the effluent composition. If the sampling frequency is shorter than the residence time of effluent within the process, the individual data points are not independent of each other and a certain amount of **redundancy** is included.

Since the influence of diurnal and/or weekly cycles on effluent quality will be known, sampling should be scheduled in such a way that the data set will not be biased; e.g. by always sampling at a time when a certain batch process in a plant is off-line, the resulting data set could contain a low bias. If the permit conditions specify a maximum **95 percentile** concentration in an effluent, it will also not be accurate always to sample at a time when the concentration is higher than average. Therefore, one would normally wish to eliminate the effect that the diurnal and weekly cycle might have on the data, unless the very aim of a sampling programme is to detect these cycles.

To get a sample that is more representative in time, two procedures could be followed, depending on **economic considerations** and on the **information needs**:

- For a daily sample: sample at **regular** intervals during the day; for a weekly sample: sample at **regular** intervals during the week (at least twice within the period of a cycle). If the aim is to describe the cyclical variation, more than three samples within a cycle are needed.

- Specify that the sampling intervals should not be equal to 24 hours or 7 days, to ensure that sampling occur at different times of the day or on different days of the week.

It is important to determine what the consequences are of exceeding a limit as specified in the permit conditions. The time that such an exceedance would take to have serious consequences should be used as a guideline of how long the sampling intervals should be. Where effluent is accumulated in storage dams and discharged as one batch, the sampling schedule should obviously be co-ordinated with the batch cycles.

The probability that the underlying distribution of independent effluent quality data would be normal is good, but this should be verified (Section D.6.2).

D.3 Effluent Discharge Impact Monitoring

D.3.1 Identify information expectations

The impact of the discharge on the receiving water should be measured, together with compliance with the permit conditions. Information that can be expected from these monitoring programmes should allow a valid comparison against some stated hypothesis for the water quality in the receiving water. A common hypothesis will be stated as: the **upper** 95 % confidence limit of the 95 percentile of the measurements of variable **x** is less than or equal to the receiving water quality objective set at the point of measurement. Note that this hypothesis statement also contains criteria for parameter estimation.

Information developed from this monitoring can also be used to evaluate permit conditions. For those cases where the permit conditions were set with very little data, a relatively short-term programme should be begun to evaluate the effectiveness of the selected conditions. That is, the monitoring should determine whether or not the effluent, even if it meets the permit conditions, increases the concentrations in the receiving water beyond the objectives. The purpose of the evaluation, as well as the duration of the evaluation period should be stated in the monitoring system documentation. Sample collection and analysis demands are often higher for this evaluation than for simple compliance checking, so the programme should be carefully planned. Data analysis procedures, interpretation of results, and guidelines for subsequent decision-making should also be explicitly stated.

D.3.2 Establish statistical design criteria

Analysis of the impact of a point source on the receiving water will require a wider range of hypothesis tests and statistics calculations than compliance checking. Two relevant questions must be answered, namely:

- Does the discharge significantly change the receiving water quality (by comparing the upstream to the downstream water quality)
- If so, is the resultant water quality unacceptable in terms of the RWQO or other guideline values?

The hypothesis for the first question relates the water quality measured upstream of the discharge with that measured downstream. One might formulate a hypothesis that relates, say, the means of the observations at the two sites; however, the real issue is the point comparison of each observation. A relevant hypothesis can be stated as: The concentration measured downstream of the discharge is equal to the concentration measured upstream on the same day. An appropriate hypothesis test could be: Reject the hypothesis if the 95 % confidence interval for the mean of the differences, calculated over some time interval, does not include zero. That hypothesis can be tested with a number of procedures, including either the well-known one-sample **Student's t-test** that assumes an underlying normal distribution, or the distribution-free **signs** test that tests the randomness of the ordering of positive and negative differences between the two measurements. Those procedures are described in most introductory statistical texts, for example, *Introduction to the Theory of Statistics* (Mood *et al.*, 1974).

It may be unlikely that the effluent has zero effect on the receiving water, but that the allowable effect has been determined. In that case, the hypothesis test would not compare the differences to zero, but to the allowable effect. For example, if the effluent is expected to increase the electrical conductivity of the receiving water by 10 mS/m, the hypothesis test would be: Reject the hypothesis if the 95 % confidence interval for the mean of the differences, calculated over some time interval, does not include 10.

One must be aware of the difference between statistical significance and water quality significance. It is possible to detect a statistical significance between two sets of observations when the actual difference is insignificant in terms of the water uses. The second question listed above addresses that issue.

The hypothesis test for the second question is very similar to the one for compliance monitoring, namely, that **some statistic** (often the 95 percentile) of the measured concentrations is less than or equal to the receiving water quality objective. Calculation procedures are as described above.

D.3.3 Design of a monitoring network

To ensure that the standard set for the effluent water quality is sufficient to attain the management objective in the receiving water, the receiving water body will be sampled and analysed. The DWAF is responsible for the assessment of the receiving water quality on a catchment and national level (not described in this manual); the permit holder is responsible for monitoring to describe the local effects of their discharge on the receiving water, as stipulated in the conditions of the permit, to be used for assessing the impact of the discharge.

- **Location of the sampling sites**

The number of sampling sites depends on considerations of:
- The size of the target water quality population e.g. the target population is equal to the water quality of a reach in a river
- The variation in water quality within the target population.

Clearly, other factors - such as the financial implications of the number and location of sites - will have to be taken into consideration at some point. Nevertheless, the primary selection of the sites should be determined according to water quality requirements.

The **macrolocation** and **microlocation** of the sampling sites have to be determined (Sanders *et al.*, 1987, pp.101-104).

The **macrolocation** within a river basin is usually determined by political boundaries, areas of major pollution loads, population centres, etc. The reason for sampling a certain reach of a river would be established in the phase where **information expectations** are identified.

The **microlocation** is the specific point in that reach where the water will be sampled. The microlocation will be a function of the representativeness of the samples of the target water quality population . The target water quality population will have been identified by the information users in the information phase of the design of the water quality monitoring system.

- **Lateral variability**

Sampling should be done at a place downstream of complete mixing of the discharge. This can be determined by doing a simple **analysis of variance** on multiple samples taken at different points along the lateral transect.

This technique will show if the variability can be attributed to random variation alone or also to the lateral position of the sampling point. Incomplete mixing could be a reason for variability that cannot be ascribed to random effects. To sample only at one point where non-random variation occurs along the lateral transect would introduce a bias in the data used to describe the water quality of a whole population.

The technique involves determining whether a significant difference exists between two or more sets of sample data. This is done to compare sets of data collected under different circumstances to determine whether they can be considered to have equal means at a given level of significance. Sanders and Ward (1978, p.77) supply details on how the test is conducted. Most handbooks on statistical methods will also give detailed information on this technique.

In practise a river is often sampled close to the bank, because that is the most accessible point. It should be noted, though, that in many cases the assumption that the water quality at this point is representative of that along the lateral transect of the river is not valid. If a point can be located where complete mixing along the lateral transect has taken place, sampling could be done there. It is, however, not always possible to locate such a point; e.g., where the effect of a specific discharge in a water body is being monitored, the water may not mix completely before another discharge enters the water body. In such cases a possible course of action could be to sample at various points along the lateral transect. Depending on information needs, these samples can be analysed individually or mixed together to form one representative sample.

- **Longitudinal variability**

If a reach is sampled at only one longitudinal position, it is necessary to verify the representativeness of the water quality at that point. Longitudinal variability could be caused by other unidentified sources, e.g. diffuse sources, such as groundwater or surface run-off. Multiple samples at different longitudinal positions of the reach could be taken and the results analysed by means of a **one way analysis of variance** (see previous section on **lateral variability**), to determine whether variability exists that cannot be ascribed to random effects. If the test indicates significant variability due to the longitudinal location, more than one sampling point along the river reach would be needed to describe the water quality of the whole reach.

Depending on practical and/or cost considerations, it is not always possible to increase the number of sampling points along the reach to get a representation of the whole reach. In such cases, however, it is of the utmost importance to document the existence of variation along the reach in the water quality monitoring design report. The users of the information generated by the monitoring system should be aware:

- That the information contains a bias, due to the longitudinal location of the sampling point(s)
- In what direction the bias is
- What the possible magnitude of the bias is.

- **Monitoring variable selection**

The variables that are chosen to be monitored will be determined by the **information expectations** (Section D.5). These variables will depend on the characteristics of the effluent, as well as the **receiving water quality objectives**.

Due to the rapid increase of new compounds that find their way into the environment, it is not feasible to measure every possible variable. To detect long-term trends, an "indicator" type of measurement will be utilised, e.g. measuring total dissolved solids, dissolved oxygen or electrical conductance, to give a general indication of the water quality in a water body. Biological monitoring is also possible, but care should be taken in the selection of the type of biological monitoring in order to ensure that any potential impact is properly assessed.

The following procedure should be followed to decide whether a new variable should be added to an existing monitoring programme. **Figure 1** shows a flow chart for the procedure.

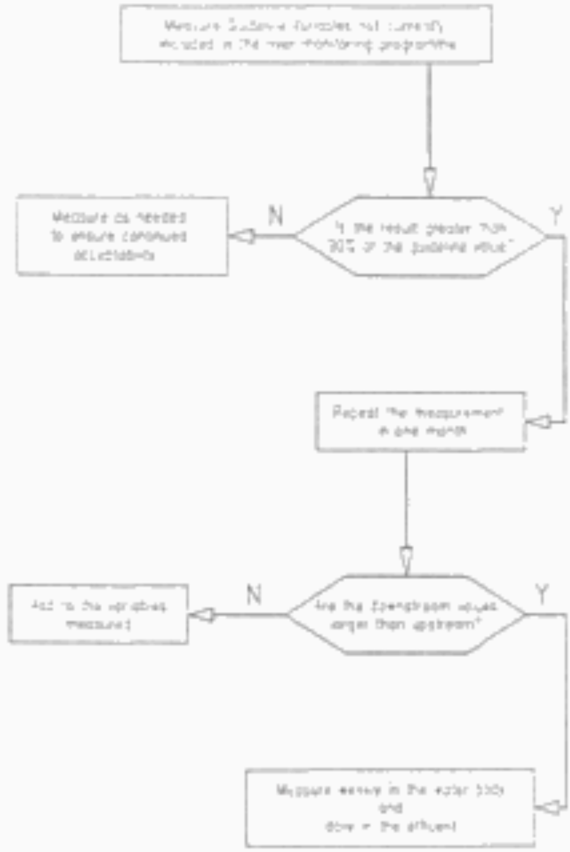

Figure 1 Determine the need to add new variables to existing monitoring programme

- Sample and analyse for suggested variables that are not part of the existing sampling and analysis programme - collect samples from the upstream as well as the downstream sampling points.

- For those results that are greater than 90 % of the guideline,
  - repeat the measurements again one month later.

- For the case where both the measurements are larger at the downstream point than at the upstream point by an amount that is large compared to the precision of the analysis, the discharge is likely to be the cause of the increase and the water body's fitness for use is likely to be impaired.

Add the variable to the routine weekly river analysis.

Add the variable to the routine daily effluent analysis.

- For the case where at least one of the measurements is larger at the upstream site than at the downstream site, the discharge is not likely to be a source of contamination, but the water body's fitness for use is likely to be impaired, it is suggested that the monitoring authority add the variable to its routine analysis.

Add the variable to the routine analysis conducted by the monitoring authority.

- For those results that are less than 90 % of the guideline, or less than the limit of detection for the variables with a guideline specified at the detection limit, fitness for use is not likely to be impaired (although bioaccumulation could lead to chronic effects), but monitoring should be continued on an infrequent basis, perhaps once or twice during months with low flow conditions (e.g. during March and August), to ensure that the quality is maintained.

Measure as needed to ensure continued acceptability.

- **Sampling frequency**

As with **effluent compliance monitoring** (Section D.2), the sampling frequency is a trade-off between the information expectations of the programme and economic and physical constraints. Therefore it is important to determine the minimum number of samples needed to obtain the expected information.

Some of the physical and economic constraints are the distance of sampling sites from the laboratory, the means of transport to the sampling sites, the number of sampling sites within the network, the ability of the laboratory to process the samples and the cost of the analyses.

D.4 Audit monitoring

D.4.1 Identify information expectations

Auditing consists of checking that the permit conditions have been met. In terms of the monitoring, it implies that DWAF collects samples from the same locations as the discharger, at approximately the same times, using the same sampling procedures, and measures the same variables. The information that can be expected from the audit monitoring should allow a comparison to be made between results of the discharger's monitoring and results of DWAF monitoring. Any substantial variation between the results should be investigated. The DWAF will submit reports with the results of the audit monitoring to the discharger.

D.4.2 Establish statistical design criteria

Audit monitoring seeks to compare the effluent and river samples collected by DWAF with the results submitted by the discharger. The purpose of the monitoring is to ensure the submitted results are sufficiently accurate. As described above for impact monitoring, the issue is to compare two measurements, rather than to compare a statistic for two sets of measurements. An appropriate hypothesis is, therefore, that the difference between the two measurements is equal to zero. The hypothesis test is to reject the hypothesis if the 95 % confidence interval for the mean of the differences, calculated over some time interval, does not include zero. Calculation procedures for the hypothesis test can include the **Student's t-test** or the **signs test**. A reference is given in the description of Effluent Discharge Impact Monitoring (see Section D.3).

D.4.3 Design of a monitoring network

- **Location of monitoring points**

Sampling should be done at the same location(s) as the discharger uses for the effluent compliance monitoring programme.

- **Monitoring variable selection**

The same variables as the ones monitored for effluent compliance should be monitored in the auditing programme.

- **Sampling frequency**

A sampling frequency of approximately once a month would be appropriate.

D.5 Identify information expectations

The information developed from water quality monitoring is used for many purposes, including describing how water quality changes over space or time or locating the major factors that affect water quality. However, information from water quality monitoring that is related to regulatory permits is limited to several well defined purposes. The objectives for permit monitoring are generally:

- To determine compliance with permit conditions, referred to below as compliance monitoring
- To estimate the impact of the discharge on the receiving water, referred to below as impact monitoring
- To audit the monitoring conducted by the dischargers themselves, referred to as audit monitoring.

A general description of overall water quality in the receiving water is not part of permit-related monitoring. On occasion, it might be possible to use data, collected in the receiving water as part of a permit-related monitoring programme, to evaluate trends in water quality variables. However, the primary objective of a discharger's monitoring should be to describe:

- The quality of the effluent discharged to the receiving water
- The effects of the specific discharge on the receiving water quality relative to the water quality management objectives.

Each of the objectives listed above for permit-related monitoring has different requirements in terms of the sampling frequency, the variables sampled, the location of the sampling sites, responsibility for sample collection, and data analysis. In order to provide efficient and effective data collection, each of the aspects of the monitoring programme must be designed to achieve the objective associated with the information expectations.

Specific information requirements for the three types of permit-related monitoring systems are described in Sections D.2, D.3 and D.4.

D.6 Establish statistical design criteria

The product of this step in the design process is a statement of the hypothesis to be tested or the statistic to be estimated during statistical analysis. A hypothesis, denoted as H_o, is an assertion about the distribution of one or more random variables. A test of a hypothesis is a rule or procedure for deciding whether to reject the hypothesis or not. A statistic is a function of the observed data only.

The median or the sample mean is an example of a statistic. Its calculation depends only on the observed data and not on knowledge of an underlying distribution or any of its parameters.

The random component of water quality measurements makes the use of statistical analysis necessary. If each measurement were absolutely accurate and no unaccountable fluctuation occurred, the measurements could be compared directly with the standard or objective. Any exceedance of the measured values could be immediately determined. However, the errors and natural variability in relation to the measured values, and the economic consequences of the decision, are large enough to make the use of statistics necessary.

Specific statistical design criteria for the three types of permit-related monitoring systems are described in Sections D.2, D.3 and D.4.

D.6.1 Statement of the hypothesis

The hypothesis will generally deal with the comparison of some statistic of the observed data, either in the effluent or in the receiving water, with a predetermined value, either the effluent standard or the receiving water quality objective. The design criteria include the hypothesis to be tested, and the significance level to be used in the hypothesis test.

An example of a hypothesis is the statement, "The 95 percentile of the underlying distribution is less than or equal to 25." A test of the hypothesis could be to reject the hypothesis if the upper 90 % confidence limit of the sample 95 percentile is less than 25.

The data analysis for permit compliance depends on the conditions set for the discharge.

A "probabilistic statement" of the allowable discharge conditions makes the hypothesis selection easier. An example of such a probabilistic statement is that the effluent (or receiving water) will be below x mg/ℓ at least 95 % of the time. Stating the permit in such terms will, in effect, determine the hypothesis test. Ideally, the significance level will also be stated.

The common alternative to a probabilistic statement of permit conditions is to simply state a concentration (or less commonly a mass) that is allowed to be discharged. That can be interpreted as the maximum allowable concentration; i.e., if the measurement is ever greater than the permit condition, a violation has occurred. This approach does not account for measurement errors (those that occur during the analytical procedures) or for sampling errors (those that occur during sample collection, storage, and transport).

D.6.2 Estimate of a statistic

The design criteria for estimation of a statistic include the value to be calculated, such as, for example, the mean, median, or 95 percentile and the confidence required.

The statistical criteria, including the hypothesis and statistics to be calculated, should be stated as part of the permit conditions.

If the information expectations require the establishment of some **statistic** (e.g. a mean or 95 percentile), the number of observations needed to estimate the statistic can be calculated as a function of the required **precision** and **confidence** in the statistic. It should be borne in mind that if, for instance, the annual mean of a variable is determined by sampling a population a number of times throughout the year, the calculated mean is only an estimate of the actual mean. The actual mean of a population is always unknown and can only be estimated with an accuracy that depends on the variability of the population and the frequency of sampling.

Since the statistic will be used to make important management decisions, it is important to decide on the precision and confidence in the estimated statistic before embarking on a monitoring programme. It should therefore be decided beforehand what **error** would be acceptable in the final results. By **error** is meant the difference between the **sample** and the **actual** statistic, such as the difference between the **sample** mean and the **true population** mean. It should also be decided what **confidence** is to be placed in the final result. If, for instance, the annual mean chloride concentration at a certain sampling point is to be determined, and it is decided that 1 mg/ℓ would be an acceptable error, the confidence level in the result should be 95 %, and the mean is calculated as **x** mg/ℓ, there would be a 95 % confidence that the actual mean would lie somewhere in the range of **x**-1 to **x**+1 mg/ℓ.

Different criteria could be used to determine the required **confidence level** and **acceptable error**, for example, the precision of the analytical method or the economic impact of an inaccurate estimate. Another consideration could be the need to keep the confidence level uniform for all the variables throughout the monitoring programme. One way to specify the acceptable error is to take it as one tenth of the imposed standard of a variable.

The 95 % confidence level is most widely used, the only reason being that it has become a statistical tradition to accept a 5 % level of uncertainty. The desirable level of confidence in a statistic should be a function of the seriousness of the consequences of not meeting a specified standard. Normally, the 95 % confidence level would be adequate, and is recommended to ensure uniformity.

Whatever criteria are used, both the **confidence level** and the **acceptable error** must be chosen with due regard to the purpose for which the statistic is required.

If enough historical data on the water quality population are available to enable the monitoring system designer to make assumptions regarding the **statistical characteristics** of the population, namely the **underlying distribution** and the **variance**, it is possible to use statistical formulae to relate the **sampling frequency** to the **confidence level** and the **acceptable error**, depending on what **statistic** is estimated by sampling the population. The most likely statistics that would be estimated are the **mean** and the **95 percentile**. In the case of the **95 percentile**, a higher sampling frequency is usually needed than for the **mean** to obtain the same **confidence level** and **acceptable error**, due to the larger uncertainty surrounding the data at the extreme limits of the population distribution. The use of an appropriate statistical software package could greatly simplify the analyses of historical data to determine required sampling frequencies.

Sanders and Ward (1978, p.157) supply information on how the required **sampling frequency** to estimate a mean can be calculated if estimates for the **population variance** and the **acceptable error** are available. Gilbert (1987, p.141) supply information on the number of samples needed to estimate a percentile. This method of determining the number of observations needed to establish a percentile results in very high frequencies.

The Monte Carlo analysis of data can overcome the problem of small data sets to a large extent and the calculated sampling frequency should only be used if it is necessary to determine a percentile value based on the observations alone.

To apply formulae to calculate the required **sampling frequency**, an initial estimate of the standard deviation should already be available. The use of these formulae therefore requires that historical data from the population that is to be sampled is available. In some cases, before a monitoring system is designed, much data will already have been collected from which an estimate of the standard deviation could be derived. If the population is the water quality throughout a whole year, and data for only one month were used to estimate the standard deviation, it should be borne in mind that the variability for the month in which the samples were collected might not be representative of the variability for the whole population, i.e. the water quality throughout the year. This might be the case if water quality samples were taken from a river during a period when the flow fluctuates less or more than it does on the average throughout a full year. This is a limitation which has to be accepted, but it emphasises the necessity of re-evaluating the performance and efficiency of the monitoring design as more data becomes available after the implementation of the system.

Another important consideration in the application of statistical formulae to calculate **sampling frequencies** is that these formulae usually assume that the data from samples are **normally distributed** and **independent**. Water quality data obtained from sampling water bodies are in many cases not normally distributed. To determine the **underlying distribution** of a population, the

Chi-Square Goodness-of-Fit Test or the **Kolmogorov-Smirnov Test** (Bowker and Lieberman, 1972) can be used if background data on the water quality variable population are available. The **Kolmogorov-Smirnov Test** is more powerful in the sense that the test is better able to reject the null hypothesis, (i.e. that the sample cumulative distribution function is the same as the hypothesised cumulative distribution), when it is false. These tests could be used as tools to verify whether the underlying distribution can be approximated by a normal distribution. Most of the non-normal variables encountered in the study of water and effluent can be **normalised** by using a transformation (Sanders and Ward, 1978, p.182).

The other assumption made is that the separate data points are independently distributed, i.e. in a time series an individual data point would not have any influence on the following data point. This assumption is very important, since it influences the estimate of the variance. It stands to reason that water quality data would not be independent, unless the interval between sampling events is very large. Two types of variability that cause data to be interdependent are **cyclical variation** and **serial correlation** (Sanders and Ward, 1978, p.182). Both influence the estimate of a population's variance.

Seasonal variation is normally the most significant predictable cyclical variation, and can be ascribed to meteorological factors. Other types of cyclical variation include **diurnal cycles**, which are normally due to the earth's rotation and **weekly cycles**, which are a result of human activities such as flow control from dams or discharge patterns.

Serial correlation is the phenomenon observed when an individual data point is influenced by a certain number of the preceding samples. Therefore the individual data points are not independent of each other and a certain amount of **redundancy** is inherent in such a data set. If the monitoring aim is to obtain a statistic such as the annual mean or 95 percentile, one would wish to choose a sampling frequency which would eliminate all redundancy.
The most accurate way to assess the variability of e.g. an annual mean, would be to subtract the time related cyclical component from the data and to take the effect of auto-correlation into account when calculating an estimate of the variance of a population.

If background data from a population are available, a visual inspection of a plotted time-series will usually indicate a strong cyclical component, provided that there are at least three data points within one cycle period. Steele (1974) and Sanders and Adrian (1978) suggest a commonly used seasonal model to describe the cyclical variation in a data set. The parameters of this model can be established for the model to best reflect the cyclical variation in a data set. The cyclical component can be removed by subtracting the identified cyclical contribution from each data point.

The establishing of the parameters of a model that describes cyclical variation is an involved process. A simpler procedure to identify and remove the cyclical contribution from a data set could be used, after it has been established that there is indeed a strong cyclical variation in the data set:

- Use an **analysis of variance** (Sanders *et al.*, 1987, p.77) to identify the months with means that are significantly different from each other

- Lump the months with means that are not significantly different together
- Calculate the means of the different seasons
- Subtract the means of the seasons (seasonal components) from the data values in the various seasons.

If the required number of samples, calculated by the method described by Sanders and Ward (1978, p.157) which assumes independence between data, results in a sampling interval so short that independence cannot be assumed, serial correlation must be taken into account. Sanders *et al.* (1987, p.184) describe methods to quantify serial correlation, using the simple Markov model. Loftis and Ward (1980) and Sanders (1974) presented more complex methods to quantify serial dependence structures for use in confidence interval estimates.

Serial correlation can be taken into account when calculating **a required sampling frequency** by using an adapted version of the formula that estimates the variance of a population (Loftis and Ward, 1980; Sanders *et al.*, 1987, p.185).

The **number of samples per year** can be determined as a function of other data analysis techniques as well (Sanders and Ward, 1978), e.g. if annual means were to be tested for significant differences between years, the number of samples to detect a given difference level can be determined;

Where more than one variable is concerned, as in most cases, different approaches can be followed to determine a desirable sampling frequency. The simplest of these would be to compute separate sampling frequencies for each of the variables and take the highest of the calculated frequencies. To increase the cost-efficiency of the monitoring programme, the variables requiring lower frequency sampling could possibly be sampled and/or analysed only on some of the occasions. Although this approach needs a little more planning, it will increase the efficiency of the monitoring programme without reducing the information that is gained from it.

All the approaches described so far resulted in the setting of fixed frequencies (**fixed frequency** sampling). This approach is preferable if the **information expectation** is to develop a representative estimate of a statistic, such as the mean or a percentile. It would be unfair to sample more when higher concentrations are expected. This method is called **exceedance driven sampling**. This is an appropriate sampling technique if the aim is to detect as much as possible violations of an absolute standard, if a permit stipulates a limit which should never be exceeded (Valiela and Whitfield, 1989).

Another deviation from fixed frequency sampling is **flow-stratified** sampling. If the aim of a monitoring programme is to estimate loads in a water body that are expected to be higher at high flow rates, e.g. loads that result from surface run-off, it would be sensible to concentrate sampling during the high flow events (Richards and Holloway, 1987).

Documentation of the logic used in relating the sampling frequency to the information to be produced is crucial, regardless of how the decision to sample at a specific frequency was arrived at. The design of the monitoring system should be recorded according to standard guidelines supplied by DWAF.

D.7 Design of a monitoring network

The design of a monitoring network is a part of the process to set up a total water quality monitoring system. This is the third step in the design of a water quality monitoring system. The design of a network consists of three elements, namely:

- The location of the sampling sites
- The selection of monitoring variables
- The sampling frequency.

The monitoring data collected during an effluent discharge evaluation will generally be quite different from the data required for permit-related monitoring; however, the information gained about the statistical characteristics of the effluent and the receiving water can be used to estimate sampling frequencies and locate sampling sites.

The site-specific nature of water quality monitoring requires that local characteristics of the discharge and the receiving water be evaluated to determine the appropriate design conditions. Obviously, if one of the issues in determining the permit conditions is the site of the effluent discharge point, the sampling site location for the receiving water can be selected only after final decisions have been made.

Specific details of these elements as applied to the three types of permit-related monitoring systems are described in Sections D.2, D.3 and D.4.

D.8 Develop operating plans and procedures

A critical aspect of a monitoring system is its day-to-day operation. It is here that the routine work is done and even the most carefully designed monitoring network will be worthless if raw data are not gathered, recorded and analysed in a controlled, systematic and, most importantly, well documented manner.

While the impact assessment may not produce comprehensive documentation for the operating plans and procedures, it should nonetheless address, or outline plans for addressing, the important aspects outlined below.

The issues associated with the development of operating plans and procedures that are described below are applicable to *all* permit-related monitoring systems.

D.8.1 Sampling procedures

The objective of sampling is to obtain samples that accurately represent the water body or effluent being sampled.

Inconsistency in sampling procedures - over time and space - is likely to be one of the most problematic parts of a monitoring system. It is only through thorough training and careful documentation that consistency can be achieved.

A number of items need to be addressed in this area:

- Sample collection routes

  Sample collection routes need to be planned to ensure they are as efficient as possible in terms of time and distances covered.

- **Sample taking procedures**

  Sample taking procedures should be done consistently; using the same type of equipment and sampling only at the exact places specified in the monitoring network.

  In the case of some variables, field recordings might be needed to determine values. In these cases care must be taken to ensure consistency of results. Equipment needs to be calibrated and serviced regularly. If new equipment is used, this should be documented in the sampling log (see below).

- **Sample preservation methods**

  Both physical (e.g. cold storage) and chemical (e.g. mercuric chloride) sample preservation methods can be used, depending on the water quality variable that is to be analysed.

  It is important that preservation is done consistently to give reproducible results. Procedures should be established for disposal of chemical preservatives.

- **Transport of samples to the laboratory**

  In most cases it is important that samples are delivered timeously to laboratories for analysis.

- **Labelling of samples**

  Samples should be clearly marked with date, time and sampling site, together with any additional information that may be required by the laboratory. Markings should be made in such a way that they cannot accidentally be erased. If possible, standard labels should be used.

- **Sampling logs**

  The use of sampling logs to record much of the above information is essential to keep track of changes to, and problems with, the regular operation of the sampling programme.

  Sampling logs should be used to keep track of:
  - Personnel involved in sampling
  - Date, time and location of samples
  - Delivery to laboratory
  - Any unusual occurrences e.g. weather at the time of sampling

- Deviation from expected routines e.g. lack of access to a regular sampling site.

Sampling logs should be filed and easily accessible by both sampling staff and those responsible for supervising the monitoring programme.

Sampling logs should be reviewed on a regular basis - quarterly or annually, depending on the scale of the sampling programme - to determine if continual problems necessitate changes to the sample programme.

- **Equipment requirements**

  A full equipment inventory should be established, and this must be linked to an equipment service and replacement programme. Calibration of equipment for field measurements is especially important. Where possible, duplicate equipment needs to be available to field staff so that measurement of critical data is not hindered.

- **Staff requirements**

  Correctly trained staff that can carry out the required sampling routines is a critical component of this operational area. Change-over in staff has the potential to disrupt a sampling programme. Ideally, new staff should be trained by the current incumbents *before* they leave. Where this is not possible, good documentation on all aspects of the sampling programme should be available so that new staff can take over and operate the system as before.

D.8.2 Laboratory procedures

Selection of an appropriate laboratory to analyse the water quality samples should be done in conjunction with the permit holder and the DWAF. A number of important aspects need to be considered in this selection:

- **Available facilities, equipment and staff**

  The laboratory in question should have access to all the equipment that is required to perform the necessary analyses.

  Laboratory staff should be competently trained and hold appropriate qualifications.

- **Analysis methods**

  Selection of appropriate analysis methods is very important if consistent results are to be obtained. For any given water quality variable, there can be a number of analytic methods employed to measure it. Some methods are more widely used and exact procedures have been set out for these; the *Standard Methods* handbook (APHA, 1989) contains many of these. The SABS has also published standard methods.

If a laboratory adopts other analysis methods, then there should be agreement between DWAF and the permit holder on the use of those methods.

Any change in analytical procedures or analysis methods should be clearly documented as this could lead to changes in water quality measurements and statistics which are *not* the result of actual changes in water quality.

- **Laboratory quality control**

  Those involved in the selection of the laboratory should be satisfied that the laboratory managers have a comprehensive quality control programme in place, and that this is regularly audited to ensure that it is consistent and up-to-date. This is an important subject in its own right and cannot be fully addressed here. Taylor and Stanley (1985) have gathered a number of papers on this topic.

It is likely that larger organisations will have access to their own laboratories and will prefer to use these for the cost and time benefits that they offer. All the above selection criteria apply equally to such laboratories, but there are also additional criteria or problems that should be considered in these cases.

- **Staff and equipment "overloading"**

  The primary role of most staff in the in-house laboratories of large organisations is analysis for internal operations. Often, the institution of a new monitoring programme will result in additional work for equipment and staff already operating close to maximum capacity. In this case provision must be made to obtain the additional staff and/or equipment that will be needed.

  An example of a problem that can cause complications for quality control is that samples taken from different monitoring points - plant operations, effluent discharge, river sites - can have considerably different concentrations. Depending on the analysis methods employed, this may cause problems in the detection of very low or very high values.

- **Consistency of results**

  In-house laboratories, because of problems such as overloading, may occasionally give samples to outside laboratories for analysis. These problems can also occur with commercial laboratories. These occurrences should be carefully documented as different analysis methods may give different results. If there are doubts about consistency or reproducibility of results, auditing samples can be taken simultaneously by different parties and sent to different laboratories for independent analysis.

D.8.3 Data handling and analysis systems

The end result of the operational step of the monitoring programme is the production of data. This can become the end point of the monitoring system itself if the data are not easily accessible, or its existence is not known, or the data are stored in an ambiguous fashion. Thus there is a need for carefully designed data handling and analysis systems to overcome these and other problems.

Ward *et al.* (1990) identify two fundamental parts of data handling systems: laboratory and field data systems, and general purpose water quality data archive systems. Current monitoring systems, which can generate much data require computerised data base systems for data storage and analysis.

- **Laboratory and field data systems**

  It is often the case that permit holders have laboratory and field data systems in place. These systems are usually quite specialised and should not be made a part of a more general system. However, an easy-to-use interface to extract data for use in a general purpose system does need to be established.

- **General purpose water quality data archive system**

  These systems are usually operated by government departments; the DWAF runs a database system known as POLMON (POLlution MONitoring) which has been used in the past to store data on effluent dischargers and water users. It is in the process of being upgraded to store a wider range of water quality data, and to interface with other new systems that are being developed, e.g. Geographical Information Systems (GIS).

In any systems that are used, attention needs to be given to the following:
- Checks that data are being entered regularly
- Checks on the accuracy of the data that is entered
- How non-detects are stored.

Data analysis systems are used to present data graphically or analyse data statistically. These results should be in a form that can be linked to reports. A number of commercially available packages exist for both desktop and mainframe computing environments. The more sophisticated ones will be able to carry out all the various tests required for analysing water quality. It may be possible to link the analysis routines or packages to the data storage system.

The DWAF analyses compliance monitoring data using a specially developed software package called COMPLY (CSIR, 1994). The program uses both simple screening and Monte Carlo analysis to determine compliance of an effluent with a level set in the permit conditions (see Section D.2.3).

D.8.4 Integrated sampling programmes

In general the policy of the DWAF that the "polluter pays" means that the permit holder will be responsible for implementing the monitoring programme acceptable to the DWAF. In some situations, duplicate samples might be taken by both parties, on occasion, for verification or auditing purposes. The DWAF will only carry out river sampling where no one specific industry is causing an impact.

In those situations where samples are taken by different parties, it is even more critical that all involved understand, agree on and document the operational procedures involved.

Certain issues e.g. whether or not to select a common laboratory or how and where data will be stored, might assume more importance and decisions on this matters should be clearly documented.

D.9 Develop information reporting procedures

The objective of a monitoring system should *not* be to collect data; it should rather be to produce *information* that will meet the information expectations. Reporting is the link between those operating the system and the decision makers who use the information. Regular communication via reports ensures that the results are made known and allows those responsible for the system to evaluate its performance. Reporting procedures and formats should be documented. Thus, resources need to be allocated to develop and maintain the reporting function.

The issues associated with reporting that are described below are applicable to *all* permit-related monitoring systems.

D.9.1 Types, timing and distribution of report

Reports can, and should, be produced for a number of information users. Questions that should be answered when developing different types of reports are:

- **Who are the *information users*?**

  Information users are those individuals, or concerns, that need to use information to make decisions, evaluations or recommendations. It is important that reports are not just produced for those involved in the immediate operation of the system, but also for those who can be affected by the information produced.

  In the case of a discharger responsible for monitoring an effluent and/or a water body, information users might be:

  - Those within the concern who operate the system;
  - Senior technical personnel e.g. plant chemist or environmental officer;
  - Top management e.g. general manager;
  - DWAF personnel e.g. pollution control officer

- **What are the *information expectations* of the users?**

  The information expectations of the users should be linked to one or more of the *objectives* of the monitoring system.

For example:

- A senior manager may want to know if the effluent is meeting the standard set by the DWAF.
- A pollution control officer may want to know if all the required samples have been taken.

- **What is the *extent of the information* needed?**

  Generally, the higher the user is in the decision-making hierarchy, the more condensed the information should be. In this regard, reports with an emphasis on graphical presentation should be considered.

Reports should be produced on a regular basis. Ad hoc or special reports might be required from time to time, but the emphasis in the design of the monitoring system should be on timeous supply of standardised information to the users.

The exact timing of the reports will depend, to a large extent, on the site-specific conditions e.g. if a discharge contains substances which are likely to have an immediate impact should levels increase, then more frequent reporting would be required. The timing of reports should also be linked to the sampling frequency; a widely spaced sampling frequency would necessitate less frequent reports.

The minimum interval between reports should be one year; in those cases where the situation is expected to change more rapidly, quarterly or monthly reports will be more appropriate.

Automation of reports, through standard computer printouts, will greatly reduce the time and effort needed. Automation is usually the best way to produce regular reports, especially those that are required more frequently. Automation will help ensure both that reports are distributed to the correct people, and that the information is presented in a consistent manner.

D.9.2 Reporting formats

Ward *et al.* (1990) point out the lack of agreement on the use of appropriate reporting formats within the water quality monitoring community i.e. there is a lack of standardisation in reporting formats. However, the exact reporting layout is not as critical as ensuring that all the required information has been presented.

It is unusual for a report to present pages of the original raw data; instead, summary statistics are used. Summary statistics can either be presented in tabular or graphical format. Accompanying explanatory text might also be appropriate e.g. to highlight a non-routine change in the sampling programme.

A sample tabular report, showing how one particular set of statistical information could be presented for a number of monitoring points, is presented in **Table 1**. In each column there is a description of the type of information it would contain. Again, the decision as to which information should be presented is dependant on the *information expectations* of the user of the report.

Table 1 Sample tabular report for multiple monitoring points

		Medians			
Monitoring Point	Dates From-To	Segment	Quarters 1 2 3 4	Annual (Yr)	Proportion Exceedances
The monitoring point identity number and/or description	*The start and end dates of the most recent monitoring period i.e. segment*	*A period of monitoring defined by the start/ end dates*	*The median values for each of the most recent quarters*	*The median for the year to date*	*The number of times the observations exceeded the standard, as a proportion of the total observations*

Another sample tabular report, showing how different sets of statistical information could be presented for a single monitoring point, is presented in **Table 2**.

Table 2 Sample tabular report for a single monitoring point

Monitoring Point:____________________

Monitoring Period from: _/_/_ to: _/_/_

Variable	Standard*	Maximum	95 percentile	Median	Minimum

Note: * as specified in Permit No: ____

A sample graphical report, showing how information similar to that presented in **Table 2**, could be alternatively depicted, is shown in **Figure 2**.

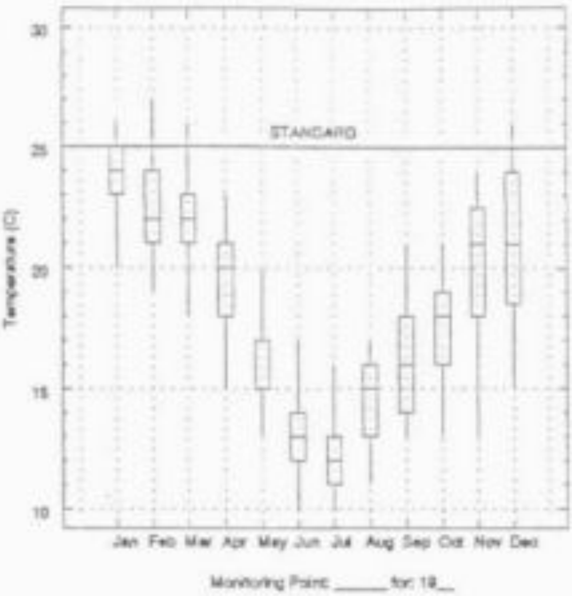

Figure 2 Sample graphical report : Box-and-whisker plot

D.9.3 Monitoring programme evaluation

Evaluation of the monitoring programme is necessary both to determine if the system is producing information to meet the *design goals* and to determine if changes in the system are needed to meet changing *information expectations*.

The most obvious way to test if the system is producing the correct information is to survey the users using either formal questionnaires or informal discussions. For example: the sampling personnel could be interviewed to re-evaluate the initial choice of sampling sites. "Fine tuning" could be undertaken to identify the best place to take samples.

Expansion of the monitoring system, with time, is quite likely. *However, no ad hoc changes should be made.* All changes should follow a set procedure and be properly documented. Changes should be justified and approved by all parties concerned; the discharger and the DWAF should be involved in this process.

Consistent operation of the monitoring system over time is critical to obtaining comparable data and information. Where operational changes or other ad hoc changes occur e.g. staff changeovers, new sampling equipment, different analytical laboratory, etc. the water quality data should be evaluated to see if these changes result in an apparent "change" in water quality.

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APPENDIX E:
Additional Literature

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APPENDIX F:
Information on Models

APPENDIX F: Information on Models

A list of locally used water quality and hydrological models is given below. This list is followed by a number of tables containing more detail on each listed model. The tables are followed by a list with addresses of the developers, vendors and local sources of information mentioned in the tables. All information was collected up to the end of 1993, and may have subsequently changed.

Models have been classified broadly according to their main characteristics. However, in many instances a model contains elements of two or more classes.

Summary list of available water quality and hydrological models

I. WATER QUALITY MODELLING

I.A. Streams/Reservoirs

(i) BETTER: Assesses the effects of management options on reservoir water quality
(ii) CE-QUAL-W2: Dynamic, One-dimensional water quality model for unsteady flows in rivers, streams, reservoirs and estuaries
(iii) Dissolved Oxygen Model: Expert Advisor. Gives guidance on using the Streeter-Phelps equation
(iv) DYNTOX (Dynamic Toxicity Model)
(v) DYRESM: Hydro-dynamic, one-dimensional reservoir model
(vi) Estuarine systems model: Simulates the response of the estuary (in terms of physical dynamics and water quality and ecological indices) to different management policies
(vii) EXAMS II (Exposure Analysis Modelling System)
(viii) EXPMOD1 and EXPVAR1: Models effects of conservative effluent discharge from a single point
(ix) FLUX 4.2 (Stream load computation model)
(x) HSP (Hydrocomp Simulation Program): One-dimensional water quality and flow simulation program
(xi) IMPAQ: Monthly time-step water quality model. Catchment export and reservoir simulation
(xii) MIKE 11: River Modelling Package
(xiii) MIKE 21: Modelling system for two-dimensional free surface flows
(xiv) MINLAKE: A dynamic one-dimensional water quality model for lakes and reservoirs
(xv) NACL02: Dynamic deterministic daily tributary routing model
(xvi) NACLM2: Monthly single reservoir model
(xvii) One-dimensional hydrodynamic and transport dispersion estuary model
(xviii) QUAL2E and QUAL2EU (Stream Water Quality Models)
(xix) REMDSS (Reservoir Eutrophication Model Decision Support System)
(xx) SAW (Spill Analysis Workstation): Spill Analysis Workstation for the simulation of oil spills and spills of dangerous chemicals into the aquatic environment
(xxi) SEDIMENT: Instream sediment transport model
(xxii) SERATRA (Instream sediment-contaminant transport model)
(xxiii) SIMCAT (Water quality model for river systems)
(xxiv) WASP5.01 (Water Quality Analysis Simulation Program Modeling System)
(xxv) WRPM: Water Resource Planning Model

I.B. Surface Runoff

(i) ACRU-HSPF LINK (Includes the ACRU and HSPF programmes, with integration routines): Surface runoff water quality model
(ii) CREAMS (Chemical, Runoff and Erosion from Agricultural Management Systems model)
(iii) DISA (Daily Irrigation and Salinity Analysis model)
(iv) FLOSAL: Conceptual model for water and salt balances and flows in an irrigated catchment
(v) HSPF (Hydrological Simulation Program Fortran)
(vi) NACL01: Determinstic daily rainfall-runoff simulation and conservative pollutant balance
(vii) NACLM1: Monthly model for catchment conservative pollutant balance
(viii) PEXPM (Phosphate Export Model): Daily time-step, semi-distributed phosphate export model
(ix) WQT: Deterministic monthly system hydro-salinity simulation model

I.C. Groundwater

(i) BURNS (Model for estimating the downward leaching of salts through soil)
(ii) HELP: Hydrologic Evaluation of Landfill Performance
(iii) LEACHM: Leaching Estimation and Chemistry Model
(iv) SUTRA (Saturated-Unsaturated Transport): Finite element simulation model for saturated-unsaturated fluid-density dependent groundwater flow
(v) TETrans: Trace Element Transport Model

I.D. Equilibrium models

(i) JESS (Joint Expert Speciation System)
(ii) MINTEQA2: An equilibrium chemical speciation model for metals for aqueous systems

II. HYDROLOGICAL MODELLING

II.A. Surface water

(i) DETFLOOD (Deterministic hydrological model): Determination of the flood magnitude/frequency relationship
(ii) DISTRAIN/DROUGHT: Analysis of district rainfall records (93 districts)
(iii) Drought Durations Simulation Model
(iv) FLOODCAT: Catalogue of historical floods in South Africa
(v) FLOODWATCH: (Flood warning system)
(vi) GENRAIN (Rainfall sequence generation model)
(vii) LITPACK: Integrated modelling system for littoral processes and coastline kinetics
(viii) Multiple Reservoir Simulation Program

(ix) OPRULES and ECONYLD: Models to help optimise water resource development

(x) REGFLOOD (Regional flood analyses model): Determination of the flood magnitude / frequency relationship

(xi) Riparian zone management model: Expert system

(xii) SHELL (Suite of models, incorporates Monthly Pitman Model and RESSIM): Utility which facilitates the simulation of surface runoff for various land-use scenarios, as well as reservoir simulation

(xiii) WRSM90 (Water Resources Simulation Model): Latest version of the Pitman Model

(xiv) WRYM: Water Resource Yield Model

II.B. Groundwater

(i) ACRU (Agricultural Catchments Research Unit agrohydrological modelling system): Soil moisture budgeting and hydrological systems model

(ii) FLAM (Forest Land Allocation and Management Model)

(iii) Forest evaporation and interception models

(iv) WREVAP (Evaporation Estimating Model)

II.C. Integrated surface and groundwater models

(i) MIKE-SHE: Distributed, physically based, hydrological modelling system

(ii) TOPOG: A physically based, deterministic, distributed parameter, catchment model

(iii) Variable Time Interval Model: A variable time interval, semi-distributed model of catchment hydrology

Detailed descriptions of listed models

NOTE: An address list of developers, vendors and local sources of information mentioned in the tables is supplied on page 311.

I. Water quality modelling

I.A. Streams/Reservoirs

Table (i): **BETTER** (Drewes, 1992)

Name of Model	Description	Input
BETTER	Assesses the effects of management options on reservoir water quality.	Meteorological data and reservoir parameters.
Output	**Use of Output**	**Databases accessed**
Plots showing variation in water quality with depth and distance from dam wall.	To assess which outlets to use to optimise reservoir and outlet water quality.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
Tennessee Valley Authority	Public domain software. No charge.	J Pretorius, JN. Rossouw WATERTEK (Pretoria)

Table (ii): CE-QUAL-W2 (Weddepohl, 1990)

Name of Model	Description	Input
CE-QUAL-W2	Dynamic, one-dimensional water quality model for unsteady flows in rivers, streams, reservoirs and estuaries*. Hydrodynamic and water quality components. *Model has not been applied locally for estuarine simulation.	Hydrodynamic component: river grid information, constant quantification, initial conditions and boundary conditions, river cross-sectional data. Water quality component: output from the hydrodynamic component, various rate coefficients for chemical reactions, location, concentrations and flows of effluent inputs Meteorological data
Output	**Use of Output**	**Databases accessed**
Solution to the non-linear St. Venant equation, temperature, DO, CBOD, organic N, ammonia N, nitrate N, ortho-phosphate P, coliform bacteria and dissolved iron, and the effects of algae and sediments.	For the simulation of branched river systems with multiple hydraulic control structures and reservoirs. The model simulates the transient water quality conditions associated with highly unsteady flows that can occur on regulated streams.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
US Army Engineer Waterways Experiment Station	Unknown.	Dr AJ Bath Ninham Shand, Pretoria

Table (iii): Dissolved Oxygen Model: Expert Advisor (Hohls, pers. comm., 1993; Pauer and Kelly, 1990; Pauer and Kelly, 1991)

Name of Model	Description	Input
Dissolved Oxygen Model: Expert Advisor.	Gives guidance on using the Streeter-Phelps equation; estimates parameters and variables for the equation; performs sensitivity analyses on parameters.	COD, BOD (biochemical oxygen demand) in effluent, toxicity, river and effluent flows and river width, depth, velocity and length.
Output	**Use of Output**	**Databases accessed**
Advises on the suitability of Streeter-Phelps model for use in a particular application.	Output used as input into the Streeter-Phelps Dissolved Oxygen equation.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
WATERTEK (Pretoria)	Not for sale; used in research and contract work.	Derek Hohls WATERTEK (Pretoria)

Table (iv): DYNTOX (Dynamic Toxicity Model) (Ambrose and Barnwell, 1989)

Name of Model	Description	Input
DYNTOX (Dynamic Toxicity Model).	A waste load allocation computer program that uses probabilistic dilution techniques to estimate concentrations of toxic substances or fractions of whole effluent toxicity.	Flow and concentration information for the stream and waste source. Continuous simulation requires continuous daily records. The Monte Carlo method requires mean, variance and lag-one correlation for the 4 inputs. A log-normal analysis requires mean, variance and log-normal distribution for the 4 inputs. A toxicity measure is required for evaluation of the output.
Output	**Use of Output**	**Databases accessed**
Continuous, Monte Carlo and Log-normal simulations. Frequency and duration of daily average contaminant concentration in the receiving water body.	Analysis (based on probabilities) of the frequency and duration of toxic concentrations from a waste discharge.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
CEAM	Public domain software. No charge.	No known local contact.

Table (v): DYRESM (Bath, pers. comm., 1993)

Name of Model	Description	Input
DYRESM	Hydro-dynamic, one-dimensional reservoir model Uses Lagrangian numerical scheme	Salinity, temperature, hydrological data, meteorological data
Output	**Use of Output**	**Databases accessed**
Temperature and salinity profile	Used for stratification studies (e.g. for bubble plume aeration)	None
Developer / Vendor	**Price**	**Local source(s) of information**
University of Western Australia, Perth	Unknown	Dr AHM Görgens Ninham Shand, Cape Town

Table (vi): Estuarine systems model (Drewes, 1992)

Name of Model	Description	Input
Estuarine systems model.	Simulates the response of the estuary (in terms of physical dynamics and water quality and ecological indices) to different management policies (e.g. flood releases, mouth breaching).	Approximately 40 input parameters, including: inflow, tidal range, catchment area, salt flux through the mouth, height of the sill at the mouth and estuary bathometry.
Output	**Use of Output**	**Databases accessed**
Time dependent graphs of : water volume, salinity, stratification, mouth condition, etc. Values for indices of water quality and ecology. Management policy rating.	For evaluation of management policies for estuaries and in understanding why certain estuaries function as they do.	Some SADCO information, EMATEK database
Developer / Vendor	**Price**	**Local source(s) of information**
EMATEK (Stellenbosch)	Not for sale; used in research and contract work.	J Slinger EMATEK (Stellenbosch)

Table (vii): EXAMS II (Exposure Analysis Modelling System) (Weddepohl and Stasikowski, 1990)

Name of Model	Description	Input
EXAMS II (Exposure Analysis Modelling System)	Interactive modelling system that allows the user to specify and store properties of chemicals and ecosystems, modify via simple commands and conduct rapid investigations and error analyses of the transport and probable aquatic fate of synthetic organic chemicals.	Chemical loadings on each sector of the ecosystem, molecular weight, solubility, ionisation constants of the compound, sediment sorption, biosorption, biotransformation, photolysis, hydrolysis, oxidation, volatisation, system geometry and hydrology, direction and strength of dispersive and advective transport paths.
Output	**Use of Output**	**Databases accessed**
20 tables summarising input data and predictions of chemical exposure, fate and persistence. Exposure summary includes expected temporal environmental concentrations due to user specified pattern of chemical loadings. Fate summary gives distribution of chemical in the system and the relative dominance of each transport and transformation process. Printer plots of longitudinal and vertical concentration profiles. Time-based graphics.	Used to investigate and analyse the transport, transformation and probable aquatic fate of synthetic organic chemicals in freshwater bodies.	Entry of extensive data derived from limnological literature or field surveys allowed. Program can be run with a much reduced data set when the chemistry of a compound of interest precludes some of the transformation processes.
Developer / Vendor	**Price**	**Local source(s) of information**
CEAM	Public domain software. No charge.	J Pretorius WATERTEK (Pretoria)

Table (viii): EXPMOD1 and EXPVAR1 (Weddepohl and Stasikowski, 1990)

Name of Model	Description	Input
EXPMOD1 and EXPVAR1	Deterministic models.	Pollutant concentration or effluent flow rate could be constant or variable, depending on the model chosen.
Output	**Use of Output**	**Databases accessed**
Plots of pollutant concentration versus distance downstream of the discharge point.	Models effects of conservative effluent discharge from a single point.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
WATERTEK (Pretoria)	Not for sale; used in research and contract work.	JN. Rossouw WATERTEK (Pretoria)

Table (ix): **FLUX 4.2 (Stream load computation model)** (Rossouw, N, pers. comm., 1993).

Name of Model	Description	Input
FLUX 4.2 (Stream load computation model)	Stream Load Computation Program. Estimates the loadings of nutrients passing a sampling station.	Flow, paired flow and water quality data.
Output	**Use of Output**	**Databases accessed**
Load time series.	Estimates loadings of nutrients or other water quality components passing a river sampling station over a given period of time.	Department of Water Affairs and Forestry - hydrological and water quality databases.
Developer / Vendor	**Price**	**Local source(s) of information**
Developer: Dr. WW Walker. Vendor: North American Lake Management Society.	US$40	JN. Rossouw WATERTEK (Pretoria) and G Quibell DWAF

Table (x): HSP (Hydrocomp Simulation Program) (Weddepohl and Stasikowski, 1990)

Name of Model	Description	Input
HSP (Hydrocomp Simulation Program)	One-dimensional water quality and flow simulation program	One-dimensional flow and water quality equations.
Output	**Use of Output**	**Databases accessed**
The receiving water module can simulate seventeen parameters with one-dimensional flow and water quality equations.	To simulate one-dimensional flow and water quality.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
CEAM	Public domain software. No charge.	No known local contact.

Table (xi): IMPAQ (Bath, pers. comm., 1993)

Name of Model	Description	Input
IMPAQ	Monthly time step water quality model. Catchment export and reservoir simulation. Assumes complete mixing in reservoir. Linked with ARSP suite of models (system analysis models).	Monthly sequence of water quality data (Total Dissolved Solids, Suspended Solids, Total Phosphorus, algae, *E.coli*) and monthly hydrological data.
Output	**Use of Output**	**Databases accessed**
Monthly hydrological and water quality data for reservoir	Used for the evaluation of waste load scenarios	None
Developer / Vendor	**Price**	**Local source(s) of information**
Ninham Shand, BKS Inc.	Not for sale Used in contract work	Dr AJ Bath Ninham Shand (Pretoria)

Table (xii): MIKE 11 (River Modelling Package) (Blake, pers. comm., 1993)

Name of Model	Description	Input
MIKE 11 River Modelling Package.	A dynamic, one-dimensional modelling tool for detailed design, management, planning and operation of simple and complex rivers, channels and irrigation systems. Simulation of flow, water quality and sediment transport in estuaries, rivers, irrigation systems, channels and other water bodies.	Input depends on module or add-on module being used. 1.Hydrodynamic Module with add-on modules: flood forecasting, dambreak, urban drainage, control structures, quasi-steady state and automatic calibration of bed resistance. 2.Hydrological NAM Module. 3. Unit Hydrograph Module 4. Advection-Dispersion Module with advanced cohesive sediment transport. 5. Non-cohesive Sediment Transport and Morphology Module with graded sediments. 6. Water Quality Module with heavy metals and eutrophication. 7. Hydrological Information System (statistical package). 8. GIS (Arc/ Info interface features).
Output	**Use of Output**	**Databases accessed**
Depends on the module or being used (see input parameters for summary): includes the simulation of hydrology, hydrodynamics, advection-dispersion and cohesive sediment transport, water quality and non-cohesive sediment transport in estuaries, rivers, irrigation systems, channels and other water bodies, statistical processing, analysis and presentation of input data and model results, colourgraphics data checking, analysis and presentation of results and information stored in the databases and interfacing with Arc/ Info (GIS).	Detailed design, management, planning, operation and the simulation of hydrology, hydro-dynamics, advection-dispersion and cohesive sediment transport, water quality and non-cohesive sediment transport in simple and complex estuaries, rivers, irrigation systems channels and other water bodies. Statistical processing, analysis and presentation of input data and model results, colourgraphics data checking. Analysis and presentation of results and information stored in the databases.	The databases are independent of the operating system, so data can be transferred between computers and other databases. The databases facilities can be used independently as a general hydrological database for river basins.
Developer / Vendor	**Price**	**Local source(s) of information**
Danish Hydraulic Institute	Price available on request: EMATEK (Stellenbosch)	K Blake, J Slinger, P Huizinga EMATEK (Stellenbosch)

Table (xiii): MIKE 21 (Modelling system for two-dimensional free surface flows) (Blake, pers. comm., 1993)

Name of Model	Description	Input
MIKE 21 Modelling system for two-dimensional free surface flows	A modelling system for two-dimensional free surface flows, including advection-dispersion, water quality, heavy metals, eutrophication and sediment transport in estuaries, coastal waters and seas.	Unknown.
Developer / Vendor	**Price**	**Local source(s) of information**
Danish Hydraulic Institute	Price available on request: EMATEK (Stellenbosch)	K Blake, J Slinger, P Huizinga EMATEK (Stellenbosch)

Table (xiv): MINLAKE (Dynamic one-dimensional water quality model for lakes and reservoirs) (Venter, pers. comm., 1993)

Name of Model	Description	Input
MINLAKE	A dynamic one-dimensional water quality model for lakes and reservoirs. Provision is made for simulation of: Water temperature, mixing depth, dissolved phosphate, detritus, DO, TSS, TDS, nitrate, ammonia, and up to 3 classes of chlorophyll-*a*. Model has been adapted and calibrated for Roodeplaat Dam near Pretoria. The calibration is not specific to Roodeplaat Dam and should be valid for other South African reservoirs.	Daily meteorological data (solar radiation, wind speed, precipitation, etc.), daily hydrological data (average inflow rates and temperatures, flow rates of discharges), inflow water quality variables, kinetic coefficients for specific processes, and physical reservoir constants.
Output	**Use of Output**	**Databases accessed**
Depth profiles of simulated variables, as well as time-series at specified depths, goodness-of-fit statistics.	Testing the feasibility of different reservoir management alternatives that will affect the eutrophic state of the reservoir.	Department of Water Affairs and Forestry, Weather Bureau
Developer / Vendor	**Price**	**Local source(s) of information**
Prof H Stefan, St Anthony Falls Hydraulic Laboratory, USA.	Original programme free of charge from developers Locally adapted model: expected release early 1994	Dr M Wentzel/Ms A Venter Dept. of Civil Engineering University of Cape Town OR Mr M du Plessis Water Research Commission Pretoria

Table (xv): **NACL02** (Herold, pers. comm., 1994)

Name of Model	Description	Input
NACL02 (Dynamic deterministic daily tributary routing model)	Dynamic deterministic daily time step tributary routing model with modular structure. Simulates movement of both water and conservative pollutant. Includes wetland and riparian irrigation routines. Part or all of the channel surface area can be defined as wetland, with different evaporation factors. Account is taken of the transport of conservative salts between the main channel and surrounding flood plain. The model is fully documented in HRU Report No. 3/81, Water Systems Research Group, University of the Witwatersrand.	Meteorological data, output from NACL01 (or time series of daily catchment runoffs and pollutant solute concentrations derived from alternative catchment model), river reach linkage definition, channel reach characteristics, riparian irrigation and wetland characteristics.
Output	**Use of Output**	**Databases accessed**
Time series of simulated daily flows and conservative solute concentrations at user-defined points in the system.	Output can be used as input to a plotting program (NACL03), which permits the comparison of simulated and observed flows, pollutant concentrations and pollutant loads and produces a statistical summary; or as input to plotting program RANK02, which plots duration curves of modelled and/or observed daily values. Output can also be used as input to any other custom made simulation model or presentation software that has been developed for some specific purpose.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
Dr C E Herold, Stewart Scott Incorporated (developed under secondment to the Water Systems Research Group, University of the Witwatersrand)	Public domain (developed during WRC research project).	Dr C E Herold, Stewart Scott Incorporated, Sandton.

Table (xvi): NACLM2 (Herold, pers comm, 1994)

Name of Model	Description	Input
NACLM2 (Monthly single reservoir model)	Monthly time step single reservoir model. Simulates reservoir water and conservative pollutant balance. Two cells are used to simulate a plug-flow effect with a month-long memory. The model is fully documented in HRU Report No. 1/80, Water Systems Research Group, University of the Witwatersrand.	Time series of simulated monthly catchment runoff and conservative pollutant concentrations generated by NACLM1. Meteorological data. Reservoir storage-area relationship. Time series of reservoir abstractions.
Output	**Use of Output**	**Databases accessed**
Time series of simulated monthly reservoir storage, outflow and corresponding solute concentration. Summary of simulated reservoir water and pollutant balances.	Evaluate expected range of water quality and storage state in reservoir. Output can be used as input to plotting program (NACLM3), which includes statistical output, or as input to other presentation software.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
Dr C E Herhold, Stewart Scott Incorporated (developed under secondment to the Water Systems Research Group, University of the Witwatersrand).	Public domain (developed during WRC research project).	Dr C E Herold, Stewart Scott Incorporated, Sandton.

Table (xvii): One-dimensional hydrodynamic and transport dispersion estuary model. (Drewes, 1992)

Name of Model	Description	Input
One-dimensional hydrodynamic and transport dispersion estuary model.	Computes water levels and flows continuously. Computes concentrations of constituents in estuaries.	Topographic data. Water level variations. River flows. Dispersion characteristics.
Output	**Use of Output**	**Databases accessed**
Water levels. Flows. Concentrations of constituents.	Investigation of impact of developments and circulation problems and to quantify research results.	No databases are accessed; specific yield data are collected and prepared for model input.
Developer / Vendor	**Price**	**Local source(s) of information**
EMATEK (Stellenbosch)	Not for sale; used in research and contract work.	Piet Huizinga EMATEK (Stellenbosch)

Table (xviii): QUAL2E and QUAL2EU (Stream Water Quality Models) (Drewes, 1992 and Weddepohl, 1990)

Name of Model	Description	Input
QUAL2E and QUAL2EU (Stream Water Quality Models)	Model assesses the effects of various waste loads on stream water quality.	Meteorological data, stream hydrology, reservoir parameters, waste load and headwater conditions.
Output	**Use of Output**	**Databases accessed**
Stream flows, heat balance and stream water quality by individual variable.	Assesses effects of various waste loads on stream water quality and determines minimum or maximum values of water quality variables.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
CEAM	Public domain software. No charge.	G du Plessis, JN Rossouw or D Hohls WATERTEK (Pretoria) or Dr AJ Bath Ninham Shand, Pretoria or G Quibell DWAF

Table (xix)3: **REMDSS (Reservoir Eutrophication Model Decision Support System)** (Drewes, 1992)

Name of Model	Description	Input
REMDSS (Reservoir Eutrophication Model Decision Support System)	A decision support system for eutrophication control in reservoirs. The model simulates phosphorus export from a catchment, simulates the fate of the phosphorus in a reservoir and converts the ambient phosphorus concentration into chlorophyll-*a* concentration; both of these are measures of algal biomass.	
Output	**Use of Output**	**Databases accessed**
Time series of monthly in-lake phosphorus and chlorophyll-*a* concentrations.	Scenario analyses and long-term planning. Simulates a range of chlorophyll-*a* concentrations which can be expected in a reservoir and to evaluate different eutrophication control measures.	Dept. of Water Affairs and Forestry hydrological and chemical databases.
Developer / Vendor	**Price**	**Local source(s) of information**
WATERTEK (Pretoria)	R90	JN. Rossouw WATERTEK (Pretoria)

Table (xx): **SAW (Spill Analysis Workstation)** (Blake, pers. comm., 1993)

Name of Model	Description	Input
SAW (Spill Analysis Workstation)	Spill Analysis Workstation for the simulation of oil spills and spills of dangerous chemicals into the aquatic environment.	
Developer / Vendor	**Price**	**Local source(s) of information**
Danish Hydraulic Institute	Price available on request: EMATEK (Stellenbosch)	J Slinger, K Blake EMATEK (Stellenbosch)

Table (xxi): SEDIMENT (Weddepohl and Stasikowski, 1990)

Name of Model	Description	Input
SEDIMENT	Instream sediment transport model; uses dynamic, one-dimensional equations.	Data requirements are extensive.
Output	**Use of Output**	**Databases accessed**
Flow and sediment quantities.	Highly accurate simulations of flow and sediment quantities.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
Colorado State University.	Unknown.	No known local contact.

Table (xxii): SERATRA (Instream sediment-contaminant transport model) (Weddepohl and Stasikowski, 1990)

Name of Model	Description	Input
SERATRA (Instream sediment-contaminant transport model).	Dynamic, two-dimensional finite-element model; simulates time-varying vertical and longitudinal distribution of sediments and associated pollutants, using major mechanisms.	Quantities of various sediment types, pesticides, heavy metals, radionuclides and some toxic materials can be modelled.
Output	**Use of Output**	**Databases accessed**
Dissolved, suspended, particulate and settled states of parameters in flow-through water systems. Sediment transport submodel: transport, deposition and scouring of 3 sediment size fractions of cohesive and non-cohesive sediments.	To predict time-varying longitudinal and vertical distribution (transport and fate) of sediments and sediment associated pollutants.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
CEAM	Public domain software. No charge.	No known local contact.

Table (xxiii): SIMCAT (Water quality model for river systems) (Weddepohl and Stasikowski, 1990)

Name of Model	Description	Input
SIMCAT (Water quality model for river systems)	Computer program for which the river is divided into numbered reaches. The Monte Carlo method is used. Calculations begin at an upstream boundary and proceed downstream from feature to feature.	Physical parameters for reaches (quality, length, flow), river and effluent quality data (mean, standard deviation), location data of river features (5th percentile flows, mean flow, tributaries, discharge points).
Output	**Use of Output**	**Databases accessed**
Downstream water quality (estimated with the mass balance equation): ammonia N, chloride and BOD; monitors fate of averaged data; calculates confidence intervals and compliance estimates.	Modelling water quality of river systems, accounting for the effects of features, adding in contributions from diffuse sources and catering for natural purification.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
Institute of Hydrology, Wallingford, UK	Unknown.	No known local contact.

Table (xxiv): WASP5.01 (Water Quality Analysis Simulation Program) (Weddepohl and Stasikowski, 1990)

Name of Model	Description	Input
WASP5.01 (Water Quality Analysis Simulation Program Modeling System)	General framework for modelling contaminant transport and fate in surface waters; based on a compartment approach and applicable in 1, 2 or 3 dimensions. TOXI4 simulates transport and transformation of chemicals and particulate material to predict dissolved and sorbed chemical concentrations in bed and overlaying waters. The dissolved eutrophication model, EUTRO4, predicts DO and phyto-plankton dynamics affected by nutrients and organic material.	A water body is represented by a series of computational segments. Inputs that must be specified include: Segment volume and types and hydraulic coefficients; loads, boundary conditions and initial concentrations for each state variable; dissolved fractions of each variable; the phase of the variable (dissolved or particulate) and solids transport fields.
Output	**Use of output**	**Databases accessed**
Dissolved and sorbed chemical concentrations in bed and overlaying waters, predictions of DO and phytoplankton dynamics affected by nutrients and organic material and transport and transformation of up to 8 state variables in the water column and sediment bed.	Used to simulate all 8 state variables and the interactions between them for problems relating to BOD, DO dynamics, nutrients and eutrophication and bacterial, organic chemical and heavy metal contamination. WASP4 input and output linkages have been provided to other stand alone models.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
CEAM	Public domain software. No charge.	J Pretorius WATERTEK (Pretoria) or Dr AJ Bath Ninham Shand (Pretoria)

Table (xxv): WRPM (Water resource planning model (GR Basson, pers. Comm., 1994)

Name of Model	Description	Input
WRPM (Water Resource Planning Model)	Multi-reservoir simulation model including water resource allocation, network solving and water quality sub-models. Facilitate the integration of large water resource systems and perform operational decisions including water restriction implementation, inter-basin transfer management and the evaluation of cost saving operating rules. Perform scheduling analysis to determine implementation programmes for augmentation schemes based on reliability (risk) principals. Water quality modelling (Total Dissolved Solids) including blending options and the effect thereof on the yield of a system. Both historical and stochastic analysis can be performed.	Hydrological data including streamflow, rainfall, evaporation and relevant catchment developments. Water quality calibration parameters for salt wash-off (catchment), demand centre (urban users), irrigation block and channel reach sub models. System configuration including reservoir characteristics, transfer link capacities, hydro power installation parameters and operating rule definition. Water resource allocation definition and yield / reliability characteristic curves. Projected demands for each abstraction point in the system. Implementation dates of augmentation options and warm-up operating rules when new schemes are introduced.
Output	**Use of Output**	**Databases accessed**
Tabular output of reservoir levels, channel flows and analysis summary of elements in a system. Water resource allocation decision table for each decision performed. Probabilistic curtailment (restriction) projections, reservoir level and channel flow projections all in tabular format.	The tabulated output is captured into probabilistic graphs projecting reservoir levels, curtailment levels and system supply in relation with system demand. The graphical output is used to select appropriate operating rules and determine implementation programmes for augmentation options.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
BKS Incorporated / ACRES International / Department of Water Affairs & Forestry	Contractual agreement	P G van Rooyen BKS, Pretoria or J A van Rooyen Department of Water Affairs & Forestry, Pretoria

I.B. Surface runoff

Table (i): ACRU-HSPF LINK (Kienzle, pers. comm., 1993)

Name of Model	Description	Input
ACRU-HSPF LINK (Includes the ACRU and HSPF programmes, with integration routines)	Surface runoff water quality model. A procedure links hydrological output from the model ACRU into the water quality routines of HSPF, via a Water Data Management programme (WDM). Variables such as surface runoff, interflow, baseflow, as well as sediment load can be simulated with ACRU, and input into HSPF, to estimate the fate of phosphorus, nitrates or *E. Coli*	Climatic data (e.g. rainfall and evaporation), land-use, topographical and soil data
Output	**Use of Output**	**Databases accessed**
Water quality and hydrology data	Used for the simulation of phosphorus, nitrates, sediment and *E. Coli*	None
Developer / Vendor	**Price**	**Local source(s) of information**
Department of Agricultural Engineering, Univ. of Natal, and CCWR	Not available - integrated model in development stage Expected release in 1994	Dr SW Kienzle Dept. of Agricultural Engineering, Univ. of Natal

Table (ii): CREAMS (Chemical, Runoff and Erosion from Agricultural Management Systems model) (Weddepohl and Stasikowski, 1990)

Name of Model	Description	Input
CREAMS (Chemical, Runoff and Erosion from Agricultural Management Systems model)	Physically based, daily simulation model comprising 3 interlinked components: a hydrology component that drives the erosion component, which in turn, together with the hydrology component, drive the nutrient/pesticide (water quality) component.	Numerous input requirements that require field measurements for many variables.
Output	**Use of Output**	**Databases accessed**
The model estimates runoff, erosion/sediment transport, plant nutrient and pesticide yield from field sized areas.	Estimates quantities and quality of P, N and pesticides that are removed from agricultural land surfaces, transported predominantly overland and ultimately deposited into streams	None.
Developer / Vendor	**Price**	**Local source(s) of information**
U.S. Dept. of Agriculture	Unknown.	Dr AHM Görgens Ninham Shand (Cape Town) and Gordon Platford, Sugar Association Experiment Station (Mount Edgecombe)

Table (iii): **DISA (Daily Irrigation and Salinity Analysis Model)** (Görgens, 1992)

Name of Model	Description	Input
DISA (Daily Irrigation and Salinity Analysis Model)	A conceptual model of water and salt balances and flows in an irrigation shceme, with daily time resolution and menu-driven in/output	Daily time-series of rainfall, A-pan evaporation, upstream inflows and TDS, spatial data on all aspects of irrigation scheme layout, soils, physiographic boundaries, crops.
Output	**Use of Output**	**Databases accessed**
Daily flow, TDS or state variable values at any pre-specified points of interest: extensive output manager for graphics, both on screen and plots.	Planning of irrigation scheme development/extension i.t.o. salinity impacts. Optimise operation of irrigation water supply system to minimise salinity.	- Department of Water Affairs and Forestry - Department of Agriculture - Weather Bureau - CCWR - SIRI
Developer / Vendor	**Price**	**Local source(s) of informations**
Ninham Shand Inc, in conjunction with the Department of Water Affairs and Forestry.	Cost of supply: ± R 80	Dr. AHM Görgens Ninham Shand CAPE TOWN

Table (iv): **FLOSAL (Irrigation scheme planning model)** (Görgens, pers. comm, 1992)

Name of Model	Description	Input
$FLOSAL_d$ $FLOSAL_m$	A conceptual model of water and salt balances and flows in an irrigated catchment , with monthly and daily options.	Daily/Monthly time series of rainfall, A-pan evaporation, upstream inflows and TDS, spatial data on the river system, dams, irrigation scheme and crops.
Output	**Use of Output**	**Databases accessed**
Numerical or printer plots of daily or monthly flows, TDS and state variables at pre-specified points of interest.	Evaluation of irrigation scheme impacts on river salinity.	- - Department of Agriculture - Weather Bureau - CCWR - Institute for Soil, Climate and Water
Developer / Vendor	**Price**	**Local source(s) of informations**
Former National Institute for Water Research, CSIR	Unknown	Dr. AHM Görgens, Ninhan Shand, CAPE TOWN OR M van Veelen, BKS

Table (v): HSPF (Hydrological Simulation Program Fortran) (Drewes, 1992)

Name of Model	**Description**	**Input**
HSPF (Hydrological Simulation Program - FORTRAN)	Models quantity and quality of runoff from a catchment (including point sources). Also simulates the instream processes. Used to model urban and rural catchments from field size to several catchments.	Rainfall, evaporation, point source data, catchment parameters such as: • soil type • cover • slope • land use. Receiving-reach dimensions.
Output	**Use of Output**	**Databases accessed**
Water quantity and a large number of water quality parameters at user specified points in a reach.	Can be used to determine mean and total loads of various pollutants, total outflow and a profile of outflow rate at various points in the catchment. Output can be obtained as an ASCII file. The ANNIE software can be used for this process.	User-created database (a "time series store") and, through a software package called ANNIE, use of a Watershed Data Management file (WDM).
Developer / Vendor	**Price**	**Local source(s) of informations**
CEAM	Public domain software. No charge.	Brian Gardner; WATERTEK CSIR (Durban)

Table (vi): NACL01 (Herold, pers. comm., 1994)

Name of Model	Description	Input
NACL01 (Deterministic daily rainfall-runoff simulation and conservative pollutant balance)	Deterministic daily time step catchment rainfall-runoff simulation and conservative pollutant balance. Rainfall-runoff modelling is based on the Pitman model (daily version of WRSM90). The water quality component takes account of the accumulation on and wash-off from paved and previous catchment surfaces. Soil moisture and groundwater storage balances are accounted for. The model is fully documented in HRU Report No. 3/81, Water Systems Research Group, University of the Witwatersrand.	Meteorological data, catchment characteristics, model calibration parameters
Output	**Use of Output**	**Databases accessed**
Time series of simulated daily catchment runoff and corresponding daily conservative pollutant concentration and load. Optional output of daily surface and soil moisture pollutant storage states and soil moisture water storage. Output can also be aggregated into monthly totals. Summary of simulated catchment water and pollutant balances.	Simulation of natural and developed conditions. Short and long-term catchment response to catchment development. Output can be used as input to plotting program (NACL03), or as input to the tributary routing model (NACL02) or a system simulation model (such as NACL09). Can be used to path deficient records of river water quality.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
Dr C E Herold, Stewart Scott Incorporated (developed under secondment to Water Systems Research Group, University of the Witwatersrand)	Public domain (developed during WRC research project)	Dr C E Herold, Stewart Scott Incorporated, Sandton.

Table (vii): NACLM1 (Herold, pers. comm., 1994)

Name of Model	Description	Input
NACLM1 (Simplified monthly time step catchment conservative pollutant balance model)	Monthly time step model to simulate catchment conservative pollutant balance. It is a simplified version of NACL01 that excludes catchment rainfall-runoff simulation. The water quality component takes account of the accumulation and wash-off of soluble solids on paved and previous catchment surfaces, and the effect of sub-surface storage. Provision is made for growth in diffuse source pollutant generation due to anthropogenic land use changes or atmospheric deposition. The model is fully documented in HRU Report No. 1/80, Water Systems Research Group, University of the Witwatersrand.	Observed or synthetic monthly catchment runoff time series. Model calibration parameters.
Output	**Use of Output**	**Databases accessed**
Time series of simulated monthly catchment runoff and corresponding monthly conservative pollutant concentration and load. Summary of simulated catchment water and pollutant balances.	Output can be used as input to plotting program (NACLM3), which includes statistical output, or as input to monthly time step reservoir simulation model (NACLM2).	None.
Developer / Vendor	**Price**	**Local source(s) of information**
Dr C E Herold, Stewart Scott Incorporated (developed under secondment to the Water Systems Research Group, University of the Witwatersrand).	Public domain (developed during WRC research project).	Dr C E Herold, Stewart Scott Incorporated, Sandton.

Table (viii): PEXPM (Phosphate Export Model) (Hughes, pers. comm., 1993)

Name of Model	Description	Input
PEXPM (Phosphate Export Model).	Daily time step, semi-distributed phosphate export model. Based on SCS runoff model approach.	Several related to SCS model for runoff generation and input phosphate levels from socio-economic data.
Output	**Use of Output**	**Databases accessed**
Phosphate loads, storages and runoff.	Assessing phosphate loads from developing urban areas.	Can use CCWR rainfall and flow data.
Developer / Vendor	**Price**	**Local source(s) of information**
Prof. DA Hughes	Unknown.	Prof. DA Hughes Rhodes University

Table (ix): WQT (Herold, pers. comm., 1994)

Name of Model	Description	Input
WQT (Deterministic monthly hydro-salinity system simulation model)	Deterministic monthly time step hydro-salinity system simulation model comprising catchment wash-off, channel reach, irrigation, reservoir, demand centre, junction node and blending junction sub-models. The catchment wash-off module allows for the accumulation and wash-off of soluble solids from pervious and impervious catchment surfaces, sub-surface storage effects and anthropogenically induced growth in diffuse source conservative pollutant generation. Channel reaches can accommodate wetlands, seepage losses, inputs from upstream modules and point sources and riparian irrigation abstractions and return flows. Growth in wetland areas can be simulated. The irrigation module takes account of multiple cropping, irrigation efficiency, canal losses, and sub-surface storage. Allowance is made for reservoir commissioning and changes in capacity at specified dates during the simulation. Documentation includes the model documentation and calibration procedure guide.	Meteorological data. Catchment runoff time series, point abstraction and interbasin water transfer time series, water demand time series, irrigation details, reservoir characteristics, observed flow and concentration time series (for purpose of model calibration), model calibration parameters.
Output	**Use of Output**	**Databases accessed**
Time series of simulated monthly flows, solute concentrations and loads and dam storage at user-specified points in the system. Optional summary of simulated water and salt balances for each module.	Analysis of complex river system. Evaluation of effect of water resource management options on water quality and effect of water quality-driven operating rules on system yield. Prediction of effect of development. Output can be used as input to plotting programs or other presentation software. Output can also be used as input to any other custom made simulation model or data analysis program that has been developed for some specific purpose.	None
Developer / Vendor	**Price**	**Local source(s) of information**
Dr C E Herold (Stewart Scott Incorporated) / Mr R B Allen (BKS Water Resources Associates) / RSA Department of Water Affairs and Forestry	Not yet commercially available.	Dr C E Herhold (Stewart Scott, Sandton) or Dr M S Basson (BKS, Pretoria).

I.C. Groundwater

Table (i): BURNS (Model for estimating downward leaching of salts through soil) (Du Plessis, pers. comm., 1993)

Name of Model	Description	Input
BURNS	Capacity type leaching model for non-reacting salts, based on the concept that water content in soil segments vary between a maximum (field capacity) and minimum (evaporation limit). Simulates the downward movement of salt by equilibrating salt already present in a segment with incoming concentration and transferring volume exceeding field capacity to next lower segment.	Daily amounts of rainfall and evaporation, salt application and irrigation volume. Initial water and salt contents of each soil layer. Water content constants per segement.
Output	**Use of Output**	**Databases accessed**
Soil profile (water content and salt concentration in different soil layers). Water volume and salt load leaching from bottom soil layer.	Originally developed to predict redistribution of nitrate during early stages of plant growth. Optimising methods of leaching saline soils.	None. User creates input files with rainfall, evaporation and irrigation data and soil characteristics.
Developer / Vendor	**Price**	**Local source(s) of information**
I G Burns, National Vegetable Research Station	Public domain	H M du Plessis Water Research Commission

Table (ii): HELP (Hydrologic Evaluation of Landfill Performance) (Harris, pers. comm., 1993)

Name of Model	Description	Input
HELP : Hydrologic Evaluation of Landfill Performance	Quasi-two-dimensional deterministic computer-based water budget model; computes runoff, evapotranspiration, percolation, lateral drainage.	Daily rainfall, mean monthly temparatures, mean monthly solar radiation, leaf area indices, soil characteristics and design specifications.
Output	**Use of Output**	**Databases accessed**
Daily monthly and annual water budgets	The hydrological evaluation of landfill performance	Unknown
Developer / Vendor	**Price**	**Local source(s) of information**
U.S. Army Engineers / U.S. Environmental Protection Agency	Unknown	No known local contact

Table (iii): **LEACHM (Leaching Estimation and Chemistry Model)** (Du Plessis, pers. comm., 1994)

Name of Model	Description	Input
LEACHM	A process-based model of water and salt movement, transformation, plant uptake and chemical reactions in the unsaturated zone. Versions to model nitrogen and pesticide reactions are available.	Extensive data on soil profile's physical and chemical characteristics, initial and boundary conditions, crop characteristics, quantities and composition of applied water, pan evaporation.
Output	**Use of Output**	**Databases accessed**
Changes in soil profile's chemical composition and water content, leachate volume and composition, evaporation and transpiration.	Use to predict changes in soil profile and leachate composition under a given set of environmental and other conditions.	None. User creates input files.
Developer / Vendor	**Price**	**Local source(s) of information**
Dr R J Wagenet / J L Hutson Dept of Agronomy, Cornell University	Unknown	Prof J H Moolman University of Stellenbosch or Mr H M du Plessis Water Research Commission

Table (iv): **SUTRA (Saturated-Unsaturated Transport)** (Harris, pers. comm., 1993)

Name of Model	Description	Input
SUTRA (Saturated-Unsaturated Transport)	Finite element simulation model for saturated-unsaturated fluid-density dependent groundwater flow, with energy transport or chemically reactive single-species solute transport.	Geometry of finite element mesh, flow parameters, transport parameters, reaction and production parameters, boundary conditions, fluid source data, concentrations, flux at boundaries.
Output	**Use of Output**	**Databases accessed**
Plots of pressures, temperatures or concentrations at nodes, fluid velocity	Provides clear accurate answers only to well-posed, well defined problems; otherwise, provides help in visualising conceptual model of flow and transport regimes.	No external database
Developer / Vendor	**Price**	**Local source(s) of information**
U.S. Geological Survey, Environmental Science and Engineering	US$400	Dr. J Harris, Steffen, Robertson and Kirsten

Table (v): TETrans (Trace Element Transport Model) (Du Plessis, pers. comm., 1993)

Name of Model	Description	Input
TETrans	Capacity type leaching model similar to BURNS, but which additionally considers 'bypass' flow and upward movement of water and salts as well as chemical exchange and adsorption reactions.	Fairly extensive data on each soil segment's chemical characteristics and water content constants, as well as initial conditions, crop characteristics, quantity and composition of applied water, and evapotranspiration.
Output	**Use of Output**	**Databases accessed**
Changes in chemical composition of soil liquid and solid phases, water content, composition and volume of leachate.	Released in 1990. Limited applications to date. Use to predict changes in soil profile and leachate composition under a given set of environmental and other conditions.	None. User creates input files.
Developer / Vendor	**Price**	**Local source(s) of information**
Dr D Corwin, US Salinity Laboratory	Public domain	Prof J H Moolman Univ of Stellenbosch or Mr H M du Plessis Water Research Commission

I.D. Equilibrium models

Table (i): JESS (Joint Expert Speciation System) (Murray, pers. comm., 1993)

Name of Model	Description	Input
JESS (Joint Expert Speciation System)	An equilibrium chemical speciation model for metals, inorganic and organic ligands in aqueous systems	Identity of main chemical constituents; their total concentrations; temperature
Output	**Use of Output**	**Databases accessed**
Identity and concentrations of major forms of constituents; saturation state of solid phases; partial pressures of gases; amounts of solids precipitated; estimation of water quality indexes: Corrosivity, Langelier, Ryznar, Sodium Adsorption Ratio	Detailed information can be obtained on chemical interactions in a wide range of systems including natural waters (fate of heavy metals in the environment), water treatment systems, hydro-metallurgical processes etc.	The JESS Thermodynamic data contains data for more than 23 000 chemical reactions including nearly 800 mineral and solid phases.
Developer / Vendor	**Price**	**Local source(s) of information**
WATERTEK (Pretoria)	Not for sale; used in research and contract work.	K Murray WATERTEK (Pretoria)

Table (ii): MINTEQA2 (Pretorius, pers. comm., 1993)

Name of Model	Description	Input
MINTEQA2	An equilibrium chemical speciation model for metals for aqueous systems.	The accompanying PRODEFA2 interactive program creates the input files, accesses the currently available reaction species from the MINTEQA2 database and defines other solid, aqueous or adsorption reaction species not yet in the thermodynamic database.
Output	**Use of Output**	**Databases accessed**
Concentrations of various forms of input chemical constituents in solution.	Calculating equilibrium composition of dilute solutions in natural systems, solving a wide range of complex equilibrium problems involving reaction among aqueous solutions, gasses, mineral phase and sorbed phase species	MINTEQA2 thermodynamic database of over 1400 chemical species. No thermodynamic data are available for the 7 sorption submodels of the model.
Developer / Vendor	**Price**	**Local source(s) of information**
CEAM	Public domain software. No charge.	J Pretorius WATERTEK (Pretoria)

II. Hydrological modelling

II.A. Surface water

Table (i): **DETFLOOD (Deterministic hydrological model)** (Alexander, pers. comm., 1993)

Name of Model	Description	Input
DETFLOOD (Deterministic hydrological model)	Determination of the flood magnitude/frequency relationship	Weather bureau station no. and location; rainfall data; physical parameters of river and catchment; vegetal cover and permeability categories; veld type zone; lightning ground flash densities; RMF K-values.
Output	**Use of Output**	**Databases accessed**
Flood-frequency relationship	All applications including design of dams, bridges, urban drainage, etc.	Department of Water Affairs and Forestry TRIO2
Developer / Vendor	**Price**	**Local source(s) of information**
Prof. WJR Alexander	Software included in publication Flood Hydrology for Southern Africa	Prof. WJR Alexander Dept. of Civil Engineering University of Pretoria

Table (ii): **DISTRAIN/DROUGHT (District rainfall analysis models)** (Alexander, pers. comm., 1993)

Name of Model	Description	Input
DISTRAIN/DROUGHT	Analysis of district rainfall records (93 districts)	Monthly district rainfall records.
Output	**Use of Output**	**Databases accessed**
Tables and coloured maps of South African rainfall	Reference for the determination of the severity of above or below average district rainfall.	Weather Bureau rainfall records.
Developer / Vendor	**Price**	**Local source(s) of information**
Prof. WJR Alexander	R50	Prof. WJR Alexander Dept. of Civil Engineering University of Pretoria

Table (iii): **Drought Durations Simulation Model** (Zucchini and Adamson, 1984)

Name of Model	Description	Input
Drought Durations Simulation Model	Based on daily rainfall accumulation in a "bucket" with a 10 mm capacity and water loss using an exponential function (% of total per day). Determines length of drought in days.	Generated daily rainfall for 500 years.
Output	**Use of Output**	**Databases accessed**
Total count of droughts in length classes in each 100 year period over a 500 year record for summer/winter half years in ASCII file	Determining the no. of droughts of various durations for rainfall stations in 100 year intervals.	D Le Maitre RAINMOD.TAB
Developer / Vendor	**Price**	**Local source(s) of information**
W Zucchini Dept. of Mathematics and Statistics, University of Cape Town	Unknown.	D Le Maitre FORESTEK (Pretoria)

Table (iv): **FLOODCAT (Reference catalogue of historical floods)** (Alexander, pers. comm., 1993)

Name of Model	Description	Input
FLOODCAT	Catalogue of historical floods in South Africa	Local information
Output	**Use of Output**	**Databases accessed**
Description of each event, on-screen maps.	Reference	None
Developer / Vendor	**Price**	**Local source(s) of information**
Prof. WJR Alexander	R100	Prof. WJR Alexander Dept. of Civil Engineering, University of Pretoria

Table (v): **FLOODWATCH (Flood warning system)** (Alexander, pers. comm., 1993)

Name of Model	Description	Input
FLOODWATCH	Flood warning system	Real time rainfall, river flows and reservoir storage.
Output	**Use of Output**	**Databases accessed**
Graphs and tables of immediately preceding rainfall	Local flood warning systems	Real time rainfall, river flows and reservoir storage.
Developer / Vendor	**Price**	**Local source(s) of information**
Prof. WJR Alexander	Unknown	Prof. WJR Alexander Dept. of Civil Engineering University of Pretoria

Table (vi): **GENRAIN (Rainfall sequence generation model)** (Zucchini and Adamson, 1984)

Name of Model	Description	Input
GENRAIN (Rainfall sequence generation model)	Stochastic rainfall simulation model based on regression models.	Rainfall stations and codes, random number seed, time interval, output file name
Output	**Use of Output**	**Databases accessed**
Rainfall per year in an ASCII file.	Generates stochastic rainfall records (daily, monthly, yearly) for 2500 weather stations for statistical analysis and modelling.	D Le Maitre ZUCCINI.TAB
Developer / Vendor	**Price**	**Local source(s) of information**
W Zucchini and PT. Adamson Dept of Mathematics and Statistics University of Cape Town	Unknown.	D Le Maitre, A Chapman FORESTEK (Jonkershoek)

Table (vii): LITPACK (Blake, pers. comm., 1993)

Name of Model	Description	Input
LITPACK	Integrated modelling system for littoral processes and coastline kinetics.	
Developer / Vendor	**Price**	**Local source(s) of information**
Danish Hydraulic Institute	Price available on request: EMATEK (Stellenbosch)	J Slinger, K Blake EMATEK (Stellenbosch)

Table (viii): **Multiple Reservoir Simulation Program** (Hughes, pers. comm., 1993)

Name of Model	Description	Input
Multiple Reservoir Simulation Program.	A monthly time step multiple reservoir simulation model.	Size and characteristics of reservoir basins, connection details, water consumption details, operating rules and others.
Output	**Use of Output**	**Databases accessed**
Overflow, consumption levels and others.	Design of reservoir systems and their operation.	Uses output from a runoff model (e.g. the Pitman model) and rainfall input from CCWR database
Developer / Vendor	**Price**	**Local source(s) of information**
Prof. DA Hughes	Unknown.	Prof. DA Hughes Rhodes University

Table (ix): **OPRULES and ECONYLD** (Alexander, pers. comm., 1993)

Name of Model	Description	Input
OPRULES and ECONYLD	Models to help optimise water resource development.	Hydrological data, catchment characteristics, dam basin characteristics, environmental criteria.
Output	**Use of Output**	**Databases accessed**
Reservoir and environmental yields and economic benefits.	Water resource development.	Hydrological.
Developer / Vendor	**Price**	**Local source(s) of information**
Prof. WJR Alexander	Available on request.	Prof. WJR Alexander Dept of Civil Engineering University of Pretoria

Table (x): REGFLOOD (Regional flood analyses model) (Alexander, 1991)

Name of Model	Description	Input
REGFLOOD (Regional flood analyses model)	Determination of the flood magnitude / frequency relationship.	Records of annual flood peak maxima
Output	**Use of Output**	**Databases accessed**
Tables and graphs for various statistical distributions.	All applications including design of dams, bridges, urban drainage, etc.	Department of Water Affairs and Forestry Hydrological database.
Developer / Vendor	**Price**	**Local source(s) of information**
Prof. WJR Alexander	Software included in publication Flood Hydrology for Southern Africa	Prof. WJR Alexander Dept. of Civil Engineering University of Pretoria

Table (xi): Riparian zone management model (Drewes, 1992)

Name of Model	Description	Input
Riparian zone management model.	Expert system for management of riparian zones.	Locational, vegetation and management objectives.
Output	**Use of Output**	**Databases accessed**
Options for management.	Conservation and water production assessments.	No formal databases accessed. Soil and vegetation data generated by user.
Developer / Vendor	**Price**	**Local source(s) of information**
FORESTEK (Jonkershoek)	Not for sale; used in research and contract work.	JM Bosch FORESTEK (Jonkershoek)

Table (xii): **SHELL** (De Smidt, pers. comm., 1993)

Name of Model	Description	Input
SHELL (Suite of models, incorporates Monthly Pitmann Model and RESSIM)	Utility which facilitates the simulation of surface runoff for various land-use scenarios, as well as reservoir simulation. Incorporatess the monthly Pitmann model, RESSIM reservoir simulation routine, and different file handling routines. User sets up framework to customise multiple model runs for different time slices, with option to route output from Pitmann model to RESSIM for reservoir simulation	Meteorological data (rainfall, evaporation), demand (irrigation, etc.), land-use data
Output	**Use of Output**	**Databases accessed**
Monthly stream flows, reservoir data	Studying different catchment scenarios	None
Developer / Vendor	**Price**	**Local source(s) of information**
Ninham Shand Inc, Cape Town	Not for sale Used in contract work	Dr AHM Görgens Ninham Shand, Cape Town

Table (xiii): **WRSM90 (Water Resources Simulation Model)** (Pitman, pers. comm., 1993; Hughes, pers. comm., 1993)

Name of Model	Description	Input
WRSM90 (Water Resources Simulation Model)	Latest version of the Pitman Model. Monthly time step catchment simulation model, incorporating water resource systems components.	Pitman model parameters, hydrometeorlogical data, details of reservoirs, irrigation areas and other abstractions and discharges.
Output	**Use of Output**	**Databases accessed**
Simulated monthly runoff, reservoir levels, water usage and statistics.	Reservoir yield, system analysis, stochastic analysis.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
B Pitman Stewart Scott Inc.	R2000	H. Maaren Water Research Commission or G Shultz Steffen Robertson & Kirsten or B Pitman Stewart Scott Inc.

Table (xiv): WRYM (Water resource yield model) (GR Basson, pers. comm., 1994)

Name of Model	Description	Input
WRYM (Water Resource Yield Model)	Multi reservoir simulation model based on network solving techniques. Determine capability of water resource systems using historical and stochastic streamflow sequences. Evaluation of operating rules. Model most water resource structures including hydropower generation.	Hydrological data including streamflow, rainfall, evaporation and relevant catchment developments. System configuration including reservoir characteristics, transfer link capacities, hydropower installation parameters and operating rule definition.
Output	**Use of Output**	**Databases accessed**
Tabular output of reservoir levels, channel flows and summary output of the yield from a system. The output is produced either for a single sequence or a multi-sequence (stochastic) analysis.	Develop historical draft / yield graphs and determine the historical firm yield of a system. Develop yield / reliability curves which represents the yield characteristics of a system for both long and short-term analysis. Produce probabilistic projections for reservoir levels and channel flows.	None.
Developer / Vendor	**Price**	**Local source(s) of information**
ACRES International / BKS Incorporated / Department of Water Affairs and Forestry	Contractual agreement	PG van Rooyen, Department of Water Affairs and Forestry

II.B. Groundwater

Table (i): ACRU (Agricultural Catchments Research Unit agrohydrological modelling system) (Du Plessis, 1992; Tarboton and Schulze, 1992)

Name of Model	Description	Input
ACRU (Agricultural Catchments Research Unit agrohydrological modelling system)	Soil moisture budgeting and hydrological systems model. Rainfall-runoff estimates are primary outputs.	Daily rainfall, temperature, soil physical properties, vegetal cover, reservoir dimensions, irrigation drafts and requirements.
Output	**Use of Output**	**Databases accessed**
Runoff values and statistics for risk assessment. Soil water budgets. Crop yields.	Risk assessment, crop yield estimates, reservoir reliability, project viability studies and land-use planning.	Daily rainfall, temperature and pan evaporation from the Computing Centre for Water Research. Data for soil and vegetation generated by user.
Developer / Vendor	**Price**	**Local source(s) of information**
Prof. RE Schulze Dept of Agriculatural Engineering University of Natal	Public domain software. No charge.	A Chapman or D Scott; FORESTEK (Jonkershoek) or Dr SW Kienzle Dept. of Agricultural Engineering, Univ. of Natal

Table (ii): FLAM (Forest Land Allocation and Management Model)

Name of Model	Description	Input
FLAM (Forest Land Allocation and Management Model)	Hydrological (tree water use) silvicultural (plantation, operational management and planning) model which uses regression, simulation and optimisation methods.	Land facet attributes, site index values, silvicultural data and growth curves for species.
Output	**Use of Output**	**Databases accessed**
Site indices for selected species, growth curves for the species, cumulative timber volumes and water use for the species, a silvicultural regime and harvest schedule.	Helps land owners and managers decide on appropriate species, silviculture regime, plantation layout and areas to exclude given a particular timber or pulp market, limits on water use, water quality, prescriptions for riparian zones and non-afforestable land.	D Le Maitre FLAMCAT.TAB
Developer / Vendor	**Price**	**Local source(s) of information**
FORESTEK (Pretoria)	Not for sale; used in research and contract work.	D Le Maitre, G Meyer FORESTEK (Pretoria)

Table (iii): Forest evaporation and interception models (Drewes, 1992)

Name of Model	Description	Input
Forest evaporation and interception models.	Forestry models	Meteorological and tree specific data.
Output	**Use of Output**	**Databases accessed**
Water use by trees.	Water efficiency determinations; research.	No formal databases. Soil and vegetation data generated by user.
Developer / Vendor	**Price**	**Local source(s) of information**
FORESTEK (Nelspruit) and FORESTEK (Jonkershoek).	Not for sale; used in research and contract work.	P Dye, FORESTEK (Nelspruit), D Versfeld, FORESTEK (Jonkershoek), or RE Smith FORESTEK (Pretoria)

Table (iv): WREVAP (Evaporation Estimating Model) (Drewes, 1992)

Name of Model	Description	Input
WREVAP (Evaporation Estimating Model).	Evaporation estimates using complementary relationship theory for terrestrial and water surfaces.	Radiation, temperature, humidity and surface characteristics.
Output	**Use of Output**	**Databases accessed**
Evaporation depths over time.	Research and evaluation procedures.	No formal databases accessed. Soil and vegetation data generated by user.
Developer / Vendor	**Price**	**Local source(s) of information**
FI Morton, Canada	Public domain software. No charge.	RA Chapman FORESTEK (Jonkershoek)

II.C. Intergrated surface and groundwater models

Table (i): MIKE-SHE (Blake, pers. comm., 1993)

Name of Model	Description	Input
MIKE-SHE	Distributed, physically based hydrological modelling system for a wide range of water resource problems related to surface and groundwater management, contamination and soil erosion.	Unknown.
Developer / Vendor	**Price**	**Local source(s) of information**
Danish Hydraulic Institute	Price available on request: EMATEK (Stellenbosch)	J Slinger, K Blake EMATEK (Stellenbosch)

Table (ii): **TOPOG** (Chapman, pers. comm., 1993)

Name of Model	**Description**	**Input**
TOPOG Modules: 1. TOPOG-YIELD and 2. TOPOG-IRM (IRM Integrated Rate Methodology)	TOPOG is a physically based, deterministic distributed parameter catchment model that simulates lateral transfer of water through overland flow, with a linkage between an unsaturated zone model and a groundwater model. TOPOG-YIELD simulates hydrographs from catchment, vegetation, climatic and soils data. TOPOG-IRM does all of the above but also models carbon assimilation by plants and growth yield of vegetation.	Daily rainfall, direct and diffuse radiation, maximum and minimum temperature, vapour pressure deficit, soil saturated hydraulic conductivity, volumetric soil moisture contents at saturation and air dry conditions capillary length scales, soil depth and vegetation parameters. (For many of these parameters, S.A. data do not exist and must be estimated.)
Output	**Use of Output**	**Databases accessed**
Daily volume of outflow, masses of assimilated carbon on various parts of the plant, evapotranspiration, leaf area indices, radiation and stream-power weighted indices. All outputs and soil moisture redistributions can be mapped spatially.	Hydrograph simulation, growth yield modelling, predicting spatial distribution of erosion and landslide hazard and recharge to aquifers.	User-created databases used where possible, otherwise values inserted manually into menus.
Developer / Vendor	**Price**	**Local source(s) of information**
CSIRO	Model and training workshop (obligatory) R20 000.	Arthur Chapman FORESTEK (Jonkershoek)

Table (iii): **Variable Time Interval Model** (Hughes, pers. comm., 1993)

Name of Model	**Description**	**Input**
Variable Time Interval Model	A variable time interval, semi-distributed model of catchment hydrology.	Procedures are available to assess parameters from physical catchment data.
Output	**Use of Output**	**Databases accessed**
All components of catchment hydrology (runoff, evaporation, soil moisture, groundwater recharge, etc.)	Detailed assessment of catchment hydrological response, including effects of land use change.	Can use CCWR rainfall and observed flow data directly.
Developer / Vendor	**Price**	**Local source(s) of information**
Prof. DA Hughes	Unknown.	Prof. DA Hughes Rhodes University

Addresses of developers/vendors/local sources of information

ACRES International
(Fax: +27 11 888-1967)

BKS Inc.
P O Box 3173
Pretoria
0001
South Africa
(Fax: +27 12 663-2662)

CCWR (Computing Centre for Water Research)
c/o University of Natal
P O Box 375
Pietermaritzburg
3200
South Africa
(Fax: +27 331 61896)

CEAM (Centre for Exposure and Assessment Modeling)
US EPA
Athens
Georgia
30613
United States of America

Colorado State University
Fort Collins
Colorado
United States of America

CSIR
P O Box 395
Pretoria
0001
South Africa

CSIRO
Division of Water Resources
Canberra ACT
2601
Australia

Danish Hydraulic Institute
Agern Allé 5
DK-2970
Horsholm
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(Fax +45 762567)

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University of Cape Town
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Dept. of Agricultural Engineering
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Cornell University
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NY 14853
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Department of Water Affairs and Forestry
P Bag X313
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(Fax: +27 12 323-4472)

Environmental Science and Engineering
U.S. Geological Survey
(Fax: 091 813-3711637)

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Freshwater Research Unit
University of Cape Town
Rondebosch 7700
(Fax: +27 21-6503726

Institute for Soil, Climate and Water
Private Bag X79
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0001
(Fax: +27 12-3231157)

Institute for Water Research
Rhodes University
Grahamstown
6140
South Africa

Institute of Hydrology
Wallingford
Oxfordshire
United Kingdom

National Vegetable Research Station
Wellesbourn
Warwick

Ninham Shand (Pretoria)
P O Box 95262
Waterkloof
0145
South Africa
(Fax: +27 12 3462253)

Ninham Shand (Cape Town)
P O Box 1347
Cape Town
8000
South Africa
(Fax: 27 21-251634)

North American Lake Management Society
One Progress Blvd.
Box 27
Alachva
FL 32615-9536
United States of America

Scientific Software Group
P O Box 23041
Washington D.C.
20026-3041
United States of America
(Fax: 091 202-6206793)

Steffen, Robertson and Kirsten
P O Box 55291
Northlands
2116
South Africa
(Fax: +27 11-8808086)

Stewart Scott Inc.
P O Box 784506
Sandton
2146
South Africa
(Fax: +27 11-883 6789)

Sugar Association: Experiment Station
Private Bag X02
Mount Edgecombe
4300

Tennessee Valley Authority
Water Quality Department
311 Broad Street
Chattanooga
TN 37402-2801
United States of America

U.S. Army Engineers / U.S. Environmental Protection Agency
Municipal Environmental Research Laboratory
Cincinnati
Ohio
United States of America

US Army Engineer Waterways Experiment Station
US Army Corps of Engineers
3909 Halls Ferry Road
Vicksburg
MS 39180-6199
United States

US Salinity Laboratory
4500 Glenwood Drive
Riverside
Ca 92501
USA

Water Research Commission
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Water Systems Research Group
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WATERTEK (Durban)
P O Box 17001
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WATERTEK / EMATEK
P O Box 320
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WATERTEK (Pretoria)
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Other models relating to water resources

The following additional models were identified, but there was insufficient information available to include them in the tables of detailed descriptions.

The models in the first group have been developed, or applied, locally and contact organisations for these models are listed in the previous section.

- Instream flow requirements of rivers, contact person: Dr. JM King, Freshwater Research Unit, University of Cape Town
- CRAM: Catchment resources allocation model, FORESTEK, CSIR
- CMS: Catchment management systems, FORESTEK, CSIR
- Water Use From Forest Canopies, P Dye, FORESTEK, CSIR
- Hydrological model, E Painting, (diffusion model), BOUTEK, CSIR
- PEM: Phosphorus Export Model, simple model to simulate the accumulation, wash-off and transport of phosphorus from a non-point source dominated catchment, WATERTEK, CSIR
- Phosphorus Budget Model, WATERTEK, CSIR
- Chlorophyll Concentration Model, predict mean annual chlorophyll concentration from mean annual phosphate concentration, WATERTEK, CSIR
- RORB: Monash University Model: a single event flood model, Institute for Water Research, Rhodes University
- HYMAS: Hydrological Model Application System. All the models used by the Institute for Water Research, Rhodes University, are packaged as an integral part of HYMAS, which includes routines for parameter estimation, time series data manipulation, model setup and running and results analysis.

The following models were developed overseas, but local results have not been published. The contact person for more technical information is Bruce Wilson, Minnesota Pollution Control Agency, (612) 296-9210. Orders should be placed at NALMS office, One Progress Blvd., Box 27, Alachua, FL 32615:

- EUTROMOD v. 2.4: Spreadsheet for watershed and lake assessments, version includes northern and Midwestern lake (US) refinements, As-Easy-As-Shareware version 2.4 is required to run EUTROMOD.

- CNET.wk1: Implements empirical models for predicting eutrophication and related water quality conditions in reservoirs, spreadsheet, requires Lotus 1-2-3 v. 2 or higher.

- LRSD.wk1: Designed for statistical evaluation of lake / reservoir sampling program designs. Assumed monitoring objectives include estimation of the long-term mean at a station and/or detection of a step change in the mean between two time periods, spreadsheet, requires Lotus 1-2-3 v. 2 or higher.

- PONDSIZ.wk1: Worksheet to assist engineers and planners in designing wet detention ponds for water quality control. Design concepts are derived from US EPA's Nationwide Urban Runoff Program and other studies, requires Lotus 1-2-3 v. 2 or higher.

- PONDNET.wk1: Worksheet for routing flow and phosphorus through networks of detention ponds, requires Lotus 1-2-3 v. 2 or higher.

A variety of modelling software is also available from the Scientific Software Group in Washington, D.C. The annual publication *Environmental Engineering, Water Resources: Software and Publications* supplies information on the latest available software packages, especially in the groundwater field. Prices range from $30 to $205. Some of the models are also available free of charge from the USEPA. A number of publications, mainly on groundwater related topics are also available from the Scientific Software Group.

Many of these models are available either as *extended memory* (EM) versions, which require a 386 or 486 machine with minimum 2 MB RAM, a math co-processor and hard drive, or as PC versions, which only require 640K RAM, a math co-processor and hard drive.

The available software packages include the following water quality related models:

Mixing zone expert system:

- CORNELL MIXING ZONE EXPERT SYSTEM (CORMIX). Can be used for analysis, prediction and design of aqueous toxic or conventional pollutant discharges into diverse waterbodies. Version 2.10 combines CORMIX1 - for submerged single point discharges, CORMIX2 - for submerged multiport diffuser discharges and CORMIX 3 - for buoyant surface discharges, into a single comprehensive system for modelling diverse types of aqautic pollutant discharge into all types of receiving water bodies, including streams, rivers, lakes, reservoirs, estuaries and coastal waters. Available from

CEAM, Athens, Georgia - contact person T Barnwell, E-mail address: BARNWELL@athens.ath.epa.gov.

On catchment modelling:

- HYDROLOGY SYSTEM (EDSC). Designed primarily for hydrologic analysis of both simple and complex drainage basins, this model can be used as a tool for determining runoff from various historical and synthetic storms and in modelling flood control measures such as detention basins with various outlet structures.

- SWMM: Storm Water Management Model, is a U.S. EPA model for analysis of quantity and quality problems associated with urban runoff. All aspects of the urban hydrologic and quality cycles may be modelled including rainfall, snowmelt, surface and subsurface runoff, flow routing through the drainage network, storage and treatment. Statistical analyses may be performed on long-term precipitation data and on output from continuous simulation.

On groundwater modelling:

- IFDMOD (Integrated Finite Differences Model), simulates three-dimensional groundwater flow.

- FLOWPATH, by Waterloo Hydrogeologic, is a two-dimensional steady-state groundwater flow and wellhead protection analysis model for the calculation of hydraulic heads, groundwater velocities, time-related pathlines, capture zones, water balances, and steady-state drawdown distributions. It is based on the finite-difference formulation allowing for the simulation of confined, leaky, or unconfined flow in heterogeneous and anisotropic porous media. It allows for irregularly spaced grids. Groundwater pathlines, travel times and velocities are calculated using the particle tracking method.

- FLOWCAD, by Waterloo Hydrogeologic, is a two-dimensional transient-state groundwater flow model for the calculation of time-variant hydraulic heads and drawdowns. It is based on the finite-difference formulation allowing for the simulation of confined, leaky, or unconfined flow in heterogeneous and anisotropic porous media.

- FLONET, by Waterloo Hydrogeologic, is a two-dimensional cross-sectional steady-state groundwater flow model. It computes potentials, streamlines, and groundwater velocities in a vertical section through a confined or unconfined aquifer. The model is based on the dual formulation of potentials and stream functions developed by Dr. EO Frind of the University of Waterloo.

- AQUIFEM was developed by the Ralph M Parsons Laboratory for Water Resources and Hydrodynamics, located at the Massachusetts Institute of Technology. The model performs analyses of two-dimensional horizontal groundwater flow. It can model anisotropic, heterogeneous, phreatic or confined, leaky or non-leaky aquifers under transient or steady-state conditions.

- SWIM is a menu-driven set of programs that allows the user to simulate soil-water balances using numerical solutions of the basic soil-water flow equations. SWIMEV is the simulations program. It employs recently developed numerical techniques for solving the soil-water flow equation. Within the limitations of Richards' equation, a user can simulate infiltration, redistribution, deep drainage, simultaneous evapotranspiration by up to four types of vegetation, transient surface-water storage and runoff.

- MODFLOW: a recent implementation of the USGS model, "A Three-Dimensional Finite-Difference Ground-Water Flow Model", by MG Mc Donald and AW Harbaugh. This model represents flow in one, two or three dimensions in confined and unconfined aquifers under steady-state or transient conditions. A local contact for information on the model is the Institute for Water Research, Rhodes University.

- MODPATH is a 3-D particle tracking program for use with MODFLOW.

- MODFLOWP is the USGS program for estimating parameters of a transient or steady-state, three-dimensional, groundwater flow model using nonlinear regression. Any spatial variation in parameters can be defined by the user.

- PROCESSING MODFLOW (PM) is a graphical processor that integrates MODFLOW and MODPATH.

- MODLOCAL is used to construct local MODFLOW models from an existing regional MODFLOW model. A number of additional utility packages for MODFLOW are also available.

- MOC: USGS "Computer model of two-dimensional solute transport and dispersion in ground water", by LF Konikow and JD Bredehoeft. The model is applicable to steady state or transient flow and is based on a finite-difference grid. The aquifer can be heterogeneous and/or anisotropic. The model allows the specification of injection or withdrawal wells and of spatially varying diffuse recharge or discharge. Other utility packages for MOC are also available.

- MOCDENSE: USGS "A Two-Constituent Solute-Transport Model for Ground Water Having Variable Density", developed by WE Sanford and LF Konikow. This model simulates solute transport and dispersion of either one or two constituents in groundwater where there is two-dimensional, density-dependent flow. The model simulates flow in a cross-sectional plane. Constituents are assumed to be conservative, and density and viscosity are a function of concentration only. Other utility packages for MOCDENSE is also available.

- HST3D: USGS "A Computer Code for Simulation of Heat and Solute Transport in Three-Dimensional Ground-Water Flow Systems", by KL Kipp. The model simulates groundwater flow and associated heat and solute transport in three dimensions. It is primarily intended for analysis of flow, heat and solute transport in the saturated zone of a groundwater system with variable or constant density and viscosity.

- INTERSAT is capable of solving one-, two- or three-dimensional models. It can model heterogeneities near a well, heterogeneous anisotropy, well-bores, and allows the user to determine numerically complex type curves for heterogeneous formations. The model includes the WATER-BUDGET PACKAGE, which allows the user to examine water budgets in a user-defined rectangular cubic region, and the SURFACE-WATER PACKAGE, which allows the user to specify the domain or area for a surface water feature. It also includes the EVAPOTRANSPIRATION PACKAGE for interactive data entry of evapotranspiration data.

- INTERTRANS: a three-dimensional solute-transport model which uses the particle tracking technique in simulating contaminant advection and dispersion. A MODFLOW conversion utility program, CONMOD, is included with INTERTRANS, which converts MODFLOW output (permeabilities, heads, node locations) into INTERTRANS input format.

- MODRET: an interactive program for analysing infiltration from stormwater retention/detention ponds in unconfined aquifers. MODRET was developed utilising the USGS groundwater flow model, MODFLOW. The model assumes a homogeneous and isotropic unconfined aquifer system. Pre- and postprocessors are also included in the package.

- FLOWTHRU is based on a two-dimensional anisotropic vertical section through water bodies which are long in the direction perpendicular to the direction of regional groundwater flow. The model was developed specifically for shallow lakes, but can also be applied to wetlands, rivers, streams, canals, channels and drains. It is mainly used for:
  - determining the depths of groundwater capture zones near shallow water bodies, and
  - as an educational tool, to visualise flow patterns near surface water bodies.

- FEMSEEP: a groundwater flow and contaminant transport model based on the finite-element method with a particle tracking algorithm. The major components of the model include groundwater flow, advective transport, and advective-dispersive transport. It's capable of solving steady and non-steady flow and solute transport in a two-dimensional horizontal plane, a vertical cross-section, or three-dimensional axisymmetric system. The aquifer can be confined, unconfined, or leaky. The model is specifically suited for local groundwater investigations and aquifer remediation projects. It can be used for designing extraction, injection, and recharge systems, and for predicting the performance of the system.

- AQUA solves two-dimensional groundwater flow and transport equations. The model is designed to solve such problems as groundwater flow with nonhomogeneous and anisotropic flow conditions, and steady-state and transient transport of contaminants and heat with velocity-dependent dispersion, convection, decay and adsorption. It allows for a large number of pumping and injection wells and areal variation of leakage and infiltration.

- SEEP/W analyses geotechnical engineering seepage and pore-water pressure dissipation problems. The formulation makes it possible to consider analyses ranging from simple saturated steady-state problems to sophisticated saturated/unsaturated time-dependent problems. SEEP/W and CTRAN/W must be used together.

- CTRAN/W models contaminant transport through soil and rock. Simple problems, such as tracking particles in response to the movement of water, or complex ones, such as analysing processes involving diffusion, dispersion, adsorption, and radioactive decay, can be solved. CTRAN/W and SEEP/W must be used together to analyse contaminant transport. SEEP/W computes the water flow velocity, water content, and water flux. CTRAN/W uses these parameters to compute the contaminant migration.

- MOTRANS: Numerical model for multiphase flow and transport of multicomponent organic liquids. It is a finite-element model to simulate the flow of water, dense or light non-aqueous phase liquid (NAPL) and air, and transport of up to five partitionable species in two-dimensional vertical section through saturated and unsaturated zones in Cartesian or radial co-ordinates.

- VENTING is an interactive program to estimate hydrocarbon recovery from the unsaturated zone by vacuum extraction.

- SOILPROP is a program to estimate unsaturated soil hydraulic properties and their uncertainty from particle size distribution (PSD) data.

- SPILLVOL is a program to estimate areal hydrocarbon distributions and integrated volumes from well fluid level data.

- SPILLCAD is a program for hydrocarbon spill site assessment and remedial design evaluation.

- MULTIMED: Multimedia Exposure Assessment Model, is a U.S. EPA program which simulates the transport and transformation of contaminants released from a waste disposal facility into the multimedia environment. Release to either air or soil, including the unsaturated and saturated zones, and possible interception of the subsurface contaminant plume by a surface plume are included in the model.

- PESTRAN: Pesticide Transport, is a U.S. EPA program for evaluating the transport of organic pollutants through soil to groundwater.

- BIOPLUME II is a U.S. EPA model of two-dimensional transport of dissolved hydrocarbons under the influence of oxygen-limited biodegradation. Three sources of oxygen are provided: initial dissolved oxygen in the unconfined aquifer, natural recharge of oxygen across the boundaries and vertical exchange of oxygen from the unsaturated zone.

- SWIFT/486 is a three-dimensional model to simulate groundwater flow, heat (energy), brine and radionuclide transport in porous and fractured geologic media. The primary equations for fluid (flow), heat and brine are coupled by fluid density, viscosity and porosity. In addition to transient analysis, it offers a steady-state option for coupled flow and brine.

On estuarine modelling:

- AQUASEA is a program to solve tidal flow problems in estuaries and coastal areas, wind-driven lake circulation, harbour oscillations, and problems involving transport of mass, heat and suspended solids. The model is based on the solution of the two-dimensional shallow water equations including bed resistance, wind stress, Coriolis force, and non-linear convective terms. The transport model includes sources, decay, and convective and dispersive transport.

On biodegradation:

- BIO1D is a one-dimensional modelling code which simulates biodegradation and sorption in contaminant transport. The package serves as an educational tool for understanding the relative importance of various physico-chemical and biochemical processes.

APPENDIX G:
General and Special Standards

APPENDIX G:
General and Special Standards

GOVERNMENT GAZETTE 18 MAY 1984 NO 9225

REGULATION No. 991 18 May 1984

REQUIREMENTS FOR THE PURIFICATION OF WASTE WATER OR EFFLUENT

By virtue of the powers vested in me by section 21(1)(a) of the Water Act, 1956 (Act 54 of 1956) I, Sarel Antoine Strydom Hayward, in my capacity as Minister of Environment Affairs and Fisheries, hereby prescribe the following requirements for the purification of waste water or effluent produced by or resulting from the use of water for industrial purposes.

1. SPECIAL STANDARD:

Quality standards for waste water or effluent arising in the catchment area draining water to any river specified in Schedule I or a tributary thereof at any place between the source thereof and the point mentioned in the Schedule, in so far as such catchment area is situated within the territory of the Republic of South Africa.

1.1 Colour, odour or taste:
The waste water or effluent shall not contain any substance in a concentration capable of producing any colour, odour or taste.

1.2 pH:
Shall be between 5,5 and 7,5.

1.3 Dissolved oxygen:
Shall be at least 75 per cent saturation.

1.4 Typical (faecal) coli:
The waste water or effluent shall contain no typical (faecal) coli per 100 millilitres.

1.5 Temperature:
Shall be a maximum of 25 °C .

1.6 Chemical oxygen demand:
Not to exceed 30 milligrams per litre after applying the chloride correction.

1.7 Oxygen absorbed:

The oxygen absorbed from acid N/80 potassium permanganate in 4 hours at 27 °C shall not exceed 5 milligrams per litre.

1.8 Conductivity:

1.8.1 Not to be increased by more than 15 per cent above that of the intake water.

1.8.2 The conductivity of any water, waste water or effluent seeping or draining from any area referred to in section 21(6) of the aforementioned Water Act shall not exceed 250 milli-Siemens per metre (determined at 25 °C) .

1.9 Suspended solids:
Not to exceed 10 milligrams per litre.

1.10 Sodium content:
Not to be increased by more than 50 milligrams per litre above that of the intake water.

1.11 Soap, oil and grease:
None.

1.12 Other constituents:

1.12.1 Constituents:

	Maximum concentration in milligrams per litre
Residual chlorine (as CP)	Nil
Free and saline ammonia (as N)	1.0
Nitrates (as N)	1.5
Arsenic (as As)	0.1
Boron (as B)	0.5
Total chromium (as Cr)	0.05
Copper (as Cu)	0.02
Phenolic compounds (as phenol)	0.01
Lead (as Pb)	0.1
Soluble ortho-phosphate (as P)	1.0
Iron (as Fe)	0.3
Manganese (as Mn)	0.1

Cyanides (as Cn)	0,5
Sulphides (as S)	0,05
Fluoride (as F)	1,0
Zinc (as Zn)	0,3
Cadmium (as Cd)	0,05
Mercury (as Hg)	0,02
Selenium (as Se)	0,05

1.12.2 The waste water or effluent shall contain no other constituents in concentrations which are poisonous or injurious to trout or other fish forms of aquatic life.

2. SPECIAL STANDARD FOR PHOSPHATE:

Waste water or effluent arising in the catchment area within which water is drained to any river specified in Schedule II or a tributary thereof at any place between the source thereof and the point mentioned in the schedule, in so far as such catchment area is situated within the territory of the Republic of South Africa shall not contain soluble ortho-phosphate (as P) in a higher concentration than 1,0 milligram per litre.

3. GENERAL STANDARD:

Quality standards for waste water or effluent arising in any area other than an area in which the SPECIAL STANDARD is applicable, as described in paragraph 1.

3.1 Colour, odour or taste:

The waste water or effluent shall not contain any substance in a concentration capable of producing any colour, odour or taste.

3.2 pH:

Shall be between 5,5 and 9,5.

3.3 Dissolved oxygen:

Shall be at least 75 per cent saturation.

3.4 Typical (faecal) coli:

The waste water or effluent shall not contain any typical (faecal) coli per 100 millilitres.

3.5 Temperature:

Shall be a maximum of 35 °C .

3.6 **Chemical oxygen demand:**
Not to exceed 75 milligrams per litre after applying the chloride correction.

3.7 **Oxygen absorbed:**
The oxygen absorbed from acid N/80 potassium permanganate in 4 hours at 27 °C shall not exceed 10 milligrams per litre.

3.8 **Conductivity:**

3.8.1 Not to be increased by more than 75 milli-Siemens per metre (determined at 25 °C) above that of the intake water.

3.8.2 The conductivity of any water, waste water or effluent seeping or draining from any area referred to in section 21(6) of the aforementioned Water Act shall not exceed 250 milli-Siemens per metre (determined at 25 °C).

3.9 **Suspended solids:**
Not to exceed 25 milligrams per litre.

3.10 **Sodium content:**
Not to be increased by more than 90 milligrams per litre above that of the intake water.

3.11 **Soap, oil or grease:**
Not to exceed 2,5 milligrams per litre.

3.12 **Other constituents:**

3.12.1 Constituents:

	Maximum concentration in milligrams per litre
Residual chlorine (as Cl)	0.1
Free and saline ammonia (as N)	10.0
Arsenic (as As)	0.5
Boron (as B)	1,0
Hexavalent chromium (as Cr)	0.05
Total chromium (as Cr)	0.5
Copper (as Cu)	1.0
Phenolic compounds (as phenol)	0.1
Lead (as Pb)	0.1
Cyanides (as Cn)	0.5
Sulphides (as S)	1.0
Fluoride (as F)	1,0
Zinc (as Zn)	5.0

Manganese (as Mn)	0,4
Cadmium (as Cd)	0,05
Mercury (as Hg)	0,02
Selenium (as Se)	0,05

3.12.2 The sum of the concentrations of the following metal shall not exceed 1 milligrames per litre: Cadmium (as Cd), chromium (as Cr), copper (as Cu), mercury (as Hg) and lead (as Pb).

3.12.3 The waste water or effluent shall contain no other constituents in concentrations which are poisonous or injurious to humans, animals, fish other than trout, or other forms of aquatic life, or which are deleterious to agricultural use.

4. METHODS OF TESTING:

All tests shall be carried out in accordance with methods prescribed by and obtainable from the South African Bureau of Standards, referred to in the Standards Act, No. 30 of 1982, as listed in Schedule III.

NOTE:

(a) Further information and elucidation may be obtainable from the Director-General: Environment Affairs, Private Bag X313, Pretoria, 0001.

(b) Government Notices R.553 of 5 April 1962, R.969 of 22 June 1962 and R.1567 of 1 August 1980 are hereby withdrawn.

SCHEDULE I

CATCHMENT AREAS WITHIN THE TERRITORY OF THE REPUBLIC OF SOUTH AFRICA IN WHICH WASTE WATER OR EFFLUENT MUST BE PURIFIED TO COMPLY WITH THE SPECIAL STANDARD

		Division or district
1.	Hout Bay River to tidal water	Cape
2.	Eerste River to tidal water	Stellenbosch
3.	Lourens River to tidal water	Stellenbosch
4.	Steenbras River to tidal water	Caledon
5.	Berg and Dwars Rivers to their confluence ..	Stellenbosch
6.	Little Berg River to Vogelvlei weir	Tulbagh
7.	Elands and Sonderend River to their confluence	Caledon
8.	Witte River to confluence with Breede River .	Paarl, Wellington, Worcester, Tulbagh
9.	Dwars River to Ceres divisional boundary ...	Ceres
10.	Olifants River to the Ceres divisional boundary	Ceres
11.	Helsloot and Smalblaar (or Molenaars) River to their confluence with Breede River	Paarl & Worcester
12.	Hex River to its confluence with Breede River .	Ceres & Worcester
13.	Van Stadens River to tidal water	Port Elizabeth
14.	Buffalo River from the Ciskei border to where it enters the King William's Town municipal area	King William's Town
15.	Swart Kei and Klipplaat Rivers to their confluence	Tarka, Queenstown and Cathcart
16.	Bongola River to Bongola Dam	Queenstown
17.	Kubusie River to the Stutterheim municipal boundary	Stutterheim
18.	Langkloof and Kraai Rivers to their confluence	Barkly East
19.	Little Tsomo River to the Transkei border ...	St Marks
20.	Xuka River to the Elliot district boundary ...	Elliot
21.	Tsitsa and Inxu Rivers to their confluence ...	Maclear, Mount Fletcher, Tsolo and Qumbu
22.	Mvenyane and Umzimvubu Rivers to the Transkei border	Matatiele, Mount Currie and Mount Ayliff
23.	Umzimhlara River to the Transkei border ...	Mount Currie
24.	Ingwangwana River to its confluence with Umzimkulu River	Umzimkulu, Mount Currie, Polela and Underberg

		Division or district
25.	Umzimkulu and Polela Rivers to their confluence	Underberg and Polela
26.	Elands River to the Pietermaritzburg-Bulwer main road	Impendle
27.	Umtamvuma and Weza Rivers to their confluence	Bizana and Alfred
28.	Umkomaas and Isinga Rivers to their confluence	Impendle, Polela and Underberg
29.	Lurane River to its confluence with the Umkomaas River	Polela
30.	Sitnundjwana Spruit to its confluence with the Umkomaas River	Impendle
31.	Inundwini River to the Polela district boundary	Polela
32.	Inkonza River to the bridge on the Donnybrook Creighton road	Polela and Ixopo
33.	Umlaas to the bridge on District Road 334 on the farm Maybole	Richmond
34.	Umgeni and Lions Rivers to their confluence	Impendle and Lions River
35.	Mooi River to the road bridge at Rosetta	Estcourt and Lions River
36.	Little Mooi and Hlatikula Rivers to their confluence	Estcourt
37.	Bushmans River to Wagendrift Dam	Estcourt
38.	Little Tugela River and Sterkspruit to their confluence	Estcourt
39.	M'Lambonjwa and Mhlawazeni Rivers to their confluence	Bergville
40.	Mnweni and Sandhlwana Rivers to their confluence	Bergville
41.	Tugela River to its confluence with the Kombe Spruit	Bergville
42.	Inyamvubu (or Mnyamvubu) River to Craigie Burn Dam	Umvoti
43.	Umvoti River to the bridge on the Seven Oaks-Rietvlei road	Umvoti
44.	Yarrow River to its confluence with the Karkloof River	Lions River
45.	Incandu and Ncibidwane rivers to their confluence	Newcastle

		Division or district
46.	Ingogo River to its confluence with the Harte River	Newcastle
47.	Pivaan River to its confluence with Soetmelkspruit	Utrecht
48.	Slang River and the Wakkerstroom to their confluence	Utrecht and Wakkerstroom
49.	Elands and Swartkops River to their confluence	Belfast and Carolina
50.	All tributaries of the Komati River between Nooitgedacht Dam and its confluence with and including Zevenfontein Spruit	Belfast and Carolina
51.	Seekoeispruit to its confluence with Buffelspruit	Carolina
52.	Crocodile River and Buffelskloofspruit to their confluence	Belfast and Lydenburg
53.	All tributaries of the Steelpoort River down to its confluence with and including the Dwars River	Lydenburg,Belfast, Middelburg, Groblersdal
54.	Potspruit to its confluence with the Waterval River	Lydenburg
55.	Dorps River (or Spekboom River) to its confluence with the Marambanspruit	Lydenburg
56.	Ohrigstad River to the Ohrigstad Dam	Lydenburg
57.	Klein-Spekboom River to its confluence with the Spekboom River	Lydenburg
58.	Blyde River to the Pilgrims Rest municipal boundary	Pilgrim's Rest
59.	Sabie River to the Sabie municipal boundary	Pilgrim's Rest
60.	Nels River to the Pilgrims Rest district boundary	Pilgrim's Rest
61.	Houtbosloop River to the Lydenburg district boundary	Lydenburg and Pilgrim's Rest
62.	Blinkwaterspruit to Longmere Dam	Nelspruit
63.	All streams flowing into the Ebenezer Dam on the Great Letaba River	Pietersburg and Letaba
64.	Dokolowa River to its confluence with the Poltizi River	Pietersburg and Letaba
65.	Ramadiepa River to the Merensky Dam on the farm Westfalia 223, Letaba	Letaba
66.	Pienaars River and tributaries up to Bophuthatswana boundary	Pretoria, Cullinan and Warmbad

SCHEDULE II

CATCHMENT AREAS WITHIN THE TERRITORY OF THE REPUBLIC OF SOUTH AFRICA IN WHICH WASTE WATER OR EFFLUENT MUST BE PURIFIED TO CONTAIN NO SOLUBLE ORTHO-PHOSPHATE (AS P) IN A HIGHER CONCENTRATION THAN 1,0 MILLIGRAM PER LITRE

(i) Vaal River upstream and inclusive of the Bloemhof Dam;
(ii) Pienaars and Crocodile River upstream of their confluence;
(iii) Great Olifants River upstream and inclusive of the Loskop Dam;
(iv) Umgeni River upstream of the influence of tidal water;
(v) Umlaas River upstream of its point of discharge into the sea;
(vi) Buffels River upstream and inclusive of the Bridle Drift Dam;
(vii) Berg River upstream of the influence of tidal water.

SCHEDULE III

EFFLUENT ANALYSIS : SABS STANDARD TEST METHODS

	Reference number of SABS
Ammonia - free and saline	217
Arsenic	200
Bacteriological - faecal coliform, etc.	221
Boron	1 053
Cadmium	201
Calcium hardness	216
Chemical oxygen demand	1 048
Chloride	202
Chlorine - residual	1 052
Chromium - total	1 054
Chromium VI	206
Colour	198
Conductivity	1 057
Copper	203
Cyanide	204
Fluoride	205
Hardness - total	215
Iron	207
Lead	208
Magnesium	1 071
Manganese	209
Mercury	1 059
Nitrate plus nitrite	210
Nitrite	219
Oil and grease	1 051
Oxygen absorbed	220
Oxygen demand (chemical)	1 048

APPENDIX H:
Selected Extracts from the Water Act

APPENDIX H:
Selected Extracts from the Water Act

21. Purification and disposal of water used for industrial purposes and effluent. -

(1) Any person using for industrial purposes water, including sea water brought ashore, shall -

(a) purify or otherwise treat the water so used and any effluent produced by or resulting from such use, in accordance with such requirements as the Minister may from time to time, after consultation with the South African Bureau of Standards mentioned in the Standards Act, 1982 (Act No. 30 of 1982), prescribe by notice in the *Gazette* generally or in relation to water used for any particular industrial purpose, or in relation to water or effluent to be disposed of by discharging it into any particular public stream or into the sea, or in relation to water or effluent to be disposed of in any particular aréa;

(b) after he has complied with paragraph (a) discharge the purified or treated water, including water recovered from any effluent, in a manner and subject to any such requirements as may be prescribed by regulation under section 26 -

(i) if the water so used was derived from a public stream, into that public stream at the place where such water was abstracted from the stream or at such other place as the Minister may indicate;

(ii) if the water so used was sea water, into the sea at the place where such water was abstracted from the sea or at such other place as the Minister may indicate;

(c) furnish the Director-general in writing with such particulars regarding such use and the disposal of the purified or treated water, including water recovered from any effluent, as may be prescribed by regulation under section 26.

(2) Unless the Minister otherwise directs, the provisions of subsection (1) shall not apply -

(a) in respect of the use of water in any septic tank or French drain sewerage system which complies with the requirements of any law applicable thereto; or

(b) to any person who, in accordance with an arrangement with the Minister or a local authority, body or person having authority to undertake the purification, treatment or disposal of water or effluent, discharges the water used by him for industrial purposes or the effluent produced by or resulting from such use, for purposes of the purification, treatment or disposal thereof into a canal, sewer or other conduit controlled by the Minister or the relevant local authority, body or person, as the case may be.

(3) For the purposes of subsection (1) -

(a) water used for industrial, urban or domestic purposes and which is discharged for purposes of the purification, treatment or disposal thereof into a canal, sewer or other conduit controlled by a local authority, body or person having authority to undertake the purification, treatment or disposal of water or effluent, shall be deemed to be water used by that local authority, body or person for industrial purposes; and

(b) effluent which is discharged into a canal, sewer or other conduit controlled by a local authority, body or person referred to in subsection (2)(b) shall be deemed to be effluent produced or which resulted from the use by that local authority, body or person, of water for industrial purposes.

(4) (a) The Minister may -

(i) by notice in writing to a person exempt that person; or

(ii) by notice in the *Gazette* exempt a person belonging to a category of persons, on such conditions as may be specified in the notice from any of or all the provisions of subsection (1) or of a notice or regulation contemplated therein.

(b) No exemption under paragraph (a) which may result in water or effluent which does not comply with the requirements prescribed under subsection (1)(a) being discharged into a public stream or the sea, shall be granted by the Minister except after consultation with the South African Bureau of Standards.

(c) Any person prejudiced by any exemption granted under paragraph (a) may after written notice to the Minister and in the case of an exemption granted under sub-paragraph (i) of that paragraph, also to the person so exempted, lodge with a water court an objection against the continuation of the exemption or against any matter in connection with such exemption, and the water court may, after it has enquired into and considered the exemption or other matter against which the objection is lodged, confirm or withdraw the exemption or withdraw or amend any condition to which it may be subject or substitute for such condition, or add, any new condition, or make such order in connection with such exemption as it may deem fit.

(d) If a water court in terms of paragraph (c) withdraws any exemption granted under paragraph (a)(ii) or withdraws or amends any condition to which it may be subject or substitutes for such condition, or adds, any new condition, the Minister shall, by notice in the *Gazette* and with effect from the date determined by the water court, withdraw the notice by which such exemption was granted or, as the case may be, amend such notice in order to give effect to the decision of the water court.

(e) The Minister may at any time -

(i) in the case of an exemption granted under paragraph (a)(i), by written notice to the person concerned; or

(ii) in the case of an exemption granted under paragraph (a)(ii), by notice in the *Gazette*,

withdraw such exemption or, subject to paragraph (c) render the continued validity of the exemption subject to such conditions as the Minister may then determine either by the imposition of further or new conditions or by the withdrawal or amendment of conditions then existing.

(5) Any person who contravenes or fails to comply with any provision of subsection (1) or any condition imposed under subsection (4) shall be guilty of an offence.

(6) The provisions of this section, except subsection (5), shall bind the State.
[S. 2] amended by s. 5 of Act No. 56 of 1961, by s. 3 of Act No. 79 of 1967 and by s. 3 of Act No. 42 of 1975 and substituted by s. 11 of Act No. 96 of 1984.]

22. Prevention of water pollution - (1) Any person who has control over land on which any thing was or is done which involved or involves a substance capable of causing water pollution, whether such substance is a solid, liquid, vapour or gas or a combination thereof, shall take such steps as may be prescribed by regulation under section 26 in order to prevent -

(a) any public or private water on or under that land, including rain water which falls on or flows over or penetrates such land, from being polluted by that substance, or if that water has already been polluted, from being further polluted by that substance; and

(b) any public or private water on or under any other land, or the sea, from being polluted, or if that water has already been polluted, from being further polluted, by water referred to in paragraph (a) which became polluted in the circumstances described in that paragraph.

(1A) (a) The steps prescribed under subsection (1), may include steps which have to be taken on land other than the land contemplated in that subsection: Provided that such steps may only be taken by agreement with the owner of such other land.

(b) Any person referred to in subsection (1) who is unable to reach an agreement referred to in paragraph (a) with the owner of the other land concerned, shall inform the Minister accordingly in writing.

(c) The Minister may after receipt of such a notice and after such investigation as he may deem fit -

(i) if he is convinced that the taking of the required steps on the other land concerned will be excessively onerous on the owner thereof, grant exemption from the obligation to take the step concerned to the person referred to in subsection (1), and prescribe such other steps as he may consider expedient under the circumstances; or

(ii) in terms of section 60 expropriate any property on behalf of the person concerned, or take the right to use temporarily any property which he considers necessary for the taking of the steps concerned, as if the expropriation of such property or the taking of such right is connected with a Government water work.

(d) Any expenditure connected with the expropriation of any property or the taking of any right referred to in paragraph (c)(ii), shall be recovered by the Director-General from the person referred to in subsection (1).

[Sub-s. (1A) inserted by s. 14 of Act No. 68 of 1987].

(2) (a) The Minister may -

(i) by notice in writing exempt any person; or

(ii) by notice in the *Gazette* exempt a person belonging to a category of persons,

on such conditions as may be specified in the notice, from the provisions of subsection (1) or of any regulation contemplated therein.

23. **Pollution of water to be an offence.** - (1) (a) Any person who wilfully or negligently does any act which could pollute public or private water, including underground water, or sea water in such a way as to render it less fit -

(i) for the purpose for which it is or could be ordinarily used by other persons (including the Government, the South African Transport Services and any provincial administration);

(ii) for the propagation of fish or other aquatic life; or

(iii) for recreational or other legitimate purposes,

shall be guilty of an offence.

(b) If in any prosecution under paragraph (a) it is proved that the accused committed any act which could pollute water referred to in that paragraph in any manner mentioned therein, it shall be presumed, until the contrary is proved, that the accused committed such act wilfully or negligently.

(2) The provision of subsection (1) shall not apply in respect of any act performed in accordance with section 21 or 22.
[S. 23 amended by s. 3 of Act No. 45 of 1972 and by s. 4 of Act No. 42 of 1975 and substituted by s. 13 of Act No. 96 of 1984].

23A. Prevention of pollution of water through farming operations. -
(1) If the Minister is of opinion that the concentration of any livestock or any substance or the carrying on of any farming operations of any land is causing or is likely to cause the pollution of public or private water, including underground water, he may require the owner of such land or the person carrying on such operations to take, at his own expense and within a period determined by the Minister, such steps as the Minister may deem necessary for the prevention of such pollution, and may, if such requirement is not complied with, cause the required step to be taken and the expenses incurred thereby to be defrayed out of moneys appropriated by Parliament for the purpose, and may recover such expenses from the said owner or person.

(2) The provisions of section 23(2)(b) and (c) shall *mutatis mutandis* apply in respect of any steps contemplated in subsection (1) of this section.

(3) Any person who wilfully fails to comply with a requirement of the Minister in terms of subsection (1) shall be guilty of an offence.
[S. 23A inserted by s. 3 of Act No. 36 of 1971].

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INDEX

NOTE: This index only applies to the main text, i.e. there are no references to material contained in the Appendices.

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Use of the "roadmap"

The "**roadmap**" shown opposite provides a "quick and easy" method for navigating the second part of the manual; the description of the **effluent discharge investigation**. It combines a summary table of contents with a graphic view of the basic sequence and relationship between tasks in the investigation.

The left-hand side of the roadmap shows the various **modules** into which the investigation is divided. The modules in the procedure are further subdivided into one, or more, **tasks** (shown in square boxes on the roadmap). The start of each new module and task in the manual is preceded by a **coloured title page.**

The roadmap appears at the start of each **task** in the effluent discharge section of the manual, with that particular task being highlighted on the diagram (see the example in the shaded box just below the top of the roadmap).