The management of complex industrial waste discharges

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Private Bag X313 PRETORIA 0001 Tel: (012) 808 0374 Fax: (012) 808 0338

CALL FOR COMMENT

The Department hopes that this document will stimulate active participation on introducing a new approach to managing complex industrial wastewater discharges in South Africa, especially in the light of uncertainties and the challenges of capacity-building that accompany the introduction of new approaches.

Prior to embarking on any next steps, the Department invites comment from a wide range of role players in industry, science, government and other sectors on the suggested approach to investigate, pilot and potentially implement the DEEEP methodology in South Africa.

Comment should be forwarded by 30 September 2003 to:

Director: Institute for Water Quality Studies Attention: Dr S Jooste Department of Water Affairs and Forestry Private Bag X313 PRETORIA 0001 Tel: (012) 808 0374 Fax: (012) 808 0338 Email: joostes@dwaf.gov.za

FOREWORD

Managing complex industrial wastewater discharges presents numerous challenges. This discussion document introduces a new approach and methodology: Direct Estimation of Ecological Effect Potential (DEEEP).

The Department of Water Affairs and Forestry has for the past four decades controlled water pollution by managing levels of single substances in water. However, experience shows that substance-specific methods are not in themselves able to fully assess the ecological and toxicity hazard that may be posed by complex industrial wastewater discharges. Such methods are not effective in assessing the direct environmental toxicity hazard of discharges containing mixtures of substances.

For some time now, water managers and scientists have called for a more comprehensive approach to assess in a holistic manner the potential toxicity hazard of complex industrial wastewater discharges as a means to protecting the ecological integrity of aquatic ecosystems. This call is particularly relevant in light of Chapter 3 of the National Water Act (Act 36 of 1998) which focuses on the protection of the water resource itself (see also Appendix 1 for further discussion of the regulatory context).

Indeed, with the increasing necessity for sustainable development, a number of industries in their quest to improve environmental management, to ensure compliance to regulations and to avoid or reduce unnecessary spending on treatment and disposal of wastewater, has begun to investigate more holistic methodologies for directly assessing the ecological hazard of complex industrial wastewater discharges.

This discussion document reviews the current situation related to complex industrial wastewater discharges, pointing out the current approach and methods, as well as the shortcomings and remaining challenges in protecting the ecological integrity of aquatic ecosystems. The document takes a view on methodologies that could supplement the current substance-specific methods to provide an integrated and more comprehensive picture of ecological hazard, and the advantages of such methods. In particular, it introduces the Direct Estimation of Ecological Effect Potential (DEEEM) method, which the Department believes warrants further investigation in South Africa.

The implementation of such a new methodology may seem idealistic. However, in the continuing quest to improve water resource management in South Africa, it would be irresponsible not to investigate and pilot such new methodologies and approaches. Over time, in a step-by-step fashion and in cooperation with industry, scientists, government departments and other role players, it may be possible to practically implement a more comprehensive method to manage and control complex industrial wastewater discharges in South Africa.

The Department hopes that this document will stimulate active participation and debate, especially in the light of uncertainties and the challenges of capacity-building that accompany the introduction of new approaches.

Prior to embarking on any next steps, the Department invites, by 30 September 2003, comment from a wide range of role players in industry, science, government and other sectors on the suggested approach to investigate, pilot and potentially implement the DEEEP methodology in South Africa.

BARBARA SCHREINER SENIOR EXECUTIVE MANAGER: POLICY AND REGULATION

ACKNOWLEDGEMENTS

TECHNICAL TEAM

Dr S Jooste (Author), Institute for Water Quality Studies, Department of Water Affairs and Forestry Prof C Palmer, Institute for Water Research, Rhodes University Dr A Kühn, Institute for Water Quality Studies, Department of Water Affairs and Forestry Dr P Kempster, Institute for Water Quality Studies, Department of Water Affairs and Forestry

CONTRIBUTORS

Dr H van Vliet, Department of Water Affairs and Forestry Mr M P Nepfumbada, Department of Water Affairs and Forestry Mr J L J van der Westhuizen, Department of Water Affairs and Forestry Mr P Viljoen, Department of Water Affairs and Forestry Mr L Bredenhann, Department of Water Affairs and Forestry Mr P Herbst, Department of Water Affairs and Forestry Mr J van Wyk, Department of Water Affairs and Forestry Ms T Zokufa, Department of Water Affairs and Forestry

EDITOR

Ms T Greyling, Manyaka Greyling Meiring (Pty) Ltd

PRODUCTION

Ms Bernice Smit, Manyaka Greyling Meiring (Pty) Ltd

PHOTOGRAPH

Mr Brendan Hohls, Institute for Water Quality Studies

GLOSSARY

Term	Definition
Complex industrial wastewater	The National Water Act makes a distinction between general wastewater discharge and complex industrial wastewater discharge. A complex industrial wastewater discharge contains 10 percent (by volume) or more of industrial wastewater. Complex <i>sewerage</i> wastewater discharges, which are biodegradable, are only brought into consideration in this document when discharged together with complex industrial wastewater.
Complex wastewater discharge	A discharge of wastewater of which the composition and/ or impact is not known and therefor cannot be assessed. In the present context this is assumed to equivalent to the term "complex industrial wastewater" discharge as defined in regulations (Regulation no 1191 of 8 October 1999) under the National Water Act of 1998.
DEEEP	Direct Estimation of Ecological Effect Potential. This is a battery of tests that can measure toxicity of complex mixtures based on a set of parameters stemming from the results of effects, even if all constituents are not known.
Discharge	Water containing waste released directly or indirectly to a surface water resource.
Direct toxicity assessment (DTA)	Direct toxicity assessment (DTA) refers to an approach where the effect of a substance or mixture of substances on living tissue is assessed directly. This contrasts with indirect toxicity assessment where an effect is inferred from the chemical or physical characteristics of the substance, i.e. where an indirect assessment is made.
Effluent	In this document, the terms "effluent" and "wastewater" are used interchangeably. Preference is however given to the use of the term "wastewater" since this is the term employed by the National Water Act (Act 36 of 1998).
General authorisation	A General Authorisation is an authorisation to use water without a licence provided that the water use is within the limits and conditions set out in the General Authorisation. They apply only to <i>new</i> water use that took place after 1 October 1999 when the Act was fully promulgated. General Authorisations apply "generally" which means <i>any</i> such water use that takes place <i>anywhere</i> in the country, unless in areas that are specifically excluded from a General Authorisation. A General Authorisation may also apply to a particular water resource, a particular category of persons, or a specific geographic area. The intention of the General Authorisations is to allow water use of small or insignificant impacts on a water resource to take place without a licence.
Hazard	A substance having the potential to cause an undesirable or adverse effect. In this document we refer specifically to hazard with respect to the aquatic environment but in principle this could be extended to hazard with respect to human use or any water use.

Term	Definition
Hazard assessment	In general a hazard assessment is the process by which a substance's (or mixture of substances') potential to cause harm to a target group is quantified. In most cases of ecological hazard assessment, the actual target group is the ecosystem. It is normally impossible to expose ecosystems to substances in order to estimate effects, so surrogate organisms have to be used to infer effects at the ecosystem level.
	In cases where the there is insufficient knowledge to quantify the potential to cause harm, the hazard assessment may be descriptive rather than numerical. A hazard assessment (in this definition) is distinguished from a risk assessment in that a hazard assessment describes a <i>generic expectation</i> of harm, whereas a risk assessment describes a place/situation-specific expectation of harm.
	 Substance-specific hazard assessment A substance-specific hazard assessment involves exposing a target group to an individual substance (or sometimes modelling this exposure) and then assess the potential harm to this group. Complex discharge hazard assessment A complex discharge hazard assessment involves exposing a target population to a sample of the actual discharge that needs to be assessed.
Licence	In general a water use must be licensed under the National Water Act (Act 36 of 1998) unless it is listed in Schedule I, is an existing lawful use, is permissible under a General Authorisation, or if a responsible authority waives the need for a licence. A licence or water use authorisation is a legal document that entitles a person to use water within the terms and conditions of the licence. These terms and conditions may be reviewed at a review period listed in the licence, which may be any period not more than five years.
Parameter	One of a set of measurable factors that define a system and determine its behaviour. (American Heritage Dictionary of the English Language, Third Edition, 1996).
Pollution	The alteration of either physical, chemical or biological properties of the water in a way that makes it either harmful or potentially harmful to humans, the ecosystem or resource quality in general (section 1 (xv) of the National Water Act).
Risk	The likelihood of experiencing a specific undesirable effect.
RIZA	Rijksinstituut voor Zoetwaterbeheer en Afvalwaterbehandeling (Institute for Inland Water and Waste Water Treatment, in the Netherlands)
ТЕМ	'Totale Effluent Milieuhygiene' [in Dutch] or 'Whole Effluent Environmental Risk' methodology. TEM is one example of a DEEEP system.
Water resources	Chapter 1.(1) of the National Water Act defines a water resource as: "a watercourse, surface water, estuary, or aquifer". The National Water Act defines <i>water resources</i> as entire natural systems associated with water (rivers, lakes, wetlands, aquifers, estuaries and the coastal marine environment) and includes water itself, sediments, as well as the associated biota (e.g plants, animals and micro-organisms). The aquatic ecosystem is an important part of the resource.

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1. INTRODUCTION

As with many of the new strategies currently being developed and implemented in South Africa to give effect to the country's new National Water Policy and National Water Act (Act 36 of 1998), the management of complex industrial wastewater discharges is an evolving one. As shortcomings in existing approaches and methods are being pointed out, new approaches and methods are investigated and piloted, and, if found to be feasible, practically implemented. Two recent examples where development of methodologies and human resource capacity took place in tandem with pilot implementation and then implementation, are the *River Health Programme* and the resource directed measures specified in Chapter 3 of the Act.

The management of complex industrial wastewater discharges is challenging. Whereas substancespecific methods are available to assess the toxicity hazard of single substances and are being used in South Africa, experience shows that these are not in themselves able to fully assess the ecological and toxicity hazard that may be posed by complex industrial wastewater discharges. For some time now, water managers and scientists have called for a more comprehensive approach to assess in a holistic manner the potential toxicity hazard of complex industrial wastewater discharges as a means to protecting the ecological integrity of aquatic ecosystems.

This discussion document looks at the existing situation and its shortcomings and problems, and takes a view on how such shortcomings may be resolved in the future, fully recognising the challenges of implementation of a new approach and methodology.

The focus of the document is on the management of complex *industrial* wastewater discharges. Complex *sewerage* wastewater discharges, which are biodegradable, are only brought into consideration when discharged together with complex industrial wastewater. The aim is to expand the application to *all water* containing waste eventually.

1.1 STRUCTURE OF THIS DOCUMENT

The document first, in Chapter 2, provides the rationale for a holistic assessment of the toxicity hazard of complex industrial wastewater discharges.

Chapter 3 then introduces the Direct Estimation of Ecological Effect Potential (DEEEP) Method, which the Department of Water Affairs and Forestry believes may be useful and which may warrant further investigation in South Africa.

Chapter 4 presents proposals on how the DEEEP method could potentially be practically implemented in South Africa in a step-by-step fashion over time, in cooperation with industry, scientists, government departments and other role players.

Lastly, the document calls for comment on these proposals and on the uncertainties and challenges that are pointed out throughout the document.

2. RATIONALE FOR A HOLISTIC ASSESSMENT OF THE TOXICITY HAZARD OF COMPLEX INDUSTRIAL WASTEWATER DISCHARGES

The National Water Act implicitly requires that regulators make informed assessments for effective management (see Appendix 1 for the policy and regulatory context). Before a user may be allowed to discharge wastewater, the effect of that wastewater on the environment must be assessed (sections 21 and 22 of the Act). An *effect assessment* would be any (but preferably quantitative) information on how a substance or sample would affect the quality of the water resource or any part of it.

Water quality or waste discharge standards such as the *General and Special Standards*, and more recently the *General and Special Limit Values on Waste Discharges*, are usually based on data relating to the effects of single substances. This approach to water quality assessment is referred to as the substance-specific approach.

This section provides some background on the current substance-specific approach to assess the toxicity hazard of complex industrial wastewater discharges, then discusses the limitations of the substance-specific approach supported by case examples, and lastly lists the advantages of more holistic assessment of toxicity hazard that focus on the potential effect of the substance, rather than on the substance/s itself.

2.1 THE SUBSTANCE-SPECIFIC APPROACH

For the past for decades, the regulatory approach in South Africa was to prevent hazardous substances above certain concentrations from entering the aquatic environment. Analysis to assess the potential hazard of such substance/s are chemical in nature, and based on the knowledge of:

- the composition of the discharge (most usually the chemical composition)
- the known effect of each known substance on some component of the ecosystem.

Such substances are then targeted in management action. In several countries in Europe and North America, the substance-specific approach has produced lists of chemicals targeted for special management action (the so called 'black' or 'red' lists). The lists are usually based on toxicological criteria. Substances that 'fail' on these criteria are included in a list. 'Safe' levels of the listed substances are then given. In South Africa, waste discharge limits are outlined in the General Authorisation (Regulation no 1191 of 8 October 1999) (see Appendix 2 to this document).

2.2 LIMITATIONS OF THE SUBSTANCE-SPECIFIC APPROACH

There are instances where the effect of a discharge is strongly dominated by a single substance (such as a salt). In such cases, the substance-specific approach serves a key purpose.

There are numerous cases where serious ecological toxicity effects manifest not as a result of single substances, but as a result of a mixture of the substances. The listed substances in Appendix 2 in General Authorisation no 1191 of 8 October 1999 have the potential to cause an ecological hazard but there are many more besides those. The problem is that the list is practically endless, at least in terms of the current knowledge on ecological hazards.

The substance-specific approach is not effective in holistically assessing the complete environmental hazard of discharges containing mixtures of substances, e.g. complex industrial wastewater discharges, where the composition of the discharge is often not known. In particular, the results of substance-specific assessments are based on indirect or inferred information, and do not directly assess the potential effect or impact. Limitations of the substance-specific approach are as a result of the following:

- The success of the substance-specific approach in discharge management depends on knowledge of the composition of the discharge and knowledge of the effect of each component of the discharge. In complex waste discharges either, or both, of these may be missing.
- Only a limited part of the effects of complex waste discharges in water bodies can be explained in terms of chemical analyses of water.
- There are discharges for which chemical characterisation may not be possible since some of the components are not known
- Where a large number of substances in the mixture are indeed known, the substance-specific approach often is not cost-effective due to the number of assessments that have to be conducted.
- Because of its complexity, the effect of a complex discharge is difficult to assess by inference, as is done by using substance-specific assessments. When substances occur in a mixture, they can interact and behave very differently from the individual substances. In other words, complex mixtures do not respond like single substances. Complex mixtures can have substantially different environmental effects than the sum of individual substances.

- Of the several million substances that are known, only a few thousand have been characterised toxicologically. Therefore, the effects of the majority of substances in complex mixtures are unknown even if they can be identified.
- Discharges that are treated biologically (as is the case with many sewerage discharges) often result in changes in chemical composition. These changes may result in mixtures that are difficult to characterise, although the original mixture may have been relatively simple. Thus, new mixtures can be formed in wastewater that are either difficult or impossible to characterise.
- Some substances display significant toxicity at levels that are so low that chemical analyses cannot detect them. Unless information exists beforehand that such substances might occur in a discharge, it's not worth the time or money to search for them routinely.
- Although toxicity underpins the substance-specific approach, limitations result from an oversimplification of the toxicological and environmental processes that contribute to ecological hazard.

Chemical substance-specific limits or criteria that depend on chemical analysis for control of impacts are therefore of limited use in authorising and controlling the environmental consequences of the discharge of complex mixtures.

2.2.1 Cases in point

Because substance-specific assessments are based on indirect or inferred information, and do not directly assess the potential effect or impact, they have proven to be ineffective in fully assessing the impacts on water quality. A case in point is spatially localised sources of hazardous substances that may leach from a landfill site. In a recent case in the Netherlands, a sample of leachate was taken from a landfill after concerns were expressed. The complex mixture of chemicals in the sample proved to be impossible to analyse within the time frame in which the assessment was necessary. A simple selection of toxicity tests indicated that there was some transient lethality associated with this leachate, and that there might have been a more serious long-term impact, but this could not be determined conclusively based on the measurement of single substance.

In KwaZulu-Natal an industrial sea-discharges has been monitored using toxicity assessment techniques for a number of years. The response of sea-urchins has been used to assess the possible impact of the discharge on the marine environment.

Another example is that of sewage discharges. Several *ad hoc* South African studies on the discharges of municipal waste-water treatment plants showed that the process of disinfecting the discharge also made it more ecologically hazardous. Both short-term lethality and longer-term effects such as decreased fertility and possibly tumour induction were detected in these discharges although they complied with the substance-specific discharge requirements. A KwaZulu-Natal study found evidence of impacts on aquatic organisms downstream of chemically compliant sewage treatment works. In an intensive 1997 study of 10 effluents in the Netherlands, 25% of all effluents were found to be acutely toxic. Two of three discharges evaluated for all hazard parameters showed significant ecological hazard. There might be two reasons for these findings:

- Sewage treatment plants need to ensure that they kill all pathogenic microbes. They may use strong chemicals to achieve this, thereby producing an ecological hazard. Normally this hazard should be of short duration.
- Sewage treatment plants often receive effluents from a wide variety of sources, both domestic and industrial. Some substances may not be neutralised by treatment and may continue to pose an ecological hazard.

Water is being used extensively to carry many different types of industrial and household waste. Being a good solvent, water tends to display a complex composition as part of wastewater. In principle, therefore:

• All wastewater should be viewed as complex mixtures.

• Only a limited part of the effects of complex waste discharges observed in water bodies can be explained in terms of chemical analyses. Chemical substance-specific limits are thus of limited use in authorising and controlling the environmental consequences of complex chemical mixtures.

Any approach that can *directly* assess the environmental toxicity hazard of complex wastewater discharges on water resources would be an extremely valuable regulatory tool.

2.3 ADVANTAGES OF WHOLE WASTEWATER DISCHARGE ASSESSMENTS

Given the limitations of substance-specific assessments, and the risk of allowing ecological toxicity hazards to go unchecked, water resource managers and scientists have for some time now called for methodologies that will allow more complete assessment of ecological toxicity hazard, to be used in addition to the substance-specific approach.

The advantages of whole wastewater discharge assessment methodologies that can provide an *effect-specific assessment of the whole effluent* in contrast to an assessment based on a limited number of substances where the effect is inferred, are the following:

- Substances in complex discharges need not be assessed individually as to their ecological hazard. This obviates the need for knowing exactly which substances are present, and circumvents the costs of having to conduct numerous substance-specific assessments.
- Direct information on the total hazard (the potential for adverse effect) of the mixture as a whole is provided by way of assessing so-called *effect parameters*.
- The potential for combined working of the components of the mixture is included in the parameters.
- The method provides important information for known substances for which the effects are unknown.
- Whole wastewater discharge assessments do not depend on chemical analysis. Therefore, inability to detect dangerous substances will not invalidate the assessment since their effect is included in the effect parameters that are being assessed.

3. ASSESSING HAZARDS BASED ON EFFECTS: DIRECT ESTIMATION OF ECOLOGICAL EFFECT POTENTIAL (DEEEP)

Effect-based hazard assessment methodologies are able to provide insight into the combined effect of the mixture of both the known and the unknown hazardous substances in a complex discharge. The potential effects of the complex discharge are assessed directly, rather than being inferred based on the assessment results for a single substance.

There are many instances where the potential ecological effect is not apparent from data obtained through chemical analysis of single substances. Therefore, *additional methodologies* that are able to assess the potential impacts resulting from the whole wastewater discharge are required to provide an *integrated assessment of potential effects (or hazard) of waste discharge.*

The intention is not to replace substance-specific assessments, but to supplement them with assessments that can *directly* measure the potential effect of complex mixtures when the composition of the discharge is not known. Figure 1 illustrates how integrated discharge hazard assessment can be achieved using a combination of the substance-specific (or indirect) and effect-based (or direct) assessment approaches.

Internationally, various direct hazard assessment methodologies are available from across the world. These methodologies, as well as hazard parameters and tests available internationally, are discussed in Appendix 3 and were assessed for their potential applicability in South Africa.

One such methodology was found to be particularly promising. The TEM methodology ("Totale Effluent Milieuhygiene" or "Whole Effluent Environmental Risk") was developed in the Netherlands. Its

development took place in the nineteen nineties by RIZA, the Dutch Institute for Inland Water and Waste Water Treatment. The parameters and tests it uses to assess the hazard parameters are now well known internationally and well established in the scientific community. TEM includes a combination of parameters and tests and represents a suite of methodologies. This approach yields the kind of ecological hazard assessment that is required in South Africa, because:

- The TEM approach is sufficiently flexible to be adapted to local circumstances and to available capacity for conducting the necessary tests and applying the required parameters. Therefore, the proposal is to use TEM as a foundation for a South African direct hazard assessment, to be known as Direct Estimation of Ecological Effect Potential (DEEEP).
- The DEEEP methodology is conceptually well thought out and developed, and represents the culmination of 30 years of such development in the Netherlands, USA and UK. It is well tested and has been shown that it can be practically implemented. Hence, the Department believes it merits further investigation as a useful additional tool in the management and control of complex waste discharges.
- DEEEP's main attraction is that it provides a fairly direct ecological hazard assessment of known and unknown mixtures of substances. It can assess the ecological (and maybe even the human health) hazard of discharges within a coherent system of hazard parameters. Thus, it can provide the second of two legs in integrated hazard assessment (see Figure 1).
- DEEEP is equally useful in the assessment of complex industrial discharges, treated sewage point discharges and localised diffuse sources. It can be used by the regulator and the discharger alike to demonstrate environmental care.

The Department of Water Affairs and Forestry, as public trustee of the nation's water resources, has the mandatory function to protect water resources. Consequently, any suitable measure that will highlight ecological hazard of complex industrial discharges could be used in fulfilling this mandatory function. DEEEP would clearly fall in this category. As an assessment methodology, DEEEP is particularly attractive to the Department, since it is able to provide an up-front indication of the potential hazard of the discharge.

Appendix 4 provides a technical guide to DEEEP, explaining the DEEEP methodology, and the approach to selecting ecological hazard parameters and tests to assess each parameter. Appendix 5 discusses the current status of parameters and tests in South Africa for oxygen demand, acute and chronic toxicity, mutagenicity, bio-accumulation and persistence potential, refinement required for their implementation and the introduction of new hazard parameters. It also outlines assessment criteria and guidelines.

Below, we outline the advantages of the DEEEP methodology, the goals for its further refinement, and several factors towards implementing the methodology in South Africa.

3.1 ADVANTAGES OF DEEEP

Due to the suite of parameters and tests from which to choose, the DEEEP methodology can be practically implemented in South Africa in a step-wise fashion over time.

The advantages of using DEEEP include:

- Substances need not be assessed individually as to their ecological hazard.
- Effect parameters provide direct information on the hazard (the potential for adverse effect) of the mixture.
- The potential for combined working of the components of the mixture is included in the parameters.
- The effect of unknown substances is also included, as is the effects of known substances for which the effects are unknown.
- The assessment does not depend on chemical analysis. Therefore, inability to detect dangerous substances will not invalidate the assessment since their effect is included in the hazard parameters.

Due to the suite of parameters and tests from which to choose, the DEEEP methodology can be practically implemented in a step-wise fashion over time.

Note that the assessment of truly diffuse sources (such as polluted groundwater percolating into a stream) will not benefit from DEEEP any more than from a substance-specific approach. However, where spatially localised sources of hazardous substances are found (such as a landfill site) DEEEP will provide a better overall view of the environmental hazard than a substance-specific approach.



Figure 1. Approaches to discharge hazard assessment, using a combination of the substance-specific and complex discharge hazard assessment approaches. The blocks indicated by dotted lines are not elaborated on in this proposal.

3.2 GOALS FOR FURTHER REFINEMENT

The field of ecological hazard assessment is evolving and dynamic. The goal is to develop viable methods that will contribute to a more complete understanding of the hazards posed by complex waste discharges. The following should be considered:

- Are the methods practical?
- Are they reliable and 'transportable' between laboratories?

- Are they affordable?
- Do they contribute to understanding of the ecological hazard?
- Can they relate to the resource quality objectives?

Parameters, their evaluation techniques and and sampling design will need to be updated from time to time. The impetus for updating may come from desktop studies, laboratory or field observation, or from field practice. Development will be stimulated by specific questions from the Department of Water Affairs and Forestry, Catchment Management Agencies, industry, practitioners in the field of hazard assessment, or academics. In general, research and development in South Africa in this field could focus on three main themes:

- Improving the environmental realism of tests, in other words improving the reality of tests
- Improving affordability
- Capacity building.

Despite extensive studies, there are still some uncertainties around the interpretation of the hazard parameters in terms of threats to the environment. In order to fulfil its obligation as public trustee of the country's water resources, the Department of Water Affairs and Forestry will take a precautionary approach and will therefore select conservative assessment criterion values. At the same time, the department recognises that situations may arise where a conservative approach may not serve the wider community. In these cases risk-based decisions rather than hazard-based decisions may be called for. DEEEP is considered a first step toward more realistic (and also more information-rich) ecological risk assessment.

3.3 CURRENT CAPACITY TO IMPLEMENT THE METHODOLOGY IN SOUTH AFRICA, AND CAPACITY BUILDING FOR IMPLEMENTATION

A number of the DEEEP tests are already being performed in South Africa. In addition, there has been a groundswell in some quarters to the new approach:

- In 1999 a group of researchers and practitioners established the AQUATOX Forum. The Forum currently has more than 50 members. Among the Forum's goals is capacity building in the aquatic toxicity assessment community and standardisation of methodology.
- The Water Research Commission has funded some research in aquatic toxicology. This has resulted in building the capacity of the researchers involved in the techniques that were researched.
- There was sufficient interest in aquatic toxicity to establish the private-sector funded Unilever Centre for Environmental Water Quality at Rhodes University in Grahamstown.
- A number of industries in their quest to improve environmental management, to ensure compliance to regulations and to avoid or reduce unnecessary spending on treatment and disposal of wastewater, have begun to investigate more holistic methodologies for directly assessing the ecological hazard of complex industrial wastewater discharges.

Despite these initiatives, the investment in aquatic toxicity assessment remains low. A number of researchers and water resource managers have expressed the need for further stimulus and facilitation to be provided by the Department of Water Affairs and Forestry. With this Discussion Document, the Department hopes to provide such stimulus, and in particular in response to the benefits of early hazard detection and prevention as outlined in this document.

4. HOW THE DEEEP METHODOLOGY COULD POTENTIALLY BE PRACTICALLY IMPLEMENTED IN SOUTH AFRICA

Neither the technology nor the capacity currently exists in South Africa to fully implement a new approach such as DEEEP immediately. Indeed, components of the methodology could take some years to reach fruition. Nevertheless, the DEEEP methodology is flexible, and allows for

implementation in a step-by-step fashion over time, gradually increasing in usefulness and environmental realism, and allowing for capacity building.

Furthermore, a gradual introduction to the DEEEP methodology would allow time for dischargers of complex wastewater to develop capacity to perform DEEEP and for it to become part of their discharge management process, and would allow time for the regulator to assimilate DEEEP into the regulatory process.

Figure 2 outlines a model for step-by-step implementation, described in the sections below. Finally, a vision for a tiered approach to the management and control of complex wastewater discharges once DEEEP is implemented, is presented.



Figure 2. A model for step-by-step implementation of the DEEEP methodology in South Africa

4.1 KEY SUCCESS FACTORS FOR IMPLEMENTATION

Many lessons have been learned locally and internationally in the implementation of new approaches, methodologies or programmes. The implementation in South Africa of the *River Health Programme* (the National Aquatic Ecosystems Bio-monitoring Programme), which took place over a period of eight years, provided some important lessons. Initial stimulus and funding was provided by the Department of Water Affairs and Forestry. The programme required cooperation between national and provincial government, parastatals, universities and research institutions, water and waste management institutions, consultants, the private sector and other role players, went through a pilot phase, developed new approaches and methodologies for biomonitoring, worked on standardising methodologies, and is still evolving.

The following are key success factors to bear in mind in the implementation of the DEEEP methodology:

- Develop at an early stage mechanisms for networking, coordination and capacity-building
- Taking small steps, and being satisfied with small successes, especially initially.
- Focus on those areas where there is capacity and which are cost-effective
- Assign a champion or facilitator to provide ongoing stimulus and encourage networking.
- Provide opportunities for face-to-face interaction of those involved, e.g. meetings or other events.
- Regular reporting of new initiatives and progress/successes to all those involved or potentially involved.

- Innovation in test methodologies to be balanced by standardisation of tests to ensure efficient law enforcement.
- Co-operation between the public and private sectors and academics in terms of financial support, manpower requirements, capacity building and logistical support.
- Responsiveness to research and development results.
- Linkages with related aspects of the regulatory process, some of which are in themselves still evolving and being refined e.g. the suite of resource-directed measures, biomonitoring, water use authorizations etc.

4.2 DELIBERATING AND REFINING THE IMPLEMENTATION APPROACH THROUGH CONSULTATION

Prior to any next steps, the tentative approach to implementation contained in this Discussion Document needs to be deliberated and defined.

4.2.1 Objectives

During the consultation stage, the objective is for a range of role players to pool their collective experience and knowledge to achieve the following:

- establish a database of all potential contributors
- develop mechanisms for cooperation and networking, including ongoing communication with participating organisations
- identify mechanisms for knowledge transfer and capacity building
- identify potential contributing agencies and funding models
- deliberate the feasibility of testing for a range of parameters
- recommend test protocols
- compile an inventory of available capacity in the country
- deliberate the curatorship of the data gathered during the testing and pilot implementation phases.

In addition, the practicalities of integrating the methodology with the current hazard assessment approach should be deliberated within the Department of Water Affairs and Forestry and its Regional Offices. Furthermore, the value of the DEEEP methodology and the practicalities of integrating it with regulatory procedures in the management and control of complex industrial wastewater should be deliberated.

4.2.2 Process

This Discussion Document will be widely distributed to national, provincial and local government, parastatals, universities and research institutions, professional bodies, consultants, the private sector (mining, industry and other), water and waste management institutions and other role players. Written comment is invited. In addition, role players are encouraged to find opportunities to discuss the proposals amongst themselves and make recommendations for how implementation could best be achieved in a step-by-step fashion.

Should there be a need, the Department will, during the latter half of 2003, arrange a national workshop during which recommendations can be collated, and the current tentative implementation design refined.

4.3 **TESTING THE METHODOLOGY**

4.3.1 Objectives

The objectives of this phase are to:

- test those components of the methodology that are readily available, for which there is capacity and which can be achieved in a cost-effective manner
- introduce the methodology to a wide range of role players
- effect knowledge transfer

- commence with capacity building through workshops and incorporating aspects of the DEEEP methodology into applicable training courses such as the Unilever Centre for Environmental Water Quality (Rhodes University) Applied Aquatic toxicology course or the CSIR course on aquatic toxicology (a more extensive list of training provided will be generated in due course)
- develop a DEEEP-specific short (one-day) course
- establish a database on the performance of methods and response of discharges.

4.3.2 Process

This phase will be facilitated by the Department of Water Affairs and Forestry. At this early stage, the assistance and cooperation of a small group of major wastewater dischargers will be enlisted, in particular those that have already starting implementing toxicity-based hazard assessments.

In terms of testing the methodology, it is envisaged that the following will be done during this phase:

- DWAF through the Directorate: Resource Quality Services (previously known as the IWQS) will establish the tests for the various parameters in its own laboratories and start evaluating them on real discharge samples. At the same time the sampling methodology will be investigated.
- Dischargers may on a voluntary basis co-operate in this process by helping with the sampling and sharing chemical and toxicity information with the research team. The emphasis will be on the scientific information exchange.
- Introduce the DEEEP method to DWAF offices and industry through meetings and workshops as needed. The feedback may be used by water quality managers to plan the pilot implementation.
- A database in the performance of the DEEEP tests on discharges will be established at the D:RQS. With the co-operation of the dischargers, these data sets will include the data supplied by other practitioners outside the D:RQS and will be the germinal data on which inter-laboratory performance of the selected tests can be evaluated. These data will be an important contribution to the refinement of the tests assessment criteria.

During this phase, the foundation will be laid for capacity building. It is envisaged that a multistakeholder workshop will be held to:

- introduce the methodology in more detail to a range of role players
- share experiences
- contribute to the assessment of the performance of methods
- firm up the approach to pilot implementation.

In addition, once developed, a DEEEP-specific short course can be presented to participating organisations and dischargers of complex industrial wastewater and applicable training courses such as those mentioned under 4.3.1 can be presented with DEEEP as a component of the course.

The gradual implementation of the DEEEP approach would allow dischargers of complex industrial wastewater to build sufficient capacity before full implementation of the methodology, at which stage conditions to water use licenses would be informed by the results of the DEEEP methodology.

4.4 **PILOT IMPLEMENTATION**

Pilot implementation can commence once a fair number of components of the methodology have been tested and are sufficiently stable to be implemented on a pilot scale.

4.4.1 Objectives

If found feasible, the DEEEP methodology would become a decision-making tool in the control and management of complex industrial waste discharges. Thus, the objectives of pilot implementation will be:

• to test the application of the methodology in practice

- to test the application of the results of the methodology to water use authorization instruments such as licensing and license conditions
- to link with other DWAF intiatives (such as the Stategic Framework for Monitoring Water Resource quality)
- to design a specialised Aquatox database
- to develop standards for the DEEEP tests
- to continue with knowledge transfer and capacity building
- to firm up the approach to full implementation, including the development of criteria for selecting the first group of dischargers that will be required to implement the methodology during full implementation, should it be found feasible during pilot implementation.

4.4.2 Process

In order to achieve the above objectives, the Department will identify and invite an initially small group of dischargers of complex industrial wastewater to participate in pilot implementation on a voluntary basis, and without applying the results of the methodology to regulatory controls. This group could be expanded as pilot implementation gets underway.

Participating dischargers will be invited to submit data to the Department in an agreed format. The data could be used to develop standards and criteria for the ecological hazard assessment of waste discharges. At the same time, it would probably be necessary to design a specialised Aquatox database (in much the same way as the specialised *River Health* database), and that will still have to be designed to mesh with both the needs of the Department's WARMS data base and scientific requirements (such as maximum information potential).

Knowledge transfer and capacity building will continue during pilot implementation through workshops, discussion groups and training courses. It may at this stage be useful to develop a diploma course in aquatic toxicity testing at a suitable Technikon or other tertiary institution. In addition, it is proposed that pilot implementation be coupled with an annual one-day conference with invited papers on the results of pilot implementation both in terms of testing the methodology in practice and the potential application of the results of the methodology to water use authorisation.

Issues which would need to be addressed during this phase include:

- accreditation of laboratories
- participation in the performance testing audit co-ordinated by the AQUATOX forum
- evaluation and upgrading of the required suite of tests.

4.5 FULL IMPLEMENTATION

Full implementation of the DEEEP methodology, if found feasible during the pilot implementation stages, could in itself be a staged process commencing with an initially small group of dischargers of complex industrial wastewater, and expanding the group over time.

Criteria for selecting the first group of dischargers that will be required to implement the methodology during full implementation will have been deliberated during pilot implementation stage, but could include the following:

- Where the complex industrial discharge contains known or suspected ecological hazards based on the results of substance-specific assessments
- Where biomonitoring results have indicated impacts on ecological integrity of water resources
- Where during pilot implementation has raised red flags.

During full implementation, the results of the DEEEP methodology would have to be clearly linked to and integrated into other aspects of the regulatory process, such as the development of in-stream water quality objectives and river health monitoring. Evaluation of the DEEEP methodology should be at biologically appropriate time scales, e.g. an annual cycle for invertebrates and three to five years for fish. This linked biomonitoring-bioassay approach lends itself to integration with the water resource classification process and the determination of the ecological Reserve.

4.6 WHAT IS EXPECTED FROM DISCHARGERS?

To many dischargers, DEEEP may be conceptually novel to the point of appearing overwhelming. Some Do' and Don't's may help to guide the first-time reader:

DO

- Try to understand the principles behind DEEEP to the extent necessary to make informed decisions but do not (at least initially) try to understand all the technical detail.
- Keep in mind the analogies and differences to chemical analyses
- Investigate the feasibility of performing DEEEP tests in-house as opposed to outsourcing

DON'T

- Pre-judge either the advantages or disadvantages of the DEEEP approach or its components
- Be swayed by "experts" disagreements or media hype. Although the fundamental technology is sound, we still need to learn about the application of the technology and the interpretation of the results in South Africa.
- Expect sudden radical changes in water quality management policy or practice. Rather expect a gradual evolution of a new paradigm.
- Over- or under estimate the technical complexity of ecological hazard assessment. The assessment of real situations is invariably more complex than those of idealised situations, but decades of international experience provides good guidance.

5. CALL FOR COMMENT

The Department hopes that this document will stimulate active participation in introducing a new approach to managing complex industrial wastewater discharges in South Africa, especially in the light of uncertainties and the challenges of capacity-building that accompany the introduction of new approaches.

Prior to embarking on any next steps, the Department invites, by 30 September, 2003, comment on the suggested approach to investigate, pilot and potentially implement the DEEP methodology in South Africa from a wide range of role players in industry, science, government and other sectors.

Comment should be forwarded to:

Dr S Jooste Institute for Water Quality Studies Department of Water Affairs and Forestry Private Bag X313 Pretoria, 0001

Tel: (012) 808 0374 Fax (012) 808 0338 Email: joostes@dwaf.gov.za

APPENDIX 1 POLICY AND REGULATORY CONTEXT

This Appendix briefly outlines the current policy and regulatory context in South Africa, with specific reference to complex industrial wastewater discharges and the protection of water resources. This document primarily considers the ecological context, but the scope of application of DEEEP may encompass all water users.

1. THE NATIONAL WATER ACT AND THE PURPOSE OF THE ACT

The Department of Water Affairs and Forestry, as public trustee of South Africa's water resources in accordance with the National Water Act (Act 36 of 1998), has the mandate to manage water resources in a sustainable manner. In particular, the Department must act in the public trust to ensure that water is *protected, used, developed, conserved, managed and controlled* in a sustainable and equitable manner, for the benefit of all persons.

The National Water Act defines *water resources* as entire natural systems associated with water (rivers, lakes, wetlands, aquifers, estuaries and the coastal marine environment) and includes water itself, sediments, as well as the associated biota (e.g plants, animals and micro-organisms). The aquatic ecosystem is an important part of the resource.

The purpose of the Act includes the promotion of efficient, sustainable and beneficial use of water in the public interest (section 2 (d)), meeting the basic human needs of present and future generations (section 2 (a)), protecting aquatic and associated ecosystems and their biological diversity (section 2 (g)) and reducing and preventing pollution and degradation of water resources (section 2 (h)).

The Act is based on the principles of sustainability, efficiency, and equity, meaning that protection of water resources must be balanced with their development and use. Thus, the ultimate aim of water resource management is to achieve sustainable use of water, not total protection. This requires that water resources be safeguarded from over-use and from impacts which will cause degradation.

2. PROVISIONS FOR MANAGEMENT AND CONTROL OF WASTEWATER DISCHARGE

Section 21 of the Act defines eleven water uses, including the discharge itself (section 21(f)) and the manner of discharging waste or water containing waste (section 21(h)).

Water use is controlled and regulated through Chapter 4 of the Act, which outlines permissible water use and all matters pertaining to authorisation of water use. The Act classifies water uses according to the potential of impact they may have on water resources, and provides the regulatory framework for managing these risks. Generally authorised uses are those with a low potential of unacceptable impacts and such users do not have to apply for a licence. Licensed uses are those activities, if not controlled, that would have a high potential of unacceptable impact, such as discharging waste into a water course. Such users *must* apply for a license to use water. Licenses are subject to conditions, including conditions that specify the quality of water containing waste being discharged or disposed of in order to maintain the requirements of the resource. License conditions can also specify the monitoring that must take place once the water use commences.

Section 22 of the Act specifies two important conditions under which a person may discharge wastewater: if it is permissible in terms of a general authorisation, or, if it is licensed. In Regulation No 1191 of 8 October 1999 pertaining to the general authorisation of the discharge of wastewater, complex industrial wastewater is specifically excluded from the authorisation. In other words, the Regulations make a distinction between *general* wastewater discharge and *complex* wastewater discharge. It is arbitrarily assumed that a complex wastewater discharge contains 10 percent (by volume) or more of industrial water. Thus, the discharge of complex industrial wastewater is not generally authorised. Such users *must* apply for a license.

Read together, Sections 21(f) and 22(1) of the Act provide the primary context of this document, i.e. the authorisation and control of complex industrial waste discharges insofar as it affects impacts on the aquatic ecology.

3. PROTECTION OF WATER RESOURCES

For the past four decades, water pollution has been controlled in South Africa by managing levels of single substances in water. Like many other countries, South Africa protected water quality largely by controlling the concentrations of individual pollutants through the so-called end-of-pipe controls. Now, the Act makes provision for two inter-dependent but complementary strategies of *resource-directed measures* and *source-based controls* to protect water resources.

Resource-directed measures

provide the requirements for ecologically sustainable use of water resources eg. resource classification, the Reserve and resource quality objectives.

Source-based controls

ensure the requirements of the Resource-directed Measures are met through controlling (regulating) sources of impacts, e.g. water use authorisations and licences and regulations such as waste discharge standards.

3.1 Resource-directed measures

Resource-directed measures are directed at the water resource itself. They focus on the water resource as an ecosystem rather than on just water itself as a commodity. The following resource-directed measures are specified in Chapter 3 of the Act:

- a national classification system for water resources
- determining a management class for each resource
- determining the Reserve to provide for basic human needs and ecological needs
- setting resource-quality objectives to represent the desired level of protection of a water resource.

3.2 Source-based controls

Pollution is not the introduction of substances into the resource *per se*, but the introduction of substances to a level beyond which the resource would no longer be ecologically sustainable or fit for human consumption or for use by the various sectors of water users. *Pollution* refers to the alteration of either physical, chemical or biological properties of the water in a way that makes it either *harmful or potentially harmful to humans*, the *ecosystem or resource quality* in general (section 1 (xv) of the Act).

Source-based controls are used to control the sources of impacts in such a way that any impact on a water resource does not exceed the requirements set by the resources-directed measures. They control the impacts that the different kinds of uses of water have on water resources and include a wide range of measures such as:

- standards to regulate the quality of waste discharges to water resources (the so-called end-of-pipe quality)
- requirements for on-site management practices (e.g. to minimise waste at source and to control diffuse pollution)
- requirements to minimise impacts of water use generally, not just water quality aspects
- requirements for clean-up and rehabilitation of water resources that have already been polluted.

For example, Section 26 of the Act allows for regulations specifying not only *waste standards*, but also what *outcome or effect* must result from the treatment of a discharge. It can require the *assessment of the likely effect* on the quality of the water resource. The rationale for the use of the proposed methodology rests in what the general authorisations and licences should consider:

- The characteristics of the waste (Section 26(1)(h)) and the outcome or effect of its treatment (Section 26(1)(i)).
- The likely effect of the water use on the water resource and other users (Section 27(1)(f)).

Both of the above require *the effect* to be assessed. The currently-used control measures are primarily based on the assessment and management of *causes*. This is quite acceptable as long as the link between cause (for example pollution) and its effects remains clear. Some of the problems in establishing and maintaining this link were alluded to in Section 2.2. Either the sample becomes too complex to analyse or the substances detected have no effect data as yet, or the mixture acts in a way that cannot be gauged from knowledge of the composition alone. In any case, a technique that establishes a more direct link between the source of, for example, a pollutant, and its effect would not only be an advantage, but even a necessity.

The provision of the Reserve in Chapter 3 of the National Water Act adds another dimension to the problem. Not only is it necessary measure an unspecified effect, but it requires the protection of (among others) *ecosystem* function. This means that we consider effect assessment, we cannot in general only pronounce on the effect of one species. We need to provide reasonable evidence that we provide fairly *general* protection in an ecosystem comprising of a number of species and processes. This means that we need to provide effect data on more than one species and also cover some of the more important processes that occur in the aquatic environment. The selection of parameters in the DEEEP suite represents a minimalistic approach to generating these data.

Essentially, management with a view to the maintenance and improvement of aquatic ecosystem health is virtually impossible without reference to the tests included in DEEEP.

APPENDIX 2

WASTE DISCHARGE LIMITS AS OUTLINED IN GENERAL AUTHORISATION NO 1191 OF 8 OCTOBER 1999, INDICATING THOSE SUBSTANCES THAT HAVE THE POTENTIAL TO CAUSE AN ECOLOGICAL TOXICITY HAZARD

EXTRACTS

3 DISCHARGE OF WASTE OR WATER CONTAINING WASTE INTO A WATER RESOURCE THROUGH A PIPE, CANAL, SEWER OR OTHER CONDUIT; AND

DISPOSING IN ANY MANNER OF WATER WHICH CONTAINS WASTE FROM, OR WHICH HAS BEEN HEATED IN, ANY INDUSTRIAL OR POWER GENERATION PROCESS

[Section 21(f) and (h)]

"Definitions

3.6. In this authorisation unless the context indicates otherwise, any word or expression to which a meaning has been assigned in terms of the National Water Act shall have that meaning, and ...

- (ii) **"complex industrial wastewater**" means wastewater arising from industrial activities and premises, that contains
 - a) a complex mixture of substances that are difficult or impractical to chemically characterise and quantify, or
 - b) one or more substances, for which a Wastewater Limit Value has not been specified, and which may be harmful or potentially harmful to human health, or to the water resource

(identification of complex industrial wastewater will be provided by the Department upon written request);

- (iii) **"domestic wastewater**" means wastewater arising from domestic and commercial activities and premises, and may contain sewage;
- (iv) **"domestic wastewater discharge**" means a wastewater discharge consisting of 90% or more domestic wastewater, by volume, that is collected, treated and subsequently disposed of;
- (v) "industrial activity" means those activities identified in the Standard Industrial Classification of All Economic Activities (5th Edition), published by the Central Statistics Service, 1993, as amended and supplemented, under the following categories
 - a) 2: mining and quarrying,
 - b) 3: manufacturing,
 - c) 4: electricity, gas and water supply,
 - d) 5: construction;
- (vi) **"industrial wastewater discharge**" means a wastewater discharge consisting of more than 10% industrial wastewater, by volume, that is collected, treated and subsequently disposed of;
- (x) **"wastewater**" means water containing waste, or water that has been in contact with waste material;

(xi) **"wastewater limit value**" means the mass expressed in terms of the concentration and/or level of a substance which may not be exceeded at any time. Wastewater Limit Values shall apply at the last point where the discharge of wastewater enters into a water resource, dilution being disregarded when determining compliance with the Wastewater Limit Values. Where discharge of wastewater does not directly enter a water resource, the Wastewater Limit Values shall apply at the last point where the wastewater leaves the premises of collection and treatment.

Discharging of domestic and industrial wastewater into water resources

3.7(1) A person who [owns or uses land] outside of the [specified] areas , may on that property or land -

(a) discharge up to 2 000 cubic metres of wastewater on any given day into a water resource that is **not** a listed water resource referred to in Table 3.4, provided-

- (i) the discharge complies with the General Limit Values set out in Table 3.2;
- (ii) the discharge does not alter the natural ambient water temperature of the receiving water resource by more than 3 degrees Celsius; and
- (iii) the discharge is not a Complex Industrial Wastewater.

(b) discharge up to 2 000 cubic metres of wastewater on any given day into a listed water resource referred to in Table 3.4, provided-

- (i) the discharge complies with the Special Limit Values set out in Table 3.2;
- (ii) the discharge does not alter the natural ambient water temperature of the receiving water resource by more than 2 degrees Celsius; and
- (iii) the discharge is not a Complex Industrial Wastewater.

(2) A person may discharge stormwater runoff from any premises, not containing waste or wastewater emanating from industrial activities and premises, into a water resource.

SUBSTANCE/PARAMETER	GENERAL LIMIT	SPECIAL LIMIT
Faecal Coliforms (per 100 ml)	1 000	0
Chemical Oxygen Demand (mg/l)	75*	30*
рН	5,5-9,5	5,5-7,5
Ammonia (ionised and un-ionised) as Nitrogen (mg/l)	3	2
Nitrate/Nitrite as Nitrogen (mg/l)	15	1,5
Chlorine as Free Chlorine (mg/l)	0,25	0
Suspended Solids (mg/l)	25	10
Electrical Conductivity (mS/m)	70 mS/m above intake to a maximum of 150 mS/m	50 mS/m above background receiving water, to a maximum of 100 mS/m
Ortho-Phosphate as phosphorous (mg/l)	10	1 (median) and 2,5 (maximum)
Fluoride (mg/l)	1	1
Soap, oil or grease (mg/l)	2,5	0
Dissolved Arsenic (mg/l)	0,02	0,01
Dissolved Cadmium (mg/l)	0,005	0,001
Dissolved Chromium (VI) (mg/I)	0,05	0,02
Dissolved Copper (mg/l)	0,01	0,002

TABLE 3.2 Wastewater limit val	lues applicable	to discharge of wastewa	ater into a water resource.
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SUBSTANCE/PARAMETER	GENERAL LIMIT	SPECIAL LIMIT
Dissolved Cyanide (mg/l)	0,02	0,01
Dissolved Iron (mg/l)	0,3	0,3
Dissolved Lead (mg/l)	0,01	0,006
Dissolved Manganese (mg/l)	0,1	0,1
Mercury and its compounds (mg/l)	0,005	0,001
Dissolved Selenium (mg/l)	0,02	0,02
Dissolved Zinc (mg/l)	0,1	0,04
Boron (mg/l)	1	0,5

* After removal of algae"

APPENDIX 3

INTERNATIONALLY AVAILABLE METHODOLOGIES TO DIRECTLY ASSESS ECOLOGICAL HAZARD

Since the nineteen eighties and later, countries such as the United States, Britain, Germany, Belgium, Sweden, France and Denmark have realised the benefits of using complex discharge ecological hazard assessment in the management of their water resources. The use of such methodologies in combination with substance-specific methodologies provided a deeper understanding of and important contribution to the protection of the ecological integrity of their water resources.

The USA was the first to apply the so-called "Whole Effluent Toxicity" (WET) methodology. With this methodology, test organisms are exposed to wastewater to assess its possible effect on similar organisms in-stream (also referred to as Direct Toxicity Assessment (DTA) in the UK). Other countries followed suit, and developed or adapted similar methodologies in line with their particular circumstances. A good example is the Netherlands, which developed the TEM ("Totale Effluent Milieuhygiene" or "Whole Effluent Environmental Risk") methodology.

WET, DTA and TEM all require a battery of tests, rather than a single test, to improve hazard detection. No single test has yet proved to be the best to assess *all* adverse ecological effects because of the diverse composition of complex industrial wastewater. These are also flexible methodologies, within which a wide range of tests and test organisms can be used. Each country thus selects the most appropriate combination of tests and test organisms to suit its own conditions and circumstances.

Both WET and DTA are however focussed on toxicity assessment as interpreted in terms of parameters such as acute and chronic toxicity. TEM differs from these in that it also includes other 'indirect' hazard parameters such as oxygen depletion potential, bioaccumulation and mutagenicity.

1. HAZARD PARAMETERS AND TESTS AVAILABLE INTERNATIONALLY

Internationally available methodologies to assess the toxicity hazard of complex wastewater are based on firstly selecting a set of *parameters derived from the effects of discharges.* These parameters *characterise the ecological toxicity hazard.* Parameters cover effects such as acute and chronic toxicity, oxygen demand and others. Secondly, one or more tests are used to measure each parameter.

Internationally available methodologies to assess the toxicity hazard of complex wastewater are based on firstly selecting a set of *parameters derived from the potential effects of discharges*, rather than from the discharges themselves. Secondly, one or more tests are used to measure each parameter. This results in a direct measurement of the effect.

Parameters such as oxygen depletion, acute and chronic toxicity, mutagenicity, endocrine impairment and persistence potential are typical examples. Each parameter is assessed by way of one or more tests. For example, tests to evaluate oxygen depletion potential both *chemical* and *biological* (biochemical) oxygen demand tests can be used. The results of these tests are related but are not equivalent in terms of their ecological hazard interpretation.

The USA and Germany have for a number of years measured the *acute toxicity* parameter and are using the results to enforce compliance with legislation. Britian, Canada and the Netherlands have recently introduced numeric criteria to assess the acute toxicity parameter based on acute toxicity test results. Tests are available for bacteria, crustaceans, algae and fish.

Both the USA and Sweden have been extensively testing for the *chronic toxicity* parameter. Most European countries have chronic toxicity high on their priority list of parameters to test for. Most of the available tests are for crustaceans and fish, while some scientists and managers are of the opinion that the tests for bacteria and algae to assess the acute toxicity parameter could more accurately be applied to the measurement of chronic toxicity. There is also a trend to consider the use of biomarkers as a regulatory adjunct to (or even replacement for) chronic toxicity. Biomarkers are often sub-cellular

components of living organisms that respond in a particularly sensitive way to pollutants and that would give an early warning that some biological process has been compromised.

Bioaccumulation and persistence are parameters widely recognised for their importance in both aquatic and human toxicology. The rapid measurement of these parameters is in its infancy internationally, but sufficient advancement has been made to include them as as parameters in formal ecological hazard assessments.

The ability of a substance to initiate tumours can, as a rule, not be assessed directly. But it is widely accepted that one of the mechanisms that may be involved in inducing cancerous growth stems from the ability of a substance to induce or facilitate mutations in cells, i.e. its mutagenicity. Tests are available that estimate the extent to which substances induce mutations in bacterial cells. It may be argued that the fear of tumours and cancers are peculiarly human. Bacterial mutation may be of direct importance to the aquatic ecosystem since bacteria are involved in the most basic ecosystem processes such as release of nutrients, detoxification of natural toxins such as ammonia among others. Mutagenicity is therefore of importance to both human health and aquatic ecosystem health. A few well established tests exist to evaluate this parameter.

The impairment that substances bring about in the endocrine system in both humans and aquatic animals is becoming a concern with many scientists and managers. The techniques and tests that are involved in endocrine effect assessment is still largely under development.

2. TEM

As mentioned earlier, the TEM methodology ("Totale Effluent Milieuhygiene" or "Whole Effluent Environmental Risk") was developed in the Netherlands. Its development took place in the nineteen nineties by RIZA, the Dutch Institute for Inland Water and Waste Water Treatment. The parameters and tests it uses to assess the hazard parameters are now well known internationally and well-established in the scientific community.

TEM includes a combination of parameters and tests. It represents a suite of methodologies. This represents an approach that will yield an assessment that is closer to an ecological hazard assessment compared to the toxicity assessment represented by WET and DTA and so TEM is closer to what is required in South Africa.

Specific tests have been selected for TEM. Some of these specific tests may not be applicable in the South African context. It is thus proposed that the term "TEM" not be used in South Africa, since the tests and parameters that can be applied here will be slightly different, based on local needs, circumstances and capacity. Rather, the term DEEEP, i.e. Direct Estimation of Ecological Effect Potential, is proposed. Nevertheless, the strong resemblance of TEM and DEEEP (at least initially) should be recognised.

APPENDIX 4

A BRIEF TECHNICAL GUIDE TO THE DEEEP METHOD

The aim of DEEEP is to obtain a better insight into the effect of mixtures of known and unknown hazardous substances in complex industrial wastewater. As such, it can address some of the shortcomings of the substance-specific approach by providing a more complete picture of the ecological hazard of complex industrial wastewater discharges.

1. EXPLAINING THE DEEEP METHODOLOGY

The DEEEP methodology consists of a range of effect parameters that can provide direct information on the potential toxicity hazard of the complex discharge, and a battery of tests to be performed on a sample of a complex waste discharge to show up potential adverse effects. Tests can be selected according to what is easily available, cost effective and for which there is capacity. The selection of parameters and tests can periodically be revisited to ensure that they are up to date and cost-effective.

Figure 1 in this Appendix illustrates the various effect parameters and their tests, further outlined in the sections below.



Figure 1. Parameters for the direct estimation of ecological hazard, and the tests to assess each parameter

1.1 Selecting ecological hazard parameters

Effect parameters to show up the potential hazard of a sample of complex wastewater can be selected to characterise the ecological hazard that may result from many different sources, as described in Table 1. The suite of parameters listed in Table 1 has been selected specifically with a view to the assessment of *ecological hazard*. An assessment of *human health hazard* would require different or additional parameters.

The ideal is to eventually use all selected parameters in each assessment, but the DEEEP methodology is sufficiently flexible to allow the use of only those parameters for which tests and capacity are readily available. Also, since ongoing research highlights new ways substances interact with the ecosystem, this may introduce new parameters while old ones are removed. An example of a parameter that may be introduced in future, and which currently is the subject of more and more concern, is endocrine disruption, in which males become feminised and lose fertility.

An ecological hazard may vary in its severity i.e. the extent of the damage it can do to the environment. Each parameter of the hazard may also vary in severity. Each parameter is assessed by criteria which enable the calculation of a numeric rating (for example 'low' oxygen demand, 'medium' acute toxicity and 'high' mutagenicity). The criteria used in characterising the acceptability of any ecological hazard are likely to be site-specific, for example in a river that is already (and necessarily) highly utilised, "low" or 'moderate' chronic toxicity may be acceptable while in a river (or river reach) that has high ecological value, such as in nature conservation areas, 'no chronic effect' may be the only acceptable criterion. Again, the DEEEP methodology is sufficiently flexible to allow interim criteria to be used initially, to be refined over time.

The severity of an ecological hazard is assessed by using parameter-specific criteria. These criteria could be made industry-, site-, or situation-specific by suitable scientific studies.

Table 1. Effect parameters employed by DEEEP, and the ecological toxicity hazards represented by each parameter.

Effect parameter	Ecological toxicity hazards represented by the parameter
Oxygen demand (oxygen depletion potential)	The extent to which the substance or mixture serves as a nutrient to ubiquitous bacteria in the water that will cause depletion of the oxygen in the water to the detriment of larger organisms.
Acute toxicity*	Specific effects that occur within a relatively short period of exposure to a substance or mixture. Often the effect referred to is death of the organisms used in the selected tests (e.g. water fleas or fish).
Chronic toxicity*	Specific effects that occur within a relatively long period of exposure to a substance or mixture. Often the effect referred to is sub-lethal (such as growth or fertility).
Bio-accumulation	The net accumulation of substances in an organism because of the combined exposure via water, sediment and food. This characteristic may have a severe impact on ecosystems over the longer term.
Mutagenicity*	The introduction of hereditary changes in living organisms. Mutagenic substances do not necessarily cause cancer in humans but may do so. The may however be implicated in defects in any organism.
Persistence potential	A property of substances that indicate how long they remain in a specific environment before they are converted to other substances.

Note: Parameters marked with an asterisk are usually performed by direct toxicity assessment (DTA)

1.2 Selecting tests to assess each parameter

As indicated earlier, different parameters are assessed by different tests, either one or more. For example, oxygen demand, i.e. the potential for oxygen to be depleted in the water, can be tested either chemically or biologically; mutagenicity is most often assessed by the Ames test. Tests for the parameters marked with an asterisk in Table 1 are usually performed by direct toxicity assessment (DTA).

There are many practical considerations when choosing parameters and tests, such as cost, capacity and infrastructure to perform the tests etc. Each country usually selects the tests that best suite its local circumstances and conditions. Also, test methodologies evolve from a dynamic field of research. As new tests are developed, they can, if found feasible, be added to the suite of tests, or replace older ones. At the same time, the need for innovation needs to be balanced by the need for standardisation to ensure effective law enforcement.

Each situation has to be judged on its own merits as to whether DEEEP would add value.

APPENDIX 5

CURRENT STATUS OF PARAMETERS AND TESTS IN SOUTH AFRICA AND REFINEMENT REQUIRED FOR IMPLEMENTATION

The DEEEP methodology is new to South Africa, although a number of the parameters and tests are already being used in assessments in this country.

This chapter reviews the current status of parameters and tests in South Africa, and points to the refinement required for step-by-step implementation of the DEEEP methodology. Table 1 in this appendix lists the DEEEP parameters and tests available both internationally and in South Africa, and provides proposed priority rankings for implementation in South Africa.

Table 1.	DEEEP	parameters	and	available	tests,	and	proposed	priority	rankings	for
implemen	tation in	South Africa.								

Parameter	Tests available internationally	Validated?	Tests used in South Africa	Priority for implementation in South Africa
Oxygen demand	Chemical and biological estimation widely used	Yes	Chemical estimation widely used. Limited use of biological estimation	Priority A – as soon as possible
Acute toxicity	Organisms from four trophic levels	Yes	Organisms from four trophic levels	Priority A – as soon as possible
Chronic toxicity	Organisms from three trophic levels	Yes	Organisms from two trophic levels	Priority B – within 5 yrs
Bioaccumulati on potential	Three potential techniques	Not known	Not used routinely	Priority B – within 5 yrs
Mutagenicity	Various tests available	Yes	Limited but the test most often used is the Ames test	Priority B – within 5 yrs
Persistence potential	Test available	No	None	Priority D – within 10 yrs
Endocrine effects	Tests under development	Not known	Tests under development	Priority C – within 7 years (may be reprioritised depending on research and development)

1. PARAMETERS AND TESTS

1.1 Oxygen demand

South Africa already widely uses chemical assessment in the assessment of oxygen demand. Limited use of biological assessment is also made. Thus, estimation of chemical oxygen demand can be implemented immediately.

1.2 Acute toxicity

The concept of 'acute toxicity' is carried over from human toxicology and refers to severe effects (such as death) over a short exposure period (hours or days). In aquatic ecological hazard assessment a more correct term may be short term lethality. For the sake of historical continuity this term is retained. Aquatic toxicity assessments are available at a number of laboratories and have been used by a number of institutions in South Africa for some years now. The more commonly used tests are the acute toxicity tests using water fleas or fish as test organisms.

Acute toxicity can also be implemented immediately for at least one trophic level (crustaceans) and within a very short period (a few months) for fish after some culturing problems have been solved. Tests using bacteria and algae require some capital expenditure, but the technology is well developed and could be implemented by a number of laboratories.

Nevertheless, although a number of standard tests are available, a number of questions remain to be answered:

- What are the best test conditions for optimum interpretation of results?
- To what extent do nutrients interfere in the test?
- Which tests are applicable to which situations?
- What is the variability of test results in South Africa? Studies have been performed in the USA, UK and Europe, but how do we compare? This is vital in the development of standards and criteria.
- Are there simpler, cheaper or more appropriate tests? This needs to be a constant feature on the development agenda.
- Pressure is mounting internationally to abolish tests using fish. How could we gain the same information without using fish?

1.3 Chronic toxicity

"Chronic toxicity" is another term carried over from human toxicology and should probably be more precisely described as long term sub-lethality. A few laboratories in South Africa already use chronic toxicity tests with water fleas as the test organism. Nevertheless, both the number of practitioners and the range of trophic levels tested are inadequate to immediately implement this parameter and its tests. However, these tests are vital in DEEEP and capacity would have to built if DEEEP is to be successfully implemented. This is likely to take around five years.

Only one test (one trophic level) is currently being used in South Africa for toxicity assessments of freshwater. Development should thus address the following:

- Extending the number of trophic levels to at least three for fresh water organisms
- Establishing a test for at least one salt-water organism for use in saline discharges to fresh water, as well as for marine/estuarine discharges.
- Maximising information abstraction from experimental observations.
- Assessing and improving where possible the variability of test results. Again, this is vital in the developments of standards and criteria.
- Building capacity in the use of the tests.
- Investigation of simpler, more sensitive and more affordable tests.

1.4 Mutagenicity

The most commonly used test in South Africa is the Ames mutagenicity test. The current capacity for performing this test is small although a number of laboratories could be trained to do it. This would require some time, probably in the order of five years.

Both British and Dutch studies have raised concern at the use of only one test to assess this parameter. The suggestion was that more tests should be evaluated to improve the choice of tests. With limited capacity available at present in South Africa, development in this area might largely comprise desktop studies until capacity improves.

1.5 Bio-accumulation

Bio-accumulation potential is assessed using gas and liquid chromatography. Although the equipment for gas and liquid chromatography is commonly available in South Africa, it is not known whether it has been specifically applied to assess bio-accumulation potential. Initially, development should serve to introduce the use of the instruments in this context. As with the other techniques, assessment of variability is vital.

The potential for its use is therefore high. Bio-accumulation could be implemented within 1-5 years.

1.6 Persistence potential

A procedure for assessing persistence potential has been developed by RIZA in the Netherlands, although the test has not been validated yet. It is likely that validation will take place on a case-specific basis. The RIZA test (or equivalents of the test) have probably been used informally in South Africa.

The test can be adapted for South African conditions to compensate for the longer duration and greater intensity of sunlight exposure compared to Europe.

Persistence assessment could probably be implemented within 2 years but the need for this parameter might only become apparent over a longer period of time (maybe 10 years).

South Africa already has the tests to assess acute toxicity and chemical oxygen demand. Thus, these parameters and their tests could be implemented immediately. The other parameters and their tests could be phased in over a number of years, as indicated on Table 2.

1.7 Aggregating parameters in assessments

The suitability of parameters for South Africa can be assessed individually based on our local circumstances and capacity. The main issue is how the individual parameters are to be aggregated, i.e. which ones to use under which circumstances, in which combination. In its simplest form, the parameters in the DEEEP methodology are assessed individually and the overall hazard is assessed on a "fail-one-fail-all" basis. This means that each assessment is individually important and each can dominate the ecological hazard assessment.

However, alternative approaches to aggregating the individual parameter assessments could be investigated. Each of the alternatives must be evaluated until an acceptable approach is finalised. An option would be to use numerical averaging. In particular, aggregation of parameters should be aligned to inform the resource-directed measures to protect water resources in accordance with Chapter 3 of the National Water Act.

1.8 Introducing new hazard parameters

As mentioned before, the parameters in hazard assessment are likely to be dynamic; some may be removed to be replaced by others. This would require constant vigilance in terms of research and field observation.

For example, in some rivers there appears to be evidence of endocrine disruption in certain species such as crocodiles. In the case of complex discharges to these rivers, the oxygen demand parameter may possibly be replaced by an endocrine disruption parameter, assessed by a suitable test or suite of tests. The development of the suite of parameters would need to be considered on a case-specific basis.

2. ASSESSMENT CRITERIA AND GUIDELINES

In order to provide an ecological hazard assessment there is a need for assessment criteria. These criteria would generally be numerical values with which the test results can be compared to pronounce on the expected impact implied by the test result.

After an investigation RIZA provided some assessment criteria for the Dutch TEM method as indicated in Table 2.

Parameter	Test values	Hazard description
Acute toxicity	>100 Tua ¹	Highly acutely toxic
	10 – 100 Tua	Acutely toxic
	2 – 10 Tua	Mildly acutely toxic
	1 – 2 Tua	Negligibly acutely toxic
	< 1 Tua	Not acutely toxic
Chronic toxicity	>100 Tuc ²	Highly Chronically Toxic
	10 – 100 Tuc	Chronically Toxic
	2 – 10 Tuc	Mildly Chronically Toxic
	1 – 2 Tuc	Negligibly Chronically Toxic
	<1 Tuc	Not Chronically Toxic
Oxygen Demand	COD < 200 mg/l	Acceptable
	BOD < 50 mg/l	Acceptable
Mutagenicity	< 100 revertants/l	Non- or Slightly Mutagenic
	100 – 500 revertants/l	Mildly Mutagenic
	> 500 revertants/l	Strongly Mutagenic
Bioaccumulation potential	K _{ow} ³ < 100	Weak Bioconcentration Potential
	100 < K _{ow} < 1000	Mild Bioconcentration Potential
	K _{ow} >1000	Strong Bioconcentration Potential

Table 2.Criteria for ecological hazard assessment for discharges provided for the TEMmethod by RIZA in The Netherlands.

1. TUa is an acute toxic unit and is derived from calculation in an acute toxicity test. For a discharge the TUa = 100/LC50

- Uc is a chronic toxicity unit and is derived from calculation in a chronic toxicity test. For a discharge the TUc = 100/ NOEC
- 3, K_{ow} is the octanol-water partition coefficient and is a well known measure in pharmacology and toxicology used to estimate the ability of a substance transverse a cell membrane an important step in many toxicity mechanisms

The assessment criteria in Table 2 have been based not only on theoretical considerations but on practical observation. There is therefore cogent reason to accept these. We recognise however that what constitutes an ecological hazard in one country may not constitute an ecological hazard in another country and that we would have to validate these criteria locally before finally adopting them in the DEEEP method. The data gathered in the testing and pilot implementation of this method in South Africa as well as consultation with various role player will help to adapt and refine these criteria.

Principles that need to be considered in refining and adapting assessment criteria would include:

- The Department of Water Affairs and Forestry recognises that the ecological effect is not in the discharge, but in the receiving water. Furthermore, we recognise that receiving water systems are currently in different ecological states and may in future be managed with different ecological states in mind that represent different levels of ecological risk and hazard. This supplies added reason to generate receiving water specific criteria in addition to those for General Authorisation.
- The assessment of a discharge should not be so lenient as to cause damage to the ecosystem damage that may be costly or impossible to repair. On the other hand it should not be so strict as to place an unnecessary burden on the discharger worth consequent economic and other implications.

This type of information about criteria could be collected during the testing and pilot implementation of the methodology, but like all other criteria, we believe that the DEEEP assessment criteria should be reviewed from time to time.