RIVER ECOCLASSIFICATION

MANUAL FOR ECOSTATUS DETERMINATION (Version 1)

INCLUDING DETAILED METHODS FOR -

- **FISH RESPONSE ASSESSMENT INDEX**
- **MACROINVERTEBRATES RESPONSE ASSESSMENT INDEX**
- **PHYSICO-CHEMICAL DRIVER ASSESSMENT INDEX**

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Kleynhans, CJ, Louw, MD, Thirion, C, Rossouw, NJ, and Rowntree, K (2005). River EcoClassification: Manual for EcoStatus determination (Version 1). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. KV 168/05

TITLE	River EcoClassification: Manual for EcosStatus determination (Version 1)
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STUDY NAME	Ecological Reserve for rivers: The determination of the water quality present status as part of the ecological classification process
REPORT STATUS	FINAL
DATE	30 November 2005
WRC REPORT NO.	KV 168/05

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STRUCTURE OF THE MANUAL

PURPOSE OF THE MANUAL

Describe the concepts on which the EcoStatus approach is based. Establish and demonstrate its application in terms of EcoClassification as it relates to Ecological Water Requirement (EWR) determination (as part of the Ecological Reserve), Ecological Reserve monitoring, and the River Health Programme.

Provide guidance to specialists in the use of the following rule-based models -

- Physico-chemical Driver Assessment Index (PAI)
- Fish Response Assessment Index (FRAI)
- Macro Invertebrate Response Assessment Index (MIRAI)

The manual is in two sections. The first section provides an introduction, background, general process and the scientific rationale of the EcoClassification process and EcoStatus determination process.

FIRST SECTION OF THE MANUAL

Chapter 1: EcoClassification: Contains the background, introduction and a description of the EcoClassification process

Chapter 2: EcoStatus Introduction: Provides the background, introduction, scientific rationale and concepts of the EcoStatus.

The second section is the ***'how to'*** section, that is,. the more traditional manual part. Individual chapters in this section can be used on a stand-alone basis.

SECOND SECTION OF THE MANUAL

Chapter 3 - Geomorphology Driver Assessment Index: Provides information and demonstrates the geomorphology rule-based model and the determination of the geomorphology status.

Chapter 4 - Hydrology Driver Assessment Index: Provides information and demonstrates the hydrology rule-based model and the determination of the hydrology status.

Chapter 5 - Physico-chemical Driver Assessment Index: Provides guidance to an experienced water quality specialist on the use of the physico-chemical rule-based model and the determination of the physico-chemical status.

Chapter 6 - Fish Response Assessment Index: Provides guidance to an experienced fish ecologist on the use of the rule-based model and the determination of the fish status.

Chapter 7 - Macroinvertebrate Response Assessment Index: Provides guidance to an experienced aquatic invertebrate ecologist on the use of the rule-based model and the determination of the aquatic invertebrate status.

Chapter 8 - Riparian Vegetation Response Assessment Index: This index is not available yet and information is provided on the current status quo of the approach.

Chapter 9 - EcoStatus determination: Provides guidance on the use of the spreadsheets that comprise the rule-based models and the determination of the EcoStatus for different levels of EcoClassification.

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ACKNOWLEDGEMENTS

Funding:
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EXECUTIVE SUMMARY

1. ECOCLASSIFICATION

EcoClassification - the term used for Ecological Classification - refers to the determination and categorisation of the Present Ecological State (PES; health or integrity) of various biophysical attributes of rivers compared to the natural or close to natural reference condition. The purpose of EcoClassification is to gain insights into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. This provides the information needed to derive desirable and attainable future ecological objectives for the river.

The steps followed in EcoClassification are as follows -

- Determine reference conditions for each component.
- Determine the Present Ecological State for each component as well as for the EcoStatus.
- Determine the trend for each component as well as for the EcoStatus.
- Determine reasons for PES and whether these are flow or non-flow related.
- Determine the Ecological Importance and Sensitivity (EIS) for the biota and habitat.
- Considering the PES and the EIS, suggest a realistic Recommended Ecological Category (REC) for each component as well as for the EcoStatus.
- Determine alternative Ecological Categories (ECs) for each component as well as for the EcoStatus.

The EcoClassification process is an integral part of the Reserve method or, for that matter, any Environmental Flow Requirement method. Flows and quality cannot be recommended without information regarding the resulting state, that is, the Ecological Category. The Ecological Categories that are determined as part of the EcoClassification process form an essential part of most of the Reserve steps.

Biological monitoring for the River Health Programme (RHP) also uses EcoClassification to assess data in terms of the severity of changes. However, the RHP focuses primarily on biological responses as an indicator of ecosystem health, with only a general assessment of the cause-and-effect relationship between the drivers and the biological responses.

2. ECOSTATUS INTRODUCTION

The Ecostatus is defined as
'The totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna and its capacity to provide a variety of goods and services'.

It essence the EcoStatus represents an ecologically integrated state representing the drivers (hydrology, geomorphology, physico-chemical) and responses (fish, aquatic invertebrates and riparian vegetation).

The development of methods to achieve the objectives of this study, focussed on a two-step process -

- Devising consistent indices for the assessment of the EC of individual biophysical components.
- Devising a consistent process whereby the EC of individual components can be integrated at various levels to derive the EcoStatus of the river.

The principle followed here is that the biological responses integrate the effect of the modification of the drivers and that this results in an ecological endpoint.

Indices are determined for all the Driver and Response components using a rule-based modelling approach. The modelling approach is based on rating the degree of change from natural on a scale of 0 (no change) to 5 (maximum relative change) for various metrics. Each metric is also weighted in terms of its importance for determining the Ecological Category under natural conditions for the specific river reach one is dealing with.

3. ECOSTATUS SUITE OF MODELS

The following index models were developed following a similar Multi Criteria Decision Making Approach (MCDA).
Hydrological Driver Assessment Index (HAI)
Geomorphology Driver Assessment Index (GAI)
Physico-chemical Driver Assessment Index (PAI)
Fish Response Assessment Index (FRAI)
Macro Invertebrate Response Assessment Index (MIRAI)

The Vegetation Response Assessment Index (VEGRAI) is presently being developed and will be included in version 2 of this document.

Each of these models result in an Ecological Category expressed in terms of A to F where A represents the close to natural and F a critically modified condition. A chapter in manual format for each of the models are provided. The MS Excel models accompany the document as separate Excel spreadsheets.

4. ECOSTATUS DETERMINATION

The metrics of each driver component are integrated to provide an Ecological Category (EC) for each component. However, the three drivers are not integrated to provide a driver EC. The information required from the drivers refers to the information contained in individual metrics, and which can be used to interpret habitat required by the biota. This information can then be used to determine and explain biological responses.

The fish and invertebrate response indices are interpreted to determine an Instream Ecological Category using the Instream Response Model. The purpose of this model is to integrate the EC information on the fish and invertebrate responses to provide the instream EC. The basis of this determination is the consideration of the indicator value of the two biological groups to provide information on -

- Fish: Diversity of species with different requirements for flow, cover, velocity depth classes and modified physico-chemical conditions of the water column.
- Invertebrates: Diversity of taxa with different requirements for biotopes, velocity and modified physico-chemical conditions.

Due to time and funding constraints, various levels of Reserve determinations are undertaken, each with its own Ecological Water Requirement (EWR) method and modified EcoClassification process.

The EcoClassification process, and specifically the detail and effort required for assessing the metrics, varies according to the different levels. The process to determine the EcoStatus also differs on the basis of different levels of information. There are five EcoStatus levels and they are linked to the different levels of Ecological Reserve determination as follows -

- Desktop Reserve method → Desktop EcoStatus level.
- Rapid I Ecological Reserve method → EcoStatus Level 1.

- Rapid II Ecological Reserve methods → EcoStatus Level 2
- Rapid III Ecological Reserve methods → EcoStatus Level 3
- Intermediate and Comprehensive Reserve methods → EcoStatus Level 4

The five levels discussed above have been fixed considering the known constraints regarding the Reserve methods at different levels and the River Health Programme (RHP). However, the combinations of the various tools applied during the EcoStatus levels can be used in different ways. This will usually depend on the site-specific situation, the available information, available expertise, funding and time.

To design a range of EcoStatus levels, tools of different complexities have to be utilised. The tools such as the GAI, FRAI, HAI, PAI, MIRAI and VEGRAI are all reasonably detailed. As the EcoStatus levels become less complex, less-complex tools must be used (such as the Index of Habitat Integrity). These tools are the following:

- Index of Habitat Integrity (IHI)
- Desktop Habitat Integrity
- Desktop Fish Response Rating
- Desktop Invertebrate Response Rating
- Derived vegetation Response EC and Rating

The following table illustrates the use of the different tools for the different Ecostatus levels.

Table 1.1 Tools used for different EcoStatus levels

ECOSTATUS LEVELS	TOOLS											
	GAI	PAI	HAI	VEGRAI	FRAI	MIRAI	IHI	DERIVED VEG EC	DESKTOP FISH RATING	DESKTOP INVERT RATING	DESKOP HI	DERIVED VEG RATING
4	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N
3	N	N	N	N*	Y	Y	Y	Y*	N	N	N	N
2	N	N	N	N*	N	Y	Y	Y*	Y	N	N	N
1	N	N	N	N	N	N	Y	Y	Y	Y	N	N
DT#	N	N	N	N	N	N	N	N	Y	Y	Y	Y

DT: Desktop
* Once the VEGRAI has been designed and tested, it will/can be used for these levels; definitely for the RHP and will replace the derived vegetation EC.

ABBREVIATIONS

ASPT	Average Score Per Taxon
DWAF	Department of Water Affairs and Forestry
EC	Ecological Category
EcoSpecs	Ecological Specifications
EIS	Ecological Importance and Sensitivity
ER	Ecological Reserve
EWR	Ecological Water Requirements
FAII	Fish Assemblage Integrity Index
FHS	Fish Habitat Segment
FRAI	Fish Response Assessment Index
GAI	Geomorphology Driver Assessment Index
HAI	Hydrology Driver Assessment Index
IHI	Index of Habitat Integrity
ISP	Internal Strategic Perspective
IFR	Instream Flow Requirements
MCDA	Multi-Criteria Decision Analysis
MIRAI	Macro Invertebrate Response Assessment Index
PAI	Physico-chemical Driver Assessment Index
PES	Present Ecological State
RDM	Resource Directed Measures
REC	Recommended Ecological Category
RERM	Rapid Ecological Reserve Methodology
RHP	River Health Programme
RU	Resource Unit
RVI	Riparian Vegetation Index
SASS	South African Scoring System
VEGRAI	Riparian Vegetation Response Assessment Index

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1 ECOCLASSIFICATION

1.1 INTRODUCTION

EcoClassification - the term used for Ecological Classification - refers to the determination and categorisation of the Present Ecological State (PES; health or integrity) of various biophysical attributes of rivers compared to the natural or close to natural reference condition. The purpose of EcoClassification is to gain insights into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. This provides the information needed to derive desirable and attainable future ecological objectives for the river. The EcoClassification process also supports a scenario-based approach where a range of ecological endpoints have to be considered.

Components

The state of the river is expressed in terms of biophysical components -

- **Drivers (physico-chemical, geomorphology, hydrology) which provide a particular habitat template; and**
- **Biological responses (fish, riparian vegetation and aquatic invertebrates).**

Different processes are followed to assign a category (A→F; A = Natural, and F = critically modified) to each component. Ecological evaluation in terms of expected reference conditions, followed by integration of these components, represents the Ecological Status or EcoStatus of a river. Thus, the EcoStatus can be defined as the totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna (modified from: Iversen *et al*., 2000). This ability relates directly to the capacity of the system to provide a variety of goods and services.

EcoClassification must not be confused with the system for classifying water resources in section 12 of the National Water Act, which considers a range of different issues in the process of determining the class of a river, one of which is ecological.

The South African EcoStatus determination procedure has its origins in projects such as the Olifants River Reserve Study (DWAF, 2001) and the Thukela River Reserve Study (DWAF, 2004a).

PES & EcoStatus

The determination of the PES of the various components and the integrated state - the EcoStatus - forms one step within the larger EcoClassification process.

1.2 PROCEDURE

The steps followed in EcoClassification are as follows -

- Determine reference conditions for each component.
- Determine PES for each component as well as for the EcoStatus.
- Determine the trend for each component as well as for the EcoStatus.
- Determine reasons for PES and whether these are flow or non-flow related.
- Determine the Ecological Importance and Sensitivity (EIS) for the biota and habitat.
- Considering the PES and the EIS, suggest a realistic Recommended Ecological Category (REC) for each component as well as for the EcoStatus.
- Determine alternative Ecological Categories (ECs) for each component as well as for the EcoStatus.

These steps will be explained in more detail in the next sections. The flow diagram (Figure 1.1, adapted from DWAF, 2001) illustrates the process.

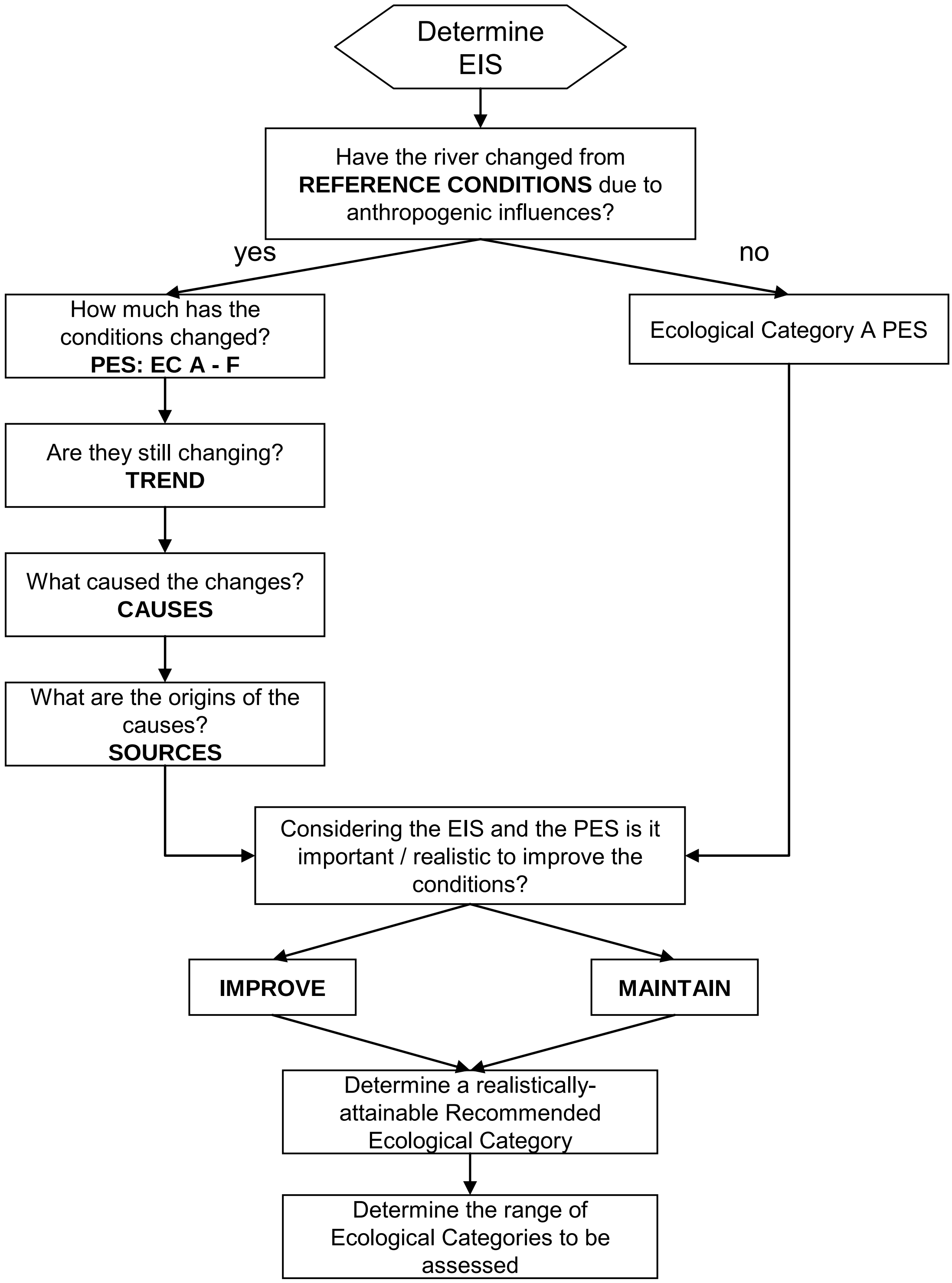

Figure 1.1 Flow diagram illustrating the information generated to determine the range of ECs for which EWRs will be determined.

Reference conditions

The European Water Framework Directive (European Commission, 2000) defines a reference condition as the expected background condition with no or minimal anthropogenic stress and satisfying the following criteria -

- It should reflect totally, or nearly, undisturbed conditions for hydromorphological elements, general physical and chemical elements, and biological quality elements.
- Concentrations of specific synthetic pollutants should be close to zero or below the limit of detection of the most advanced analytical techniques in general use.

More specifically, the reference condition describes the condition of the site, river reach or delineation prior to anthropogenic change and is formulated for each component considered in EcoStatus determination (fish, aquatic invertebrates, riparian vegetation, water quality, geomorphology and hydrology) following the process below -

- Locate the least-impacted sites, either in the same or in ecologically comparable river zones.
- Use the results of historical ecological surveys before major human impacts. If this is not possible, consider the use of survey information from ecologically comparable rivers. Use historical aerial photographs and land cover data to get an indication of the degree of catchment changes. The Internal Strategic Perspective (ISP) reports of the Department of Water Affairs and Forestry also provide relevant information.
- Use expert knowledge to derive an approximation of expected natural reference conditions.

Historical information and data, and/or data from reference sites (minimally impacted sites) are used to describe the reference conditions for the channel, hydrology, biota, and the water quality. Due to data limitations and/or the absence of any existing reference sites, the reference condition may not represent an actual natural river state, but rather the best estimate of a minimally impaired baseline state. If the river has not changed, then the PES can be described as being in a natural condition (Category A - see below). (DWAF, 2004a).

Ideally, both qualitative and quantitative data are available either of historical origin or from other representative geographical regions. If only qualitative data is available, these can still be used, although this places limitations on the type of metrics that can be calculated and used in the assessment of the ecological quality (Nijboer *et al*. 2004).

<u>Metric</u>

Metrics are systems of parameters or ways of quantitative assessment of a process that is to be measured, along with the processes to carry out such measurement. Metrics define what is to be measured. Metrics are usually specialized by the subject area, in which case they are valid only within a certain domain and cannot be directly benchmarked or interpreted outside it. Metrics can be used to track trends and resources. Typically, the metrics tracked are key performance indicators. (http://en.wikipedia.org/wiki/Metrics <http://en.wikipedia.org/wiki/Metrics> , accessed on 24 July 2005).

1.2.1 Present Ecological State

The PES of the river is expressed in terms of various components. That is, **drivers** (physico-chemical, geomorphology, hydrology) and **biological responses** (fish, riparian vegetation and aquatic invertebrates), as well as an integrated state, the EcoStatus.

<u>The use of the term 'Ecological State' with reference to Drivers</u>

Present Ecological States are determined for driver and response components. The term *Ecological* when describing the present state of the Drivers can strictly only be used in *terms of the EcoClassification process*. Therefore the present state categories of geomorphology and fish are both described using the term PES.

A rule-based procedure is followed to assign each component an Ecological Category (the PES) (A → F) using the following information sources on river and catchment modification -

- Biophysical surveys conducted during the project.
- Information and data from historical surveys, databases and reports.
- Aerial photographs and videos.
- Land-cover data.

- Internal Strategic Perspective (ISP) reports of DWAF

Expert knowledge is regularly used to estimate the degree of change to a particular component.

It must be emphasised that the A→F scale represents a continuum, and that the boundaries between categories are notional, artificially-defined points along the continuum. There may therefore be cases where there is uncertainty as to which category a particular entity belongs. This situation falls within the concept of a fuzzy boundary, where a particular entity may potentially have membership of both classes (Robertson *et al*. 2004). For practical purposes these situations are referred to as boundary categories and are denoted as B/C, C/D, and so on. The B/C boundary category, for example, is indicated as the light green to dark-blue area in Figure 1.2.

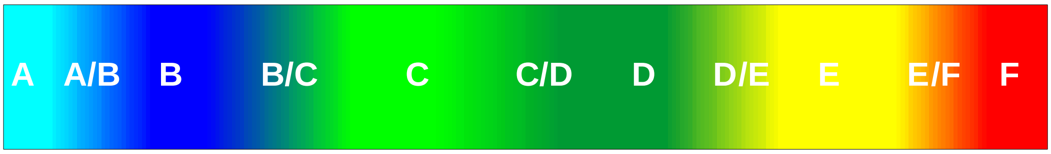

Figure 1.2 Illustration of the distribution of Ecological Categories on a continuum

<u>Indices to determine Ecological Categories for each component</u>

- **Hydrological Driver Assessment Index (HAI)**
- **Geomorphological Driver Assessment Index (GAI)**
- **Physico-chemical Driver Assessment Index (PAI)**
- **Fish Response Assessment Index (FRAI)**
- **Macro-Invertebrate Response Assessment Index (MIRAI)**
- **Riparian vegetation Response Assessment Index (VEGRAI)**

1.2.2 Trend

Trend is viewed as a directional change in the attributes of the drivers and biota (as a response to drivers) at the time of the PES assessment. A trend can be absent (close to natural or in a changed state but stable), negative (moving away from reference conditions) or positive (moving back towards natural - when alien vegetation is cleared, for instance). The ultimate objective is to determine if the biota have adapted to the current habitat template or are still in a state of flux. Generally such an assessment can be approached from a driver perspective. This means that there can be a positive or negative trend response from the biota if the drivers (specifically geomorphology and water quality) are still in a directional state of change (+ or -). In cases where further water resources development is imminent, or where a new development has just been completed at the time of assessment (such as a recently-completed dam that is filling up but operation has not yet started), a case-specific decision will have to be made on the basis of the trend assessment.

Whether the biota have adapted to driver changes will clearly depend on the type of modifications and the sensitivity of the biota to such driver changes. This will have a bearing on how important a driver metric is in a particular type of river, and also the rate, extent and intensity of driver changes. The ecological significance of these driver changes will then be fundamental to the natural attributes of the biota in terms of resilience, adaptability and fragility.

There will, then, be cases where the hydrology and water quality driver changes have occurred relatively recently but, at the time of the PES assessment, these drivers are stable (a recently-completed expansion of an irrigation area for instance, with associated increases in abstraction from the river and return flows into it). It is probable that the relative rates of change of these driver changes compared to geomorphology and biotic responses will be such that the geomorphology and biota is still in a state of flux. In these cases it will be necessary to make a qualitative interpretation of the rates of change by considering the extent to which the geomorphology and biota are expected to have responded to the driver changes in the short- to medium-term (five years) and long-term (20 years), and estimating the component categories that will prevail in the future.

1.2.3 PES cause-and-effect relationship

Causes

Disturbances and modifications that impact on the condition of a river can generally be viewed as stressors, and are considered as causes of ecological change.

Stressors occur at a particular intensity, duration and frequency that result in a change in the ecological conditions (US EPA 2000). The effect of the impact of stressors on the ecosystem are therefore, regarded as a response.

In this context it is useful to consider causes, responses and the ultimate ecological effect in terms in ecological responses primarily related to flow modifications, and those primarily non-flow related, for instance -

- A decrease in the abundance of a fish population or the species composition of a fish assemblage may be interpreted as a response to a change in flow. However, where flow is unmodified, such population and assemblage changes may be attributable to primarily non-flow related causes such as sedimentation and physico-chemical changes.
- A decrease in riparian vegetation may be caused by catchment changes such as physical removal of vegetation by whatever means, with no direct link to modified flows. Obviously a decrease in riparian vegetation will be flow-related when flow is modified beyond the natural resilience of the riparian vegetation

Often however the causes are due to a combination of the impacts of flow and non-flow related sources. An example is sedimentation caused by land-use activities (non-flow related) that can be exacerbated by decreased flows due to irrigation (flow-related).

In the analysis of the cause-and-effect scenarios of the flow and non-flow related responses, it is often useful to define the source of a stressor. This is regarded as an entity or action that releases or imposes a stressor into the water body (US EPA 2000).

1.2.4 Determine the Ecological Importance and Sensitivity (EIS)

The ecological importance of a river is an expression of its importance to the maintenance of biological diversity and ecological functioning on local and wider scales. Ecological sensitivity (or fragility) refers to the system's ability to resist disturbance and its capability to recover from disturbance once it has occurred (resilience) (Resh *et al*. 1988; Milner 1994). Both abiotic and biotic components of the system are taken into consideration in the assessment of ecological importance and sensitivity.

1.2.5 Derive a Recommended Ecological Category (REC)

The *modus operandi* followed by DWAF's Directorate: Resource Directed Measures

(RDM), is that, if the EIS is high or very high, the ecological aim should be to improve the condition of the river. However, the causes related to a particular PES should also be considered to determine if improvement is realistic and attainable. This relates to whether the problems in the catchment can be addressed and mitigated. If the EIS evaluated as moderate or low, the ecological aim should be to maintain the river in its PES.

Within the Ecological Reserve context, Ecological Categories A → D can be recommended as future states (REC - the Recommended Ecological Category) depending on the EIS and PES. Ecological Categories E and F PES are regarded as ecologically unacceptable, and remediation is needed.

REC & Components

Recommended Ecological Categories are determined for driver and response components. The term *Ecological* when describing the present state of the Drivers can, strictly speaking, be used only in terms of the EcoClassification process.

1.2.6 Determine and define alternative Ecological Categories (EC)

A scenario-based approach is followed in the Ecological Reserve determination process. This implies *inter alia* that water quantity and quality requirements must be determined for the REC as well as for alternative ECs. With reference to the REC, a range of ECs is identified and addressed in terms of water quantity and quality implications, also with reference to ecological responses and endpoints. The conditions and specifications for the alternative ECs are then set.

Ecological Categories

Ecological Categories are ascribed to driver and response components. The term *Ecological* when describing a Driver category can, strictly speaking, be used only in terms of the EcoClassification process.

USE OF TERMINOLOGY

Ecological categories and the integrated state - the EcoStatus - are determined for various purposes -

- **the Present Ecological State**
- **the Recommended Ecological Category**
- **alternative Ecological Categories (EC scenarios)**
- **predicting the resulting Ecological Category for flow and other scenarios**

This is illustrated as follows -

Determination of PES	**Determination of REC**	**Evaluation of scenarios**
Geomorphology EC = PES	Geomorphology EC = REC	Geomorphology EC
Fish EC = PES	Fish EC = REC	Fish EC
Aquatic Inverts EC = PES	Aquatic Inverts EC = REC	Aquatic Inverts EC
etc	etc	etc
Present EcoStatus	**Recommended EcoStatus**	**EcoStatus**

In this document, whenever generic processes are described around EC and EcoStatus determination, irrespective whether it is for PES etc, reference will be made to EC and EcoStatus.

1.3 APPLICATION IN ECOLOGICAL RESERVE DETERMINATION

The Ecological Reserve process comprises eight steps (Table 1.1) (Louw and Hughes 2002) which are summarised as follows -

- Determining the PES, deriving the REC and alternative ECs.
- Setting flow scenarios for various ECs.
- Determining ecological consequences for each flow scenario.
- Selecting a flow scenario and associated category to represent the Ecological Reserve.
- Designing a monitoring programme and implementing the Ecological Reserve and monitoring programme.

The EcoClassification process is an integral part of the Reserve method or, for that matter, any Environmental Flow Requirement method. Flows and quality cannot be recommended without information regarding the resulting state, that is, the Ecological Category. The Ecological Categories that are determined as part of the EcoClassification process form an essential part of most of the Reserve steps. These steps are described in Table 1.1, together with the role of EcoClassification in each step.

Table 1.1 EcoClassification input into the Ecological Reserve steps

RESERVE PROCESS	ECOCLASSIFICATION INPUT
1. Initiate RDM study (study area, RDM level & components, study team)	Not applicable
2. Define Resource Units	Not applicable
3. Define Ecological Categories and recommend one (REC)	Bulk of EcoClassification process: Determination of reference conditions, PES, EIS, REC and alternative ECs
4. Quantify Ecological Reserve Scenarios (flow scenarios)	Setting of flow scenarios for relevant ECs
5. Identify ecological consequences of flow scenarios (Ecological Reserve and operational flow scenarios)	Interpretation of consequences in terms of impact on ECs
6. DWAF Management Class decision making process.	Selection of a Management Class and associated EC
7. Reserve specification	Determination of Resource Quality Objectives for specific ECs
8. Implementation design	Design of a monitoring programme to monitor achievement of the EC associated with the Management Class
IMPLEMENT AND MONITOR	Evaluation in terms of EC.

1.4 APPLICATION WITHIN MONITORING

Beechie *et al*. (2003) point out that there are five types of uncertainty in predictions of habitat capacity -

- Predictive uncertainty, which refers to the difference between the modelled response and the "true" response.
- Parameter uncertainty, which refers to the difference between the "true" parameter (such as an average or a regression coefficient) and the parameter as estimated from the data.
- Model uncertainty, which refers to the difference between the natural system and the mathematical equation used to describe it.
- Measurement uncertainty, which refers to the difference between the "true" value and the recorded value.
- Natural stochastic variation, which refers to the inherent random variability.

These uncertainties are also relevant to the Ecological Reserve determination process, where qualitative data, expert knowledge and judgment often have to be used due to a lack of empirical information on ecological requirements in particular. The time frame to obtain such information is usually very limited and the only practical way to deal with this uncertainty is through a well-designed monitoring and assessment process.

In the Ecological Reserve context the purpose of monitoring is to determine if the required EC is attained. If this is not the case, monitoring data is used in an adaptive management fashion (Rogers and Bestbier 1997) to reconsider, re-calibrate and possibly re-construct the specifications that have been set for the biophysical components that relate to a particular desired management goal or EC. The procedure of adaptive resource management involves following the EcoClassification process to assess biophysical conditions and responses critically, to determine the current EC, resulting from the implementation of the Ecological Reserve specifications, and to compare it with REC.

Biological monitoring for the River Health Programme (RHP), also uses EcoClassification to assess data in terms of the severity of changes. However, the RHP focuses primarily on biological responses as an indicator of ecosystem health, with only an indistinct cause-and-effect relationship between the drivers and the biological responses. Within the concept of adaptive resource management, if the biological integrity indicates the possibility of generally unacceptable conditions (such as indicated by thresholds of probable concern being exceeded (Rogers and Bestbier 1997), more detailed monitoring is indicated to determine the cause and the severity of the problem and to instigate management intervention to rectify the problem.

The RHP focuses on the reference conditions and PES steps of the EcoClassification process.

2 ECOSTATUS INTRODUCTION

2.1 WHY IS AN INTEGRATED CATEGORY NECESSARY?

Previous methods to determine the Ecological Reserve for rivers (DWAF 1999) did not include the development of methods to determine the integrated Ecological Category (EC) for rivers. The determination of the integrated EC of rivers implies some form of integration of the ECs of all the components that comprise the overall EcoStatus.

The requirement for such an EcoStatus determination method became especially evident during the determination of the Ecological Reserve for the Olifants (DWAF 2001) and the Thukela (DWAF 2004a) rivers. Until 2003 the methods used were partly based on those developed for rapid Reserve determination (DWAF 1999) and those developed by IWR Environmental (now IWR Source-to-Sea) for Ecological Reserve studies at the comprehensive level in the Olifants and Thukela rivers. The aim of these methods was to provide a single but integrated index value that indicates the ecological state of a river in a simple but ecologically relevant way. However, the methods were somewhat subjective, with few explicit and consistent rules being followed. As a result, it is doubtful that the results would be replicated were the studies to be repeated by a different team of experts.

The purpose of this document is to describe a rule-based method that considers the biophysical components of a river in terms of drivers and biological responses and endpoints in an integrated way, and to derive a realistic and repeatable conclusion as to the EcoStatus of the river. The method should also enable the assessment of alternative ECs in terms of drivers and biological responses.

During the development of the methods, it became evident that the EcoStatus concept and methods are applicable to various levels of Ecological Reserve determination (DWAF 1999), and that they will also be suitable for application in the River Health Programme (RHP). The methods are, therefore, intended to provide a common ground for determining, understanding and interpreting EcoStatus.

<u>Different levels of Ecological Reserve determination</u>

There are four basic levels of Reserve assessment -

- **Comprehensive**
- **Intermediate**
- **Rapid (consisting of Rapid I, II and III)**
- **Desktop**

The levels, as the names indicate, are associated with different degrees of effort (time and cost), mostly with different levels of confidence, and different levels of complexity of tools used.

The information provided in this document is relevant for the Comprehensive method and, where there are differences for the less intensive methods, these differences will be described.

<u>Why the same EcoStatus approach for Ecological Reserve and River Health Programme?</u>

The determination of the Present Ecological State is common to both the Ecological Reserve and the RHP. The Ecological Reserve and RHP can support each other. Descriptions (by means of Ecological Category) therefore must have the same meaning when they are used in either the Ecological Reserve or the RHP. This implies that the same tools and indices should be used.

2.2 ECOSTATUS: SCIENTIFIC RATIONALE

The EcoStatus approach is centred around a number concepts and principles.

2.2.1 Ecosystem integrity / health concepts

Conceptual attributes that comprise ecosystem health (i.e. if this is present the system will be healthy) are summarized by Costanza (1992) -

- Homeostasis (tendency of biological systems to maintain a state of equilibrium)
- Absence of disease
- Diversity or complexity

- Stability or resilience
- Vigour or scope for growth
- Balance between system components

Following from these concepts of ecosystem health, the sequence for ecosystem health assessment can be viewed as embracing the following steps (Shaeffer *et al* 1988) -

- Identify symptoms of ill health
- Identify and measure signs ill health
- Make provisional diagnosis of the causes of ill health
- Conduct tests to verify the diagnosis
- Make a prognosis
- Prescribe treatment

2.2.2 EcoStatus of rivers

The following description of the EcoStatus of rivers was found to be the most appropriate to the EcoClassification approach followed in South Africa.

<u>EcoStatus Definition</u>

"The totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna and its capacity to provide a variety of goods and services" (Iversen *et al* 2000).

A river will have a natural/close-to-natural EcoStatus when the components below are close to natural (Iversen et al 2000).

a) Hydro-morphology (Geomorphology and Hydrology)

- The quantity and dynamics of flow reflect almost undisturbed conditions. The continuity of the river allows undisturbed migration of aquatic organisms and sediment transport. Channel patterns, width and depth variations, flow velocities, substrate conditions and both the structure and condition of the riparian zones correspond to almost-undisturbed conditions.

b) Water quality

- The values of the physico-chemical elements correspond to almost-undisturbed conditions.

- Nutrient concentrations remain within the range normally associated with undisturbed conditions.
- Levels of salinity, pH, oxygen balance, acid neutralising capacity and temperature remain within the range normally associated with almost - undisturbed conditions.
- Synthetic and non synthetic pollutants are close to zero.

c) Biology

- The taxonomic composition and abundance of the -
  - Riparian vegetation,
  - Phytoplankton,
  - Macrophytes,
  - Invertebrates and
  - Fish
  - correspond nearly very closely to the undisturbed conditions.

2.2.3 Indicators of ecosystem integrity / health

Environmental indicators of ecosystem health can be categorized as follows (Yoder *et al*. 2000; Novotny *et al*. 2005).

a) Stressors

These refer to large-scale influences that generally originate from anthropogenic activities, and include point and non-point loadings (including atmospheric deposition), land use influences and changes, and stream modification.

b) Exposure indicators

These include chemical parameters, whole-effluent toxicity, tissue residues, sediment contamination, habitat degradation and other changes that result in a risk to the biota.

c) Response indicators or biotic assessment endpoints

These are the direct measures of ecological integrity or ecological status. Biota is the highest level of effects of propagation of stresses throughout the ecosystem. It is desirable that endpoint indicators express three dimensions of integrity.

- Physical integrity implies habitat conditions of the water body that would sustain a balanced biological community.

- Physico-chemical integrity (referring both to chemical and physical properties of the water) refers to water and sediments that are not injurious to the aquatic biota.
- A composition of aquatic biota that is balanced, and resembles or approaches that of unaffected similar aquatic systems in the same EcoRegion without invasive species, represents biological integrity.

It is preferable that all three dimensions of endpoint assessment are conducted concurrently (Novotny *et al*. 2005).

2.2.4 A layered approach to aquatic ecosystem integrity assessment

Karr *et al*. (1986) proposed a direct relationship between stressors and integrity. Current thought favours a hierarchical or layered propagation of risks due to various landscape, point and non-point sources, and channel modification stresses that impact on biological integrity. Novotny (*et al*. 2005) suggest a four-layer hierarchical model that structurally and functionally links the catchment, landscape and pollution stresses to the biotic integrity indices. The lowest layer of the hierarchy includes metrics describing landscape, land use changes, pollutant inputs, and hydrologic/hydraulic stresses. These stresses are transformed into in-stream stresses such as concentration of pollutants in water and sediments, hydraulic/hydrologic in-stream parameters or habitat degradation. In this sense, stream modification is a stressor and represents a risk. These stresses then present a risk that certain species may be detrimentally influenced and lost from the system. Others may benefit from changes. The top-layer includes the biotic integrity indices (Figure 2.1).

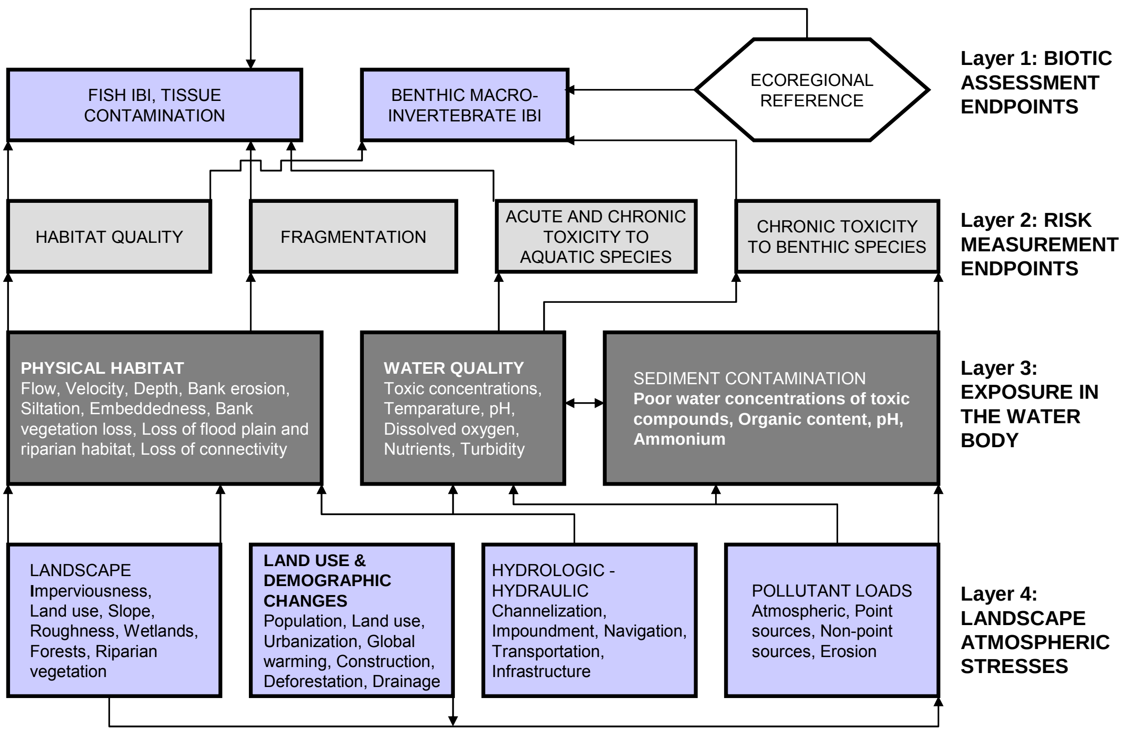

Figure 2.1 Concept of the stressors-risk-end-points propagation ecological model. Adapted from Karr *et al*. (1986) and Novotny *et al*. (2005).

a) Layer 1: Dependent variables; biotic assessment endpoints

Indices based on fish and macro-invertebrate assemblages are most often used as measures of species diversity, composition and ecological health. The outcome of such an index evaluation is a single number scoring summary but, each index also has a multimetric dimension. This means that some metrics are more affected by habitat and physical features of the channel and its riparian zone, some by flow characteristics, and some - such as deformities, erosion, lesions and tumours and species diversity - by pollutants (such as siltation, nutrients, toxics) and embeddedness.

b) Layer 2: Risks - measurement endpoints

Risks are viewed as a probabilistic potential for loss of species or genera from a system. Significant risks are associated with pollutants stored in sediments and habitat degradation. Four biological categories are affected by chemical or channel disturbance specific risks - survival, growth, reproduction and fragmentation. However, in some instances invasion by introduced (alien) species can pose a significant risk and influence the ecological risk. The risks include -

- Pollutant (physico-chemical) risks (acute and chronic) in the water column. Key metrics are toxic pollutants, dissolved oxygen, turbidity, temperature and pH.

- Pollutant risk (mostly chronic) in the sediment. Key metrics include toxic pollutants, ammonium, dissolved oxygen in the interstitial layer, organic and clay content.
- Habitat degradation risk. Key metrics include texture of the sediment, clay and organic contents, embeddedness, pools and riffle structure, bank stability, riparian zone quality, canalisation and other stream modifications.
- Fragmentation risk. This risk can result from any factor (biotic or abiotic) that causes decrease in the ability of species to migrate among subpopulations or between portions of their habitat necessary for different life-cycle stages.

Key metrics include -

- Longitudinal – presence of dams, weirs and impassable culverts.
- Lateral – Lining, embankments, loss of riparian habitat, reduction or elimination of refugia.
- Vertical – lack of the stream-groundwater interchange, thermal stratification / heated discharges, bottom lined channel.

c) Layer 3: Instream exposure stressors

Generally, these express the level of chemical and bacteriological contamination of water and sediment, channel and stream bank stability, flow and temperature variability and riparian zone effects. Transfer functions link this layer with the landscape inputs. Such functions include pollutant dilution, dissolved oxygen (steady state and variability due to eutrophication), nutrient models, sedimentation, flow and temperature.

Parameters affecting habitat suitability risk are usually included in the list of metrics defining habitat indices. Some of these are related to hydrological parameters such as high-flow / low-flow frequencies, velocity, frequency of bankfull flows and channel morphology (slope, channel dimensions, pool and riffle sequence, sinuosity).

d) Layer 4: Catchment stresses

Four groups of these stresses can be recognized -

- Morphological and riparian factors and stresses.
- Land use change stresses.
- Diffuse pollutant sources (land and atmosphere) and point source discharges.
- Hydrologic changes.

2.2.5 Current approach

Beechie and Boulton (1999) propose an approach similar to that of Novotny *et al*. (2005), where the biological fitness and survival (biological responses) in an aquatic ecosystem are determined through layers or linkages of controls or drivers to processes and to habitat effects (Figure 2.2). The essence of this interpretation is that the direct assessment of the biological response (e.g., using a biological indicator) identifies where ecosystem functions have been impaired, and may suggest causes of impairment (Beechie *et al*. 2003). This provides the general framework that was used to develop conceptual approaches and assessment models within which the current project was carried out (Figure 2.2).

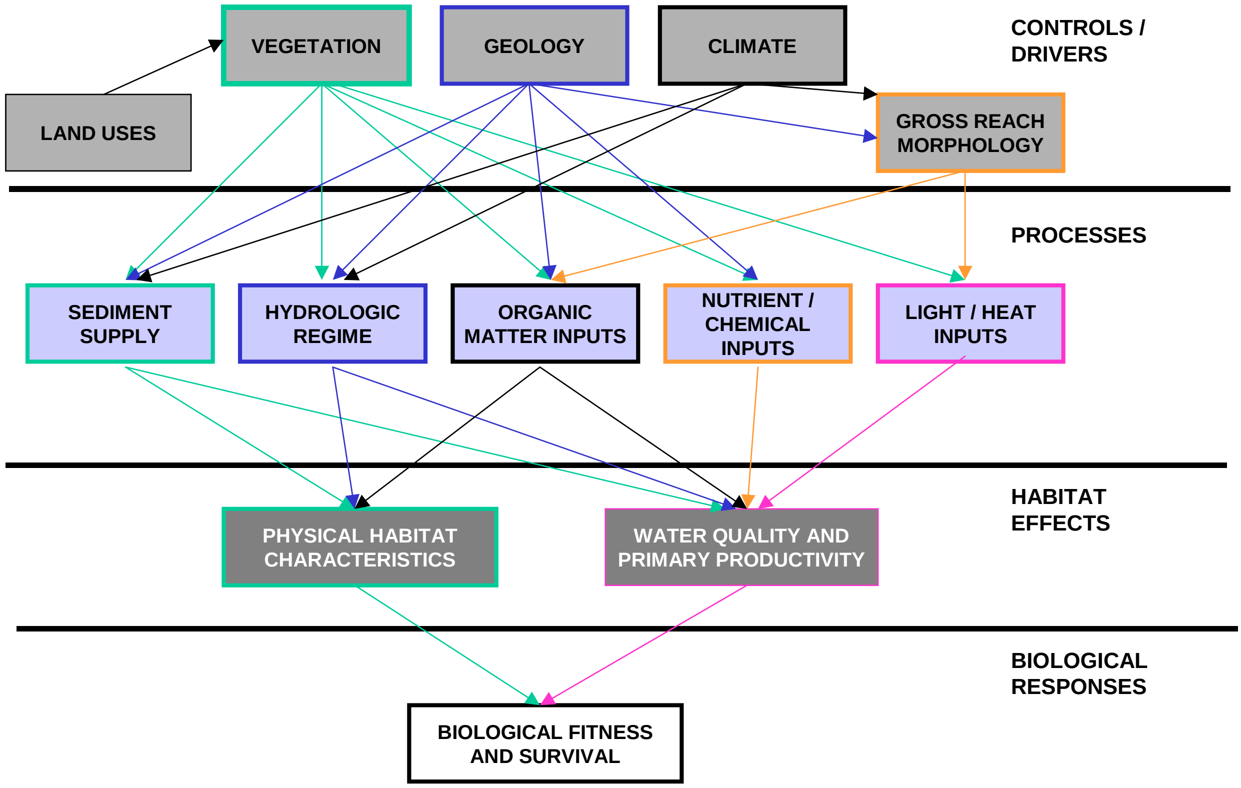

Figure 2.2 Schematic diagram of relationships between controls on catchment processes, effects on habitat conditions, and aquatic biota survival and fitness.

Black boxes indicate controls not affected by land use (adapted from Beechie and Bolton 1999).

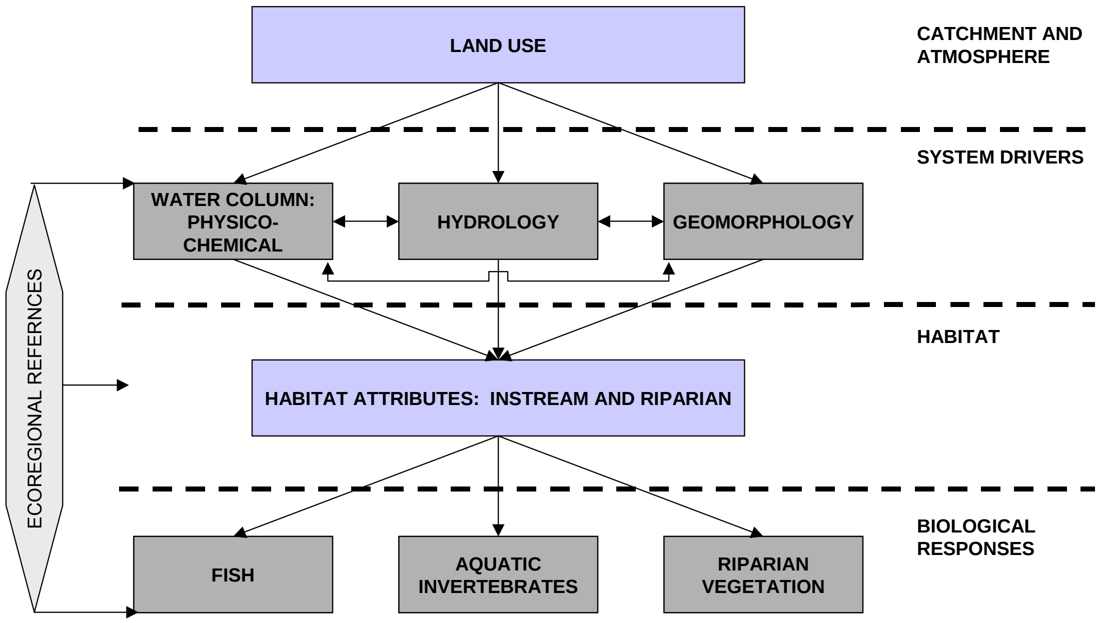

Figure 2.3 A simplified integration of influence of land use on physical driver determinants, habitats and the associated biological responses.

2.3 DETERMINATION OF THE ECOSTATUS

2.3.1 Concepts of PES and EcoStatus determination

As indicated previously, the EcoStatus approach distinguishes between physical drivers, which encompass physico-chemical attributes, geomorphology and hydrology, and the biological responses that include fish, macro-invertebrates and riparian vegetation.

Components and Metrics

The individual drivers and biological responses are referred to as *components*, while the individual attributes within each component that are assessed - to determine deviation from the expected natural reference condition - are referred to as *metrics*.

Metrics are systems of parameters or ways of quantitatively assessing a process that is to be measured, along with the processes to carry out such measurement. Metrics define what is to be measured. Metrics are usually specialized by the subject area, in which case they are valid only within a certain domain and cannot be directly benchmarked or interpreted outside it. Metrics can be used to track trends, resources etc. Typically, the metrics tracked are key performance indicators (http://en.wikipedia.org/wiki/Metrics <http://en.wikipedia.org/wiki/Metrics> , accessed on 24 July 2005)

The development of methods to achieve the objectives of this study (cf. 2.1), focussed on a two-step process (Joubert 2004) -

- Devising consistent indices for the assessment of the EC of individual biophysical components.
- Devising a consistent process whereby the EC of individual components can be integrated at various levels to derive the EcoStatus of the river.

The principle followed here is that the biological responses integrate the effect of the modification of the drivers and that this results in an ecological endpoint (cf. 2.2.4). This endpoint can be quantifiable, or it may be described in a predominantly qualitative fashion, and is presented in the form of a multimetric index.

This approach means that -

- The driver components are assessed separately (that is, an EC for each driver) and not integrated at a driver level, to provide a driver-based indication of the EcoStatus. However, the individual metrics of all the driver components are assessed in a combined fashion that allow some comparison between metrics of all drivers. This facilitates deriving the cause-and-effect relationships that are required in the interpretation and assessment of particular biological responses.
- The biological responses are assessed separately, but the resulting fish and macro-invertebrate ECs are integrated to provide an indication of the instream EC. Logically, the integration of the riparian vegetation EC and the instream EC would provide the EcoStatus. Currently, however, concepts and principles around the determination and interpretation of the EC of the riparian

vegetation still need to be resolved. Consequently, the influence of the riparian vegetation on the instream habitat is used to interpret the biological responses and endpoints at this stage. This means that, in some cases, the integrated instream biological responses are deemed to provide a reasonable indication of the EcoStatus.

Indices and models

Indices are determined for all the Driver and Response components using a rule-based modelling approach. The names of the models refer to indices, eg Hydrology Driver Assessment Index and Fish Response Assessment Index.

2.3.2 Rating, ranking and weighting, and integrating

The basis of the assessment of the importance of the metrics of biophysical components in determining the EC and EcoStatus is a Multi Criteria Decision Analysis approach (MCDA). The MCDA process allows the development of consistent rating systems or indices for the categorisation of ecosystem components and aggregates these mathematically in a theoretically justifiable way. In the current approach, the MCDA input was limited to drawing out weights for the aggregation of the subindices and indices (Joubert 2004).

a) Rating (Scoring)

A six-point rating system is followed, where metrics of the drivers and biological responses are scored in terms of the degree to which they have changed compared to the natural or close-to-natural reference (if necessary, half points such as 1.5 and so on can also be used) -

0 = No discernable change from reference/close to reference
1 = Small modification from reference
2 = Moderate modification from reference
3 = Large modification from reference
4 = Serious modification from reference
5 = Extreme modification from reference

These qualitative ratings are expert knowledge-based, and are assessed by the relevant expert in a particular speciality. It is preferable that the relative difference between for example, 0 – 1 be the same as between 3 – 4 (Joubert 2004). However, this is difficult to control and is currently exclusively based on expert knowledge.

In the case of fish, a modified approach is followed where changes in some metrics are interpreted in terms of an increase or decrease. This will be discussed further in the particular Chapter 6.

Rating

The rating requires different metrics to be scored according the relative degree of change from reference conditions.

b) Ranking and weighting

The principle of following a ranking-weighting approach is that not all driver or biological response metrics have the same relative ecological significance in all types of rivers. That is, a particular metric may be seriously modified but it may be of relatively low significance in terms of the functioning and integrity of the river. In another river (or a different section of the same river) in a different ecoregional context (Kleynhans et. al 2004), this metric may, however, be of very high ecological importance. Thus, the ranking-weighting process is done separately from the rating and should not be influenced by it.

Ranking is done as follows -

The metric of the component (driver or biological response) that is considered to be most important in influencing the EC of the component if it changed is ranked as 1. This can be formulated as -

> Considering the range from 5 to 0 of each of these metrics, which one would most affect the component (driver or biological response) if it changed from 0 to 5? (irrespective of the rating) (Joubert 2004). The next most important metric is ranked as 2, then 3, and so on.

Another way of posing this question is -

> Considering the range from 0 to 5, if a particular component is considered, which metric would contribute most to improving (or decreasing) the PES of the component. The next most important metric is ranked as 2, then 3, and so on.

In terms of geomorphology, fish and invertebrates, these components are divided into metric-groups. The questions posed above then apply to each of the metrics in a metric group. In assessing the importance of a metric group in terms of its contribution to the EC of the component, a similar ranking procedure is followed - the metric group considered to be the most important in determining the EC of the component is ranked 1, and so on.

The ranking procedure is essentially used to guide the weighting process and, except for a check-up function, plays no further role in the calculation of weights and weighted scores.

Where it is not possible to distinguish between the relative importance of metric (or metric-groups), a rank of 1 should be awarded to all metrics.

Weighting is done as follows -

The metric (or metric-group, cf. above) with a rank of 1 is awarded a weight of 100%. The weight of the metric with a rank of 2 is considered relative to its importance when compared to the metric with a rank = 1, and this can be any percentage lower than 100%. Usually expert knowledge limits the resolution to 10% and sometimes 5%.

Where all metrics (or metric-groups) are ranked as 1, they will all receive a weight of 100%.

Weighting

The weighting is required to provide an indication of the importance of the degree that the metrics have changed (that is, the rating)

c) Calculation of weighted scores

The percentage weight of each metric (or metric-group where applicable) is expressed as a proportion of the total of the percentage weights. This value is multiplied by -

- the rating,
- the total number of metrics considered and
- the maximum possible score (5)

- to provide a weighted score for a metric.

Where the weight of all metrics (or metric-groups) is 100%, the original rating will obviously be applicable.

d) Calculation of ECs for components

The calculation of the Ecological Categories of drivers and biological responses is done by totalling the weighted scores and expressing this as a percentage of the maximum. This value indicates the percentage change away from the expected reference and must be subtracted from 100 to arrive at the percentage value that represents the EC. This value is used to place the EC of the component in a particular category that ranges from A→F (Table 2.1).

Where metric-groups are used the same approach is followed for each group. However, with metric-groups, the calculation of the overall EC for a component follows a slightly different approach. In this case the EC value for each metric group is multiplied by the weight of the metric group to provide a weighted score for the group as a percentage, which is then related to an EC (Table 2.1).

Table 2.1 Generic ecological categories for EcoStatus components (modified from Kleynhans 1996 & Kleynhans 1999).

ECOLOGICAL CATEGORY	DESCRIPTION	SCORE (% OF TOTAL)
A	Unmodified, natural.	90-100
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	80-89
C	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.	60-79
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.	40-59
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.	20-39
F	Critically / Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	0-19

2.3.3 Methods for EcoStatus integration

After the Ecological Categories of the driver and ecological response components have been determined (cf.2.3.2), there remains the issue of how to integrate these to provide an indication of the EcoStatus. Deriving the EcoStatus from the Ecological Categories of components is based on the following principles –

- The Ecological Categories of the physical drivers (hydrology, geomorphology and physico-chemical integrity) are not integrated to provide a driver status.
- Information on the driver metrics: how different they are from the reference is considered when assessing the biological responses. This is an expert knowledge approach and the attributes and environmental requirements of the biota should be considered when doing this.
- The biological responses are considered to provide the best indication of the EcoStatus of the river because they integrate the effect of the driver components (cf.Figure 2.2; Beechie *et al*. 2002)

The steps in deriving the EcoStatus are -

- Criteria are considered that provide an indication of the relative indicator value of the two instream biological groups, fish and invertebrates. These criteria are used to weight the relative importance of these two groups as indicators of instream health. The Ecological Categories of the two biological groups are proportioned according to these weights and combined to provide the instream Ecological Category.
- A suitable index to get an indication of riparian vegetation Ecological Category within the EcoStatus context is not yet available. Consequently the riparian vegetation zone can only be considered conceptually and in terms of its influence on the instream EC. In this regard the influence, importance and integrity of the riparian vegetation zones - marginal, lower and upper vegetation - are considered in terms of their significance for the instream biota. Some indication of the health of the riparian vegetation can also be gleaned from the geomorphological driver where certain metrics of this driver do serve as indicators.
- The riparian vegetation Ecological Category and the instream Ecological Category are integrated based on a proportioning of weights according to the availability of high confidence information. This provides the EcoStatus of the river.
- Where riparian vegetation information is insufficient, the instream EC is used as the best indicator of the EcoStatus of the river.

More detail is provided in Chapter 9.

2.4 ECOCLASSIFICATION STEPS: COMPONENTS AND ECOSTATUS CATEGORIES

The purpose of this section is to document the relationship between component categories and EcoStatus category in terms of sequence, detail and scale.

The determination of components (drivers and responses) categories and the EcoStatus category form part of the EcoClassification process during all phases of the EcoClassification. It must be possible during all steps to unpack the EcoStatus into its constituent parts, that is, to identify and isolate the component Ecological Categories (A to F) as well as the component metrics evaluations. The relationship between EcoClassification, the Components EC and EcoStatus EC is illustrated in Table 2.2.

Note:

All levels where the breakdown from EcoStatus EC into the Components ECs is indicated also implies the breakdown into the metrics.

Table 2.2 EcoClassification steps and relationship with EcoStatus and Component Ecological Categories

EcoClassification steps	Scale and detail of determination of Role of Components and EcoStatus within each EcoClassification Step
Determine reference conditions	Undertaken for each COMPONENT
Determine Present Ecological State	Undertaken for each COMPONENT and then integrated into the ECOSTATUS using rule-based models and indices
Determine Trend (are the PES and EcoStatus still changing?)	Undertaken for each COMPONENT EC and ECOSTATUS EC by means of expert judgement
Determine causes for the PES and whether flow or non-flow related.	Undertaken for each COMPONENT
Determine the EIS	Undertaken using rule-based model for each RU and/or study sites.
Considering the EIS and the causes for the PES, define a realistic REC	Undertaken for each COMPONENT and ECOSTATUS using the rule-based models.
Determine alternative ECs	Undertaken for each COMPONENT and ECOSTATUS using the rule-based models in a predictive way.

The flow diagram (Figure 2.4) provides the Ecological Reserve determination steps and shows the interaction between Component and EcoStatus Ecological Categories (the orange letters in the flow diagram indicates whether the step is relevant for EcoStatus and/or Component Ecological Categories). This flow diagram again emphasises that all quantification is associated with a specific component and its metrics. The grey blocks indicate steps (and actions) that are not directly related to Ecological Categories.

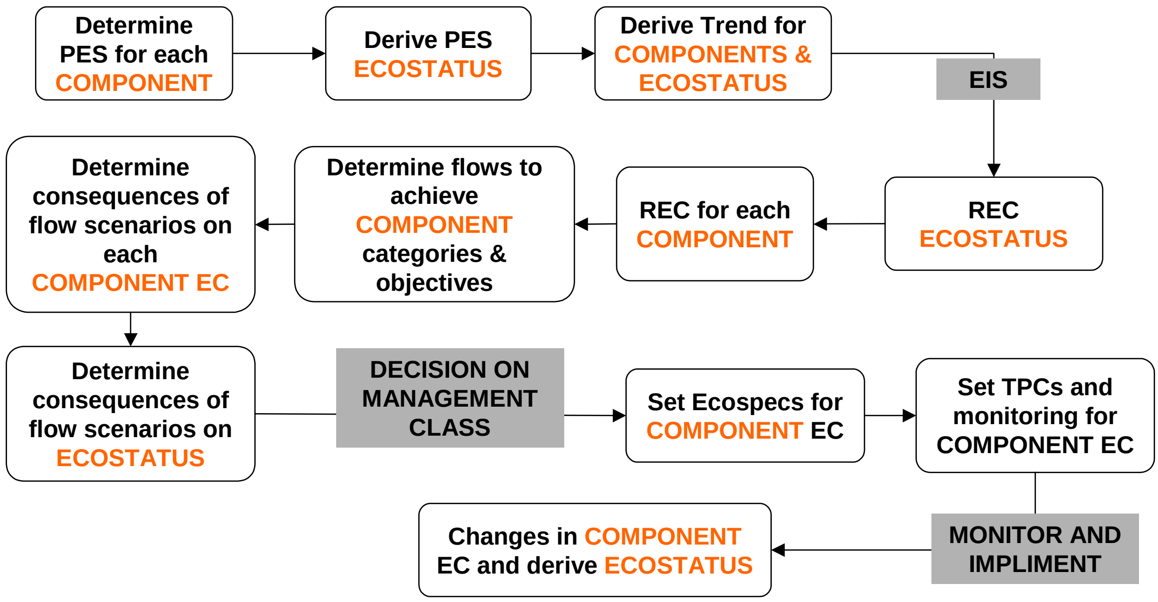

Figure 2.4 Reserve process indicating the interaction with EcoStatus and Components

Within the Ecological Reserve process, the flow and quality requirements are set by the individual specialists for the specific objectives defined by the component Ecological Categories. For example, if the objectives are to maintain the present conditions, which could consist of fish in a B PES, aquatic invertebrates in a C PES and a present EcoStatus of a B/C PES, the flows will be set to maintain Fish in a B status and aquatic invertebrates in a C status - which would result in an EcoStatus of a B/C. This means that the objectives of the EcoStatus consist of the individual objectives of each of the component categories

2.5 SCALE OF ECOSTATUS DETERMINATION

Ideally EcoStatus determination should be for some identified river reach that, in terms of the Ecological Reserve, is called the Resource Unit. If an Ecological Reserve determination is required for a whole catchment it is necessary to break down the catchment into Resource Units (RU). Each RU must be significantly different to warrant its own specification of the Reserve, and to clearly delineate the geographic boundaries of each. (DWAF 99). The following are considered when delineating RUs (DWAF 2004b) -

- Ecoregions
- Stream classification (Geomorphological classification to zone level)
- Habitat Integrity
- Water quality delineation into units
- Groundwater units (if applicable or available)
- Operation of the system

During a Comprehensive assessment of the Ecological Reserve, sufficient information should be available to apply the EcoClassification for the RU as a whole. This is, for example, aided by an aerial video that is available for the whole river, as well as a habitat integrity assessment for the river. Specific study sites (called IFR or EWR sites) are also selected within each RU, where detailed sampling and surveying are undertaken.

Within the Intermediate assessment, less information will be available, and knowledge of the river reach is obtained from ground surveys and local knowledge rather than an aerial survey and video. The process followed is, however, the same as for the Comprehensive assessment.

During the Rapid III assessment, RUs are not necessarily identified due to the time constraints associated with a rapid assessment. Available EcoRegion information is used to provide some perspective of RUs and to put the results into context. In essence, the Ecoregions and obvious operational information (if relevant) will inform the RU identification. The EcoStatus information is however targeted more towards the site than the RU due, usually, to lack of available information about the larger RU.

Within the RHP the scale and delineation of the resource for EcoStatus assessment vary widely. Ecoregions form the basis of the assessment and, within these, catchments with similar kinds of impacts are usually combined, while DWAF management units are also taken into consideration. The combination of these are termed assessment units.

3 GEOMORPHOLOGY DRIVER ASSESSMENT INDEX

This is NOT a training manual.
The guidelines presented here assume that the reader has some knowledge of fluvial geomorpholog y

3.1 INTRODUCTION

3.1.1 EcoClassification and the Geomorphology Driver Assessment Index (GAI)

This chapter describes the principles underlying the Geomorphology Driver Assessment Index (GAI) that is used to assess the Geomorphology Ecological Category and sets out guidelines for deriving the GAI. The GAI was developed as a component of the water research Commission project K5/1306 "Assessment of a Geomorphological Reference Condition – An Application for Resource Directed Measures and the River Health Programme". For further background the reader is referred to the final project report (Du Preez and Rowntree, in press.) The reader is also referred to earlier versions of the geomorphological index developed as part of the river health programme (Rowntree and Ziervogel, 1999; Rowntree and Wadeson, 2000). Other readings relevant to geomorphology and the Ecological Reserve include Rowntree (2000) and Freeman and Rowntree (2005)."

The GAI is derived using a rule-based model. This model is used to derive the Geomorphological EC of the river reach within which a study site is situated. Being a rule-based system, development has largely been a mental process, adapting the rules to best capture the geomorphological system in a structure that is logical and sensible to ecological practitioners. It is difficult to test such an index in an absolute sense as there is no reference against which to make judgements. The only real test seems to be "does it make sense?" The GAI as presented in this report is the end product of a series of indices that have been applied within the Komati EWR, the Kromme EWR, the Kat EWR and to assess the impact of a proposed dam on the Kabouga River. The GAI is the index that appears to "make the most sense" in terms of geomorphological processes and ecological response.

3.1.2 Geomorphology and River Ecosystems

The availability of suitable habitat is a vital criterion for ecosystem health. Water quality, flow hydraulics and substrate are three important habitat components of aquatic ecosystems. Channel morphology is an important habitat driver because it determines the distribution of water and its hydraulic characteristics (e.g. depth and velocity) at any given discharge. Sediment (in the form of clay, silt, sand, gravel, cobbles or boulders) or bedrock make up the morphological units and at the same time provide the substrate for vegetation and for aquatic fauna. Geomorphological processes drive channel morphology and thus geomorphology, and are among the key drivers of river ecosystem processes. Geomorphology is one of the three driver components of the Ecostatus model (Figure 9.3).

3.1.3 The Nature of Geomorphological Systems

In the geomorphological system, energy takes the form of gravitational energy (hill slopes) and kinetic energy (stream flow), while matter is comprised of sediment that is derived from the hill slopes and is transported through the river channel. Storage of sediment within the system is largely responsible for creating channel morphology. Flows of energy and matter within the geomorphological system are shown in Figure 3.1.

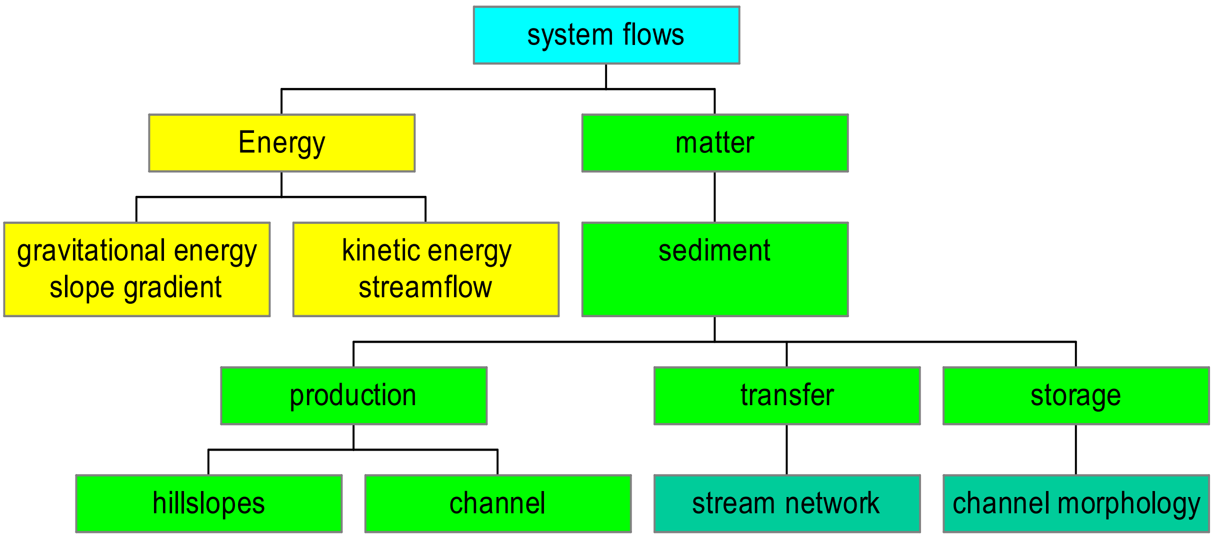

Figure 3.1 Flows of energy and matter within the geomorphological system

Connectivity is a key indicator of geomorphological system health. Connectivity allows the free flow of energy and materials through the system and, as a result, mutual adjustment between system components. Connectivity is counterbalanced by storage sites, which allow material to be retained in the system. The PES of a river's geomorphology can therefore be evaluated with respect to both increases and decreases in connectivity. Connectivity within the geomorphic system is shown in Figure 3.2.

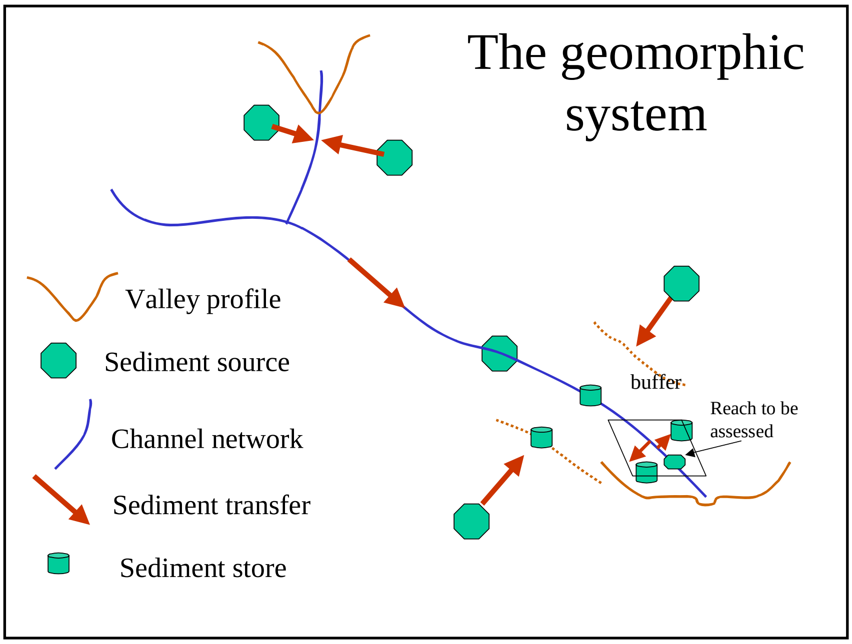

Figure 3.2 Linkages within the geomorphological system

There are three main scales of **connectivity** recognized within river systems. The first scale relates to the interface between hill slopes and the drainage network (channel-hill slope coupling), the second to longitudinal connectivity within the drainage network itself, and the third is connectivity at the reach scale. At this last scale there may be changes to longitudinal connectivity that cause energy changes within the reach (due to the presence of a weir, for instance), between the channel and the flood plain or riparian zone and between the surface of the channel bed and the underlying sediments. This latter component is termed vertical connectivity.

The second important indicator of geomorphological system change relates to the **sediment budget** for the specified reach. Changes to the reach sediment budget result from an adjustment to the balance between **sediment delivery** to the channel and the capacity of the stream flow to transport that sediment. Both increased or decreased catchment erosion and a change in channel-hill slope coupling will affect sediment delivery. Changes to the magnitude and frequency of flood events will change the capacity for sediment transport. The reach sediment budget is to some extent a reflection of changes to the extent and severity of hill slope or channel bank erosion; it is also a reflection of the change in connectivity and the effective catchment area for sediment supply (Fryers et al., in prep).

Channels can be classified as **transport-limited** or **supply-limited**. The channel is said to be transport-limited if the supply (including sediment in storage in the reach) is greater than the long-term transport capacity of the flows. The result is a true **alluvial channel** with a morphology adjusted to the magnitude and frequency of flows (the effective discharge) conveyed through it. If, however, the supply of material within the competence of the effective discharge is less than the transport capacity, the channel is said to be supply-limited. The result will be a **bedrock-controlled channel** or a channel in which the size of the bed material exceeds the competence of ‘normal’ floods (that is, those floods with a return period of between one and five years). **Mixed channels** also exist where alluvial and bedrock sections alternate. Whether a channel is supply- or transport-limited will affect its **resistance** and **resilience** to change. Bedrock channels are resistant to change but alluvial channels are more resilient.

The third indicator of system change is change to the **resistance of the perimeter** to erosional forces. Resistance to erosion is related to the size, cohesiveness of the **sedimentary material** or extent of bedrock and the effectiveness of the **vegetation cover**. Resistance factors can be applied separately to the **channel bed**, **channel banks**, **in-channel bars** and the **out-of channel flood zone**.

The last system component is the **channel morphology** itself. Channel morphology is clearly the direct link to river habitat. Unfortunately changes to channel morphology over geomorphological time are often difficult to assess. Channels are dynamic features and morphological change is the result of the cumulative effect of a sequence of flood events. It is difficult to know over what temporal scale to assess morphological change. Change also occurs at a number of different spatial scales ranging from the **bed material** and **bed structure** to the **channel cross section** (defined in terms of width and depth) to the **channel planform** (e.g. sinuosity, secondary channels) and the longitudinal pattern (e.g pool-riffle sequences). Each of these scales is linked to temporal scales of change and changes can be considered to be more severe and more permanent as the spatial scale increases.

3.2 CLASSIFICATION

Channel classification is carried out according to the guidelines presented by Wadeson and Rowntree (1999). An example of a data sheet is provided (Figure 3.3).

GEOMORPHOLOGICAL DATA SHEET: CLASSIFICATION

RIVER SYSTEM	Kat	**RECORDER**	Leanne/Kate
RIVER	Kat	**DATE**	7.02.05
SITE	K1	**LAT**	32.57002778
QUATERNARY CATCHMENT	Q94B	**LONG**	26.72191667
MAP REFERENCE	3226DA	**ALTITUDE**	640
		GRADIENT	0.00828

CHANNEL CLASSIFICATION								
Channel pattern	single thread, straight	single thread		multiple thread				
		sinuous	straight	sinuous	straight			
Reach type	mixed pool-rapid	bedrock			mixed or alluvial			
		bedrock fall	bedrock cascade	flat bedrock	pool-rapid	pool-riffle	plain bed	
		pool-rapid			step-pool	flat bed	regime	
Channel type (select ONE from each row	mixed boulder		bedrock	mixed	alluvial	fixed boulder		
		bedrock	boulder	cobble	gravel	sand	silt & clay	

CHANNEL CONFINEMENT	**Score (/5)**
broad flood plain	5
confined valley flood plain	4
flood plain confined on one side	3
incised channel (often with flood benches)	2
gorge with narrow valley floor	1.5
V-shaped valley	1
ravine	0.5
Score	**2**
confidence	**4**

MORPHOLOGICAL UNITS		tick
bedrock	waterfall	
	rock steps	
	rapid	x
	bedrock pool	
	bedrock pavement	
	bedrock island/ core bar	
	backwater	
	bedrock run	
alluvial	step	
	rapid	x
	plane bed	
	riffle	x
	run	x
	shallow pool	x
	deep pool	x
	flat' sand bed	x
	backwater	x
alluvial bars	point bar	
	lateral bar	
	mid-channel bar	x
	tributary bar	
	lee bar	
secondary channels		x
vegetated islands		x

Figure 3.3 This example shows the data sheet for the geomorphological classification of a site on the Kat River. Data are entered into yellow boxes.

a) Site identifiers

The first data block is largely self-evident. Data are required to identify the site, its location and the recorder. The channel gradient is normally estimated from the contours on a 1: 50 000 map. The distance between the two contours upstream and downstream of the site is measured. The gradient is calculated as -

$$\frac{\text{vertical height between adjacent contour (ie 20m)}}{\text{horizontal distance between adjacent contours}}$$

b) Channel classification

Channel classification is carried out according to three components - channel pattern, reach type and channel type.

- **Channel pattern** relates to the number of channels (single-thread or multiple-thread) and the sinuosity. Sinuous channels show clear meanders within the valley floor sediments whilst straight channels follow the line of the valley floor. Note that the valley floor itself may be sinuous, but the channel may be considered straight.
- **Channel type** is classified according to channel perimeter materials. Channels formed predominantly in bedrock are separated from those formed in alluvial sediments. Mixed channels include alternating sections of bedrock and alluvium. This channel type is common in South Africa. Channel type is then classified according to the dominant bed material (normally the largest 'common' size class)
- The **reach type** depends firstly on channel type. The different reach types commonly found in South African rivers are described in Table 3.1 and Table 3.2.

Table 3.1 Summary of the reach types found in alluvial systems (modified from Rowntree and Wadeson 1999, 2000)

REACH TYPE	DESCRIPTIONS
Step-Pool	Characterised by large clasts that are organised into discrete channel-spanning accumulations that form a series of steps separating pools containing finer material
Plane-Bed	Characterised by plane-bed morphologies in cobble or small boulder channels lacking well-defined bedforms.
Pool-Riffle	Characterised by an undulating bed that defines a sequence of bars (riffles) and pools.
Pool-rapid	Channels are characterised by long pools backed up behind channel-spanning steep boulder deposits forming rapids
Regime	Occur in either sand or gravel. The channel exhibits a succession of bedforms with increasing flow velocity. The channel is characterised by low relative roughness. Plane-bed morphology, sand waves, mid-channel bars or braid bars may all be characteristic.

Table 3.2 Summary of the reach types found in bedrock-controlled systems (modified from Rowntree and Wadeson 1999)

REACH TYPE	DESCRIPTIONS
Cascade	High-gradient streams dominated by waterfalls, cataracts, plunge pools and bedrock pools. May include bedrock core step-pool features
Flat Bedrock	Predominantly bedrock channel with a relatively smooth bed. Significant falls or rapids are absent.
Bedrock Fall	A steep channel where water flows directly on bedrock with falls and plunge pools
Pool-Rapid	Channels are characterised by long pools backed up behind channel-spanning bedrock intrusions with sufficient gradient to form rapids

c) Morphological Units

Morphological units are the channel components which are most closely associated with habitat. The composition and arrangement of morphological units determine the flow hydraulics at any given discharge, that is, the distribution of depth and velocity across the streambed. Morphological units also provide the substratum for organisms. They are identified separately for bedrock and alluvial sections. Descriptions of different morphological units are given in Table 3.3 and Table 3.4.

Table 3.3 Morphological units in bedrock controlled systems (modified from Rowntree and Wadeson 1999)

MORPHOLOGICAL UNIT	DESCRIPTION
Waterfall	Abrupt discontinuity in channel slope; water falls vertically; never drowned out at high flows. Height of fall significantly greater than the channel depth.
Rock steps	Step-like succession of small waterfalls drowned out at bankfull flows, height of fall less than channel depth.
Rapid	Local steepening of the channel long profile over bedrock, local roughness elements drowned out at intermediate to high flows.
Bedrock pool	Area of deeper flow forming behind resistant strata lying across the channel (includes plunge pools below waterfalls).
Bedrock pavement	Horizontal or near-horizontal area of exposed bedrock.
Bedrock island/ core bar	Accumulation of finer sediment on top of bedrock.
Backwater	Morphologically detached side channel which is connected at lower end to the main flow
Bedrock run	A channel formed in bedrock with a moderate gradient, a uniform trapezoidal cross section and low roughness relative to depth.

Table 3.4 Classification of alluvial morphological units (modified from Rowntree and Wadeson 1999)

MORPHOLOGICAL UNIT	DESCRIPTION
Step	Formed by large clasts (cobble and boulder) organized into discrete channel-spanning accumulations
Rapid	Local steepening of the channel long profile over boulders, local roughness elements drowned out at intermediate to high flows.
Plane bed	Topographically-uniform bed, lacking well defined scour or depositional features.
Riffle	A transverse bar formed of gravel or cobble, commonly separating pools upstream and downstream.
Run	A section of channel of moderate gradient with a uniform trapezoidal cross section and low roughness relative to depth.
Pool (shallow, deep)	Topographical low point in an alluvial channel cased by scour; characterised by relatively finer bed material.
Flat sand bed	Sands or fine gravels fill bed without forming distinct morphological features. Dunes or ripples may be present.
Backwater	Morphologically detached side channel which is connected at lower end to the main flow
Point bar	A bar formed on the inside of meander bends in association with pools. Lateral growth into the channel is associated with erosion on the opposite bank and migration of meander loops across the flood plain.
Lateral bar or channel side bar	Accumulation of sediment attached to the channel margins, often alternating from one side to the other so as to induce a sinuous thalweg channel
Mid-channel bar	Single bars formed within the middle of the channel, with strong flow on either side.
Tributary bar	Forms immediately downstream of a tributary junction due to the input of coarse material into a lower angled channel.
Lee bar	Accumulation of sediment in the lee of a flow obstruction
Secondary channel	High flow distributary channel on the inside of point bars or lateral bars; may form a backwater at low flows.
Islands	Mid-channel bars which have become stabilised due to vegetation growth and which are submerged only at high flows which would cause overbank flooding.

d) Channel confinement

The last component that must be completed in the classification data sheet refers to channel confinement. This is a measure of the ability of the channel to shift its position laterally. It is also a measure of the degree of coupling between the hill slope and channel. Confinement is related to the configuration of the valley floor with respect to the adjacent hill slopes. A rating of 5 is ascribed to the least confined system, which is a wide flood plain. The lowest rating is given to a narrow V-shaped ravine in which the channel fills the full width of the valley floor. A channel that is incised into alluvial terraces is given a relatively high rating (2), as the active channel is confined within the macro-channel banks.

3.3 GUIDELINES FOR ASSESSING THE ECOLOGICAL STATE FOR GEOMORPHOLOGY

3.3.1 Determining the Reference Condition for the river

The Present Ecological State for geomorphology is an assessment of the extent to which the capacity of the geomorphological system to support the reference ecosystem has been compromised through anthropogenic disturbance. The Geomorphological Reference Condition (GRC) has been defined as the "geomorphological system that supports the natural ecosystem, where a system is a set of components connected through flows of energy and matter to accomplish a set function" (Du Preez and Rowntree (in press.))

Table 3.5 Geomorphological Zonation of River Channels (after Rowntree and Wadeson, 1999)

Longitudinal zone	Macro-reach characteristics			Characteristic channel features
	Valley form	Gradient class	Zone class	
A. Zonation associated with a 'normal' profile				
Source zone	V10	not specified	S	Low gradient, upland plateau or upland basin able to store water. Spongy or peaty hydromorphic soils.
Mountain headwater stream	V1, V3	> 0.1	A	Very steep gradient streams dominated by vertical flow over bedrock with waterfalls and plunge pools. Normally first or second order. Reach types include bedrock fall and cascades.
Mountain stream	V1, V3	0.04 - 0.99	B	Steep gradient stream dominated by bedrock and boulders, locally cobble or coarse gravels in pools. Reach types include cascades, bedrock fall, step-pool, Approximate equal distribution of 'vertical' and 'horizontal' flow components.
Transitional	V2, V3, V4, V6	0.02 - 0.039	C	Moderately steep stream dominated by bedrock or boulder. Reach types include plain-bed, pool-rapid or pool riffle. Confined or semi-confined valley floor with limited flood plain development.
Upper Foothills	V4, V6	0.005 - 0.019	D	Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plain-bed, pool-riffle or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow flood plain of sand, gravel or cobble often present.
Lower Foothills	V8, V10	0.001 - 0.005	E	Lower gradient mixed bed alluvial channel with sand and gravel dominating the bed, locally may be bedrock controlled. Reach types typically include pool- riffle or pool-rapid, sand bars common in pools. Pools of significantly greater extent than rapids or riffles. Flood plain often present.
Lowland river	V4, V8, V10	0.0001- 0.001	F	Low gradient alluvial fine bed channel, typically regime reach type. May be confined, but fully developed meandering pattern within a distinct flood plain develops in unconfined reaches where there is an increased silt content in bed or banks.
B. Additional zones associated with a rejuvenated profile				
Rejuvenated bedrock fall / cascades	V1, V4	>0.02	A/B/Cr	Moderate to steep gradient, confined channel (gorge) resulting from uplift in the middle to lower reaches of the long profile, limited lateral development of alluvial features, reach types include bedrock fall, cascades and pool-rapid.
Rejuvenated foothills	V2, V3, V4, V6	0.001 - 0.02	D/Er	Steepened section within middle reaches of the river caused by uplift, often within or downstream of gorge; characteristics similar to foothills (gravel/cobble bed rivers with pool-riffle/ pool-rapid morphology) but of a higher order. A compound channel is often present with an active channel contained within a macro channel activated only during infrequent flood events. A limited flood plain may be present between the active and macro-channel.
Upland flood plain	V8, V10	< 0.005	Fr	An upland low gradient channel often associated with uplifted plateau areas as occur beneath the eastern escarpment.

Channel morphology is seen as the dynamic and indeterminate product of the geomorphological system. Experience has shown that it is difficult to predict a precise morphological end product for any given set of system variables. Although it is possible to point to characteristic channel types that occur within certain geomorphological environments, significant variability exists.

Table 3.5 should be used to give an indication of the expected channel morphology for a given reach gradient. It will be noted that for each geomorphological zone there is a considerable range of expected channel types.

3.3.2 Assessing the Present Ecological State

Given the definition of Reference Condition given in section 3.3.1, the PES for geomorphology is assessed in terms of changes to the geomorphological system, rather than changes to morphology and habitat *per se*. The PES is assessed in terms of -

- System changes that impact on flows of energy and matter.
- Changes to factors that may affect the system's resistance or resilience to change.
- Observed changes to morphology and associated habitat components.

The assessment of the PES (geomorphology) is based on a question dealing with four metric groups, that relate to change within the geomorphic system -

> ***To what extent has the capacity of the geomorphological system to support the natural ecosystem changed due to the following? -***
>
> - System connectivity
> - Sediment balance
> - Resistance of the channel to change
> - The channel morphology

Data for assessing the PES are collected in accordance with the guidelines given below. Standard data collection forms are included in the discussion of each metric group, and examples of data are given for a site on the Kat River in the Eastern Cape.

Two types of data are collected -

- **Classification data**, which allow channel typing, and can be used to guide the assessment of reference channel type (3.2).
- **Condition assessment data**, which are used directly to assess the PES.

To assess the PES, the assessor is required to -

- **Rate the degree of change** according to the guidelines given below (3.3).
- **Weight** the different components of change.
- **Give a confidence rating** from 1 (low confidence) to 5 (high confidence).

All data from the field forms are transferred automatically into a spreadsheet that automatically calculates the scores for the individual components, the final PES score and the overall confidence rating. Data are entered into two worksheets: Classification (Figure 3.3); and PES Data. The remaining worksheets contain the separate components of the rule-based model. These worksheets should not be altered by the data recorder.

GAI

Only the data sheets are completed. Worksheets comprising the GAI model should not be altered as the information is automatically transferred.

3.3.3 Ranking and weighting

Guidelines for assessing the PES are generalized and there can be no strict rules as to how to relate the degree of change, or rating, to the type of impact. This remains a matter of expert judgment based on experience. It is important that changes are rated with respect to presumed associated changes in habitat following the guidelines given in Table 3.6 (derived from Table 2.1).

Table 3.6 Habitat rating categories

Rating modification from reference	General habitat modification	Geomorphological change
0 (0-0.5) = none	No discernible impact, or the modification is located in such a way that it has no impact on habitat quality, diversity, size and variability.	Changes to channel morphology have no discernible impact on habitat quality, diversity, size and variability.
1 (0.5-1) = small	The modification is limited to very few localities and the impact on habitat quality, diversity, size and variability is also very small.	Localised changes to channel morphology that have a small impact on habitat quality, diversity, size and variability.
2 (1-2) = moderate	The modifications are present at a small number of localities and the impact on habitat quality, diversity, size and variability is also limited.	Changes to drivers or perimeter conditions have resulted in a change in channel dimensions, but habitat quality, diversity, size and variability is largely unchanged.
3 (2-3) = large	Clearly detrimental impact on habitat quality, diversity, size and variability. Large areas are, however, not influenced.	Changes to drivers or perimeter conditions have resulted in a definite change to habitat quality, diversity, size and/or variability.
4 (3-4) = serious	The modification is frequently present and the habitat quality, diversity, size and variability in almost the whole of the defined area are affected. Only small areas are not influenced.	Changes to drivers or perimeter conditions have resulted in a change in channel state (supply or transport limited channel). Widespread changes to habitat quality, diversity, size and variability
5 (4-5) = extreme	The modification is present overall with a high intensity. The habitat quality, diversity, size and variability in almost the whole of the defined section are	Irreversible changes resulting in a widespread transformation of channel morphology and associated habitats.

Rating modification from reference	General habitat modification	Geomorphological change
	influenced detrimentally.	

The level of **confidence** depends firstly on the availability and accuracy of information, and secondly on the level of the assessor's understanding of geomorphological response to a system change as indicated below in Table 3.7. For example, we may know that there is a dam upstream of the reach (confidence level 5) and we are certain from previous studies that the dam will have some impact on geomorphology, but the exact nature of the response is uncertain (confidence level 3). From the matrix in Table 3.7 we would rate our overall confidence as moderately high (4). In other cases we may be uncertain of the extent of erosion in the catchment due to poor information (2), and uncertain of the geomorphological response to increased sediment inputs (3). Our overall confidence in the rating will therefore be low (2.5).

Table 3.7 Guidelines for confidence ratings

UNDERSTANDING		Information				
		Poor		Moderate	Good	
		1	2	3	4	5
Poor understanding of both direction and amount of change	1	1	1.5	2	2.5	3
	2	1.5	2	2.5	3	3.5
Understands direction of change but cannot quantify	3	2	2.5	3	3.5	4
Good understanding of direction and amount of change.	4	2.5	3	3.5	4	4.5
	5	3	3.5	4	4.5	5

The assessment of the geomorphology EC is based on rating the four metric groups in terms of how the capacity *of the geomorphological system to support the natural ecosystem has changed due to -*

- System connectivity
- Sediment balance
- Resistance of the channel to change
- The channel morphology

Before data are collected on these different components of the GAI they should be ranked and weighted according to the relative importance that changes to each component will have on the ability of the geomorphological system to support aquatic and riparian ecosystems or the final PES score (2.3.2). The rank and associated weighting should not consider the observed degree of change.

Normally changes to system connectivity and changes to the sediment balance would be ranked 1 and 2 respectively. Some general rules are the following -

- The sediment balance will have a high ranking / weighting in a lowland alluvial system, where the bed is dominated by sands and gravels, but will have a lower weighting in higher gradient and bedrock systems that are likely to be supply-limited.
- Perimeter resistance will have a relatively high weighting for channels with uncohesive banks, as bank stability will be susceptible to changes in vegetation cover and bank steepening. Channel morphological changes, although directly related to habitat, is not normally given a high weighting because changes to channel morphology are difficult to discern and confidence levels are generally low. An example of the portion of the PES data sheet giving weightings for the different GAI metrics is given in Figure 3.4.

PES DRIVER WEIGHTING	rank	weighting
SYSTEM CONNECTIVITY	1	100
SEDIMENT BALANCE	4	50
PERIMETER RESISTANCE	2	80
CHANNEL MORPHOLOGY	3	60

Figure 3.4 PES driver weighting for Site 1 on the Kat River.
(This is in a relatively steep, mixed boulder pool-rapid reach, so the sediment balance has been given a low ranking.)

3.3.4 System Connectivity

- The format for recording data on system connectivity is shown in Figure 3.5.
- Each metric of connectivity must first be ranked and given a weighting before the rating scores are filled in.
- The GAI metric group for system connectivity is shown in Figure 3.6.
- Note that the data recorded in Figure 3.5 are carried automatically into the

spreadsheet shown in Figure 3.6.

- **Weightings** depend partly on the channel classification.
- Upstream-downstream connectivity will normally be ranked high, except in headwater streams.
- Confined channels will have a high rank for hill slope-channel connectivity.
- The weighting for within-reach connectivity will be highest in moderate gradient channels.
- Channel-floodplain connectivity will be given a relatively high weight in unconfined channels with a wide flood plain, but will be given a low weight in confined or incised channels.
- Vertical connectivity is most important in alluvial channels, least important in bedrock channels.

The ratings for changes to system connectivity are assessed according to the following guidelines per metric (note that ratings are largely based on expert judgement and experience) -

a) Hill slope-channel connectivity

Changes to hill slope-channel connectivity could be due to a change in drainage density or to catchment hardening that promotes increased runoff due to decreased infiltration.

b) Upstream-downstream connectivity

A reduction in upstream-downstream connectivity could be due to dams, weirs, causeways, bridges or landslides upstream of the study reach. The removal of any of the above, or channel straightening, increases connectivity.

c) Within-reach connectivity

Changes to in-reach connectivity might be due to local weirs, causeways or other obstructions that change the distribution of energy within the reach itself.

d) Channel-floodplain connectivity

Changes refer to the frequency that water spills out of the channel on to the flood plain or activates secondary channels. The degree of channel-flood plain connectivity can be affected directly through channel incision, channel aggradation or construction / destruction of levees or floodwalls. Indirectly connectivity is affected by changes to flood magnitude and frequency.

e) Vertical connectivity

Vertical connectivity is the connectivity between the channel surface and the channel bed or hyporheic zone. It relates both to the passage of water and the turnover of sediments. Channel armouring and hardening both decrease vertical connectivity.

SYSTEM CONNECTIVITY						
SYSTEM CONNECTIVITY	**rank**	**weighting**	**rating**	**confidence**	**flow related**	**Comment on reason for rating**
hillslope-channel connectivity	2.0	85	1.0	4.0	0.0	local gully erosion, bank erosion
upstream-downstream connectivity	1.0	100	3.0	4.5	75.0	upstream dam, infrequent causeways
within-reach connectivity	3.0	80	0.5	4.0	0.0	bridge with in-channel supports in reach
channel-flood zone connectivity	4.0	60	2.0	4.5	100.0	smaller floods
vertical connectivity	5.0	20	1.0	3.0	75.0	armouring
Other	0.0					

Relative weightings: this reach is classified as an incised upper foothills site; upstream-downstream connectivity is normally considered to have the highest rank, followed by channel hill slope connectivity. With a limited flood zone channel-flood plain connectivity is of limited importance. Bedrock outcrops are frequent in the channel so vertical connectivity is naturally constrained, so has a low weighting.

Ratings: This site lies a few kilometers below the Kat Dam which is considered to have a large to serious impact (3) on the upstream-downstream connectivity. Reduced magnitude and frequency of floods resulting from the presence of the dam has a secondary impact on channel-flood plain conductivity which is rated as moderate to large (2) while localized development of gullies and tracks has had a small to moderate (1) impact on hill slope-channel connectivity. A small to moderate reduction in vertical connectivity is ascribed to armouring of the bed (removal of fines). The resultant weighed score is 1.64. Sixty four percent of this score is flow related and the confidence score is 4.34. Information about the system is good, but the confidence is reduced due to poorer understanding of system processes.

Figure 3.5 Rating table for system connectivity with an example of rating for Site 1 on the Kat River, Eastern Cape.

<u>GAI spreadsheet</u>

Only GREY shaded cells are completed. All other cells to be left alone as they contain formulas.

SYSTEM CONNECTIVITY METRICS	Rank	%wt	RATING	Flow related?	CONFIDENCE
channel-hillslope connectivity	2	85	**1.0**	0	4.00
upstream-downstream connectivity	1	100	**3.0**	75	4.50
within reach connectivity	3	80	**0.5**	0	4.00
channel-flood plain connectivity	4	60	**2.0**	100	4.50
vertical connectivity	5	20	**1.0**	75	3.00
Other		0	**0.0**	0	0.00
Score		345.00		**63.72**	**4.34**

Figure 3.6 System connectivity component of the GAI for a site on the Kat River, Eastern Cape

3.3.5 Sediment Balance

To answer the question 'To what extent has the potential for geomorphological change been affected by changes to event hydrology and or sediment supply?' we need to consider the extent to which changes in both flood hydrology and/or sediment supply have changed the ability of the flow to transport the available sediment. The sediment balance for the reach is assessed in terms of changes to the sediment supply from the hill slopes, the sediment supply from the upstream channel and the capacity of streamflow to transport sediment.

a) Sediment supply

- Changes to the sediment supply are rated on the scale of 0-3 (no change, slight change, moderate change and large change).
- Guidelines for rating changes to sediment supply are given in Table 3.8.
- The rating for sediment supply changes should take into account the extent, severity, location and history of erosion.
- Sheet erosion that is widespread over the catchment surface may be a greater sediment source than the more obvious gullies.
- Erosion sources close to the reach should be rated higher than sources that are at a greater distance.
- Erosion will normally decrease over time, so erosion sites that have been active for over twenty years may be stabilising.
- The sediment supply rating should also take into account sediment delivery.
- The delivery ratio depends on hill slope and channel gradients, on the presence of buffer zones between hill slopes and the channel (e.g. flood plains), and the density of the drainage network.
- A well-connected gully network will increase sediment delivery, as will dirt roads and drainage ditches aligned up and down slope.
- An appropriate timeframe for sediment delivery would be in the order of decades.

Table 3.8 Guidelines for rating changes to sediment supply

Impact		SEDIMENT INPUT (from catchment) (increase)
0	None	
1	Small - Moderate	Localized gully erosion (< 10% of catchment) plus limited sheet erosion, moderately coupled to stream channel
2	Large	Active gully or sheet erosion over catchment, strongly coupled to channel
3	Serious	Extensive gully and sheet erosion over significant areas of catchment (> 50%), strongly coupled to channel
Impact		**SEDIMENT INPUT (from upstream channel reach) (increase)**
0	None	
1	Small - Moderate	Localised bank erosion on < 10 % of channel
2	Large	Bank erosion on 10 to 50 % of channel
3	Serious	Bank erosion on over 50% of channel and/or widespread channel incision
Impact		**SEDIMENT INPUT (from upstream reach (decrease)**
0	None	
1	Small - moderate	Sediment trapped by causeways or small weirs, small dam upstream of major tributaries or larger dam controlling small area of catchment
2	Large	Small upstream dam or series of larger weirs, significant mining of sediment, or large dam upstream of tributaries
3	Serious	Upstream dam trapping all coarse sediment, no significant downstream tributaries or sediment sources.

b) Transport capacity

Changes to the sediment transport capacity are related to changes in event hydrology. We need to assess the extent to which the magnitude and frequency of flood events has changed due to anthropogenic activities. These changes can be considered under three groups of discharges -

- Flows that are contained within the active channel.
- Flows that fill or overtop the active channel, inundate flood benches or the flood plain.
- Extreme events that extend beyond the normal limits of flooding as evidenced from the sequence of flood deposits and the limits of riparian vegetation.

Guidelines for rating changes to the transport capacity of flows are given in Table 3.9.

In many environments it appears that frequent floods of moderate magnitude (once every one to two years) are the most effective in transporting sediment and controlling the channel morphology, but any flow with sufficient stream power to initiate sediment movement will contribute to the process of morphological adjustment. Extreme events are almost without exception due to weather phenomena and are therefore part of the natural cycle of disturbance. It is not sensible to assess changes to the frequency of extreme events, but recent events should be noted.

Table 3.9 Guidelines for rating changes to transport capacity

Impact		DECREASES IN TRANSPORT CAPACITY (reduction in floods)
0	None	
1	Small to Moderate	Floods attenuated but volumes conserved
2	Large	Size of annual to biennial floods significantly reduced, extremes little impacted (dams controlling over 70 % of catchment; storage capacity of dam > MAR of upstream catchment
3	Serious	Annual to biennial floods eliminated, flood regime dominated by extreme events
Impact		**INCREASES IN TRANSPORT CAPACITY (increase in floods)**
0	None	
1	Small to moderate	Frequency of small floods and/ or magnitude of annual flood increased
2	Large	Base flow increased to above threshold for sediment movement
3	Serious	Base flow increased to previous bankfull level

The following activities can alter the magnitude-frequency signature of floods -

- Large upstream dams that trap many of the smaller to intermediate floods have been shown to have major impacts on downstream channels. The impact of the dam can be assessed in terms of a) the %age area of the catchment of the study reach that is controlled by the dam b) the %age of the MAR of the study reach that is controlled by the dam and c) the capacity of the dam relative to the MAR at the dam site. Dams that have a capacity in excess of its own catchment's MAR and that control over 70% of the catchment upstream of the study reach will have a large impact.
- Land use change that impacts on floods will also contribute to changes morphological change. Urban areas are a good example of a land use change that increases both the magnitude and frequency of floods, with corresponding effects on downstream channel morphology.
- Interbasin transfer schemes may increase 'normal' flows to the extent that the critical threshold for sediment movement is exceeded. Large to severe increases to the sediment transport capacity may be the result.

Where possible consult the hydrologist for an assessment of changes to event hydrology. The Hydrology Driver Assessment Index (HAI) contains two metrics that rate changes to event hydrology.

c) *Combining transport capacity (event hydrology) and sediment supply*

- A matrix is supplied to guide the assessment of changes to the sediment budget. (Figure 3.7).
- The ratings for change to sediment supply and change to sediment transport capacity, assessed according to the guidelines (Table 3.8 and Table 3.9), are applied to this matrix. This rating is carried forward to the Geomorphology EC sheet given in Figure 3.12.
- The long-term impact of changes to either the sediment supply or the magnitude and frequency of geomorphologically effective flows depends on the magnitude and direction of the change. If both changes are in the same direction the impact on channel processes is likely to be less than if they are in the opposite direction. For example, if both sediment supply and transport capacity increase together, the response is likely to be a bigger channel but with no change to its general characteristics. If, however, the sediment supply increases but the transport capacity decreases, the response will be channel aggradation with the channel becoming more strongly transport limited. The converse will lead to a propensity for a supply limited channel.

Using the matrix in Figure 3.7, it can be seen that a large positive change in sediment supply (3) and a large negative change in transport capacity (-3) are assumed to have an extreme (5) geomorphological response, whereas a large reduction in both transport capacity (3) and sediment supply (3) will only have a large geomorphological response. It should be noted that this table has been constructed from first principles as outlined above. The accuracy of the ratings needs to be tested through continued field application.

d) *Completing the sediment balance*

The sediment balance follows a different approach from the other metric groups / metrics in that it goes directly from the data sheet to the final PES sheet. The following steps are used to get to the PES rating and weighting -

- Weight the sediment balance (Figure 3.4) in the data sheet in GAI model.
- This weighting is transferred to the final PES sheet (Figure 3.12)
- Rate the sediment supply (Figure 3.7) according to the guidelines given

(Table 3.8) and provide confidence.

- Rate the transport capacity (Figure 3.7) according to the guidelines given (Table 3.9) and provide confidence.
- Derive the combined sediment balance and transport capacity rating using the matrix (Figure 3.7)
- This rating is transferred to the final PES sheet (Figure 3.12)
- This confidence and flow related percentage are transferred to the final PES sheet (Figure 3.12)

SEDIMENT BALANCE				COMMENT
	Rating	Confidence	Flow related	
CHANGE TO SEDIMENT SUPPLY	-2.00	2.5		Sediment trapped by upstream dam, but partly compensated by local hillslope erosion and reworking of sediment form alluvial fan at end of gorge.
CHANGE TO SEDIMENT TRANSPORT CAPACITY	1.00	4		Large reduction in flood magnitude due to upstream dam, but increased frequency of intermedeate events due to releases. No signficant downstream tributaries.
CHANGE TO REACH SEDIMENT BALANCE	3.00			
Score for discharge/sediment change (from matrix)	3.00	3.25	30	

change in transport capacity (discharge)

change in sediment supply	-3	-2	-1	0	1	2	3
3	5	4.5	4	3.5	3.4	3.2	3
2	4.5	4	3	2.5	2.25	2	3.2
1	4	3	2	1.5	1	2.25	3.4
0	3.5	2.5	1.5	0	1.5	2.5	3.5
-1	3.4	2.25	1	1.5	2	3	4
-2	3.2	2	2.5	2.5	3	4	4.5
-3	3	3.2	3.4	3.5	4	4.5	5
	-3	-2	-1	0	1	2	3

change in transport capacity (discharge)

Figure 3.7 Rating table for sediment balance with an example of rating for Site 1 on the Kat River.

3.3.6 Channel Perimeter Resistance

- The propensity for channel change depends on the resistance (or lack of) of the channel perimeter, including the bed, banks, bars, and out of channel flood zone.
- In all cases the present-day rating is assessed from observed characteristics.

- An assessment is then made of the expected reference conditions (those which would have occurred under ‘natural’ conditions). This allows an assessment of change to be made.
- Perimeter resistance is considered to be a function of the sediment composition of the relevant feature and, in the case of banks, flood zones and bars, of the vegetation cover. It should be noted that vegetative ground cover and root density are more important than overhead cover. Roots that extend to below the normal water level are more effective at stabilising the bank than are shallow root systems. Alien invasive woody vegetation may inhibit ground cover and, in the case for example of *Acacia mearnsii,* (introduced invasive - black wattle) may have a root system that does not extend into the saturated zone. Bank undercutting is common in these circumstances.
- The geomorphologist should consult the riparian vegetation specialist to assist in rating vegetation condition and vegetation change.

a) Bed material

The rating for bed mobility is assessed according to the size of the bed material as indicated in Table 3.10. For example a cobble bed river would be rated 1.5 and a sand or fine gravel bed river would be rated 5. Mixed beds can be given an intermediate rating (e.g. 2.5 for a cobble bed with significant patches of gravels). Note that a highest rating is given to the most mobile material, that is, the least-resistant to change.

Table 3.10 Rating the mobility of the channel bed

Bedrock/ paved	Boulder	Cobble	Coarse & medium gravel	Sand and fine gravel
0	0.5	1.5	3.5	5

b) Bank stability:

This is assessed in the first instance through considering both the perimeter material and the effectiveness of the vegetation cover according to the following table (Table 3.11). Note that the least stable banks are afforded the highest rating. Thus a channel with banks composed of sand with a dense vegetation cover (usually indigenous) affording good protection would be rated 3. The rating is then modified in accordance to the bank slope (Table 3.12). If this same bank was gently sloping ($<20^o$) the rating would be reduced from 3 to 2, indicating greater stability.

Table 3.11 Rating bank stability from bank material and vegetation cover

BANK STRENGTH		EFFECTIVENESS OF VEGETATION COVER		
		poor	moderate	dense
Low cohesion	e.g. sand/gravel	5	4	3
Moderate cohesion	e.g. mixed	4	3	2
Cohesive	e.g. silt-clay	3	2	1
Weathered bedrock / gabion wall		0.5	0.5	0.5
Intact bedrock/ concrete wall		0	0	0

Table 3.12 Rating affect of slope on bank stability

Slope class	Stability rating from Table 3.11				
	1	2	3	4	5
> 45^o	2	3	3.5	4.5	5
20 – 45^o	1	2	3	4	5
<20^o	0.5	1	2	3	4

c) Bar stability

This is assessed using Table 3.13. Note that it is possible to have bedrock bars in supply-limited channels. Vegetation on bars imparts an important stabilising influence.

Table 3.13 Rating of in-channel bar stability

STRENGTH OF BAR SEDIMENT		EFFECTIVENESS OF VEGETATION COVER		
		poor	moderate	dense
Low stability	e.g. sand/gravel	5	4	3
Moderate stability	e.g. mixed	4	3	2
	e.g. cobble	3	2	1
	e.g. boulder	1.5	1	0.5
Weathered bedrock		0.5	0.5	0.5
Intact bedrock		0	0	0

d) Out-of-channel flood zone

The stability of this component is rated using Table 3.11 above.

e) Final channel perimeter results

- The data on the different perimeter resistance components are entered into the data sheet.
- These data are automatically carried through to the perimeter resistance change metric worksheet (Figure 3.8)
- From there, the data is transferred to the final EC sheet.

PERIMETER RESISTANCE METRICS	Rank	%wt	RATING	WEIGHT	Weighed score	Flow related?	CONFIDENCE
BED MOBILITY	2	80	**1**	0.31	0.31	50.00	3.5
BANK (IN)STABILITY	1	100	**-0.5**	0.38	0.19	40.00	3.5
BAR (IN)STABILITY	2	80	**0.5**	0.31	0.15	40.00	3
FLOOD ZONE (IN)STABILITY	3	30	-2	0.12	0.23	30.00	3
TOTALS		260		1.00	0.65		
Perimeter resistance rating					**0.65**		
FLOW RELATED (%)					**55.29**		**3.38**

	BED MOBILITY	BANK (IN)STABILITY	BAR (IN)STAB-ILITY	FLOOD PLAIN STABILITY
Reference condition	2	2.5	1.5	1
Present condition	1	3	1	3
Change in perimeter resistance	1	-0.5	0.5	-2

The present-day bed is composed of cobble and boulder with small pockets of gravel. Mobility was rated as 1. The reference condition was believed to include a higher proportion of gravels, rated at 2. The present day bank stability was rated at 3, due to a moderate vegetation cover and a mixed bank material of sand, gavel and boulder. The reference condition was assumed to be slightly more stable due to a better vegetation cover. Bars are assumed to have become more stable (from 1.5 to 1) due to a small reduction in gravel and increased vegetation growth.

Figure 3.8 Assessment of changes to perimeter resistance for site on the Kat River

3.3.7 Morphological change

- Habitat changes due to morphological change are assessed separately for the substrate and channel geometry.
- Substrate changes refer to changes of sediment composition and sediment structure on the bed, bars, banks and flood zone.
- Channel geometry changes are assessed in terms of the reach type, cross-section change, loss or gain of secondary channels and channel roughness.
- A change to reach type that would represent a major change to the configuration and characteristics of the channel, but may be due to a short-term extreme event, with gradual change back towards an earlier condition.
- Cross-section change will be reflected by changes to the channel width or

mean depth, and to the width-depth ratio.

- Secondary channels contribute to habitat diversity and provide refuge during flood events. Loss or gain of secondary channels is an important indicator of habitat change.
- Channel roughness determines the hydraulic response, the mean velocity and depth of flows at any given discharge and the pattern of flow types. Roughness is contributed by sediment size and bed structure, channel form irregularities and vegetation.
- It may be difficult to assess habitat changes due to morphological change because of lack of historical information. Ideally change should be assessed in terms of actual morphological change relative to a morphological Reference Condition, but this is often difficult to carry out due to a lack of competence to assess the geomorphological reference condition for a river reach.
- Figure 3.9 provides a framework within which a geomorphology-driven assessment of change can be placed. Aerial photographs or anecdotal evidence can be used to assess historical changes to channel morphology. A field assessment of the present channel will provide evidence of ongoing change in terms for example of bank erosion, bar development, loss or gain of secondary channels. Finally the river zone, classified in terms of reach gradient and stream power, can be used to get a first approximation of expected channel morphology. These four aspects can then be compared to derive an assessment of the change rating.

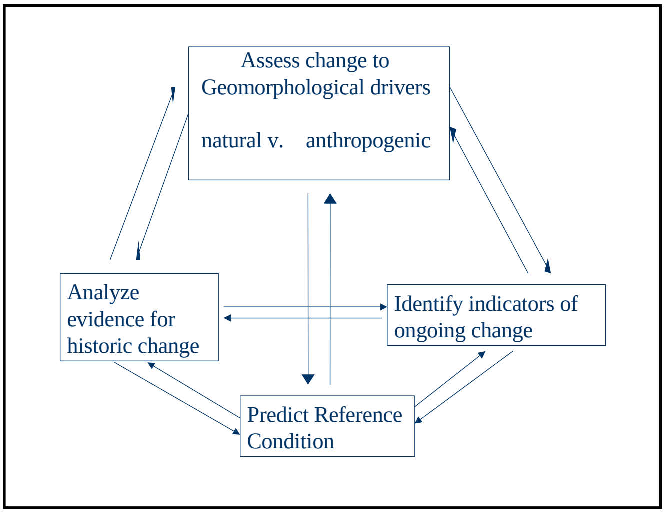

Figure 3.9 Framework for assessing morphological change

An example of the data sheet and driver metric worksheet for assessing morphological change is given in Figures 3.10 and 3.11 respectively.

MORPHOLOGICAL CHANGE ASSESS HABITAT CHANGES DUE TO:	rank	weighting	rating	confidence	flow related
SUBSTRATE CHANGES					
CHANNEL BED	1	100	2	2	55
BARS	2	90	1.5	2.5	70
CHANNEL BANK	3	80	0.5	2	40
FLOOD ZONE SEDIMENTS	4	75	0.5	2	40
HYDRAULIC GEOMETRY					
REACH TYPE	1	100	0	4	50
CROSS-SECTION SHAPE	2	80	2	2	50
SECONDARY CHANNELS	2	80	1	2	50
CHANNEL ROUGHNESS	4	50	1.5	2	50

The main substrate change is a coarsening if the channel bed due to armouring. Frequent irrigation releases have resulted in the removal of fines from between cobbles. The main change to the hydraulic geometry (channel shape) is a narrowing of the main channel due to the stabilisation of lateral bars and islands by vegetation. This in turn has increased channel roughness and created secondary channels.

Figure 3.10 Morphological changes at a site on the Kat River

PERIMETER RESISTANCE METRICS	Rank	%wt	RATING	WEIGHT	Weighed score	Flow related?	CONFIDENCE
SUBSTRATE CHANGES							
CHANNEL BED	**1**	100	2.0	0.476	0.95	55.00	2.00
BARS	**2**	90	1.5	0.429	0.64	70.00	2.50
CHANNEL BANK	**3**	80	0.5	0.381	0.19	40.00	2.00
FLOOD ZONE SEDIMENTS	**4**	75	0.5	0.357	0.18	40.00	2.00
SUB-TOTAL					1.96		
HYDRAULIC GEOMETRY							
REACH TYPE	**1**	100	0.0	0.476	0.00	50.00	4.00
CROSS-SECTION SHAPE	2	80	2.0	0.381	0.76	50.00	2.00
SECONDARY CHANNELS	2	80	1.0	0.381	0.38	50.00	2.00
CHANNEL ROUGHNESS	3	50	1.5	0.238	0.36	50.00	2.00
SUB-TOTAL					1.50		
TOTALS		210.00	4.5	1.00	1.73		
Morphology Driver status:					**1.73**		
FLOW RELATED						**53.55**	**2.08**

Figure 3.11 Morphological river status for site on the Kat River

3.4 GEOMORPHOLOGY EC

The final driver status is derived by combining the separate ratings estimated for the four different driver metrics - system connectivity, reach sediment balance, channel perimeter resistance and morphological change, as given in Figure 3.4, Figure 3.5 Figure 3.6 and Figure 3.8 respectively. These values are automatically brought forward to the final EC worksheet. The %age flow-related and confidence values are also calculated from the values derived for the separate geomorphology metrics.

GEOMORPHOLOGY DRIVERS							
METRIC SUBGROUPS	Rank	%wt	RATING	WEIGHT	Weighed score	Flow related?	CONFIDENCE
System Connectivity	1	100	1.64	0.34	0.56	63.72	4.34
Reach sediment balance	4	50	3.00	0.17	0.52	30.00	3.25
Channel perimeter resistance	2	80	0.65	0.28	0.18	55.29	3.38
Morphological change	3	60	1.73	0.21	0.36	53.55	2.08
TOTALS		290.00		1.00	1.62		
System Driver status:					**1.62**		
Driver status:(%):					**67.59**		
HABITAT DRIVER CATEGORY					**C**		
BOUNDARY CATEGORY					**n/a**		
FLOW RELATED (%)						**49.77**	**3.42**

Figure 3.12 The final driver status for the site on the Kat River

3.5 APPLICATION OF THE GEOMORPHOLOGY DRIVER ASSESSMENT INDEX

3.5.1 Completing the GAI model

All the datasheets and model sheets are discussed in 3.3 and 3.4 above. The links between the datasheet, the metric groups and the final EC are demonstrated in the flow diagram (Figure 3.13).

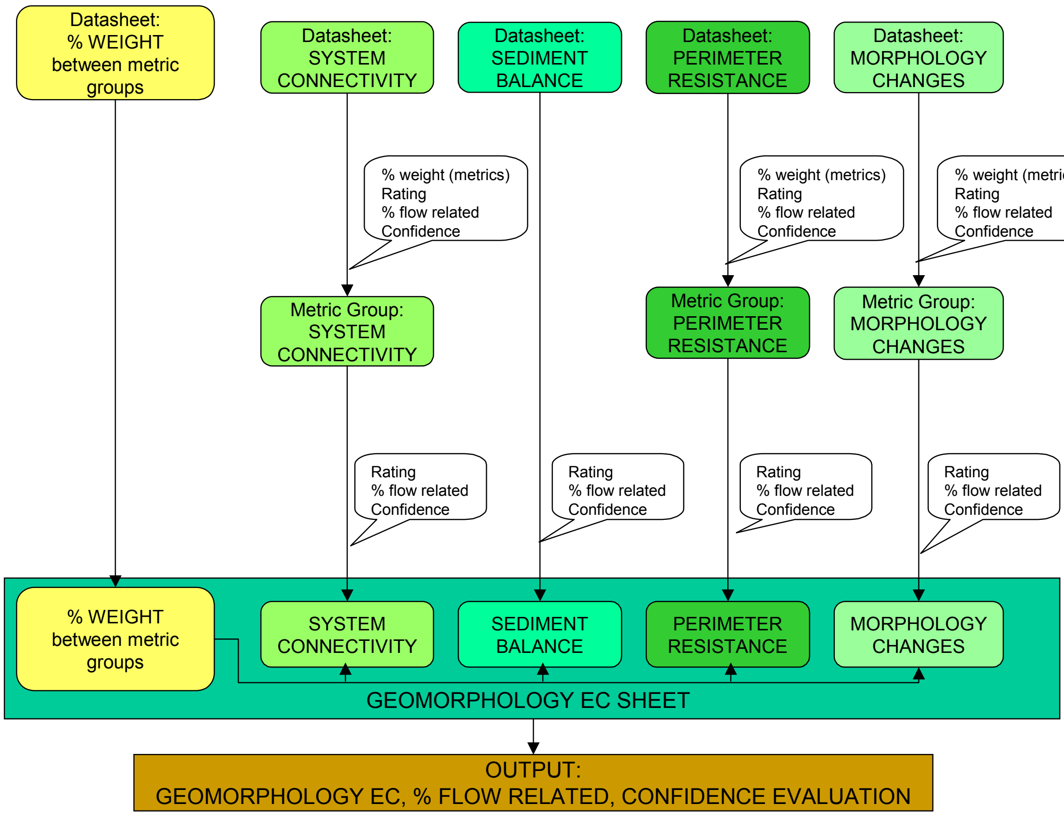

Figure 3.13 Flow diagram illustrating links between the data sheet, the metric groups and the PES

3.5.2 Geomorphological input into EcoClassification

The following table (Table 3.14) illustrates the links between the steps followed to determine the REC and the geomorphology information required.

Table 3.14 Geomorphological input into the EcoClassification

Steps	Geomorphology input
Reference conditions and PES	Classification of the river according to geomorphology zones. Run the GAI to determine the Geomorphology PES.
Trend	The assessor must consider the following alternatives - • the channel morphology has not yet responded to change in system structure but is likely to do so in the future; • the channel morphology has undergone preliminary change as a result of changes to the system structure; future change is likely to result in a change in the Ecological Category. • the channel morphology has undergone change in response to a change in system structure, but has achieved a new level of 'stable' self organisation. The geomorphologist needs to consider the time since system changes occurred, the resistance of the channel to change and the resilience of the channel. Resilience refers to the ability of the channel to reorganise itself following change. Alluvial channels are normally more resilient than bedrock channels. An index of resistance to change is assessed as part of the GAI rule-based model.
Cause for the PES	The critical causes for the PES and observed trends can be derived from the GAI

Steps	Geomorphology input
	rule-based model. Both the rating and weighting of the different geomorphological system components should be taken into account when making this assessment.
Source of the cause	The source of the causes should be noted. Example might include - Cause – system connectivity has decreased Source – upstream dam Cause – sediment balance has changed towards a more transport limited system Source – tributary catchment erosion coupled with an upstream dam
EIS	The ecological importance and sensitivity are normally rated with reference to the biological components and habitat. The geomorphologist may consider the reach to be of geomorphological importance if the reach provides unique or rare physical habitat. An example is the Pongola floodplain.
REC	The REC is decided considering the results of the EIS and on attainability. The causes and sources of geomorphology and the restoration potential must be considered. To enable the determination of flow requirements, ecological objectives (driven by ecological considerations and the implications for habitat) must be set. The geomorphologist must therefore set objectives to meet the recommended habitat requirements considering ecological inputs. The geomorphologist must give advice on how the causes of a low PES score can be addressed. The source of a low PES for geomorphology is often in the catchment or the riparian zone rather than being flow related.
Alternative ECs	Alternative ECs refer to either an improved, or degraded (from PES) EC. The gemorphology must be predicted based on a realistic set of described conditions. The GAI is used in a predictive way to derive the geomorphology objectives for the required geomorphology EC.
Ecological consequences	Ecological consequences for additional flow scenarios must be tested. The resulting geomorphology EC must be assessed and the GAI is again run predictively for this.

3.5.3 Application of the Geomorphological Driver Assessment Index to the National River Health Programme

There is scope for applying the GAI as the geomorphological index used in the National River Health Programme. Rating the ecological drivers from a geomorphological perspective would contribute to our understanding of the observed ecological responses at biomonitoring sites. However, this will usually be determined by the importance, relevance and capacity (expertise and financial) to do such an assessment specifically for RHP purposes. As indicated elsewhere, where a GAI assessment was done for other purposes, it should logically be used in the RHP assessment.

The index has not been developed specifically as a monitoring tool, but it could be used to identify the impact of major system changes over the time scale of the monitoring programme.

For more detailed monitoring of change at a site it will be necessary to make quantitative measurements of specific features such as the particle size distribution of sediment on the channel bed and bars, bed packing and embeddedness and bank erosion. Assessment forms are provided in Appendix E. These measurements will enable short-term changes to be identified; it must be remembered that these may be reversible in the short-term and do not indicate a long-term system change.

3.6 CONCLUSIONS

This chapter presents the development of a revised Geomorphological Index, the Geomorphological Driver Assessment Index (GAI). This index takes the form of a rule-based model that integrates the extent to which changes in the components of the geomorphological system are believed to compromise the natural river ecology. The GAI can be used to assess the Ecological Category of a reach, which in turn can be applied to assessing the Present Ecological State and the Recommended Ecological Category. It can also be used to examine the effect of different management scenarios on the geomorphological system. Although the development of the GAI has been within the context of determining Environmental Water Requirements, the index can also be used as a component of river health and is recommended as the standard method for carrying out geomorphological assessments within the National River Health Programme in situations where it is considered appropriate.

A fundamental difference between the GAI as presented here and earlier assessment methods is a change to the conceptualisation of the Reference Condition. Rather than seeing the Reference Condition as being a deterministic channel morphology that can be predicted from reach and catchment controls, the Reference Condition is conceptualised as a geomorphological system composed of flows, storages and responses that are dynamic and indeterminate. This thinking is in line with the systems paradigm that is being applied increasingly to fluvial geomorphology. This also provides a clearer interpretative link to biological responses than was previously the case.

4 HYDROLOGY DRIVER ASSESSMENT INDEX

This is NOT a training manual.
The guidelines presented here assume that the reader has some knowledge of EcoHydrology

4.1 ECOLOGICALLY-RELEVANT HYDROLOGY METRICS

The desired attribute of a hydrological metric is that it should provide information on the degree to which the hydrological regime has changed from the reference situation, and the ecological responses to such a change. Hydrological changes are related to a modification in the volume, timing and duration of flows of various magnitudes. Hydrological parameters can be viewed according to regime characteristics and ecosystem influences (Richter *et al*. 1996, Richter *et al*. 1998) -

- Magnitude and timing of monthly discharge conditions: Habitat availability for aquatic organisms; soil moisture for plants; influences on water temperature, oxygen levels and photosynthesis in the water column.
- Magnitude and duration of discharge conditions, especially relating to annual extreme conditions: Balance of competitive, ruderal (weedy species that often grow on waste ground) and stress-tolerant organisms; creation of sites for plant colonization; structuring of aquatic ecosystems by abiotic vs. biotic factors; structuring of river channel morphology and physical habitat conditions; plant soil moisture stress; volume of nutrient exchanges between river and floodplain; duration of stressful conditions (low oxygen levels and concentrated chemicals, for instance); duration of high flows for aeration of spawning beds in channel sediments.
- Timing of annual extreme discharge conditions: Compatibility with life-cycles of organisms; predictability / avoidability of stress to organisms; access to critical habitats during reproduction or to avoid predation; spawning cues for migratory fish; evolution of life history strategies and behavioural mechanisms.
- Frequency and duration of high / low flow pulses: Frequency and magnitude of soil moisture stress for plants; frequency and duration of anaerobic stress for plants; availability of floodplain habitats for aquatic animals; nutrient and organic matter exchanges between river and floodplain; soil mineral availability; influences on bedload transport, channel sediment textures and, duration of substrate disturbance (high pulses).

- Frequency and rate of change: Drought stress on plants; rapid exposure and isolation of spawning areas; desiccation stress on low mobility stream edge (marginal zone) organisms.

Based on these considerations, the hydrological metrics below were selected as ecologically interpretable. A guide (only) is provided on how to assess the rating.

- Low flows (using the 70% percentile)

0: No change - 5%	1: 5 - 15% change	2: 15 - 25% change
3: 25 - 40% change	4: 40 - 60% change	5: > 60% change

- No-flow duration

This guide relevant for naturally perennial rivers -

0: No change	1: 0 - 2% change	2: 2 - 4% change
3: 4 - 6% change	4: 6 - 10% change	5: > 10% change

This guide relevant for naturally seasonal rivers (values refer to fractional changes to the natural duration of zero flows) -

0: 0 - 1.05 x the duration	1: 1.05 - 1.1 x the duration	2: 1.1 - 1.2 x the duration
3: 1.2 - 1.3 x the duration	4: 1.3 - 1.5 x the duration	5: >1.5 x the duration

- Seasonality

Changes in ratio from the maximum to minimum mean baseflow month (percentage reduction in the ratio)

0: No change - 5%	1: 5 - 15% change	2: 15 - 25% change
3: 25 - 40% change	4: 40 - 60% change	5: > 60% change

- Moderate events

Moderate events refer to within-year floods. The rating evaluation is derived from knowledge of upstream landuses and structure in the river. If daily virgin and observed data are available, the time series can be compared to further aid the rating.

The assumption is that, if only small scale abstraction is taking place in the system, moderate events will not be impacted. Large scale pumping abstraction could have an impact on the smaller moderate events. Large dams or many small dams will have an impact on all moderate events. The rating will depend on the scale of the development.

It must be noted that events could increase due to (for example) pulsed releases and hydro-electric releases. This could also result in degradation of the river and would be rated high.

- Large events

Large events refer to those floods with a return period of greater than one year. Usually only very large dams (1 MAR or greater) will have an impact on these events. Even though the floods will still happen, the return period of the floods will change, that is, less frequent.

It must be noted that large events could increase due to testing of sluice gates. Large bottom sluice gates were planned for the proposed Jana Dam. It is anticipated that these will require opening once a month. This could also result in degradation of the river and would be rated as high. This situation is however less likely to happen than increases in moderate events.

4.2 DATA REQUIREMENTS

The following information - which should become available during an Intermediate or Comprehensive Reserve study, from any water resources planning study, and from the ISPs - can be used -

- Monthly natural and present-day hydrology.
- Daily naturalised hydrology and observed hydrology (converted to daily)

4.3 HYDROLOGY ECOSTATUS MODEL

An illustration of the spreadsheet to be completed is provided below (Figure 4.1). Only grey shaded cells are completed.

HYDROLOGY ECOLOGICAL CATEGORY				
HYDROLOGY METRICS	**RATING**	**Rank**	**%wt**	**CONFIDENCE**
LOW FLOWS	4.00	2	90	4.00
ZERO FLOW DURATION	1.00	1	100	2.00
SEASONALITY	2.00	2	90	2.00
MODERATE EVENTS	4.00	2	90	2.00
EVENT HYDROLOGY(HIGH FLOWS-FLOODS)	3.00	3	70	2.00
TOTALS		5		
HYDROLOGY SCORE			51.60	
HYDROLOGY ECOLOGICAL CATEGORY			**D**	
BOUNDARY EC				

Figure 4.1 Illustration of the hydrology model spreadsheet

4.3.1 Rating

The role of the hydrologist is only to complete the rating column according to the guidelines previously provided. A confidence rating from 0 (no confidence) to 5 (maximum confidence) should be provided in the confidence column. In an adjacent column, the reasoning for the rating and the confidence should be noted.

4.3.2 Weighting

The hydrologist does NOT have to complete column 1 or 2. This is the role of the ecologist, because the ecologist has to interpret the ecological importance of the different metrics for the specific river in question. This should preferably be done in consultation with the hydrologist.,

4.4 PREDICTIVE USES OF THE HYDROLOGY ECOSTATUS MODEL

During evaluation of various flow scenarios, the hydrological EC must be determined for each scenario, using the same guidelines as provided previously. This is necessary so that the resulting EcoStatus for each of the flow scenarios can be determined (See 9.7.3 and 9.7.4).

5 PHYSICO-CHEMICAL DRIVER ASSESSMENT INDEX

This is NOT a training manual.
The guidelines presented here assume that the reader has some knowledge of water quality.

5.1 INTRODUCTION

The approach and model described in this chapter is a tool that can be used to determine the present status of the physical and chemical water quality for a resource unit or a specific site. It can be applied along with the other driver models to undertake a stand-alone assessment or it can be applied as the water quality contribution to a water quantity Reserve determination (Figure 5.1).

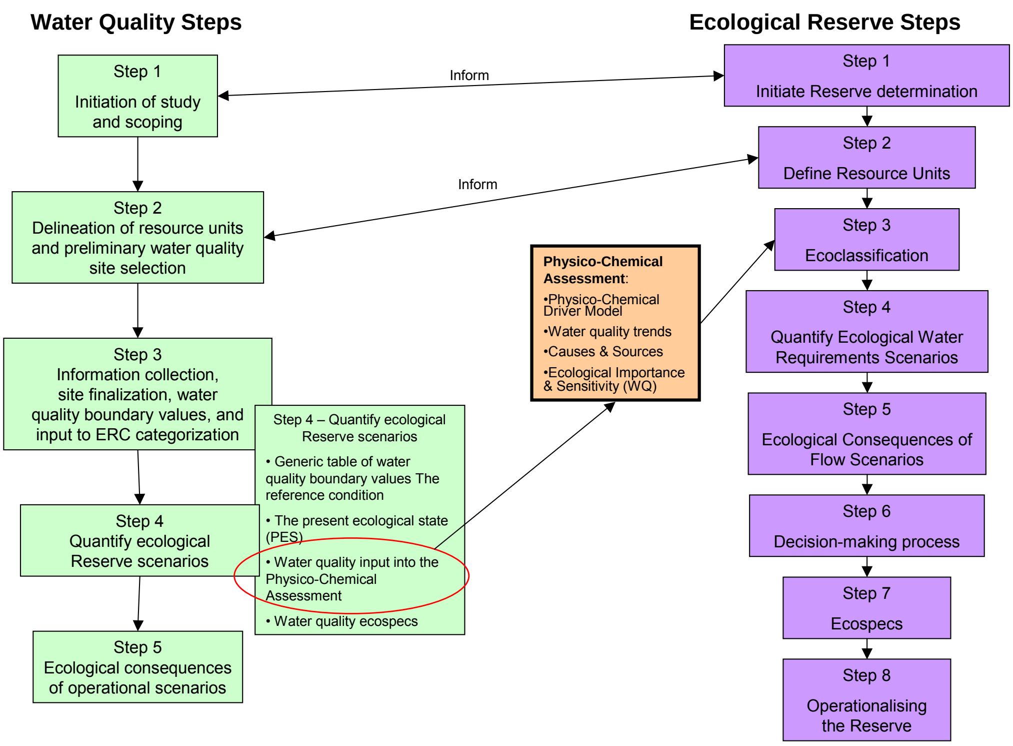

Figure 5.1 Diagram illustrating where the Physico-Chemical assessment fits into the Ecological Reserve procedures.

Assessment of the physico-chemical Ecological Category (EC) was aligned with -

- the step by step procedure for assessing the water quality component of the Ecological Reserve, and
- the methods for assessing the reference conditions, present state, and

benchmarks for individual water quality variables (such as inorganic salts and nutrients).

The step-by-step procedure and individual methods are described in Palmer *et al*. (2005). Further supporting information can be found in Jooste & Rossouw (2003).

An important difference between the default boundary values that appear in the water quality component of the Reserve methodology and this chapter, is that the water quality Reserve methodology refers to four water quality categories (Natural, Good, Fair, and Poor). This chapter is aligned with the more conventional six A-F categories (A, B, C, D, E, and F) that are currently used in the determination of the Ecological Reserve. A further difference is that, where appropriate, environmental clues about the present state have been added to the benchmark tables for the different water quality components. These include prior knowledge of the system and clues that can be observed during a site visit. It should be noted that the clues are provided to guide the present state assessment in the absence of observed water quality data. The clues should NOT be used to infer water quality concentrations. If observed water quality data AND visual observations are available, the observed data should be given preference. The visual clues can then be used to modify the rating if there is strong evidence that the data does not provide an adequate reflection of the present state (e.g. high algal growth but low nutrient concentrations).

For the purpose of the Physico-Chemical Driver Assessment Index (PAI), the A – F categories were translated to numeric ratings of 0 – 5 to facilitate the input of numeric data into the spreadsheet model (Table 5.1).

Table 5.1 Convention used to translate between the ratings, the ECs and the water quality reserve methods.

Rating	Deviation from reference conditions	A- F Categories	Natural – Poor categories
0	No change	A	Natural
1	Small change	B	Good
2	Moderate change	C	Fair
3	Large change	D	
4	Serious change	E	Poor
5	Extreme change	F	

5.2 PREPARATION

The client generally defines the geographic scope of the study area in collaboration with the study manager and key project team members. The minimum background water quality information that should be available early in the study includes -

- A map of the catchment showing the location and names of DWAF monitoring stations, towns and quaternary catchment boundaries,
- A list of the DWAF monitoring stations in the study area showing the length of the data record at each monitoring station, and
- An initial list of departmental reports dealing with water quality in the study area (river basin studies, water quality assessment studies, situation assessment studies etc.).

It is important to consider tributaries with water quality that is naturally or anthropogenically different from the main-stem of the river. Poor water quality can cause "hot spots", and good water quality can provide biotic "refugia".

5.3 DATA COLLECTION

Each resource unit must be described by a set of water quality data. The essential considerations in selecting appropriate reference and present state sites are -

- The ability of a single monitoring point to represent the whole water quality resource unit. This is assessed qualitatively by comparing aspects such as land use up- and downstream of the monitoring point.
- The occurrence and frequency of biomonitoring data near the chemical monitoring point increases the confidence of the water quality Reserve determination.

In this step the sites for data and information collection are identified and mapped -

- Identify all water quality monitoring points in each resource unit.
- Where there are inadequate data either select appropriate data from "equivalent" resource units or collect data by implementing a short-term monitoring programme.
- Compile a table with a brief narrative of land use, geology, point sources and any of the features relevant to water quality. Reference the DWAF water quality monitoring site number and the co-ordinates of the present state (PES) and reference sites in the resource unit.
- Collate all existing water quality and biomonitoring data.

- At each monitoring point, record the number of samples collected and the length of the data record. Use this information to screen out monitoring points were very few samples have been collected or where no data have been recorded for the most recent five year period. Identify, from the remaining monitoring points, potential sites that can be used for unimpacted reference sites and ones that can be used to characterize the present state.
- If there are any resource units with no biomontoring data, collect at least one SASS sample from suitable habitats near the water quality monitoring site.

5.4 PHYSICO-CHEMICAL DRIVER ASSESSMENT INDEX (PAI)

5.4.1 Introduction to the model

As with the other driver models, the physico-chemical model considers -

- The degree by which individual components of water quality has changed from reference conditions (the rating), and
- How important each individual component is in terms of biotic responses (the rank & weight) (
- Figure 5.2).

In contrast to the other driver models, the model does not consider a given level of deviation from natural and then assesses what biotic effects can result from that level of deviation. Historically, the model has been developed along the lines of an ecological risk assessment. Early on, it focussed on selecting specific ecologically-relevant end-points (that is, specific types of adverse effects that are considered unacceptable, such as mortality and inhibition of fecundity). Typically the physical and chemical status is described in terms of its hazard, expressed as the general likelihood of loss of species from the resource. This approach was abandoned because it is generally not possible to assess the seriousness of chemical determinant change. Some reference regarding the use of the water is required.

The water quality specialist is responsible for determining the rating for each metric group, and the biotic specialists are responsible for determining the weight for each metric group.

PHYSICO-CHEMICAL EC				
Physico-chemical Metrics	**Rating**	**Rank**	**%wt**	**CONFIDENCE**
pH	0.00	3	40	
SALTS	1.50	2	80	
NUTRIENTS	3.00	2	80	
TEMPERATURE	1.00	1	100	
TURBIDITY	1.00	2	80	
OXYGEN	1.00	1	100	
TOXICS	0.00	1	100	
TOTALS		7.00		
PHYSICO-CHEMICAL			81.71	
PHYSICO-CHEMICAL CATEGORY			**B**	
BOUNDARY CATEGORY			**B/C**	

Determined by ecologists

Determined by physico-chemical specialists

Figure 5.2 Illustration of PAI spreadsheet indicating responsibilities of the different specialist teams

5.4.2 Generic description for the EC

The generic method of deriving the present state for each water quality metric is illustrated in Figure 5.3.

- The first step is to determine if water quality data are available for the component at the study site. If not, a low confidence rating can be estimated based on expert opinion and environmental clues.
- If data is available, the relevant statistics are calculated and compared to the default benchmark table or a modified benchmark table to look up a rating value that is then entered into the PAI.
- The relevance of the default benchmark table is determined by the presence of water quality data at a reference site. If the relevant statistics at the reference site fall within the default “Natural” or zero rating range then the default benchmark table is accepted for the PES assessment. If the reference site statistics fall outside the “Natural” or zero rating range, then the benchmark table is modified to account for the new “Natural” range. Rules for modifying the default benchmark tables are given for the different water quality components.

Generic assessment of component present state rating

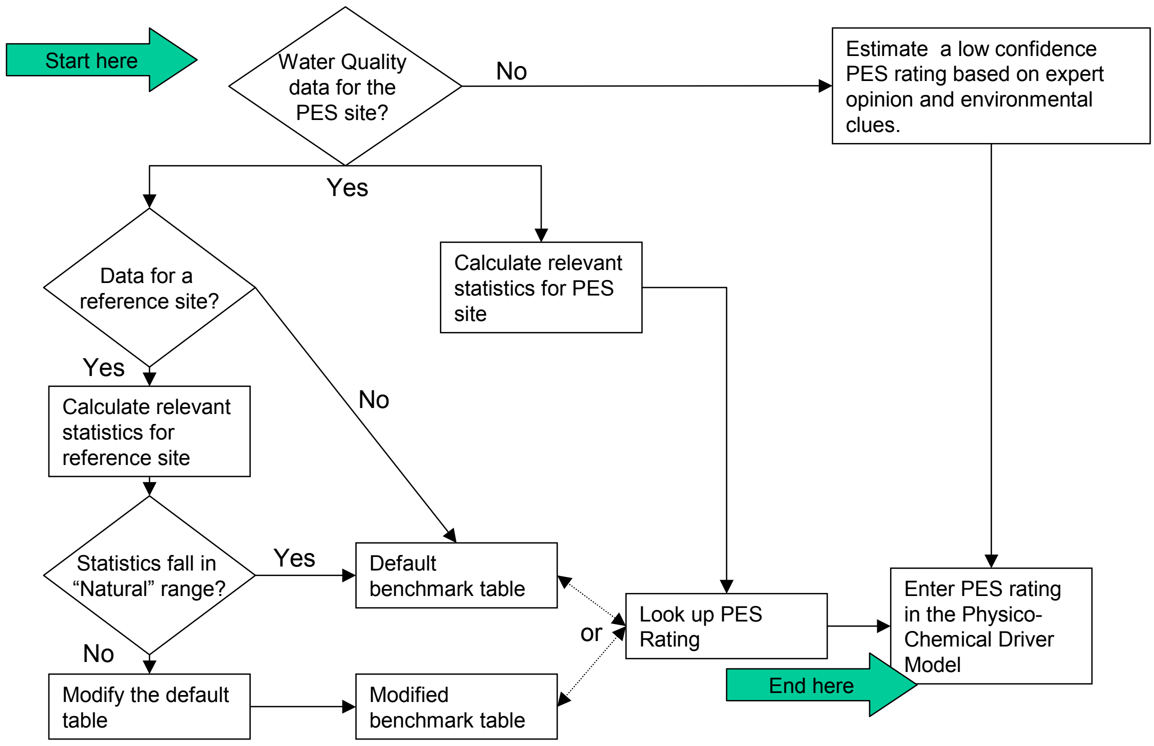

Figure 5.3 Flow diagram showing the generic method for deriving the present state rating for a particular water quality component.

5.4.3 Rules for deriving a present state rating for inorganic salts

If no data are available for inorganic salts -

- If no data are available then the present state of inorganic salts cannot easily be assessed by examining visual environmental clues. A low-confidence assessment can be based on knowledge of the catchment such as presence of saline discharges upstream of the present state site. Sources include irrigation return flows, mining and industrial discharges, etc.

If data for inorganic salts are available -

Reference conditions: Refer to reference site data to determine if the default boundary values in Table 5.2 need to be adjusted.

- The Reference condition for inorganic salts is derived from sites that are known to have a high biotic integrity, and that are known to correspond to the description of a Natural site, or one at which there is solid evidence that there is no significant anthropogenic impact. Calculate the 95th percentile values for the inorganic salts using the DWAF Stoichiometric Salt Model[1].

- If the 95th percentiles of the inorganic salts at the reference site are higher than the default boundary values in Table 5.2, then the benchmarks all change in a linear fashion, that is, all benchmarks move in such a way that the hazard response curve maintains its shape. This procedure is necessary to adjust the boundary values for rivers and streams with naturally high inorganic salt concentrations.

Present state assessment: Use the default inorganic salts benchmark table (Table 5.2) or modified inorganic salts table to determine the PES rating at the study site -

- Calculate the 95th percentile values of the inorganic salts at the present state site using the DWAF Stoichiometric Salt Model.
- Use the default rating table (Table 5.2) or adjusted rating table to look up the rating between 0 and 5 for each inorganic salt.
- Select the highest rated (worst condition) salts for the inorganic salts present state rating and enter the value into the PAI.

Table 5.2 Present state rating values for inorganic salts

PES rating	Deviation from reference condition	Water quality category	$MgSO_4$ (mg/L)	Na_2SO_4 (mg/L)	$MgCl_2$ (mg/L)	$CaCl_2$ (mg/L)	NaCl (mg/L)
0	No change	A	16	20	15	21	45
1	Small change	B	23	33	30	57	191
2	Moderate change	C	28	38	36	69	243
3	Large change	D	37	51	51	105	389
4	Serious change	E	45	64	66	141	535
5	Extreme change	F	>45	>64	>66	>141	>535

5.4.4 Rules for deriving a present state rating for nutrients

If no data are available for nutrients -

- If no nutrient or algal concentration data are available, use expert judgement and the algal growth (periphyton and phytoplankton algae) response descriptions (Table 5.3) to derive a low confidence present state rating for nutrients.

If data for nutrients are available -

[1] Available on the DWAF web site (http://www.dwaf.gov.za/iwqs/iwqso/ecorivreserve.htm)

Refer to a reference site to determine if the default boundary values in Table 5.3 need to be adjusted. If no reference site data are available, use the default boundary values in Table 5.3 unchanged -

- Confirm that the reference site is largely natural and unimpacted by examining the response variables.
- Calculate the median (50^{th} percentile) values for the ortho-phosphate (PO_4-P) (SRP) and Total Inorganic Nitrogen concentrations (TIN) using any appropriate spreadsheet or statistical software package.
- If the median of the ortho-phosphates or total inorganic nitrogen at the reference site is higher than the default boundary values in Table 5.3, then refer to the Water Quality Manual for the procedure to adjust the A, B and C nutrient boundary values. The D category boundary value remains unchanged. This procedure is necessary to adjust the boundary values for rivers and streams with naturally elevated nutrient concentrations.

Use the default nutrient table (Table 5.3) or modified nutrient table to determine the nutrient PES rating at the study site -

- The water quality specialist needs to calculate the 50^{th} percentile value for ortho-phosphate, Total Inorganic Nitrogen, and chlorophyll *a* at the present state site. Use the DWAF salt model or any appropriate spreadsheet or statistical software package to calculate the median for the two nutrients.

Use the nutrient rating table (Table 5.3) or modified nutrient table to look up the nutrient present state rating (0-5) for ortho-phosphate and TIN -

- Select the highest rated (worst condition) nutrient rating and enter the value into the Physico-Chemical Driver Model.
- If the chlorophyll *a* data (a response variable) indicates a higher rating (poorer status), or if there is strong visual evidence of excessive algal growth and the nutrient rating is low (good status) because the nutrients are taken up by the algae, then increase the present state nutrient rating by 1 to indicate a poorer state than was found when only the nutrient concentrations were considered.

Table 5.3 Present state rating values for the nutrients, ortho-phosphate (PO_4-P) and Total Inorganic Nitrogen (TIN), and for indicators of algal biomass, phytoplankton chlorophyll a and periphyton chlorophyll *a*.

Rating	Deviation from reference condition	Environmental clues about the periphyton and phytoplankton response to nutrient enrichment	PO_4 (mg/L)*	TIN (mg/L)*	Phytoplankton Chl *a* (µg/L)*	Periphyton Chl *a* (mg/m^2)*
0	No change	Natural (Oligotrophic) - pristine river and catchment, no known man-made changes to the nutrient regime, oligotrophic conditions, no visible presence of phytoplankton, thin periphyton mats (<0.5 mm thick), water clear.	<0.005	<0.25	<10	<1.7
1	Small change	Oligo – mesotrophic – minor modifications to the catchment affecting the nutrient status, phytoplankton barely evident, thin periphyton mats (<0.5 mm thick), water is largely clear. Less than 10% cover with filamentous algae.	0.005 – 0.015	0.25 - 0.70	10-15	1.7-12
2	Moderate change	Mesotrophic moderate modifications to the catchment affecting the nutrient status, some evidence of phytoplankton, medium periphyton mats 0.5-3mm thick), short filamentous algae (< 2cm long). 10 - 20% cover with filamentous algae.	0.015 - 0.025	0.7 - 1.0	15-20	12-21
3	Large change	Eutrophic –visible evidence of phytoplankton and the water appears green, thick periphyton mats (> 3 mm thick), long filamentous algae (> 2cm long). 20 - 50% cover with filamentous algae.	0.025 - 0.125	1.0 - 4.0	20-30	21-84
4	Serious change	Eutrophic conditions, visible evidence of algal phytoplankton blooms, thick periphyton mats (> 3 mm thick), long filamentous algae (> 5 cm long), periphyton rarely washed away. 50 - 80% cover with filamentous algae.	>0.125	>4.0	>30	>84
5	Extreme change	Hyper-eutrophic conditions are present, low DO and noxic odours, visible evidence of algal scums accumulating in embayments, toxic blue-green algae present or suspected to be present, periphyton <80% cover present most of the time, or long strands of filamentous algae visible. 80 – 95% cover with filamentous algae.				

* - median concentrations

Notes

- It is difficult to link periphyton biomass to stream nutrient concentrations because of the dynamic nature of biomass accrual and loss processes, and the dissolved nutrients measured in a stream reflects the nutrients that are left after uptake by the periphyton.

- The presence of some periphyton growth in natural pristine streams is not uncommon. The status of the catchment upstream of the present state site should therefore also be considered when using environmental clues to make a value judgement about the nutrient status (are there, for instance, human activities upstream of the site that contribute nutrients to the stream or river).
- In rivers with moderate to low nutrient concentrations, riffles will usually have the highest biomass, but it will generally be scoured from time to time by elevated flow velocities in this habitat. In rivers with moderate to high nutrient concentrations, runs will generally have the higher biomass because of the lower flow velocities.
- Periphyton generally goes through an accrual and loss phase. Biomass loss occurs through two processes: losses through the physical effects of flooding (sloughing, substrate instability, and suspended solids abrasion); and losses by grazing. It is therefore important to take the time of the season into account when interpreting periphyton observations.

5.4.5 Rules for deriving a present state rating for pH

If no pH data are available -

- If no pH data are available then the present state cannot be assessed easily by examining environmental clues at the PES site. The exception is the tea-coloured headwater streams (indicative of a high fulvic/humic[2] acid content) such as those found in the Western Cape and coastal swamp forests. These are generally acidic waters.

If pH data are available -

Reference conditions: Refer to a reference site to determine if the default boundary values in Table 5.4 need to be adjusted for naturally acidic or alkaline streams.

- The Reference condition for pH is derived by calculating the 5^{th} and 95^{th} percentiles of the pH data from a site that is known to have a high biotic integrity and that is known to correspond to the description of a Natural site, or one at which there is solid evidence that there is no significant anthropogenic impact.
- If the 5^{th} and 95^{th} percentiles fall within the "Natural" boundary values then

[2] The term "humic acids' is commonly used for a range of phenolic compounds the tend to produce couloured water. Technically humic acids refers to the fraction of humic substances that is not soluble in water under acidic conditions (pH < 2) but is soluble at higher pH values while fulvic acids are those soluble at any pH.

use the default benchmark table (Table 5.4) to assess the present state.

- If the 5th or 95th percentiles fall outside the “Natural” boundary values then adjust the default benchmark table (Table 5.4) using the procedure described in the Palmer *et al*. (2005).
- If no reference site data is available, then use the default benchmark table for pH (Table 5.4) unchanged.

Present state assessment: Use the default pH table (Table 5.4) or the modified pH table to determine the PES rating at the study site.

- The water quality specialist calculates the 5th and 95th percentiles for the present state pH data set. Use any appropriate spreadsheet or statistical software package to calculate the 5th and 95th percentile values for the pH data set.
- Use the pH benchmark table (Table 5.4) or the modified pH table to look up a present state rating.
- Select the highest-rated (worst condition) pH rating as the present state pH rating and enter the value into the Physico-Chemical Driver Model.
- Note: the default rating table is not applicable to Western Cape acidic streams and swamp forests. In future a pH table can be developed for different Ecoregions.

Table 5.4 Present state rating values for pH.

Rating	Deviation from reference condition	pH (5th percentile)	pH (95th percentile)
0	No change	6.5 to 8.0	6.5 to 8.0
1	Small change	5.9 – 6.5	8.0 – 8.8
2	Moderate change	5.6 – 5.9	8.8 – 9.2
3	Large change	5.0 – 5.6	9.2 – 10.0
4	Serious change	4.0 - 5.0	10.0 – 11.0
5	Extreme change	<4	>11.0

5.4.6 Rules for deriving a present state rating for dissolved oxygen

If no data are available for dissolved oxygen -

- If no dissolved oxygen data are available, use expert judgement and environmental clues for dissolved oxygen to derive a low confidence present state rating for dissolved oxygen.
- The fish and invertebrate specialists can also provide an indication of the possible dissolved oxygen status by examining the fish and invertebrate

community composition for species with a high/low tolerance for low dissolved oxygen.

If data are available for dissolved oxygen -

Reference conditions: Refer to a reference site to determine if the default boundary values in Table 5.5 need to be adjusted for streams with naturally low dissolved oxygen concentrations.

- Confirm that the reference site is largely natural and unimpacted by examining the response variables.
- Calculate the 5th percentile concentration of the reference data to set the Natural boundary. If the calculated Natural boundary is less than 6 mg/l, then use default boundary values (Table 5.5) without change.
- If no dissolved oxygen data is available for the reference site, then use the default values in Table 5.5 as given.

Present state assessment -

- Calculate the 5th percentile of the PES data and look up the present state rating in Table 5.5 or the dissolved oxygen table that has been adjusted for the reference site conditions and enter the value into the Driver Model.

Table 5.5 Present state rating values for dissolved oxygen.

Rating	Deviation from reference condition	Environmental clues about the dissolved oxygen status	Dissolved oxygen concentration* (mg/L)
0	No change	Known to be a pristine river, no known problems or concerns about dissolved oxygen; all oxygen sensitive species are present.	> 8
1	Small change	Some man-made modifications in the catchment but no known problems or concerns about DO, most oxygen sensitive species are present.	7 – 8
2	Moderate change	Some concerns about dissolved oxygen, some oxygen sensitive species are present but mostly oxygen tolerant species.	6 – 7
3	Large change	Known problems with reduced dissolve oxygen, mostly low DO tolerant species are present.	4 - 6
4	Serious change	Major know problems with low dissolved oxygen, anoxic odours sometimes present, only very low DO tolerant species present.	2 - 4
5	Extreme change	Extreme concerns about low DO, anoxic odours present most of the time, colour of the water often dark with organic material, benthic algae replaced by grey/black bacterial films and sewage fungus, no biota present most of the time.	0 – 2

* - 5th percentile value

Notes:

- A good dissolved oxygen data record is rarely available, and the water quality specialists often have to rely on single dissolved oxygen measurements and the expertise of the biotic specialists to assess the overall DO status. In these cases, greater preference should be given to the opinion of the biotic specialists than single DO measurements.
- Some foothill and lowland rivers that are regarded as largely natural can experience reduced DO concentrations due to high temperatures. In these cases, expert judgement and knowledge of the degree of catchment modification should also be considered with observed data to assess the present state.

5.4.7 Rules for deriving a present state rating for temperature

If no temperature data are available -

- If no temperature data are available, use expert judgement and the temperature descriptions to derive a low confidence present state rating for temperature.
- The fish and invertebrate specialists can also provide an indication of the possible temperature status by examining the fish and invertebrate community composition (presence or absence of cold water species). The riparian vegetation specialist can also provide information on the unnatural presence or absence of marginal vegetation that provide shading of streams.

If observed or simulated temperature data are available -

Reference conditions: If observed or simulated temperature data are available at a reference site, then -

- Sort the temperature database by month.
- Calculate the 10^{th} and 90^{th} percentiles for each month. This represents the natural reference temperature range for each month.

Present state assessment:

- Use the methods described in Jooste & Rossouw (2003) to calculate a monthly temperature distribution for the present state site, represented by the 10^{th} and 90^{th} percentile temperatures for each month.
- Calculate the deviation from the natural monthly range. For each month, calculate the absolute difference between the reference and present state 10^{th} and 90^{th} percentiles (e.g. Lower range absolute difference for month i = Reference 10^{th} percentile (month i) – Present 10^{th} percentile (month i), and,

Upper range absolute difference for month i = Reference 90th percentile (month i) – Present 90th percentile (month i)). Look up the present state rating for each month using the ratings in Table 5.6.

- The present state temperature rating is the rating obtained for the month with the highest value (poorest rating).

Table 5.6 Present state rating values for temperature.

Rating	Deviation from reference condition	Environmental clues about the temperature status	Deviation from the natural monthly temperature range (10th & 90th percentile values)
0	No change	Pristine river, catchment natural, no known problems with temperature. All temperature sensitive species present in abundances and frequencies of occurrence as expected for reference.	Natural temperature range, measured or estimated from air temperature
1	Small change	Some minor man-made changes to the river but no known changes to the natural temperature regime. Some highly temperature sensitive species in lower abundance and frequency of occurrence than expected for reference.	Natural temperature range, measured or estimated from air temperature
2	Moderate change	Moderate change to temperature, occurs infrequently. Most highly temperature sensitive species in lower abundances and frequency of occurrence than expected for reference.	Vary by no more than 2°C
3	Large change	Large change to temperature regime occurs often. Most moderately temperature sensitive species in lower abundances and frequency of occurrence than expected for reference.	Vary by no more than 4°C
4	Serious change	Serious changes to temperature regime, occurs most of the time, only biota highly tolerant to temp changes occur. All moderately temperature sensitive species in much lower abundances and frequency of occurrence than expected for reference. Temperature insensitive species may have high abundances and frequency of occurrence.	Vary by more than 4°C
5	Extreme change	Extreme changes to temperature regime, occurs all the time, only biota highly tolerant to temp changes occur. At best, only temperature insensitive species present, often with very low abundances and frequency of occurrence.	Vary by more than 5°C, up to a maximum 30°C for the upper boundary

5.4.8 Rules for deriving a present state rating for Inorganic turbidity

- Inorganic turbidity data are not routinely recorded by DWAF for streams and rivers. A quantitative method to assess the deviation from natural reference conditions was therefore not developed for the Water Quality Reserve Methodology. The assessment of the present state rating is therefore based on expert opinion and knowledge of the stream or river being assessed.
- Use on-site observations and the expert opinion of the specialist team (water quality specialist, geomorphologist, invertebrate and fish specialists) and the turbidity descriptions (Table 5.7) to derive a low-confidence present state rating for turbidity.
- Some systems are naturally turbid (the Caledon River system, for instance) and the present state assessment should be undertaken by considering reference or background conditions for the particular system being assessed.

Table 5.7 Present state rating descriptions for turbidity.

Rating	Deviation from reference condition	Environmental clues about the turbidity status
0	No change	Pristine river, no known man-made modifications of the catchment, no known concerns about turbidity, changes in turbidity appears to be natural and related to natural catchment processes such as rainfall runoff.
1	Small change	Some minor man-made modifications to the catchment, changes in turbidity appear to be largely natural and related to natural catchment processes such as rainfall runoff. Very minor effects of silting or scouring of habitats, largely of a temporary nature. Natural river processes clear newly deposited silt soon after the event.
2	Moderate change	Moderate changes to the catchment land use have resulted in unnaturally high sediment loads and high turbidity during runoff events. The impacts are however temporary. In naturally turbid rivers, minor dams, weirs or changes in salinity has resulted in lower suspended sediment during the low flow months.
3	Large change	Erosion and/or urban runoff processes are known causes of unnaturally large increases in sediment loads and turbidity, habitat often silted but it is cleared from time to time. Low amounts of periphyton algae or phytoplankton are present. In naturally turbid rivers, major dams, weirs or changes in water quality has resulted in moderately lower suspended sediment concentrations for moderate periods of the year. Some rooted water plants and benthic algae are visible during these periods.
4	Serious change	The catchment is known to have serious erosion problems, increased turbidity levels are present most of the time, large silt loads are deposited, leading to a serious reduction in habitat. Low amounts of periphyton algae or phytoplankton are present. In naturally turbid rivers, major dams, weirs or changes in water quality has resulted in substantially lower suspended sediment concentrations for extended periods of the year. The improved underwater light climate has resulted in a proliferation of rooted water plants and benthic algae during these periods.

Rating	Deviation from reference condition	Environmental clues about the turbidity status
5	Extreme change	The catchment is known to have serious erosion problems, increased turbidity levels are present most of the time, large silt loads are deposited leading to an almost total loss of habitat, silt loads are so high that fish kills have been attributed to it. In naturally turbid rivers, major dams, weirs or changes in water quality has resulted in significantly lower suspended sediment concentrations for extended periods of the year. The improved underwater light climate has resulted in extensive stands of rooted water plants and benthic algae during these periods.

Notes on the assessment of inorganic turbidity

- Water clarity, as a measure of light attenuation, rather than inorganic turbidity (a measure of light scatter) may in future be recorded as part of the River Heath Programme. Over time, this will probably be a more relevant measurement for ecosystem assessment. A modification in the attenuation of sunlight in water can have far-reaching ramifications for aquatic ecosystems because of its influence on photosynthetic fixation of energy by aquatic plants (Davies-Colley & Smith, 2001).

5.4.9 Rules for deriving a present state rating for toxic substances

Toxic substances are those listed in the South African Water Quality Guidelines for Aquatic Ecosystems, including toxic metal ions and toxic organic substances and/or substances selected from the chemical inventory of an effluent/discharge. An investigation of toxic substances is triggered by an inventory of chemical substances likely to be discharged, or biotic response (an anomalous SASS score, for instance) indicative of deteriorated conditions.

The benchmarks for toxic substances are defined by the South African Water Quality Guidelines (DWAF, 1996). The derivation procedures for the salinity benchmarks were largely modelled on the derivation procedures used in these guidelines.

For the most part, toxic substances do not occur naturally, therefore for practical purposes the reference value is equal to the laboratory detection limit. The exceptions to this are some metals such as copper and chromium, semi-metals such as selenium and arsenic and non-metals such as fluoride and ammonia. In some situations it may be necessary to take into account naturally elevated background levels of these substances. The method for adjusting the default benchmark table for these toxic substances is the same as for inorganic salts.

Present state assessment if observed data are available -

- Calculate the 95th percentile of the observed data.
- Use the toxic substances rating table (Table 5.8) to look up the present state rating.
- Select the highest-rated (worst condition) toxic substance as the rating for the toxic substances in the Physico-Chemical Driver Model.

Table 5.8 Present state rating values for toxic substances.

Toxic substance	Rating					
	0	1	2	3	4	5
Al	20	62.5	105	150	192.5	>192.5
Ammonia	15	43.75	72.5	100	128.75	>128.75
As	20	57.5	95	130	167.5	>167.5
Atrazine	19	48.75	78.5	100	129.75	>129.75
Cd soft*	0.2	0.7	1.2	1.8	2.3	>2.3
Cd mod**	0.2	0.95	1.7	2.8	3.55	>3.55
Cd hard***	0.3	1.625	2.95	5	6.325	>6.325
Chorine (free)	0.4	1.75	3.1	5	6.35	>6.35
Cr(III)	24	115	206	340	431	>431
Cr(VI)	14	67.5	121	200	253.5	>253.5
Cu soft*	0.5	1.025	1.55	1.6	2.125	>2.125
Cu mod**	1.5	3.025	4.55	4.6	6.125	>6.125
Cu hard***	2.4	4.875	7.35	7.5	9.975	>9.975
Cyanide	4	32.5	61	110	138.5	>138.5
Endosulfan	0.02	0.075	0.13	0.2	0.255	>0.255
Fluoride	1500	2510	3520	2540	3550	>3550
Pb soft*	0.5	1.625	2.75	4	5.125	>5.125
Pb mod**	1	3	5	7	9	>9
Pb hard***	2	5.75	9.5	13	16.75	>16.75
Hg	0.08	0.525	0.97	1.7	2.145	>2.145
Phenol	60	200	340	500	640	>640

*For use in soft water (Hardness less than 60mg $CaCO_3$/l)

** For use in moderately hard water (Hardness between 60 – 119 mg $CaCO_3$/l)

***For use in hard water (Hardness greater than 120 mg $CaCO_3$/l)

5.4.10 Additional water quality information about trends, causes and sensitivity to change

The objective of the physico-chemical present state assessment is to determine whether -

- The river water quality has changed from a reference condition due to anthropogenic changes and by how much (physico-chemical EcoStatus model). The change from the reference condition is determined by comparing the present water quality state to a reference condition. This process was described above for each water quality variable, and
- If the water quality is currently changing, by how much, how fast and why (described below).

a) Water quality trends

Many water quality constituents exhibit seasonal changes. This activity is aimed at determining if there is a short- or long-term trend in key constituents. This requires an examination of the data record to determine if there is a trend (stable, increasing, decreasing) and, if the causes for the trend remain unchanged, whether the rate of change would result in a change in category (or half a category) within 5 years (short-term) and within 20 years (long-term).

The two most common water quality changes are due to salinisation (build-up of salts) and eutrophication (build-up of nutrients) and it is recommended that the trend be determined for the Total Dissolved Solids (TDS), phosphate and total inorganic nitrogen. Methods for determining the trend are described in Jooste & Rossouw (2003). Once the annual trend has been determined for the three variables, the present state can be extrapolated for the next 5 years and the next 20 years to determine if the trend can be anticipated to result in a change in category or half a category.

b) Causes and sources of water quality change

The water quality specialist needs to examine the factors that affect the present status. List the impacts on water quality and separate these into flow-related and non-flow related activities. These are referred to as the causes. The determination of whether the causes are flow or non-flow related is important, as this influences the decision whether mitigation solely by flow manipulation is possible and appropriate, or whether source-directed measures are necessary. Non-flow related impacts include waste water effluent discharges, irrigation return flows etc. Flow related impacts include warming of water due to shallower water depths and lower turbidity due to longer water retention times in the system.

c) Ecological importance and sensitivity (EIS) (water quality considerations)

The ecological importance of a river is an expression of its importance to the maintenance of ecological diversity and functioning on local and wider scales, and both abiotic and biotic components of the system are taken into consideration. (DWAF 1999)

The water quality specialists are specifically requested to rate the "Sensitivity to flow-related water quality changes" on a scale of "low, moderate, high, very high" and to state their confidence in the evaluation.

The full text of the water quality criterion is (DWAF 1999) "*Sensitivity to flow related water quality changes - This assessment should also consider the size and flow of the stream in terms of its sensitivity to water quality changes. A decrease in the natural flow volume may, for example, result in a diminished assimilative capacity (in the situation where effluent forms part of the total flow volume) or may cause natural water quality variables (such as. water temperature and oxygen) to reach levels detrimental for biota (also applicable to increases in flow). The assumption regarding the sensitivity of "smaller" streams is also applicable here. In terms of organic pollution load, it has been pointed out that slow-flowing deep rivers will be impacted over greater distances than fast flowing shallow rivers, where re-aeration rates will be high. Assessment is based on available information and expert judgement*".

Guidelines that are provided for this assessment are -

Rating	Explanation
Very High Rating = 4	Streams of a particular size (usually "small") and with abundant habitat types highly sensitive to water quality changes related to flow decreases or increases at all times.
High Rating = 3	Streams of a particular size (usually "small") and with some habitat types being highly sensitive to water quality related changes related to flow decreases or increases at all times.
Moderate Rating = 2	Streams of a particular size (often "larger") and with some habitat types being sensitive to water quality related flow decreases or increases during certain seasons.
Marginal/low Rating = 1	Streams of a particular size (often "larger") and with habitat types rarely sensitive to water quality change related to flow decreases or increases.
None Rating = 0	A rating of none is not appropriate in this context

d) Special considerations

Under natural conditions the delineation may have had a particular channel and substrate that resulted in a particular rate of loss of depth and/or velocity (that is, habitat in general), and a consequent influence on water quality characteristics such as oxygen and temperature with a natural decrease in flow. This sensitivity will also be influenced by the natural climatic attributes of the area within which the delineation lies.

Presently the amount of flow that is abstracted may result in a different rating of the sensitivity of habitat to flow modification, that is, the amount of flow left may be so low that the current sensitivity is now rated as higher than under natural conditions. This may result in the delineation now being more sensitive to flow related water quality changes than under natural.

5.5 PHYSICO-CHEMICAL ASSESSMENT WITHIN THE RHP

Water quality assessment in these situations is done according to the instream component of the IHI (Kleynhans 1996) (cf 0). This usually means that little specific information on water quality issues is available, and that information on the condition of the upstream catchment has to be used as an indirect indication of impacts on water quality. In some cases information on water quality from other studies and from DWAF water quality stations may be available. This information can be considered in the rating and supplemented with data on the biological condition of the river and known cases of fish mortalities. A more recent approach made use of diatom (which are good indicators of physico-chemical conditions) to supplement and aid the rating of physico-chemical condition (RHP 2005).

5.6 DETERMINING PHYSICO-CHEMICAL CONSEQUENCES

One of the requirements of the EcoClassification process is to determine the ecological consequences of various flow scenarios. Water quality consequences of these flow scenarios must be determined (cf. 9.7.4) and this is undertaken through concentration modelling (Malan & Day, 2002). The results of the concentration modelling must then be used to populate the PAI. This information is then provided to the ecologists for assessment and the impact on the responses ECs and the EcoStatus is determined.

6 FISH RESPONSE ASSESSMENT INDEX (FRAI)

The guidelines presented here assume that the reader has some experience of fish ecology.

6.1 RATIONALE FOR FISH ASSEMBLAGE ASSESSMENT

6.1.1 Fish stress in general

Fish stress is described and characterized as follows -

- It is viewed as a condition where the response to a stimulus or stressor results in a state where an extension of the physiological condition occurs beyond the normal resting phase (Brett, 1958).
- Stress is seen as a state of threatened homeostasis that is re-established by a complex of adaptive responses (Chrousos, 1998). In this sense then, response to stress is an adaptive mechanism that permits the fish to cope with real or perceived stressors in order to maintain its normal or homeostatic state and is not necessarily detrimental to the fish.
- The mechanism of stress response is complex and involves primary (neuroendocrine), secondary (metabolic) and tertiary responses. Tertiary responses involve whole-animal performance characteristics (growth, swimming capacity and disease resistance) and modified behavioural patterns (feeding and aggression). These three levels of stress response are integrated and interregulated (Barton *et al*., 2002).

Stressors have been grouped according to Barton *et al*., 2002 -

- Chemical (e.g., contaminant and pollution exposure, low oxygen concentrations and acidification),
- Physical (e.g., handling capture, confinement and transport),
- Perceived (e.g., stimuli evoking startle response and presence of a predator)

The general adaptation syndrome (Selye 1950) states that a fish passes through three stages of response to stress -

- An alarm phase during which the fish perceives the stimulus and recognition of it as a threat to homeostasis,

- A resistance stage when the fish mobilizes its resources to adjust to the disturbance and maintain homeostasis,
- An exhaustion phase that follows if the fish, in spite of activating a stress response, is incapable of coping with the disturbance.

The first two phases are manifested by measurable physiological changes. The last phase is the maladaptive phase, usually associated with the development of pathological states that influence the health and condition of fish and that can eventually result in mortality (Barton *et al*. 2002).

Studies have shown that repeated exposure to mild stressors can habituate fish and attenuate the neuroendocrine and metabolic responses to subsequent exposure to stressors (Reid *et al*. 1998). However, if the intensity of the stressor is very severe or long-lasting, physiological response mechanisms may be compromised and can become detrimental to the fish's health and well-being, causing "distress" (Barton *et al*., 2002). In this context the response of the immune system must also be considered. If this system is compromised, increased susceptibility to diseases will occur. Overcrowding, rapid changes in temperature, salinity and dissolved oxygen are common stressors affecting immuno-compotence in fish (Rice and Arkoosh, 2002).

The detailed relationship between stress that impacts individual fish, then the population and eventually the assemblage or community, is highly complex. However, for the purposes of predicting and assessing the response of fish, it is assumed that stress on an individual fish will eventually be manifested in the population and assemblage.

6.1.2 Fish habitat

The quantity and quality of available habitat can be used as an indirect indication of the effect of stressors on individual fish and populations. This relationship between habitat condition and fish condition is possible because characteristics of fish evolve in response to the properties of habitats. The habitat is the template on which life-history strategies are formed (Southwood, 1977; DeAngelis & Curnutt, 2002). Following this, predictions on the traits of individual fish species present (as well as assemblage characteristics such as species richness) can be made on basis of the habitat.

For the assessment and evaluation of the fish assemblage response to habitat conditions, it is important that fish habitat and its components be properly defined (Bain & Stevenson, 1999) -

- Habitat: "specific type of place within an ecosystem occupied by an organism, population or community that contains both living and nonliving components with specific biological, chemical, and physical characteristics including the basic life requirements of food, water, and cover or shelter."
- Habitat component: "single element (such as velocity, depth, or cover) of the habitat or area where an organism lives or occurs. Component is synonymous with attribute."
- Habitat diversity: The number of different habitat types within a given area.

More specifically for the purposes of this study, habitat is specifically defined as - Any particular combination of velocity, depth, substrate and associated cover (such as marginal and overhanging vegetation, undercut banks, root wads, aquatic macrophytes, water column), physico-chemical attributes (such as temperature, oxygen concentration, turbidity) and biological attributes (that is, food sources) that provide a fish with its life-stage requirements at that particular point in time and geographically.

Within the scope of this definition, consideration should be given to the duration of the combination of these habitat features to satisfy the requirements of particular life-history stages of a species during particular seasons or events.

6.1.3 Interpretation of fish assemblage responses to habitat changes

Over evolutionary time, A particular habitat or a range of habitats used by fish species shape their characteristics. It follows that species do best in the habitats in which they evolved and that changes in habitat extent and characteristics can impose various levels of stress on populations. Changes in habitat may, therefore, be indicators of the well-being or condition of particular species or assemblages (DeAngelis & Curnutt, 2002).

A particular combination of habitat features may not necessarily provide optimum conditions for the specific life-history stage requirements of a fish at the time, frequency, duration and place when they are required. This may be the result of anthropogenic impacts on the habitat (such as flow reduction, sedimentation of habitat, and physico-chemical changes), or it may even be a situation where a particular species occurs only marginally and is, even under natural conditions existing under sub-optimal conditions. This relates to stress, and will result in compensatory mechanisms being activated in order to establish homeostasis in response to these stressors. It follows that species occurring marginally, and which are naturally already subject to higher stress than under optimal conditions, will have a narrow stress buffer. In such as case, a relatively “small” decrease in the flow may, for example, already result in a pronounced stress effect due to particular critical habitats or critical habitat features being in limited supply naturally. It follows that differences in the requirements of different species constituting the fish assemblage may result in a change in the assemblage when the natural flow regime changes (including natural disturbance regimes).

It is essential to consider all habitat features, both flow and non-flow related, even if they are difficult to measure and predict quantitatively (types of cover, physico-chemical attributes, flow, the food source, for instance). Even when flow and the resulting hydraulic habitat seems suitable for a particular EC and species requirements, responses of features such as temperature, oxygen and the available food source may be so negative that the ability of a species to adapt to such conditions may become severely compromised.

Habitat assessment as an indirect indicator of stress as such can never be an ideal replacement for direct measurement of fish condition. However, it is acknowledged that measuring responses of fish populations and assemblages to environmental disturbance can be very difficult, and that surrogate approaches (even if they are imperfect) are needed wherever possible to assess these changes (DeAngelis & Curnutt, 2002).

The approach followed here to assessing fish response to driver characteristics is based on a qualitative combination of species attributes, habitat resulting from driver changes and fish survey information.

6.1.4 Requirements for the assessment of fish assemblage response to driver conditions.

Based on the above-mentioned considerations, the following approach is followed to relate drivers and the resulting habitat to fish species stress -

- Information on the life-history strategies and habitat preferences and requirements of each of the selected species should be compiled. An expert

-opinion database that includes a semi-quantitative rating of the intolerances, cover preferences and flow (velocity)-depth preferences is available for the majority of South African fish species (Kleynhans, 2003). Where this database is not sufficient, available literature on South African freshwater fish, as well as local experts, should be consulted.

- The habitat features are evaluated in terms of their suitability to the requirements of the species constituting the assemblage. This includes consideration of breeding requirements and early life-history stages, survival/abundance, frequency of occurrence in a river section, cover, health and condition and water quality.
- It would be logical to follow an approach where habitat integrity is assessed in terms of the biological group of concern, and then assess the response of the fish based on this habitat template. However, the fish response assessment index that was developed actually includes assessment of habitat integrity as part of the fish response metrics being considered. This is achieved by considering the ecological state of driver metrics that can potentially influence the habitat template for fish.

6.2 INFORMATION REQUIREMENTS FOR FISH EC DETERMINATION

6.2.1 Establish reference conditions

Two main sources of information to determine fish species expected to be present under reference conditions (actual or derived) can be used -

- Historical information from the river delineation under consideration can be used to provide an indication of reference conditions. Often such information can be related to conditions prior to major impacts on rivers, thereby providing a good indication of pre-impact conditions.
- In the absence of actual data for the river delineation, information on other river reaches or neighbouring rivers can be used to compile a list of species expected under reference conditions. Often this can be achieved by filling gaps in the distribution of species such as *Anguilla* where absence in a river section can be used to derive presence upstream and downstream of such a section. In other cases the presence / absence of species within a different river in the same ecoregional context can be used to derive reference presence in the river delineation being considered.

Interpreting fish assemblage responses within the reference situation is based on the fish habitat segment approach (FHS, Kleynhans 1999). The FHS refers to a portion of a stream in which the fish assemblage remains "generally homogeneous due to the relative uniform nature of the physical habitat" (Ramm 1988). The boundaries of a fish habitat segment can be expected to vary according to the temporal and spatial variability (natural and human-induced) of environmental conditions in a segment. The purpose of defining fish habitat segments is to provide a basis that can be used to specify reference biological conditions in such segments with regard to the indigenous fish species that can be expected to occur, their frequency of occurrence, and general health and well-being. In addition, it is potentially possible to define reference habitat conditions that can be expected to occur at a broad level (Kleynhans 1999).

6.2.2 Site selection

The objectives when considering fish sampling sites for fish EC determination are -

- Habitat present at the site should be representative of the RU or river delineation under consideration. However, for EC determination consideration should also be given to including sites with habitats that may actually be relatively uncommon in the river delineation, but which provide habitat for specialized or intolerant species or intolerant life-stages of some species (critical habitat). Information gleaned from such sites can provide a level of sensitivity to the EC determination that may otherwise – that is, when only representativeness is considered - be difficult to obtain in some rivers.
- If at all possible sites should not be close to artificial structures such as bridges and weirs, as information from such sites may not necessarily be representative of the river delineation. However, where no alternative is available, consideration of results from such sites should be considered with caution. In certain cases sampling in weirs may be considered as the only alternative when the river is seasonal and permanent pool size is artificially enlarged by the construction of a weir. Downstream from such weirs, some limited flow may occur during the low flow season. Some fish species find habitat at such places and their presence may be useful for a limited assessment of river conditions (physico-chemical conditions for example, and even an indication that flows may at times be suitable for the completion of the life-cycle).
- Habitats at the site should be amenable to sampling. Factors such as the ease with which various sampling techniques such as electro-shocking and seine netting (including nets of various dimensions) can be used, should be

considered. In the case of comprehensive and intermediate Reserve determination where detailed information is desirable, effort is usually focussed on a limited number of sites. Consequently the opportunity exists in such cases to do relatively intensive sampling (such as employing large seine nets and increasing sampling effort) than the case would be with rapid Reserves and for RHP purposes. Rapid Reserve determinations are usually limited to one or two sites that are easy and rapid to sample. The RHP strives to sample as many sites as possible as rapidly as possible in order to provide a representative or synoptic view of the health of the particular catchment.

- Factors such as accessibility and safety (in terms of dangerous animals and crime) are very important.

6.2.3 Data collection

a) Habitat assessment

Habitat assessment refers to an evaluation of fish habitat at a site in terms of the diversity of velocity-depth classes present and the presence of various cover types at each of these velocity-depth classes. This provides a framework within which the presence, absence and frequency of occurrence of species can be interpreted. Habitat assessment includes a general consideration of impacts that may influence the condition or integrity of fish habitat at a site.

(i) Habitat diversity assessment

Four velocity-depth classes are distinguished (based on Oswood and Barber 1982) and can be interpreted as hydraulic habitat types (Jordanova *et al*. 2004) -

- Slow (<0.3 m/s), shallow (<0.5 m): This includes shallow pools and backwaters.
- Slow (<0.3 m/s), deep (>0.5 m): This includes deep pools and backwaters.
- Fast (>0.3 m/s), shallow (<0.3 m): Shallow runs, rapids and riffles fall in this category.
- Fast (>0.3 m/s), deep (>0.3 m): Deep runs, rapids and riffles fall under this category.

These classes can easily be recognised by experienced field workers.

Within each of the velocity-depth classes, five broad cover types are distinguished (Kleynhans 1999) -

- Overhanging vegetation: Thick vegetation overhanging water by approximately 0.3 m and not more than 0.1 m above the water surface (Wang *et al.* 1996).

- Undercut banks and root wads: banks overhanging water by approximately 0.3 m and not more than 0.1 m above the water surface (Wang *et al.* 1996).
- Stream substrate: The degree to which various substrate components (rocks, boulders, cobbles, gravel, sand, fine sediment and woody debris ("snags")) provide cover for fish are judged qualitatively. No detailed assessment of the stream substrate and estimation of the contribution of individual components are attempted. The composition of the substrate is handled, therefore, in a descriptive manner.
- Aquatic macrophytes: Submerged and emergent plants are included and a qualitative estimate made of the cover value for fish.
- Water column: Where there is sufficient water depth, the water column will also function as cover (in terms of lessening predation from aerial predators, for instance).

Estimates of the relative ecological importance of velocity-depth and cover classes (Table 6.1) at a site are partly based on the area covered (estimated as a percentage).

Table 6.1 Abundance scoring of velocity-depth and cover classes (adapted from Rankin 1995)

Descriptor	Relative ecological value/abundance score	Occurrence (% of area covered)
None	0	0
Rare	1	0-5
Sparse	2	5-25
Common	3	25-75
Abundant	4	75-90
Very abundant	5	90-100

Depending on the size of the river, a site with a low percentage of a particular velocity-depth and cover class can still actually cover a substantial area at a site. A low rating is unrealistic in such a situation. This is compensated for by judging the qualitative value of depth-flow classes for fish. Percentage of area covered is only used, therefore, as a guideline in this estimation.

General flow conditions at the time of sampling are qualitatively assessed following the approach in Table 6.2.

Table 6.2 Qualitative assessment of flow conditions during sampling (adapted from Dallas 2005).

Water level	Description
Dry	No water flowing.
Isolated pools	Pools that have a trickle of water between them, but no evident flow.
Low flow (dry season base flow)	Water well within the active channel; water probably not touching the riparian vegetation.
Moderate flow (wet season base flow)	Water within the active channel; water likely to be touching riparian vegetation in places.
High flow	Water filling the active channel; water completely into riparian vegetation.
Flood	Water above active channel.

(ii) Habitat Condition

Possible impacts on habitat condition at the site are assessed by considering the condition of the local catchment and the channel condition as indicated in Table 6.3 and Table 6.4.

Table 6.3 Assessing the condition of the local catchment based on intensity of land-use activities.

Impacts are rated on scale of 0 to 4: 0 = none, 1 = limited, 3 = extensive, 4 = entire (from Dallas 2005).

Land-use	Within riparian zone	Beyond riparian zone	Potential impact on River Health	Level of confidence (H,M,L)	Comments (e.g. distance upstream/downstream, time since disturbance, etc.)
Afforestation – general					
Afforestation – felled area					
Agriculture – crops					
Agriculture – livestock					
Agriculture – irrigation					
Alien vegetation infestation					
Aquaculture					
Construction					
Roads					
Impoundment (weir/dam)					
Industrial Development					
Urban Development					
Rural Development					
Informal settlement					
Recreational					
Sewage Treatment Works					
Nature Conservation				N/A	
Wilderness Area				N/A	

Land-use	Within riparian zone	Beyond riparian zone	Potential impact on River Health	Level of confidence (H,M,L)	Comments (e.g. distance upstream/downstream, time since disturbance, etc.)
Litter/debris					
Disturbance by wildlife					
Other:					

Table 6.4 Channel condition (in-channel and bank modifications).

Impacts are rated on scale of 0 to 4: 0 = none, 1 = limited, 3 = extensive, 4 = entire (from Dallas 2005).

In-channel and bank modifications	Upstream		Downstream		Comments
	Impact score	Distance	Impact score	Distance	
Bridge – elevated; in-channel supports					
Bridge – elevated; side-channel supports					
Causeways / low-flow bridges					
Bulldozing					
Canalisation – concrete / gabion					
Canalisation – earth / natural					
Gabions / reinforced bank					
Fences – in channel					
Gravel, cobble and/or sand extraction					
Roads in riparian zone – tar					
Roads in riparian zone – gravel					
Dams (large)					
Dams (small) / weir					
Other:					

b) Fish survey

Due to practical considerations, fish surveys are usually done during the low-flow period of the year.

Sampling effort and results are reported per flow-depth class sampled. However, where the mosaic of flow-depth classes makes it difficult or impossible to do this (combinations of fast-deep and fast-shallow classes, for instance), the dominant flow-depth class should be used as the unit of reference for sampling effort, but the presence of other flow-depth classes should also be indicated.

The following apparatus are often used for catching fish in the different velocity-depth classes -

- Slow-shallow: A small seine net (5 m long, 1.5 m deep, mesh size = 1 mm) can be used to sample fish. An electrical shocking apparatus (e.g. AC, 250V, 800W) can also be used. Capture results are recorded as number of fish caught during each effort with a net, or the number of fish caught per time unit (minutes) with an electroshocker.

- Slow-deep: A large seine net (e.g. 70 m long, 1.5 m deep, mesh size 2.5 cm) can be used. A cast net, (diameter = 1.85 m, mesh size = 2.5 cm) can used in pools not suitable for beach seining. Capture results are recorded as number of fish caught during each effort.
- Fast-shallow: An electrical shocking apparatus (e.g. AC, 250V, 800W) one operator and two dip net handlers) is used in such habitat types. Capture results are recorded as number of fish caught per time unit (minutes).
- Fast-deep: An electrical shocking apparatus is used in these habitat types. Capture results are recorded as number of fish caught per time unit (minutes).

However, apparatus used in the different velocity-depth classes have not yet been standardized nationally. It can be expected that standardization will also have to be considered in terms of regional aspects such as ecoregions, stream types, stream size and the fish species present. Manpower available for surveys will also play a role in the type of apparatus that can be used. Prior to any standardization, it is important that the apparatus and effort spent in sampling fish be kept similar in a particular river and for a particular study. This also applies to monitoring surveys.

All species sampled are counted and anomalies such as tumours, external parasites and other abnormalities are indicated. Although fish length is usually not measured, age groups can roughly be categorized according to juveniles and adults. The presence of ripe-running individuals can also be noted.

Although guidelines for representative sampling at a site needs specification for streams of different sizes and different fish species richness, sampling at sites in the Crocodile River (Kleynhans 1999) followed the following general approach -

- Standard electro-shocking effort: > 20 minutes per site (that is, time electricity actually applied in the water).
- Standard small seine (see above) net effort: 2 efforts per site.
- Standard large seine (see above) net effort: 3 efforts per site.
- Cast net (see above) effort: 20 throws per site.

However, this is only generalization, and the effort will obviously also depend on the size of the river as well as the species richness.

Other fish sampling methods (such as fish traps and fish fykes) can be used where suitable. Destructive sampling methods such as fish poisons and gill nets are not used. It is important to note that all velocity-depth classes are not necessarily present or possible to sample at a site, and that all sampling methods and apparatus are not necessarily applied at a site.

The RHP Rivers Database is currently under revision. It may be suitable for capturing certain aspects of the fish sampling but also incorporates data from the perspective of the RHP which may not be completely relevant to the EcoClassification-EcoStatus process followed in ecological Reserve determinations. Eventually, all data will be stored in the Water Management System (WMS) being developed by DWAF. The forms provided in this document (Appendix A) should be used to capture relevant fish related data.

6.3 FRAI: RATIONALE

With reference to the concepts of the response of fish to stress, the determination of the fish PES is essentially based on -

- An interpretation of the environmental requirements, preferences and intolerances of fish species constituting the natural assemblage in a particular river delineation, and
- Their responses to changes in habitat conditions as brought about by changes in driver components and its respective metrics.

The procedure followed to determine the fish EC is an integration of ecological requirements of fish species in an assemblage and their derived or observed response to modified habitat conditions. “Derived” in this case refers to situations where little or no observed information is available and the fish response is primarily based on expert knowledge on species requirements assessed against driver changes. “Observed” then refers to an assessment consisting of a combination of fish sampling results as well as consideration of species requirements and driver changes. This procedure is referred to as the FRAI (Fish Response Assessment Index).

It must be emphasized that although the FRAI uses essentially the same information as the FAII (Fish Assemblage Integrity Index; Kleynhans 1999), it does not follow the same procedure. The FAII was developed for application in the broad synoptic assessment required for the RHP and does not have a particularly strong cause-and-effect basis (cf. **1.2.3**). The purpose of the FRAI, on the other hand, is to provide a habitat-based cause-and-effect underpinning to interpret the deviation of the fish assemblage from the reference condition. If required, the FAII can still be calculated for comparative purposes. However, the current tendency is to use the FRAI even for RHP purposes (RHP 2005).

6.4 FRAI: COMPONENTS AND CALCULATION

6.4.1 Compiling the list of species for the reference and observed situation

The number of species expected for the reference condition for various levels of the velocity-depth, flow dependence, cover and physico-chemical metric groups, should be compared with the observed (sampled) data to determine deviation from the reference situation. Where sampling is not representative (not all habitats were sampled, for instance) or effective (difficult conditions to employ a particular sampling method), some generally common species such as *Clarias gariepinius* and *Oreochromis mossambicus* may be absent. In such a situation the species likely to be present - based on habitat, presence of closely related species and other environmental conditions - may be used to supplement the list of "observed" species. If such an approach is used it is essential that this be indicated explicitly, as it will have an influence on the confidence of the fish EC determination.

6.4.2 Fish intolerance and habitat preference database

The sections that follow address the information contained in a database that was compiled in 2001 and the approach that was followed to obtain this information (Kleynhans 2003). The database information used in the FRAI is contained in the FRAI spreadsheet model.

a) Species intolerance ratings

Intolerance in this context refers to the degree to which a species is able to withstand alterations of the environmental conditions under which it occurs. This includes modification of physical habitat characteristics (such as depth, velocity, marginal vegetation, bottom substrate, food source), as well as physico-chemical characteristics of the water. Habitat preferences provide a large amount of information that is useful in determining the degree to which a species can be regarded as tolerant, moderately intolerant and intolerant. Experimental information on the intolerance of various South African fish species is, however, largely lacking, and the assessment of the degree to which species are tolerant or intolerant usually has to be based on field observations and expert knowledge.

Two components are taken into account in estimating the intolerance of fish species for calculation of the FRAI: requirement for flowing water during different life-stages; and association with unmodified physico-chemical conditions. Both of these aspects are scored for a species according to -

- Low requirement / specialisation (rating = 1),
- Moderate requirement / specialisation (rating = 3) and
- High requirement / specialisation (rating = 5).

Intolerance ratings for each of the two components provided by experts are averaged and the average interpreted as -

- 1-2 = Tolerant
- >2-3 = Moderately tolerant
- >3-4 = Moderately intolerant
- >4-5 = Intolerant

The assessment of the two components of species intolerance is approached in the following way -

i) Requirements for flowing water during different life-stages

Species differ with regard to their requirements for flowing water during different life-stages. The work of Crass (1964), Gaigher (1969), Pienaar (1978), Kleynhans (1984), Bell-Cross and Minshull (1988), Skelton (1993), Weeks *et al.* (1996), and Russel and Rogers (1998) should be consulted for information on habitat preferences. Three general groups are distinguished -

- Species not requiring flow during any part of the life-cycle. However, increased habitat suitability and availability resulting from increased flow can be expected to benefit such species. With some species, flow will stimulate breeding activities and stimulate migration. Score = 1
- Species requiring flow during certain phases of the life-cycle - to breed in particular habitats (often fast flows) for instance, or make nursery areas with suitable cover available. Generally, increased habitat suitability and availability resulting from increased flow can be expected to benefit such species. Flow will stimulate breeding activities and stimulate migration. Score = 3
- Species requiring flow during all phases of the life-cycle. Often prefer fast flow and clear water and use these conditions both for breeding and feeding purposes. Score = 5

ii) Requirement for unmodified physico-chemical conditions

Very little information on the physico-chemical requirements of South African fish is available. Consequently, resort has to be made to the previously-observed associations of certain fish species with modified and unmodified physico-chemical conditions as compared to the reference. This can take the form of the association of fish species with different habitats in a variety of geographical areas. For instance, the preference of some species for fast flowing, turbulent, clear water tend, in natural or minimally developed catchments, to be associated with habitats with unmodified physico-chemical conditions. Conversely, in catchments that are extensively developed and the water often polluted, some species will still be able to survive in habitats such as pools, which may even be stagnant. It is surmised that these species are relatively tolerant to impaired physico-chemical conditions. This approach is similar to that followed by Lyons *et al.* (1995) in information-scarce situations in Mexico. The following general rating approach is followed -

- Species that can survive and breed under severely modified physico-chemical conditions - Score = 1.
- Species that can survive and breed under moderately modified physico-chemical conditions -. Score = 3.
- Species that require largely unmodified physico-chemical conditions to survive and breed - Score = 5.

Due to the lack of any detailed information this approach must be seen at best as giving an indirect and relative indication of physico-chemical requirements.

b) Velocity-depth preferences

Fish species velocity-depth preferences were scored according to the preference for the four velocity-depth classes (cf. 1.2.3) –

- Slow-shallow
- Slow-deep
- Fast-shallow
- Fast-deep

Each of these is scored according to -

- 0 = No preference/irrelevant
- 1 = Low preference
- 3 = Moderate preference
- 5 = High preference

Velocity-depth preferences provided by experts are averaged and the average interpreted as -

- 0 = No preference / irrelevant
- >0 -1= Very low preference - coincidental?
- >1-2 = Low preference
- >2-3 = Moderate preference
- >3-4 = High preference
- >4-5 = Very high preference

c) Cover preferences

These features are considered to provide fish with the necessary cover (such as refuge from high flow velocity, predators and high temperatures) to utilise a particular velocity-depth class (cf. 6.2.3) (Kleynhans 1999) -

- Overhanging vegetation
- Undercut banks and root wads
- Stream substrate
- Aquatic macrophytes
- Water column

Each of these is scored according to -

- 0 = No preference / irrelevant
- 1 = Low preference
- 3 = Moderate preference
- 5 = High preference

6.4.3 Rating of metrics

The FRAI is based on the assessment of metrics within metric groups. These metrics are assessed in terms of -

- Habitat changes that are observed or derived, and
- The impact of such habitat changes on species with particular preferences and intolerances.

“Impact” of habitat changes on species can be interpreted in terms of fish responses associated with health and condition, abundance or frequency of occurrence; all relative to the expected or derived reference condition. Depending on historical data and ecological information on physical drivers and fish species ecological requirements, these responses can be quantified or expressed in narrative (qualified) terms. The degree of quantification as well the extent of historical data and ecological insights and knowledge will have an influence on the confidence in the results.

The increase or decrease in the abundance or frequency of occurrence of species in terms of the reference situation is usually difficult to determine or derive quantitatively. However, it is often possible for local experts to at least rate the relative change from the expected reference situation.

In the case of velocity-depth, cover and flow modification metrics, ratings are based on a directional change (decrease or increase). Although this rating approach is followed, the increase / decrease response is only used within the metric-group itself to allow some perspective on the nature of changes. For the calculation of the fish EC, only absolute values (that is, not considering directional changes) are used. Impact rating for the health and condition, migration and introduced species metric groups are all considered to be one-directional (negative) on frequency of occurrence of the native species.

The relationship between the drivers and the various fish response metric groups are indicated in Figure 6.1.

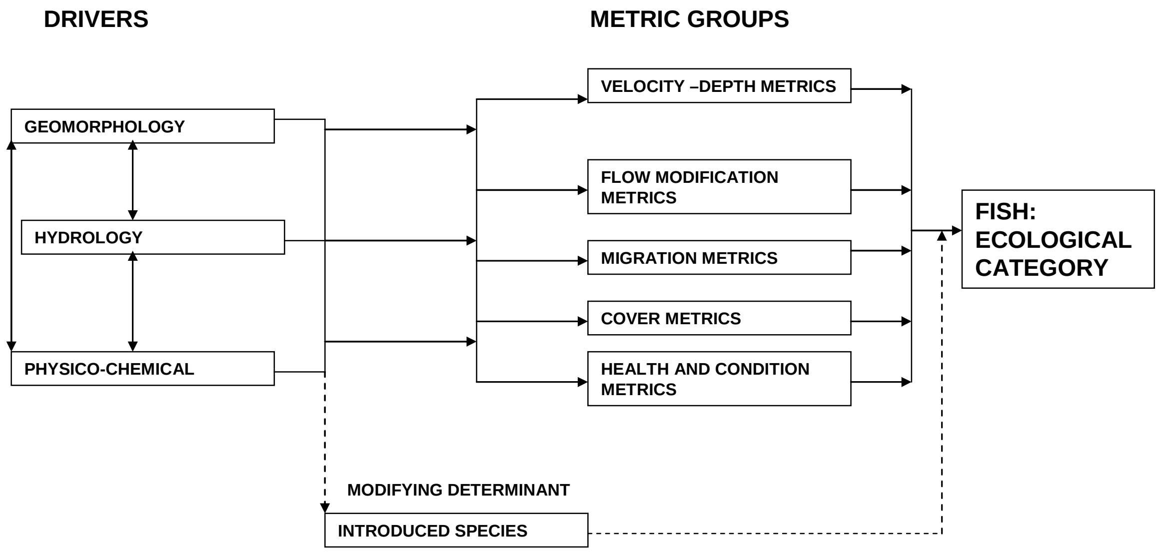

Figure 6.1 The relationship between drivers and fish metric groups.

The following metric groups and metrics were selected as potentially good indicators of changes in fish assemblages and habitat conditions.

a) Velocity-depth classes

This metric group is assessed based on a change in the "commonness" of the velocity-depth classes compared to the reference condition, and the response of the fish assemblage to the changes. This assessment is based on baseflow (low flow) conditions usually within the dry season (when surveys usually occur). However, apart from considering conditions during sampling, the general change based on driver information should be derived for all seasons.

i) Velocity-depth class changes

Information from the geomorphological (sediment movement) and hydrological (flow modifications) driver groups are used to do the assessment. These changes can be based on empirical information supplemented by derived changes to the fish assemblage or based on the changes to driver components that will be reflected by particular fish species responses -

- Commonness of fast-deep conditions
- Commonness of fast-shallow conditions
- Commonness of slow-deep conditions
- Commonness of slow-shallow conditions

These changes are rated according the following scheme -

- -5 = Extreme loss from reference (absent)
- -4 = Serious loss from reference
- -3 = Large loss from reference
- -2 = Moderate loss from reference
- -1 = Small loss from reference
- 0 = No change from reference
- 1 = Small increase from reference
- 2 = Moderate increase from reference
- 3 = Large increase from reference
- 4 = Serious increase from reference
- 5 = Extreme increase from reference (completely dominant)

This assessment of the change of velocity-depth classes from the reference condition is used as a basis for the rating of changes in the fish assemblage However, these ratings are independent of the fish assemblage response, that is, the ratings are not factored into the fish response assessment in the FRAI model.

ii) Fish assemblage changes

To provide a reasonable level of response interpretation, only fish species with a high or very high preference for the respective velocity-depth groups are considered.

Based on empirical fish data, as well as derived data (based on velocity-depth class changes), and with reference to velocity-depth class preferences of the fish species, how did the following change? (cf.6.2.3) -

- Response of species with high to very high preference for fast-deep conditions
- Response of species with high to very high preference for fast-shallow conditions
- Response of species with high to very high preference for slow-deep conditions
- Response of species with high to very high preference for slow-shallow conditions

The rating system follows the approach indicated under the velocity-depth class metric group.(cf 6.4.3, a, i).

b) Cover

Species have particular requirements for habitat conditions that provide cover from adverse environmental conditions and predation. A modification in habitat may be related to flow changes (increase or decrease) or physical modification such as bank collapse and sedimentation.

i) Cover class changes

Information from the geomorphological and hydrological components and metrics, as well as the riparian vegetation, is used to do the assessment. These changes can be based on empirical information supplemented by derived changes to the fish assemblage, or based on the changes to driver components and metrics that will be reflected by particular fish species responses -

- Commonness of overhanging vegetation
- Commonness of undercut banks and root wads
- Commonness of substrate types that can serve as cover
- Commonness of instream vegetation
- Commonness of sufficient water column depth that can serve as cover

The rating system follows the approach indicated under the velocity-depth class metric group.(cf 6.4.3, a, i).

This assessment of the change of cover classes from the reference condition is used as a basis for the rating of changes in the fish assemblage. However, these ratings are independent from the fish assemblage response, that is, the ratings are not factored into the fish response assessment in the FRAI model.

ii) Fish assemblage changes

To provide a reasonable level of response interpretation, only fish species with a high or very high preference for the respective cover classes are considered (cf.6.2.3) -

- Response of species with a very high to high preference for overhanging vegetation. Reduction may indicate lowered water levels, bank erosion or physical destruction of overhanging vegetation.
- Response of species with a very high to high preference for undercut banks and root wads. Reduction may indicate lowered water levels, bank erosion and bank collapse.
- Response of species with a high to very high preference for a particular substrate type. Reduction may indicate sedimentation (embedding of cobbles and gravel in riffles, for instance), or algal growth.
- Response of species with a high to very high preference for instream vegetation. Reduction may indicate lowered water levels or physical destruction of aquatic macrophytes.
- Response of species with a very high to high preference for the water column. Reduction of species may indicate lowered water levels or loss of depth due to sedimentation (in pools). Predation from aerial predators may be an important factor.

The rating system follows the approach indicated under the velocity-depth class metric group. (cf 6.4.3, a, i).

b) Flow modification

This metric group is interpreted based entirely on the level of requirement that various species (or life-stages of a species) have for flowing water. The aspects of the impact of flow modification on physical habitat attributes are considered under other metric groups such as cover and velocity-depth classes.

i) Changes in flow characteristics

Information from the hydrological driver group is used for the assessment. These changes can be based on empirical information supplemented by derived changes to the fish assemblage or based on the changes to driver components that will be reflected by particular fish species responses -

- Increase or decrease in no-flow conditions

- Increase or decrease in low-flow conditions
- Change in seasonality
- Increase or decrease in moderate events
- Increase or decrease in events (high flow, floods)

The rating system follows the approach indicated under the velocity-depth class metric group. (cf 6.4.3, a, i).

This assessment of the change of cover classes from the reference condition is used as a basis for the rating of changes in the fish assemblage However, these ratings are independent from the fish assemblage response, that is, the ratings are not factored into the fish response assessment in the FRAI model.

ii) Fish assemblage changes

Fish response assessment is based on empirical information supplemented by derived changes to the fish assemblage, or based on hydrological driver changes that will be reflected by particular fish species responses (cf.6.2.3) -

- Response of species intolerant of no-flow conditions
- Response of species moderately intolerant of no-flow conditions
- Response of species moderately tolerant of no-flow conditions
- Response of species tolerant of no-flow conditions

Rating of these responses follows the approach indicated under velocity-depth class metric group.

c) Migration

The severity of the impact of obstruction of fish movement on the distribution, abundance and survival of a fish species in the particular river forms the basis of the assessment. Migration can be related to breeding, feeding and survival life-history strategies.

i) Changes in population connectivity

Any modification that results in the fragmentation of fish populations is considered.

The presence and extent of the following are considered in evaluating the impact on and response of migratory species -

- Weirs and causeways
- Impoundments
- Physico-chemical barriers
- Flow modifications

These changes are rated according the following -

- 0 = None, or no potential impact
- 1 = Small; limited with small potential impact on movement.
- 2 = Moderate; notable and with potential impact on movement.
- 3 = Large; clear potential impact on movement.
- 4 = Serious; clear and serious potential impact on movement.
- 5 = Extreme; clear and critical potential impact on the movement.

This assessment of the potential loss of connectivity is used as a basis for the rating of changes in the fish assemblage However, these ratings are independent from the fish assemblage response, that is, the ratings are not factored into the fish response assessment in the FRAI model.

ii) Fish assemblage changes

Distribution and abundance responses of migratory species are based on empirical information or can be derived from the potential impact of various geomorphological, hydrological and physico-chemical changes. Three broad levels of migratory requirements form the basis of the assessment -

- Response in terms of distribution/abundance of species with catchment scale movements
- Response in terms of distribution/abundance of species with requirement for movement between reaches or fish habitat segments
- Response in terms of distribution/abundance of species with requirement for movement within reach or fish habitat segment

Ratings are done according to -

- 0 = No change from reference
- 1 = Small change from reference; only a small part of the stream network or reach is inaccessible
- 2 = Moderate change from reference; moderate part of the stream network or reach is inaccessible
- 3 = Large change from reference; a large part of the stream network or reach is inaccessible
- 4 = Serious change from reference; an extensive part of the stream network or reach is inaccessible
- 5 = Extreme change from reference; the entire stream network or reach is inaccessible

e) *Response to physico-chemical conditions: health and condition*

Health and condition of species are a reflection of the well-being of fish. Adverse environmental conditions (caused by decrease in food availability, modified physico-chemical conditions, decrease in preferred habitat, for instance, all of which may be related to flow alteration) may result in physiological stress conditions that impact on the immune system of species, resulting in deterioration of health and condition. For the FRAI, modified physico-chemical conditions are the primary consideration.

i) Changes in physico-chemical conditions

The following physico-chemical driver information is used to assess potential responses of the fish assemblage -

- pH
- Salts
- Nutrients
- Temperature
- Turbidity
- Oxygen
- Toxics

In the absence of a specific physico-chemical assessment, ratings are done according to -

- 0 = No change from reference
- 1 = Small change from reference
- 2 = Moderate change from reference
- 3 = Large change from reference
- 4 = Serious change from reference
- 5 = Extreme change from reference

ii) Fish assemblage changes

Direct observation of health assessment is based on observations on deformities, fin erosion, lesions and tumours (DELT) and consideration of driver status. Where such information is limited, information on the physico-chemical driver group should be used to derive the expected response of the species expected under reference conditions. For the purpose of the FRAI determination, it is accepted that all species should be in a healthy condition (reference = 0) and that deviation from this could only be negative.

Health and condition responses are considered in terms of four metrics -

- Response of species intolerant of modified physico-chemical conditions

- Response of species moderately intolerant of modified physico-chemical conditions
- Response of species moderately tolerant of modified physico-chemical conditions
- Response of species tolerant of modified physico-chemical conditions

Rating of responses is as for the changes in physico-chemical conditions.

f) Introduced species

The relevance of this metric group is that introduced species may have a dominant impact on the native fish assemblage, while the physical drivers may actually be in a close to reference condition. In this sense, the introduced species metric can be seen as a modifying determinant that does not necessarily impact the fish assemblage through habitat changes as the other metric groups do (Figure 6.1).

Introduced fish species can have a severe effect on the habitat structure (indirectly influencing the natural fish assemblage) and the fish assemblage structure itself through predation. The potential impact of the species is based on the characteristics of the species (that is, its size, trophic preferences and feeding methods). The distribution (and indirectly the abundance) is considered to be another aspect that will determine the impact of an introduced species (that is, whether it has highly invasive properties and is generally tolerant to environmental conditions). The number of introduced species under each metric should also be considered.

The attributes of the native species present should be considered in terms of how vulnerable they are to the impact of introduced species. The habitat characteristics in the river delineation, in combination with the requirements of the introduced species, can also be used to derive the impact of such species on the native ones. For the purpose of the FRAI determination, no introduced species should be present (reference = 0), and any deviation from this can only be negative.

Two groups of introduced species are considered in terms of competition (predation and competition for resources) and habitat modifiying impacts -

- The potential competition impact of introduced (including predators) species.
- How widespread (frequency of occurrence) are introduced competitors
- The potential impact of introduced habitat modifying species.
- How widespread (frequency of occurrence) are habitat modifying species.

i) Impact guidelines

- Predaceous species / habitat modifying species with a critical impact on native species = 5
- Predaceous species / habitat modifying species with a serious impact on native species = 3-4
- Predaceous species / habitat modifying species with a moderate impact on native species = 2-1
- Predaceous species / habitat modifying species with no impact on native species, or are absent completely = 0

ii) Distribution guidelines

- 0 = absent
- 1 = present at very few sites (<10%)
- 2 = present at few sites (>10-25%)
- 3 = present at about >25-50 % of sites
- 4 = present at most sites (>50-75%)
- 5 = present at almost all sites (>75%)

6.4.4 Weighting of metrics and metric groups

a) Ranking and weighting of metrics

The procedure indicated in 2.3.2 is followed and the fundamental question is: Which metric would make the most significant contribution to improving (or degrading) the metric groups and the PES? In all cases the species expected under reference (natural) conditions should be perused in terms of their number and rating per velocity-depth, flow dependence, cover and physico-chemical metric groups (6.4.3)

The following are important considerations in terms of the fish metric groups -

i) Velocity-Depth Classes

Weights are awarded in terms of the natural attributes of the metric. Consequently, ranking and weighting should consider the importance of the velocity-depth metrics in terms of the natural characteristics of the fish assemblage in the reach. This means that if there is only one species with a very high / high preference for fast-deep habitat and it also naturally occurs at a very low abundance, then it may not be a good indicator in the sense that its absence may not convey much information in terms of driver changes. Conversely a species with a very high / high preference for fast-deep habitat and which naturally occurs at high abundances may convey much information in terms of driver modification when it is absent.

Species with a very high preference for a particular velocity-depth class are usually weighted heavier than species with a high preference. In addition, it would be expected that species with a very high to high preference for fast flow classes would be weighted more heavily than for the slow flow classes.

Detailed data may contribute to a higher weight for a particular metric relative to any of the other metrics. Derived data is also awarded a lower weight than empirical data.

ii) Cover

The number of species with a particular cover preference could be used as an indicator of the rank. In addition, characteristics of the type of river being investigated should be considered. This may mean, for example, that a large number of species with preference for marginal vegetation may be present, but that the presence of a lower number of species with a preference for substrate cover may actually be better candidate for ranking higher if the river were to be improved.

iii) Flow Modification

Similar considerations are appropriate here as in the case of the velocity-depth metric group. Usually it would be expected that the more flow intolerant species would tend to be weighed higher than the more flow tolerant species. Again the number of species involved and their expected abundance or frequency of occurrence should be considered.

iii) Migration

Species with catchment scale movements, followed by species with movement between FHSs or reaches, and then movement within a FHS, would often be ranked 1, 2 and 3 respectively. However, considerations such as the number of species involved should also be considered.

v) Physico-chemical conditions: Health and Condition

The number of species under each metric should be considered for its indicator value as well as the number of species and their commonness under reference conditions. The expected list of species with their intolerances to modified physico-chemical conditions, should also be used to estimate the weight of each of these metrics.

vi) Introduced Species

Obviously, the approach here is not related to a natural reference that includes introduced species. Rather, the ranking consideration is which of the impacts of which metrics of the introduced species would be most important to remove in order to improve the EC of the native fish assemblage. This means that the ecological characteristics of these species and their frequency of occurrence are also considered here (as it was in the rating).

b) Weighting of metric groups

The weighting process is indicated in section 2.3.2

c) Calculation of fish EC

The calculation method for the fish EC is indicated in section 2.3.2. The basic ranking question is the same in that the consideration is which of the metric groups would make the largest contribution to the improvement (or degradation) of the native fish assemblage.

6.5 FRAI: PRACTICAL APPLICATION

Essentially, all information required to understand and apply the FRAI is provided in the previous section(s). The FRAI spreadsheet model provides fundamentally the same information but within the practical hands-on application of the FRAI. The purpose of this section is thus to provide a concise description of the steps to follow and aspects to consider in the application of the FRAI.

The sheets in the FRAI spreadsheet model (MS Excel) are arranged in the following sequence (the shortened names used in the model are indicated here). Examples of the sheets are in Appendix B.

6.5.1 Raw data

The purpose of this sheet is merely to allow the user to summarize all the fish data available so that it is easy to access when the FRAI is applied. No particular prescriptions on how to use it are supplied, but it would be useful to tabulate fish species according to various sampling surveys (current and historical) in the river delineation under investigation. Additional background information, such as catch per unit effort, can also be summarized here. This information should allow the compilation of a list of species for the reference condition as well as the present condition.

6.5.2 Assemblage

The sheet consists of two tables that have to be manually adjusted or sized depending on the number of fish species involved. The first table is for the species expected under natural reference conditions. Four letter abbreviations for species names are entered and the relevant information is automatically provided through a lookup link with hidden tables (these are the relevant database information mentioned 6.4). The first letter in the abbreviation usually refers to the genus name and the next three letters to some combination of the species name. The second table functions the same as the first, but only the species actually sampled and/or derived to be likely to be present are listed here. Summary statistics occur at the bottom of each table.

It is important to note that this sheet is not linked to the metric group sheets in order to do any automatic calculations and assessments. The information on this sheet forms the primary basis for expert knowledge application in the metric group sheets and must continually be perused when rating and weighting in the metric group sheets are done. Cell information blocks are provided where appropriate, to assist with interpretation.

6.5.3 ABBREV (Species names and abbreviations)

The scientific names, popular names and the abbreviation of scientific names of species are provided. The first letter in the abbreviation usually refers to the genus name and the next three letters to some combination of the species name. However, although the genus names of some species have changed (such as some large yellowfish changed from *Barbus* to *Labeobarbus*) the abbreviation used is the one indicated here and not the would-be updated version. The purpose of this sheet is merely to allow the user to lookup abbreviations. The sheet is not linked to any other sheet.

6.5.4 Metric groups

The approach regarding the metric groups as such is similar and the relevant information is supplied on the FRAI spreadsheet itself. Information that should be entered is indicated in grey shaded cells. All other cells are protected. The FRAI model also provides an automated graphic presentation of the weighed metrics in each group to make comparison of metrics easier.

It is important that in all cases where metrics are rated, the motivation for the rating be indicated as fully as possible. This can include arguments around the species that should be present, habitat conditions they prefer and that are absent, and conclusions derived from the drivers. Also, reasons why a particular rank is awarded to a metric (or metric group) should be indicated. The main purpose of this is to provide some level of audit to the assessment. Comments and supporting information should be indicated in comment blocks of the spreadsheet linked to the appropriate cell.

The following metric groups are considered in sequence (the name of the sheet and the full metric group name is provided as well as the sheet with the graphics presentation of the metric group assessment) -

- VELDEPTH (Velocity-depth metric group); VELDEPTHGRAPH
- COVER (Cover metric group); COVERGRAPH
- FLOWMOD (Flow modification metric group); FMODGRAPH
- MIGRATION (Migratory species metric group); MIGGRAPH
- PHYSCHEM (Physico-Chemical metric group); PHYSCHEMG
- INTRO (Introduced species metric group); INTROGRAPH

6.5.5 Determining the EC

This involves the integration of the individual metric group assessments into an overall index value that represents the EC for the fish assemblage. Only ranking and weighting is done here as the individual metric group index values are used as an automated input. These scores are used to calculate the weighed score where the weight for each group is considered. The index value that results from this calculation is directly related to one of the ecological categories, A→F.

The fish EC is indicated in the EC sheet. A graphical presentation of the EC is provided in the ECGRAPH sheet.

6.6 FRAI: INTERPRETATION OF EC RESULTS

Only two examples of the FRAI EC results will be interpreted here. Only the contribution of metric groups' values to the FRAI index value will be discussed in terms of its significance and implications.

6.6.1 Example 1

Figure 6.2 provides the information on the estimated response of the fish assemblage based on the metric groups. According to this, information on the flow modification and velocity metric groups carried the highest weight in terms of their significance when considering the improvement in river condition. These metric groups had index values of respectively 60.8% and 68%. Both are strongly linked to flow situations in the river and this indicates that there may possibly be a water flow and volume problem in the river (quantity).

The migration metric group scored particularly badly, and this is linked to various forms of obstruction to migration of fish species in the river. However, due to a relatively low number of species involved, this metric group was ranked 3.

The cover metric group indicated good cover for the species present, while the health / condition group indicated that physico-chemical conditions were also good. No introduced species were present.

Water quantity issues are therefore the primary reasons for the EC of 63.3 %, which relates to an EC of C or a boundary category of C/D.

During or following the FRAI EC interpretation, the relevant driver components and their metrics should also be queried to establish if the fish EC relates to a driver change. However, if biological data is particularly good the biological response may be indicative of a driver change not indicated by the driver metrics.

Depending on the EIS for the river (that is, it may be high or very high), it may be that the EC is too low and that specific attention will have to be given to improving flow conditions as well as addressing migration problems (which may be directly related to obstructions that causes flow problems).

FISH METRIC GROUP	ABBREVIATION	METRIC GROUP: CALCULATED SCORE	FISH EC:BASED ON WEIGHTS OF METRIC GROUPS CALCULATED WEIGHT	WEIGHTED SCORE FOR GROUP	RANK OF METRIC GROUP	% WEIGHT FOR METRIC GROUP
VELOCITY-DEPTH METRICS	**VD**	60.77	0.24	14.78	2.00	90.00
FLOW MODIFICATION METRICS	**FM**	68.00	0.27	18.38	1.00	100.00
MIGRATION METRICS	**MG**	36.47	0.22	7.89	3.00	80.00
COVER METRICS	**CM**	84.00	0.16	13.62	4.00	60.00
HEALTH/CONDITION METRICS	**HM**	80.00	0.11	8.65	5.00	40.00
IMPACT OF INTRODUCED SPP	**IS**	0.00	0.00	0.00	0.00	0.00
						370.00
FISH EC				**63.32**		
FISH EC CATEGORY				**C**		

Figure 6.2 Example of the calculation of the fish EC according to the FRAI. Scenario without introduced species.

6.6.2 Example 2

Figure 6.3 is similar to Figure 6.2 with the exception that the impact of introduced species was considered and ranked as 2 with a weight of 90%. As can be seen, this caused the EC to drop to 38.1%, which relates to an EC of E or a boundary category of D/E. The implications of this are that a major cause of the deterioration of the EC is actually not related to flow, cover or physico-chemical conditions, but to the impact of introduced species. This will have an obvious influence on the Resource Quality Objectives that will be set for the river.

FISH METRIC GROUP	ABBREVIATION	METRIC GROUP: CALCULATED SCORE	FISH EC:BASED ON WEIGHTS OF METRIC GROUPS CALCULATED WEIGHT	WEIGHTED SCORE FOR GROUP	RANK OF METRIC GROUP	% WEIGHT FOR METRIC GROUP
VELOCITY-DEPTH METRICS	**VD**	60.77	0.20	11.89	2.00	90.00
FLOW MODIFICATION METRICS	**FM**	68.00	0.22	14.78	1.00	100.00
MIGRATION METRICS	**MG**	36.47	0.17	6.34	3.00	80.00
COVER METRICS	**CM**	84.00	0.13	10.96	4.00	60.00
HEALTH/CONDITION METRICS	**HM**	80.00	0.09	6.96	5.00	40.00
IMPACT OF INTRODUCED SPP	**IS**	65.56	-0.20	-12.83	2.00	90.00
						460.00
FISH EC				**38.10**		
FISH EC CATEGORY				**E**		

Figure 6.3 Example of the calculation of the fish EC according to the FRAI. Scenario with introduced species.

6.7 FRAI: PREDICTIVE USES

Using the FRAI spreadsheet model, it is possible to make some qualitative predictions as to how the fish assemblage is likely to respond when changes in driver components, and specifically particular driver metrics, are changed. Essentially these predictions will be of a conceptual nature, with uncertain confidence of how close to reality they actually are.

The question could, for instance, be asked as how the fish assemblage in a particular river would react if particular flow characteristics were changed. This may be an increase in low flow durations compared to the current situation and would occur during the spawning season. Depending on the attributes of the fish assemblage and the severity of the increase in low flow periods, it would then be possible to venture a prediction as how species dependent on particular habitat conditions would react to such changes when impacts on their spawning and nursery habitat, as well as possible physico-chemical conditions are considered. When applying the FRAI in this way it is important that the ranks and weights for individual metrics and metric groups be kept constant (the same as for the determination of the PES) as these are based on the natural characteristics of the river. The only exception here is the introduced species metric group.

The alternative question could also be asked in terms of increasing or decreasing the PES of the fish and then attempting to relate this change to particular driver changes. In such a situation the focus may be on one particular guild of species that utilizes a particular velocity depth class, has a certain flow intolerance, cover preference and physico-chemical requirements. If the impact scores of these relevant metrics are deteriorated the response of the PES could be checked through the application of the FRAI. An attempt may then be made to relate these changes to particular driver conditions if sufficient hydraulic information at a site is available. Quantified information on the requirements of indicator species representing the guild may be essential if this route is followed.

6.8 FRAI: USES WITHIN MONITORING

The purpose of using the FRAI within a monitoring framework relates to posing hypotheses as to the REC for the river and the fish. With such an approach the FRAI can be used in a predictive manner (cf. 6.7) to derive an REC as well as alternative ECs. These could then be used as the basis of monitoring the attainment of a particular REC in terms of the fish assemblage by considering the response of particular metrics and metric groups when an ecological Reserve is implemented. Monitoring will provide the basis to determine if the ecological objectives are being achieved in terms of the fish assemblage as it was derived based on the FRAI. Adaptive environmental monitoring and assessment can provide the framework within which the monitoring information can be used to re-assess and review the attainment of the ecological objectives for the river (Holling 1978, Rogers and Bestbier 1997, Roux et al. 1999).

7 MACROINVERTEBRATE RESPONSE ASSESSMENT INDEX (MIRAI)

The guidelines presented here assume that the reader is experienced in aquatic invertebrate ecology.

7.1 SCIENTIFIC RATIONALE

7.1.1 Basis of deriving and interpreting aquatic invertebrate response to driver changes

a) The role of aquatic invertebrates in river structure

Invertebrates include all animals without backbones. In rivers this includes aquatic insects, larvae of insects with terrestrial (often flying) adult forms, as well as mussels, clams, snails and worms that are aquatic throughout their life cycle (Allan 1995, O'Keeffe and Dickens 2000). Aquatic macroinvertebrates have been used to assess the biological integrity of stream ecosystems with relatively good success throughout the world (Rosenberg and Resh 1993, Resh *et al*. 1995, Barbour *et al*. 1996), more commonly than any other biological group (O'Keeffe and Dickens 2000).

Aquatic macroinvertebrate assemblages and communities offer a good reflection of the prevailing flow regime and water quality in a river. In addition they form an essential component of the riverine ecosystem (O' Keeffe and Dickens 2000, Weber *et al* 2004, Allan 1995, Skorozjewski and de Moor 1999). They are important processors of transported organic matter in rivers, serve a vital function in purifying the water in a river and also provide a valuable food source for larger animals within and even outside the system (Skorozjewski & de Moor 1999, O' Keeffe and Dickens 2000, Weber *et al* 2004, Allan 1995).

In order to continue functioning optimally, species in a river system require regular inputs of nutrients and sediments, as well as flowing water. A specific river system supports a particular assemblage of species forming functional communities within reaches. These communities are adapted to the prevailing flow conditions that control temperature, sediment transport and nutrient flows. A decrease or increase in flow, sediment transport or nutrient loads will lead to changes in community structures through loss of certain species and increases in others, as well as providing conditions for a range of new or otherwise scarce species to flourish.

The four major components of a stream system that determine productivity for aquatic organisms are -

- flow regime,
- physical habitat structure (e.g., channel form and substrate distribution),
- water quality (e.g., temperature, dissolved oxygen), and
- energy inputs from the watershed (e.g., nutrients and organic matter) (Milhous and Bartholow 2004).

Distribution of an aquatic macroinvertebrate population is ultimately set by the physical-chemical tolerance of the individuals in the population to an array of environmental factors. The distribution pattern resulting from habitat selection by a given aquatic macroinvertebrate species reflects the optimal overlap between habit (mode of existence) and physical environmental conditions that comprise the habitat - substrate, flow and turbulence, for example. Thus, the discontinuous, patchy, distribution pattern of an aquatic macroinvertebrate population is the result of interplay between habitat, habit and the availability of food resources (Cummins, 1993).

b) Aquatic Invertebrate habitat

Aquatic physical habitat refers to the environment for the instream biota created by the interaction of the physical structure of the channel (the geomorphology) and the flow regime (discharge pattern over time). Habitat functions as a temporally and spatially variable physical, chemical, and biological template within which aquatic invertebrates can exist (Poff and Ward, 1990; Orth, 1987). Numerous studies have demonstrated the importance of physical habitat quantity and quality in determining the structure and composition of biotic communities (e.g. Modde *et al*., 1991; Aadland, 1993; Ebrahimnezhad and Harper, 1997).

In the context of this document, habitat can be defined as any combination of velocity, depth, substrate (bedrock, cobbles, vegetation, sand, gravel, mud), physico-chemical characteristics (such as chemical composition, turbidity, oxygen concentration, temperature) and biological features (food source and predators) that will provide the organism with its requirements for each specific life stage at a particular time and locality. These habitats can be grouped into specific invertebrate biotopes such as Stones-in-current, Stones-out-of-current, Aquatic vegetation (in or out of current), Fringing vegetation (in or out of current).

c) Interpretation of aquatic invertebrate responses to habitat changes

Populations of benthic animals reflect the micro-environment, which is an important factor in the soundness of the river ecosystem, on a scale smaller than the riverbeds of pools and riffles. Populations of benthic animals also reflect the topographic features of rivers and the effects of improvement works on the river environment (Yabe and Nakatsugawa 2004).

Suitable environmental conditions and resources (quantity, quality and timing) have to be available in order to sustain a viable long-term population (Statzner and Higler, 1986; May and MacArthur, 1972; Pianka, 1974; Colwell and Futuyma, 1971). Because a variety of factors, such as environmental conditions and resources, are required to meet the life history requirements of species, the success of aquatic organisms can be limited by a single factor or by a combination of factors (Hardy 2000).

Since many aquatic organisms have specific habitat requirements, seasonal variation in these factors may lead to seasonal variation in the distribution and abundance of benthic macro-invertebrates. Variation in discharge often translates into differences in wetted perimeter, hydraulic conditions and biotope availability. For example, biotopes such as runs become riffles under low-flow conditions, and marginal vegetation may change from lotic to lentic. Temperature often varies with season and the life cycles of many aquatic organisms are cued to temperature. Temperature may affect the rate of development, reproductive periods and emergence time of organisms. All organisms also have a range of temperatures over which optimal growth, reproduction and general fitness occur, and temperatures outside this range may lead to the exclusion of taxa unable to tolerate extreme highs or lows (Hawkins *et al*. 1997).

It is essential that all habitat features are considered when evaluating the suitability of habitat for aquatic invertebrates. As an example one can consider a river that has an extensive Stones-In-Current (SIC) biotope comprising a variety of velocities and depths and adequate water quality, but the stones are covered with a thick layer of filamentous algae. In this example one would not expect the diverse invertebrate community normally associated with the SIC biotope, due to the large amounts of filamentous algae on the cobbles. This will result in a lower EC than expected.

The approach followed in assessing invertebrate response to driver characteristics is based on a qualitative combination of information gained by a field survey, the available habitat as a result of driver condition, and the traits of the invertebrates present.

d) Requirements for the assessment of aquatic invertebrate assemblage response to driver conditions.

The following approach is used to relate drivers and the resultant habitat to the aquatic invertebrate condition -

- Information on the habitat preferences and requirements of each of the taxa present should be obtained. A draft (incomplete) spreadsheet that includes a semi-quantitative rating of the intolerances (based on SASS weights), substrate (habitat) preferences and velocity preferences is included in the Macro Invertebrate Response Assessment Index (MIRAI). Where this database is not sufficient, available literature on South African aquatic invertebrates as well as local experts should be consulted. A project has recently been initiated to improve and expand the information captured in this spreadsheet.
- The habitat features are evaluated in terms of their suitability as well as the requirements of the aquatic invertebrates inhabiting the region. This includes consideration of breeding requirements (where known), abundance and frequency of occurrence in a river section, biotopes and water quality.
- Although it would be logical to assess habitat integrity and then to assess the response of the invertebrates based on this habitat template the MIRAI indirectly includes habitat integrity as part of the index. Habitat integrity is therefore not considered separately to guide invertebrate response assessment.

7.2 INFORMATION REQUIREMENTS FOR EC DETERMINATION

The determination of aquatic invertebrate EC is essentially based on -

- An interpretation of the environmental requirements, preferences and intolerances of Invertebrate taxa constituting the natural assemblage in a particular river delineation, and
- Their responses to changes in habitat conditions as brought about by changes in driver components.

The MIRAI is used to determine the Invertebrate EC. It is done by integrating the ecological requirements of the invertebrate taxa in a community or assemblage and their response to modified habitat conditions.

Although the MIRAI can be determined using information collected during a standard SASS survey (Dickens and Graham 2002), it can also be determined using more detailed information. Chutter (1998) developed the SASS protocol as an indicator of water quality. It has since become clear that SASS gives an indication of more than mere water quality, but rather a general indication of the present state of the invertebrate community. Because SASS was developed for application in the broad synoptic assessment required for the River Health Programme (RHP), it does not have a particularly strong cause-effect basis. The aim of the MIRAI, on the other hand, is to provide a habitat-based cause-and-effect foundation to interpret the deviation of the aquatic invertebrate community (assemblage) from the reference condition. This does not preclude the calculation of SASS scores if required. However, the recent tendency is to use the MIRAI even for RHP purposes (RHP 2005) and it is now the preferred approach.

7.2.1 Information required for the application of the MIRAI

a) Establish Reference Conditions

There are two methods for determining the taxa expected to occur under natural (reference) conditions -

- A minimally-impacted site in the same Level II EcoRegion and geomorphological zone with similar habitat can be used as a reference site, and information from this reference site can be used to compile a reference list of taxa for the area under consideration.
- In the absence of a suitable reference site, information from similar sites in different rivers, as well as any historical information available, can be used to compile a derived reference list of taxa expected under reference conditions. A thorough knowledge of the area under consideration is essential in order to compile a suitable referenced list. The occurrence of taxa in a different river, within the same ecoregional context, can be used to derive reference conditions in the river delineation being considered.

b) Site selection

One of the most important factors in selecting a sampling site is the aim of the study. A site selected for the RHP aimed at determining the state of a river may differ from a site selected for a Reserve study. Whatever the main aim of the study, the site should at least have suitable habitat for the aquatic macro-invertebrates. The site should be either representative of the river delineation or should represent a critical section of the river (such as a section of the river that will stop flowing before the rest of the river). Reserve sites are usually compromise sites between the requirements of the different disciplines involved. For example, a site that is suitable for invertebrates may be too complex to model accurately, while a site preferred by the hydraulician may not provide suitable habitat for the biota.

An "ideal" macro-invertebrate site would be a site at which all or most of the invertebrate biotopes are present. This means that the site would have Stones-in–current, Stones-out-of-current, Vegetation-in-current, Vegetation-out-of-current, Sand, Gravel and Mud. In addition to a variety of biotopes, the biotopes will also be of good quality and quantity. As an absolute minimum the site should have at least either a stony biotope or a vegetation biotope.

When dealing with strictly alluvial rivers, such as the lower Mhlathuze River that is characterised by a sandy bottom, it is important that there is enough vegetation present to provide adequate habitat for the invertebrates. Moving sand (in current) is such an inhospitable habitat for invertebrates that it is often nearly devoid of life.

c) Data collection

Before the site visit and actual sampling it is important to collect all available invertebrate data for the river. This will include a literature survey as well as a search on the Rivers Database and contacting specialists that have worked in the area previously. This background information will assist in setting reference conditions. Recent information will ensure greater confidence in the present state of the invertebrate community.

d) Habitat assessment

The main aim of a habitat assessment is to evaluate the template on which the invertebrates exist. An organism can only occur at a site if suitable habitat exists, and it is therefore essential to assess not only the habitat quality and quantity but also the diversity of available biotopes. The field-data sheets (Table 6.3,Table 6.4 ,Table 7.1 Table 7.2 and Table 7.3) were designed for use in the RHP, but the information collected is also of use in Reserve studies. More details about the data-sheets as well as an explanation of the terminology used are given in the River Health Programme – Site Characterisation field-manual (Dallas 2005).

One of the routine habitat assessments has been the Invertebrate Habitat Assessment System (IHAS) developed by Mcmillan (1998). IHAS is a measure of the SASS biotopes sampled. It has, however; become clear that IHAS requires validation and testing, although the basic data remains of value. As an interim measure it was decided to continue using a modified IHAS (Table 7.4) where certain parameters (Stream Characteristics) including the scoring system have been omitted (Dallas 2005). This modified version of IHAS enables one to record details about the biotopes sampled, thus assisting in the interpretation of the invertebrate community.

Table 7.1 Stream dimensions

Estimate widths and heights by ticking the appropriate categories; estimate average depth of dominant deep and shallow water biotopes.

(m)	< 1	1-2	2-5	5-10	10-20	20-50	50-100	>100
Macro-channel width								
Active-channel width								
Water surface width								

Bank height – Active channel			
(m)	< 1	1-3	>3
Left Bank			
Right Bank			

Dominant physical biotope	Average Depth (m)	Specify physical biotope type
Deep-water (>0.5m) physical biotope (e.g. pool)		
Shallow-water (<0.5m) physical biotope (e.g. riffle)		

Table 7.2 Substratum composition

Estimate abundance of each material using the scale: 0 – absent; 1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 - entire

Material	**Size class (mm)**	**Bed**	**Bank**
Bedrock			
Boulder	> 256		
Cobble	100 – 256		
Pebble	16 – 100		
Gravel	2 – 16		
Sand	0.06 – 2		
Silt / mud / clay	< 0.06		

Degree of embeddedness of substratum (%)
0-25
26-50
51-75
76-100

Table 7.3 Invertebrate biotopes

(present at a site compared to those actually sampled)

Summarised river make up: **('pool' = pool only; 'run' only; 'riffle/rapid' only; '2mix' = 2 types, '3mix' = 3 types)**				
pool	run	Riffle/rapid	2 mix	3 mix

Rate abundance of each SASS and specific biotope present at a site using the scale: 0 – absent; 1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 – entire. Add additional specific biotopes if necessary.

		Specific Biotope					
SASS Biotope	Rating		Rating		Rating		Rating
Stones in current		Riffle		Run		Boulder rapid	
		Chute		Cascade		Bedrock	
Stones out of current		Backwater		Slackwater		Pool	
		Bedrock					
Marginal vegetation in current		Grasses		Reeds		Shrubs	
		Sedges					
Marginal vegetation out of current		Grasses		Reeds		Shrubs	
		Sedges					
Aquatic vegetation		Sedges		Moss		Filamentous algae	
Gravel		Backwater		Slackwater		In channel	
Sand		Backwater		Slackwater		In channel	
Silt/mud/clay		Backwater		Slackwater		In channel	

Table 7.4 Invertebrate Habitat Assessment System (IHAS)

SAMPLING HABITAT **Stones in Current (SIC)**						
Total length of white water (riffle/rapid) (in metres)	none	0-1	>1-2	>2-3	>3-5	>5
Total length of submerged stones in current (run) (in metres)	none	0-2	>2-5	>5-10	>10	
Number of separate SIC areas kicked (not individual stones)	0	1	2-3	4-5	6+	
Average stone size's kicked (cms); (<2 or >20 is '<2>20'); (gravel is <2; bedrock is >20)	none	<2>20	2-10	11-20	2-20	
Amount of stone surface clear (of algae, sediment etc.) (%)	n/a	0-25	26-50	51-75	>75	
Protocol: time spent actually kicking SICs (in minutes), (gravel/bedrock = 0 min)	0	<1	>1-2	2	>2-3	>3
Vegetation						
Length of marginal vegetation sampled (river banks) (in metres)	none	0-½	>½-1	>1-2	2	>2
Amount of aquatic vegetation/algae sampled (underwater) (in metres^2)	none	0-½	>½-1	>1		
Marginal vegetation sampled in or out of current	none		In current	Out of current		both
Type of vegetation (percent leafy vegetation as opposed to stems/shoots) (aquatic vegetation only = 49%). (E.g. Mostly leafy = >75%; mostly stems/shoots = 1-25%)	none		1-25	26-50	51-75	>75

Other Habitat / General						
Stones out of current (SOOC) sampled: (in metres^2)	none	0-½	>½-1	1	>1	
Sand sampled: (in minutes) (‘under’ = present, but only under stones)	none	under	0-½	>½-1	1	>1
Mud sampled: (in minutes) (‘under’ = present, but only under stones)	none	under	0-½	½	>½	
Gravel sampled: (in minutes) (if all gravel, SIC stone size = ’<2’	none	0-½	½	>½**		
Bedrock sampled: (‘all’=no SIC, sand, or gravel; then SIC stone size =’>20’	none	some			all**	
Algal presence: (‘1-2m^2’=algal bed; ‘rocks’=on rocks; ‘isol.’=isolated clumps)	>2m^2	rocks	1-2m^2	<1m^2	Isol.	none
Tray identification: (Protocol – using time: ‘corr’ = correct time)		under		corr		over

7.3 MIRAI: DETERMINING THE EC

7.3.1 Rating approach

The rating approach for the MIRAI is basically the same as the generic description in section 2.3.2. The MIRAI comprises four different metric groups that measure the deviation of the invertebrate assemblage from the reference (expected) assemblage in terms of flow modification, habitat modification and water quality modification, as well as system connectivity and seasonality.

The first step in determining the Present Ecological State (PES) of the invertebrates is to complete the data sheet (see appendix D). This includes the abundance and frequency of occurrence (if possible) of the different invertebrate taxa under natural (reference) conditions, as well as the abundance and frequency of occurrence (if possible) of the invertebrate taxa present. For this index an increase in abundance and/or frequency of occurrence, as well as a decrease in abundance and/or frequency of occurrence, is seen as an impact or change compared to natural. The six point rating system works as follows -

- 0 = No change from reference
- 1 = Small change from reference
- 2 = Moderate change from reference
- 3 = Large change from reference
- 4 = Serious change from reference
- 5 = Extreme change from reference

In addition to the rating of the different metrics, each metric (and metric group) is also ranked and weighted according to its importance in determining the EC of the invertebrate assemblage (cf 2.3.2). Basically each metric is ranked in terms of which metric (if it changed from worst to best) would best indicate good integrity in terms of the metric group. In other words, which metric is the most important in determining the present state of the invertebrates. The ranking procedure is only used to guide the weighting and is not used in any calculation.

The metric ranked 1 (most important) is weighted 100%. The other metrics are then ranked as a percentage relative to the most important metric. It is important to remember that all metrics with the same rank must have the same weight, and that a lower ranked metric - 3, say - must have a lower percentage weight than a higher ranked metric - 2, for instance.

7.3.2 Flow modification

In order to facilitate the evaluation of the impact of different flows on the invertebrate community four different velocity categories have been defined -

- Very fast flowing water >0.6 m/s
- Moderately fast flowing water 0.3-0.6 m/s
- Slow flowing water 0.1-0.3 m/s
- Very slow flowing/standing water <0.1 m/s

Each invertebrate taxon has been assigned a velocity preference score (0-5), based on previous surveys and personal experience. These velocity preference scores are indicated on the Data sheet of the MIRAI set of spreadsheets (Appendix D). It is recognised that these preference scores are preliminary, and a project has been approved to identify more final preference scores for a number of the more flow sensitive taxa. The velocity preference scores were allocated according to the following system -

- 0 = No preference
- 1 = Very small preference
- 2 = Small preference
- 3 = Moderate preference
- 4 = High preference
- 5 = Very high preference

In the flow modification metric group the presence / absence, as well as the abundance and/or frequency of occurrence of taxa in all velocity categories, are evaluated. It is important to only consider a taxon in one of the velocity categories. If, for example, a taxon has a high preference for very fast flowing water, but only a moderate preference for moderately fast flowing water, it will be assessed in the very fast flowing water category.

The MIRAI makes provision to assess the presence / absence of taxa as well as their abundance and frequency of occurrence. Although the frequency of occurrence will generally be more useful than abundance, the paucity of data often necessitates the use of abundance information. However, if sufficient information is available it is preferable to use the frequency of occurrence, rather than the abundance information only.

7.3.3 Habitat modification

In order to facilitate the evaluation of the impact of habitat changes on the invertebrate community, five different habitat types have been defined -

- Bedrock: Due to the small size of invertebrates, it was decided to include boulders with bedrock in the same biotope. Bedrock and boulders include all hard surfaces larger than 256mm. It includes bedrock / boulders that are in current as well as those out-of-current.
- Cobbles: The cobbles biotope also includes pebbles. As such the cobbles biotope includes all hard surfaces within the 16-256 mm size range. As in the case of the bedrock both in-current and out-of-current cobbles are considered.
- Vegetation: The vegetation biotope includes all vegetation that can provide habitat for invertebrates. As such it includes both fringing and aquatic vegetation that might be either in-current or out-of-current
- Gravel, Sand and Mud: This biotope is a combination of the smaller grain types (<16 mm size class) and includes gravel, sand and mud both in-current as well as out-of-current.
- Water column: This biotope includes the water surface and the water column.

Habitat preference scores were allocated in the same way as the velocity preference scores (Appendix D). The evaluation used to rate the present state is also the same as was used to rate the flow modification metric group.

7.3.4 Water Quality modification

To facilitate the evaluation of changes in water quality on the invertebrate community, four different groups were identified. These groups are based on SASS5 weights (Appendix D). At this stage, the water quality evaluation can therefore only be done at family level. If any species level information is available, it will be taken into account separately when rating the water quality metric group.

- High requirement for unmodified physico-chemical conditions: SASS5 weights 12-15
- Moderate requirement for unmodified physico-chemical conditions: SASS5 weights 7-11
- Low requirement for unmodified physico-chemical conditions: SASS5 weights 4-6
- Very low requirement for unmodified physico-chemical conditions: SASS5 weights 1-3

In addition to the normal set of metrics regarding the presence / absence and the abundance and/or frequency of occurrence of taxa, two additional metrics - the SASS5 score and the ASPT value - are included.

Guidelines for rating SASS and ASPT changes are as follows -
SASS scores as a percentage of the reference SASS score

- >90% = 0
- 80-90% = 1
- 60-80% = 2
- 40-60% = 3
- 20-40% = 4
- <20% = 5

ASPT scores as a percentage of the reference ASPT value

- >95% = 0
- 90-95% = 1
- 85-90% = 2
- 80-85% = 3
- 75-80% = 4
- <75% = 5

7.3.5 System Connectivity and Seasonality

The system connectivity metrics should only be used where migratory taxa (eg. Paleomonidae and *Varuna*) are expected to occur under reference conditions. In certain instances seasonal differences also come into play. These metrics should be used where one would expect seasonal changes in the invertebrates usually related to changes in flow pattern (cf 7.3.6).

7.3.6 EC

The four metric groups (see appendix D) are combined to derive the invertebrate EC. These metric groups are according to the method described in the rating approach section 7.3.1. The metric group that will best indicate the response of invertebrates in a particular river or at a particular site is ranked 1 with a weight of 100%. The fourth metric group (system connectivity and seasonality) is not always relevant. If it was not included in the assessment, it should receive a weight of 0%.

The model automatically calculates the EC based on the percentage of reference. It does not, however, indicate the boundary categories, which include a measure of personal judgement. As a guidance, 2% under or over the percentage that defines the EC boundary indicates a boundary category. For example, 78.5% will equate to a B/C category.

7.3.7 Interpretation of flow and non-flow related impacts

The reasons for a specific EC can be determined by interrogating the composition of the EC, that is, which of the metric groups is most impacted. By unpacking the EC and the metric groups one can discover how the invertebrate composition has changed, and if it is due to flow or non-flow related impacts. If, for example the major reason for the change in EC is due to flow modification, one has to unpack the flow modification metric group to determine which of the metrics are most responsible for the change. From this one might be able to make recommendations regarding the maintenance or possible improvement of the invertebrate assemblage.

7.4 MIRAI: PREDICTIVE USES

MIRAI can also be used in a predictive way. The likely changes in flow, habitat and water quality can be described and the response to these changes used to modify the list of taxa present at the site. Possible changes can either be a loss or gain, or a change in the abundance and/or frequency of occurrence of taxa.

After changing the invertebrate composition on the data sheet of the MIRAI, the model can then be run in a predictive way to determine the EC under various different scenarios. It must, however, always be remembered when using the MIRAI predictively that the likelihood of the EC depends on the accuracy of the expected changes in the invertebrate community.

7.5 STEPWISE PROCEDURE FOR RUNNING THE MIRAI

- Determine the reference conditions
- Complete the data sheet
- Fill in the Season column if applicable
- Rank and weight the flow modification metrics.
- Sort the data according to the >0.6m/s velocity category.
- Compare the observed (present) taxa to the expected (reference) taxa.
- Rate the metric accordingly, indicating the reason for the rating in the comment block
- Repeat the process (3-6) for the other metrics and metric groups
- Rank and weight the metric groups.

8 RESPONSES: RIPARIAN VEGETATION RESPONSE ASSESSMENT INDEX (VEGRAI)

The riparian vegetation index (RVI) was developed for use in the RHP (Kemper, 2001). Although highly relevant information is collected during implementation of the index, the results are often difficult to interpret (Withers 2003). Some development towards a riparian vegetation model for application in the Reserve determination process took place during 2004. However, there are still several practical and conceptual issues that have to be resolved before such a model can be recommended as a standard approach. These include the assessment of the riparian zone according to different lateral zones, such as the marginal, lower and upper zones. In addition, different inundation levels that relate to the response of the vegetation should be considered. The detail required for various levels of Reserve determination and for the RHP is also an important consideration. It seems likely that the envisaged index will be impact0based due to the problems associated with defining a reference condition directly.

The first steps in the development of a riparian vegetation response index will be taken in 2005 when a number of specialist workshops will be held, during which concepts will be developed and objectives defined. This will result in a prototype index which will subsequently be tested and adapted as necessary.

Until an appropriate riparian vegetation model has been developed it is suggested that the following aspects be considered -

- The relationship of the instream biota with riparian vegetation is an important matter when considering instream biological response.
- Some information on the ecological condition of the riparian vegetation can be obtained from metrics of the geomorphology driver or the vegetation information of the IHI,
- The riparian zone component of the IHI considers vegetation removal and invasion by alien plants as the two basic indicators of vegetation condition.
- In terms of the instream biota the marginal vegetation zone of the riparian vegetation is extremely important due to the cover it provides to instream biota.
- The influence of the two other vegetation zones (lower and upper riparian

vegetation zones) on instream biological response are usually less prominent and direct.

9 ECOSTATUS DETERMINATION

9.1 ASSESSMENT OF DRIVERS

As pointed out (cf.2.3.3), metrics of each driver component are integrated to provide an Ecological Category (EC) for each component. However, the three drivers are not integrated to provide a driver EC. The information required from the drivers refers to the information contained in individual metrics, and which can be used to interpret habitat required by the biota. This information can then be used to determine and explain biological responses.

9.2 USE AND INTERPRETATION OF DRIVER METRICS FOR INSTREAM BIOLOGICAL RESPONSES

The basis of this approach is the general biological response that would be expected from the instream biota given a particular combination of driver conditions. The following are the essential aspects of this approach -

- As pointed out (cf.2.3.3), metrics of each driver component are integrated to provide an EC for each component. This provides an overall indication of the habitat template to which the biota would respond.
- However, for the interpretation and assessment of biological responses, individual driver metrics should also be looked at and interpreted. Metrics that indicate, for example, changes in the flow conditions (such as an increase in the frequency of low flow conditions), provide important information as to the way instream biota would respond.
- The reference condition, temporal and spatial characteristics of the habitat are key considerations for the interpretation of habitat and biological responses. Biological responses are determined and explained qualitatively.
- The basis of this approach is the general biological response that would be expected from the instream biota and the riparian vegetation.

9.3 DETERMINATION OF INSTREAM RESPONSE EC

The spreadsheet used to determine the Instream Response EC is illustrated in Figure 9.1. Note that only the grey cells have to be completed.

INSTREAM BIOTA	Importance Score	Weight	EC %	EC	Boundary EC
FISH					
1.What is the natural diversity of **fish** species with different flow requirements	4	90			
2.What is the natural diversity of **fish** species with a preference for different cover types	3	80			
3.What is the natural diversity of **fish** species with a preference for different flow depth classes	3	80			
4. What is the natural diversity of **fish** species with various tolerances to modified water quality	4	100			
FISH ECOLOGICAL CATEGORY	14	350	**81.0**	**B**	**B/C**
AQUATIC INVERTEBRATES					
1. What is the natural diversity of **invertebrate** biotopes	3	100			
2. What is the natural diversity of **invertebrate** taxa with different velocity requirements	3	100			
3. What is the natural diversity of **invertebrate** taxa with different tolerances to modified water quality	3	100			
AQUATIC INVERTEBRATE ECOLOGICAL CATEGORY	**9**	300	**65.0**	**C**	**n/a**
INSTREAM ECOLOGICAL CATEGORY (No confidence)		650	**72.5**	**C**	**n/a**

INSTREAM ECOLOGICAL CATEGORY WITH CONFIDENCE	Confidence rating	Proporitons	Modified weights
Confidence rating for **fish** information	3.5	0.54	43.62
Confidence rating for **macro-invertebrate** information	3	0.46	30.00
	6.5	1.00	73.62
INSTREAM ECOLOGICAL CATEOGORY	**EC**		**C**
	Boundary EC		**n/a**

Figure 9.1 Illustration of the Instream spreadsheet

9.3.1 Instream Response model

The purpose of this model is to integrate the EC information on the fish and invertebrate responses to provide the instream EC. The basis of this determination is the consideration of the indicator value of the two biological groups to provide information on -

- Fish: Diversity of species with different requirements for flow, cover, velocity depth classes and modified physico-chemical conditions of the water column.
- Invertebrates: Diversity of taxa with different requirements for biotopes, velocity and modified physico-chemical conditions.

The rating of criteria importance is achieved according to the following process -

- Rating is done separately for fish and invertebrates.
- Each of these criteria is scored in terms of its relative importance as an indicator of a diversity of habitat conditions. The score for each of the criteria is expressed on a scale 1→5, where 5 = very high indicator value and 1 = very low indicator value.
- The highest score is awarded a weight of 100%, and those lower receive lower weights. Weights are standardized by expressing individual weights as a proportion of the total of all weights.
- Standardized weights are multiplied by the score to provide a weighted score.
- The average of all standardized weights is calculated.
- The average standardized weights for fish and invertebrates are summed. The fish and invertebrate average standardized weights are expressed as a proportion of this sum.
- These proportions are multiplied by the fish and invertebrate PES. The resulting values are summed to provide a value that is related to one of the ECs (A→F).
- Confidence in the detail and quality of the fish and invertebrate information respectively is considered by rating information on the two groups according to a scale as follows -

  1 - low confidence

  2 - low to medium confidence

  3 - medium confidence

  4 - medium to high confidence

  5 - high confidence.
- Low confidence (1) will be where there are derived data and very scarce data. High confidence (5) will be where observed information and ecological knowledge on the biota are available.
- Confidence scores are expressed as a proportion of the sum. These values are multiplied by the respective ECs of the fish and invertebrate groups to provide the instream EC, considering confidence and proportioned accordingly.

This approach is similar to the Multi-Criteria Decision Analysis (MCDA) approach followed for calculating driver EC.

9.3.2 Completing the spreadsheet

The sequence below is followed to complete the spreadsheet.

a) Fish

- Questions to assess the indicator value of fish -

What is the natural diversity of fish species with different flow requirements?

Assess according to the number of species with -

Requirement for flowing water during all stages of life-cycle.

Requirement for flowing water during breeding activities.

No requirement for flowing water during any stage of life cycle.

What is the natural diversity of fish species with a preference for different cover types?

Assess according to number of species with a preference for different cover types. (marginal vegetation, overhanging vegetation, undercut banks, substrate, instream vegetation, water column)

What is the natural diversity of fish species with a preference for different velocity depth classes?

Assess according to number of species with a preference for various velocity-depth classes. FD, FS, SS, SD

What is the natural diversity of fish species with various tolerances to modified water quality?

Assess according to number of species intolerant of modified physico-chemical conditions.

Moderately intolerant of modified physico-chemical conditions.

Moderately tolerant of modified physico-chemical conditions

Tolerant of modified physico-chemical conditions.

- Fish specialist to complete the weight column. The question with the highest importance is weighted as 100% and the rest proportionately lower.
- The fish EC percentage must be copied from the FRAI into the appropriate block.
- Boundary categories must be filled in where relevant (usually 2% on either side of the cut-off between categories).
- Confidence rating of 1 (low confidence) to 5 (high confidence) must be completed by the fish specialists.

b) Invertebrates

- Questions to assess the indicator value of invertebrates

What is the natural diversity of invertebrate biotopes?

Assess according to the diversity of biotopes present (SIC, SOC, MV IC, MV

OC, Aquatic vegetation, Gravel, Sand, Mud, Water Column etc).

What is the natural diversity of invertebrate taxa with different velocity requirements?

Assess according to the number of invertebrate taxa with different velocity requirements (Very Fast, Fast, Slow, Very Slow)

What is the natural diversity of invertebrate taxa with different tolerances to modified water quality?

Assess according to the number of taxa with a -

High requirement for unmodified physico-chemical conditions (SASS weight 12-15)

Moderate requirement for unmodified physico-chemical conditions (SASS weight 7-11)

Low requirement for unmodified physico-chemical conditions (SASS weight 4-6)

Very low requirement for unmodified physico-chemical conditions (SASS weight 1-3)

- Invertebrate specialist to complete the weight column. The question with the highest importance is weighted as 100% and the rest proportionately lower.
- The invertebrate EC percentage must be copied from the MIRAI into the appropriate block.
- Boundary categories must be filled in where relevant (usually 2% on either side of the cut-off between categories).
- Confidence rating of 1 (low confidence) to 5 (high confidence) must be completed by the invertebrate specialists.

9.4 DIFFERENT LEVELS OF ECOSTATUS DETERMINATION

Due to time and funding constraints, various levels of Reserve determinations are undertaken, each with its own Ecological Water Requirement (EWR) method and modified EcoClassification process. These EWR methods are referred to as -

- Desktop
- Rapid I, II and III
- Intermediate
- Comprehensive

The EcoClassification process, and specifically the detail and effort required for assessing the metrics, varies according to the different levels. The process to determine the EcoStatus also differs on the basis of different levels of information. There are five EcoStatus levels and they are linked to the different levels of

Ecological Reserve determination as follows -

- Desktop Reserve method → Desktop EcoStatus level.
- Rapid I Ecological Reserve method → EcoStatus Level 1.
- Rapid II Ecological Reserve methods → EcoStatus Level 2
- Rapid III Ecological Reserve methods → EcoStatus Level 3
- Intermediate and Comprehensive Reserve methods → EcoStatus Level 4

The five levels discussed above have been fixed considering the known constraints regarding the Reserve methods at different levels and the River Health Programme (RHP). However, the combinations of the various tools applied during the EcoStatus levels can be used in different ways. This will usually depend on the site-specific situation, the available information, available expertise, funding and time. The best available information should always be used, for instance -

- EcoStatus Level 3 is the method used for the RHP. If hydrology information is available, the HAI should be undertaken even if other Driver information is not available.
- Desktop EcoStatus Level: It could be that a Desktop level is required for a certain river for which a FRAI has been undertaken. The FRAI will then be used, rather than a Desktop estimate of the fish EC (see details of methods below).

The RHP mostly focuses on biological responses with only a very generalized indication of cause-and-effect relationships, and is often done for purposes of State-of-Rivers Reports (SoR).

The general relationship between the levels of detail, scale and purpose for the ecological Reserve and the RHP is indicated in Figure 9.2.

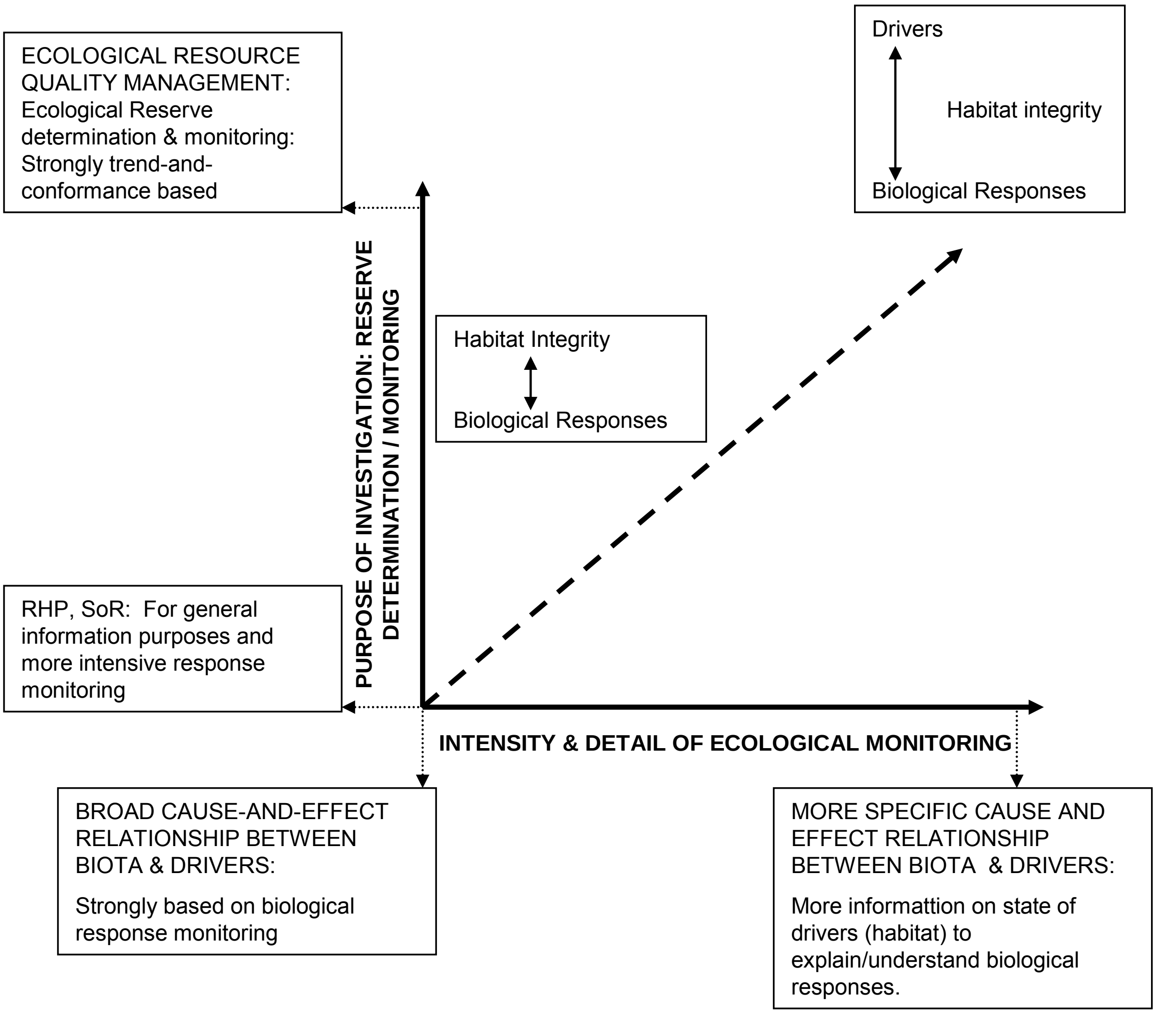

Figure 9.2 Levels of detail for EcoStatus determination for Reserve and RHP purposes

To design a range of EcoStatus levels, tools of different complexities have to be utilised. The tools discussed in the previous chapters (GAI, FRAI, HAI, PAI, MIRAI and VEGRAI) are all reasonably detailed. As the EcoStatus levels become less complex, less-complex tools must be used (such as the Index of Habitat Integrity). These tools are the following -

- **Index of Habitat Integrity (IHI)**

  This tool has been in place for about 15 years (Kleynhans 1996) and can function as a surrogate for Driver information. The IHI is applied for both the Instream (nine metrics) and the Riparian areas (eight metrics). Two levels of IHI exist, one based on an aerial video of the river, and one based on site- or ground-based information. The tool / model used is the same for both.
- **Desktop Habitat Integrity**

To accommodate the time constraints associated with desktop levels in general, a modified IHI was developed, based on available information. It does not distinguish between Instream and Riparian, and addresses only six metrics.

- **Desktop Fish Response Rating**

  The rating for this is based on broad considerations that take into account available data, considering the general characteristics of the fish assemblage for the particular stream delineation. This may be based on actual data, data derived from neighbouring streams with empirical fish data, and fish response derived from habitat conditions. Where data from neighbouring streams are used, these streams should fall within the same ecoregional context. The following aspects can also cause a decrease in fish assemblage integrity and should be considered for a composite assessment -

  - Change in habitat conditions, such as flow modifications
  - Increase in sedimentation
  - Modified physico-chemical conditions
  - Loss in cover
  - Presence of introduced species.

- **Desktop Invertebrate Response Rating**

  The rating for this is based on broad considerations taking available data into account, considering the general characteristics of the invertebrate assemblage for the particular stream delineation. This may be based on actual data, derived data from neighbouring streams with empirical invertebrate data, and invertebrate response derived from habitat conditions. Where data from neighbouring streams are used, these streams should fall within the same ecoregional context. The following aspects can also cause a decrease in invertebrate assemblage integrity and should be considered for a composite assessment -

  - Change in habitat conditions, such as flow modifications
  - Increase in sedimentation
  - Modified physico-chemical conditions

- **Derived vegetation Response EC and Rating**

  The Response EC for Levels 1, 2 and 3 is derived from the Riparian Habitat Integrity using two metrics -

  - Vegetation removal
  - Presence of exotic vegetation.

  The output is an EC and EC percentage which is used in the EcoStatus calculation as discussed in detail below. The rating for the desktop assessment is based entirely on the condition of bank and riparian zone. The rating (0 – 5) given for this metric is therefore used as the rating for the Vegetation Response.

<u>EC and Ratings</u>

Note: **EC refers to a % converted to a Category (eg FRAI output)**
Rating refers to a value of 0 to 5 which can indirectly refer to a Category (eg Desktop Fish Response rating - 0 = A and 5 = F)

<u>Levels of EcoStatus determination</u>

Ecostatus Desktop Level→	**Desktop Reserve assessment**
EcoStatus Level 1→	**Rapid I Ecological Reserve method**
EcoStatus Level 2→	**Rapid II Ecological Reserve method**
EcoStatus Level 3→	**Rapid III Ecological Reserve method and River Health Programme**
EcoStatus Level 4→	**Intermediate and Comprehensive Reserve methods**

9.4.1 EcoStatus Level 4 determination

a) General approach

The flow diagram (Figure 9.3) explains the process to determine the EcoStatus during a Comprehensive and Intermediate Ecological Reserve assessment, that is, when driver information as well as riparian vegetation information is available.

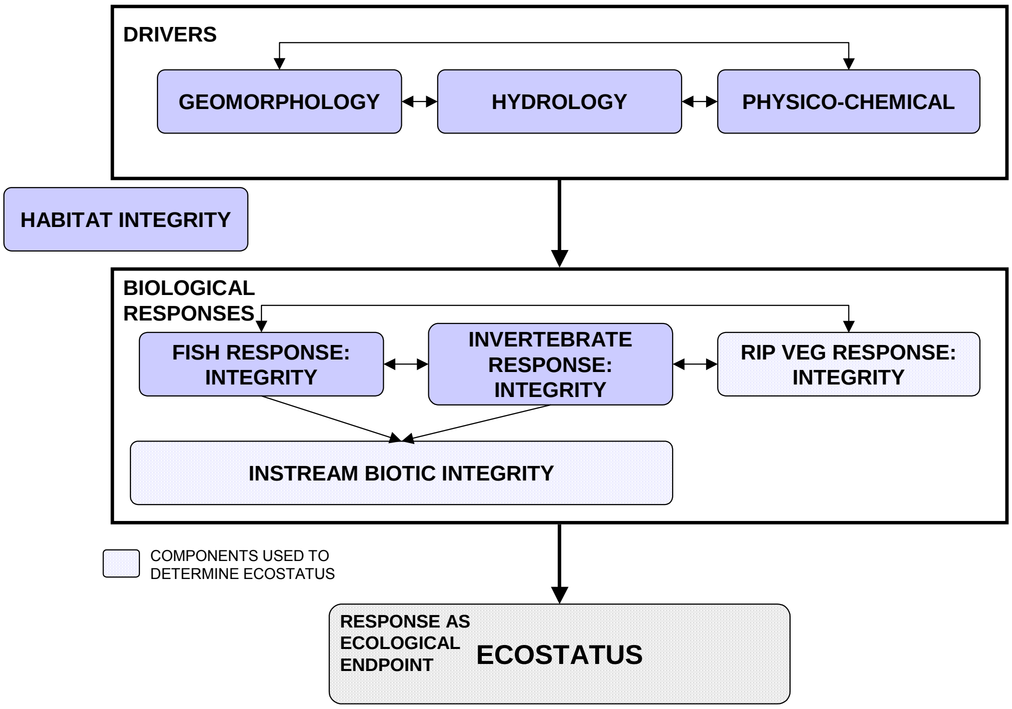

Figure 9.3 EcoStatus Level 4 determination

b) Ecostatus

The EcoStatus represents the ecological endpoint and is therefore a combination of the biological responses - fish, invertebrates (already integrated in the instream response) and riparian vegetation. A detailed Habitat Integrity assessment (usually based on an aerial video) is undertaken as part of the delineation of RUs and the outcome used as a verification of the Driver ECs. Any significant discrepancy between the Driver assessments and the Habitat Integrity will require re-assessment.

The EcoStatus consists of a combination of the Instream and the Riparian Vegetation ECs. Confidence scores are expressed as a proportion of the sum. These values are multiplied by the respective ECs of the instream and riparian groups to provide the EcoStatus EC considering confidence and proportioned accordingly. The confidence assessment is done on a similar basis as for the Instream EC (cf. 9.3.1)

The following spreadsheet illustrates the procedure (Figure 9.4).

NOTE: Only fill in the shaded (grey) cells in spreadsheet / model (see illustrations).

ECOSTATUS WITH CONFIDENCE	Confidence rating	Proporitons	Modified weights
Confidence rating for instream biological information	3.25	0.62	45.57
Confidence rating for riparian vegetation zone information	2	0.38	15.24
	5.25	1.00	60.81
ECOSTATUS	**EC**		**C**
	Boundary EC		**C/D**

Figure 9.4 Illustration of the EcoStatus Level 4 model

The information regarding the instream and riparian category and the instream confidence is already available and automatically linked to this spreadsheet. The confidence rating for riparian vegetation is added into the equation to determine the final EcoStatus.

The integration of the riparian vegetation EC into the EcoStatus must be carefully considered under particular circumstances. The vegetation could be in much worse condition than the instream biota due to non-flow related sources such as the presence of alien vegetation and/or removal of vegetation. At all times, however, it must be considered whether those attributes of vegetation, specifically in the marginal and lower zone that play a role in the instream integrity, are still functioning.

NOTE: In the absence of a vegetation response score and category, the Instream Response EC becomes the EcoStatus

9.4.2 EcoStatus Level 3 determination

a) General process

The flow diagram (Figure 9.5) explains the process to determine the EcoStatus when applying the Rapid Ecological Reserve Method (Level III) (RERM III). During a RERM III assessment, driver and riparian vegetation are assessed in general and not by the relevant specialists. Only the instream specialists are involved.

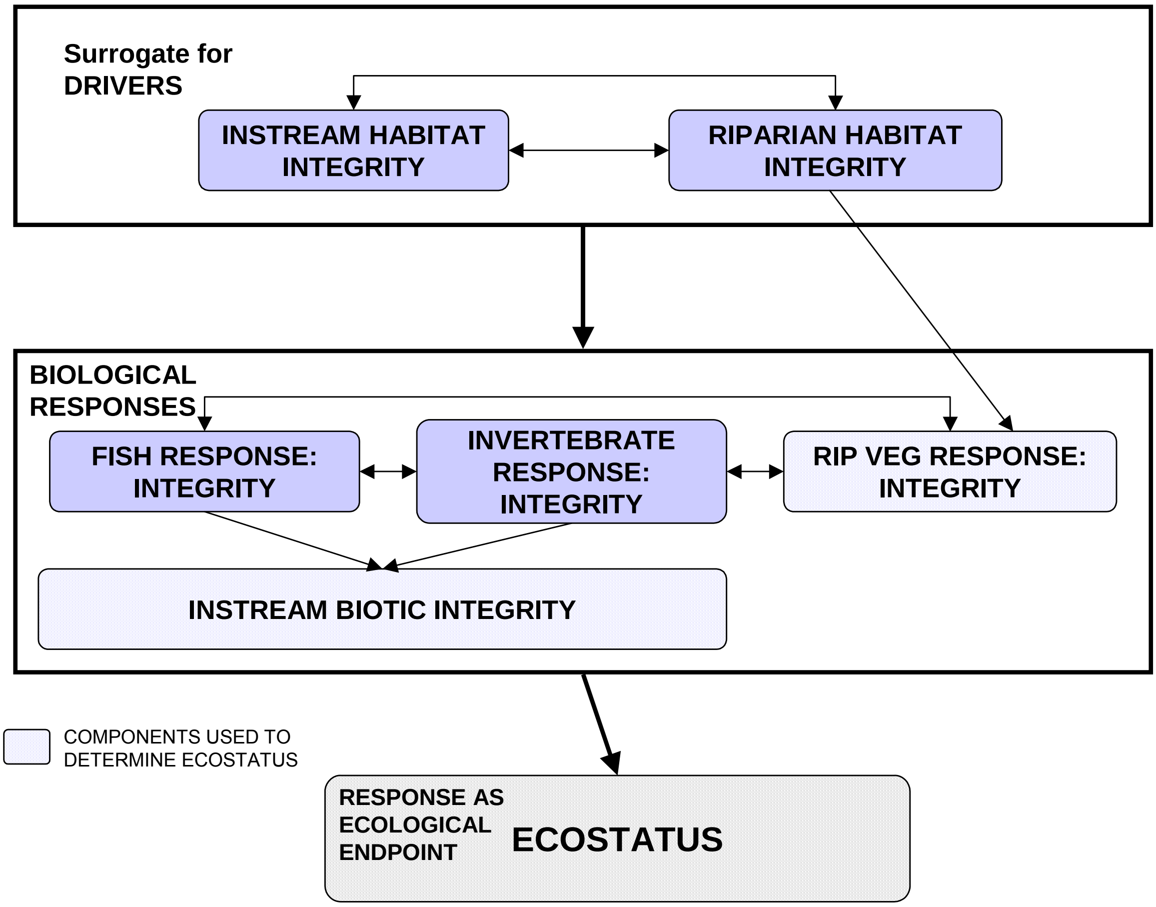

Figure 9.5 EcoStatus Level 3 determination

To accommodate the less detailed process and fewer specialists involved, the following changes from the EcoStatus Level 4 method are required -

- The habitat integrity operates as a substitute for the drivers (Figure 9.5, Figure 9.6, Figure 9.7).
- The vegetation decrease and exotic vegetation metrics of the riparian habitat integrity are used as a substitute for the riparian vegetation response.

b) Instream Habitat Integrity assessment

The Instream Habitat Integrity assessment (Kleynhans 1996) is completed according to the metrics and the evaluation as shown in the illustration of the model (Figure 9.6)

DELINEATION:	Diep River
PRIMARY	
WATER ABSTRACTION	10
FLOW MODIFICATION	10
BED MODIFICATION	8
CHANNEL MODIFICATION	11
WATER QUALITY	6
INUNDATION	4
TOTAL (OUT OF 150)	
SECONDARY	
EXOTIC MACROPHYTES	0
EXOTIC FAUNA	0
SOLID WASTE DISPOSAL	0
TOTAL (OUT OF 75)	
INSTREAM HABITAT INTEGRITY SCORE	71
ECOLOGICAL CATEGORY	C

NONE(0); SMALL (0-5); MODERATE (6-10);
LARGE (11-15); CRITICAL (21-25)

Figure 9.6 Instream Habitat Integrity model

c) Riparian Habitat Integrity assessment

The Riparian Habitat Integrity Assessment (Kleynhans 1996) is completed according to the metrics and the evaluation as shown in the illustration of the model (Figure 9.7). Without a Riparian Vegetation Response assessment, the vegetation decrease and exotic vegetation metrics are used to determine an Ecological Category (Figure 9.7)

DELINEATION	Diep River
VEGETATION DECREASE	13
EXOTIC VEGETATION	21
BANK EROSION	14
CHANNEL MODIFICATION	11
WATER ABSTRACTION	2
INUNDATION	2
FLOW MODIFICATION	2
WATER QUALITY	0
TOTAL (OUT OF 200)	65
RIPARIAN ZONE HABITAT INTEGRITY SCORE	**30.25**
ECOLOGICAL CATEGORY	**E**
RIPARIAN VEGETATION RESPONSE SCORE	**37.44**
ECOLOGICAL CATEGORY	**E**

NONE(0); SMALL (0-5); MODERATE (6-10); LARGE (11-15);
CRITICAL (21-25)

Figure 9.7 Riparian Habitat Integrity model

d) Responses and EcoStatus determination

The FRAI, MIRAI, and Instream models as used in the EcoStatus Level 4 determination are still valid. As the EcoStatus is primarily targeted towards the Instream integrity, and as the derived vegetation EC is inherently of lower confidence, the instream EC comprises two thirds of the EcoStatus. The use of the derived (from Riparian Habitat Integrity) vegetation response EC to calculate the EcoStatus must be carefully assessed. In this case the derived vegetation score will be of low confidence. As a guide, if the vegetation EC differs by 2 categories or more from the instream EC, the results should not be incorporated into the EcoStatus. The EcoStatus model therefore differs only with the weights.

Remember: The EcoStatus is primarily targeted towards the Instream integrity.

9.4.3 EcoStatus Level 2 determination

a) General process

The flow diagram (Figure 9.8) explains the process to determine the EcoStatus when applying the Rapid Ecological Reserve Method (Level II) (RERM II). During a RERM II assessment, one ecological specialist is involved to provide information on the category of river as well as somebody that can undertake a flow measurement and calculate the discharge. This specialist should be able to undertake a SASS survey and complete the MIRAI.

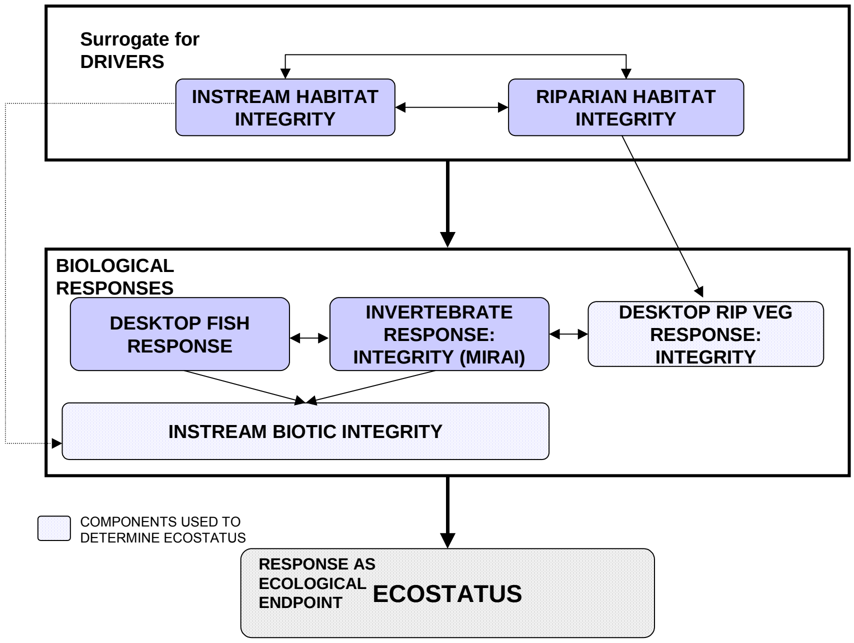

Figure 9.8 EcoStatus Level 2 determination

b) Responses and EcoStatus

To accommodate the less detailed process and fewer specialists involved, the following changes from EcoStatus Level 3 method are required -

- The invertebrate integrity is the only response component assessed comprehensively, that is, by using the MIRAI.
- The fish response is determined using a Desktop approach. In essence, the EC of the fish is estimated using a rating of 0 (no impact = A EC) to 5 (critically modified = F EC). The relationship between the 0 to 5 rating, the category and the conversion to the percentage is provided in Table 9.1. The specialist undertaking the study should contact a relevant fish specialist for the area to obtain this information. If no fish information is available the fish EC should not be considered.

Table 9.1 Desktop EC rating conversion

Desktop EC rating	EC	% range	Converted %
0	A	100 - 90	95
1	B	89 - 80	85
2	C	79 - 60	70
3	D	59 - 40	50
4	E	39 - 20	30
5	F	19 - 0	10

- To accommodate the lack of fish response information, the instream habitat integrity results are brought into the equation to calculate the Instream EC. The instream EC is therefore a combination of the Instream Habitat Integrity the MIRAI EC and the estimated fish Desktop EC.
- To accommodate the lower confidence of the Desktop fish EC compared to the MIRAI EC and the Instream Habitat Integrity, the Desktop fish EC is weighted as 10% with both the MIRAI and Instream Habitat Integrity weighted at 45%
- As the EcoStatus is primarily targeted towards the Instream integrity, and as the derived vegetation EC is inherently of lower confidence, the instream EC comprises two thirds of the EcoStatus.
- The riparian information is used in the same way as for Level 3.

The Ecostatus is therefore calculated using a different spreadsheet (Figure 9.9) than for Level 3.

ECOSTATUS LEVEL 2		
	RATING	EC
HABITAT INTEGRITY		100
INVERTEBRATE RATING		80
DESKTOP FISH RATING	0	95
INSTREAM EC%		90.5
INSTREAM EC		A
DESKTOP VEGETATION		80
ECOSTATUS %		86.13
ECOSTATUS EC		B
BOUNDARY EC		n/a

Figure 9.9 EcoStatus Level 2 model

9.4.4 EcoStatus Level 1 determination

a) General process

The flow diagram (Figure 9.10) explains the process to determine the EcoStatus when applying the Rapid Ecological Reserve Method (Level I) (RERM I). During a RERM I assessment, one ecological specialist is required to undertake the site / reach-based habitat integrity, and to source available information from other specialists.

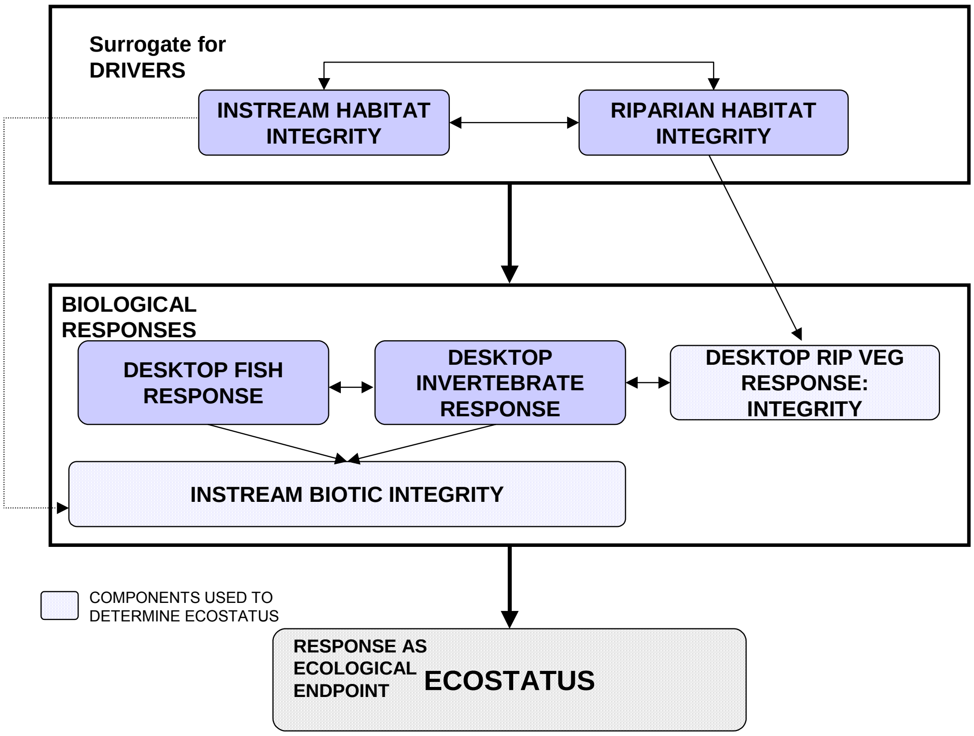

Figure 9.10 EcoStatus Level 1 determination

b) Responses and EcoStatus

To accommodate the less-detailed process, the following changes from EcoStatus Level 2 method are required -

- The invertebrate response is determined using a Desktop approach. In essence, the EC of the invertebrates is estimated using a score of 0 (no impact = A EC) to 5 (critically modified = F EC). The specialist undertaking the study should contact a relevant invertebrate specialist for the area to obtain this information. This approach is the same as for fish in the Level 2 assessment.
- To accommodate the lack of fish and invertebrate response information, the instream habitat integrity results are brought into the equation to calculate the Instream EC. The instream EC is therefore a combination of the Instream Habitat Integrity and, the Desktop fish and invertebrate ECs.
- To accommodate the lower confidence of the Desktop invertebrate and fish ECs compared to the Instream Habitat Integrity, the Desktop fish and invertebrate ECs are both weighted as 10 % with the Instream Habitat Integrity weighted at 80%.
- As the EcoStatus is primarily targeted towards the Instream integrity, and as the derived vegetation EC is inherently of lower confidence, the instream EC comprises two thirds of the EcoStatus.
- The riparian information is used in the same way as for Level 3 and Level 2.

The Ecostatus is therefore calculated using a different spreadsheet (Figure 9.11) than for Level 2.

ECOSTATUS LEVEL 1		
	RATING	EC
HABITAT INTEGRITY		100
DESKTOP INVERTEBRATE RATIN	0	95
DESKTOP FISH RATING	0	95
INSTREAM EC%		99
INSTREAM EC		A
DESKTOP VEGETATION		80
ECOSTATUS %		91.74
ECOSTATUS EC		A
BOUNDARY EC		

Figure 9.11 EcoStatus Level 1 model

9.4.5 EcoStatus Desktop Level determination

a) General process

The Desktop Reserve Level requires the use of the Desktop Reserve Model that estimates a flow requirement based on the hydrological region in which the river occurs, and for a specific Ecological Category. An appropriate Desktop Level EcoStatus (Figure 9.12) assessment was designed for use with the Desktop application as well as when assessments for planning purposes on large scale have to be undertaken.

As the name indicates, this method is at desktop level, and is therefore based on available information and expert judgement. Time constraints will also not allow for any detailed application of the standard EcoStatus models and/or a site visit.

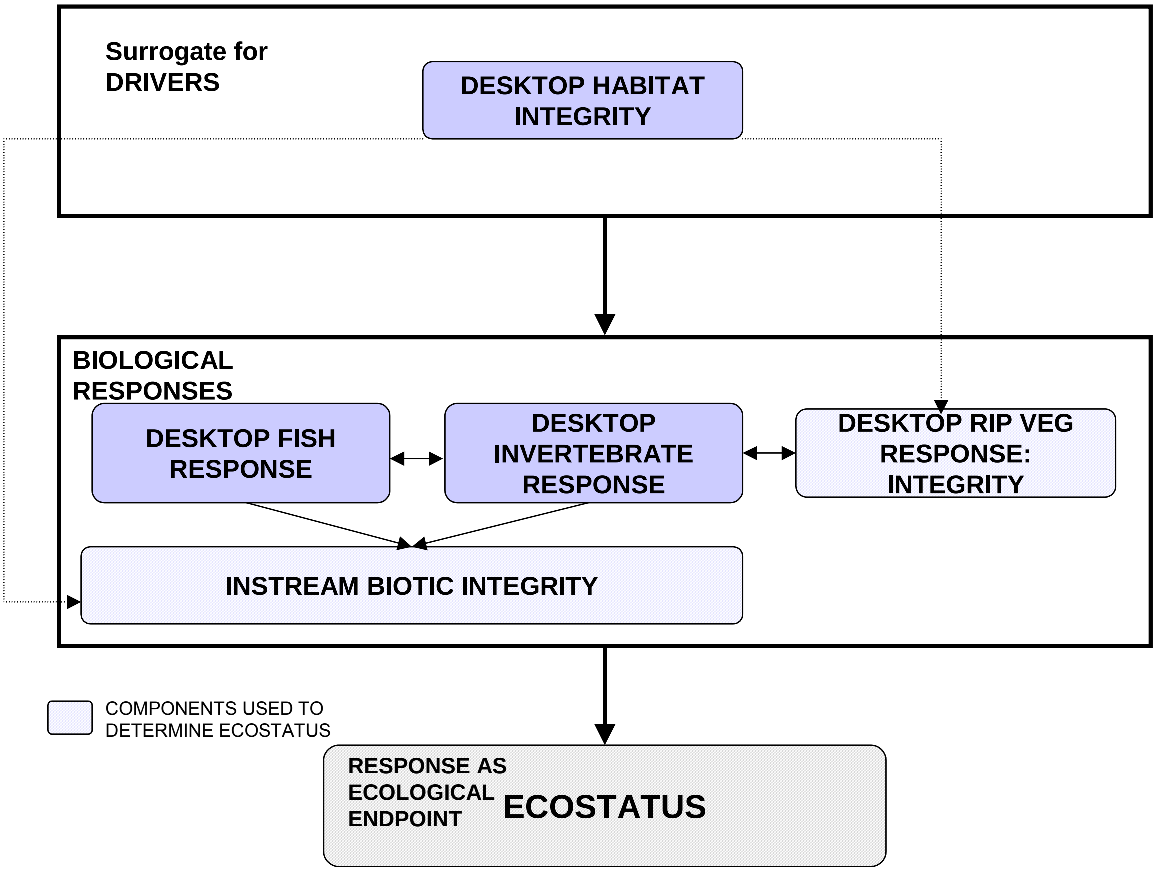

Figure 9.12 Desktop EcoStatus determination

b) Responses and EcoStatus

To accommodate the less-detailed process, the following changes from EcoStatus Level 1 method are required -

- A desktop habitat integrity that allows for a coarse assessment was developed. This assessment rates the habitat according of a scale of 0 (close to natural) to 5 (critically modified) according to the following metrics -
  - Bed modification
  - Flow modification
  - Introduced Instream biota
  - Inundation
  - Riparian / bank condition
  - Water quality modification
- This Desktop Habitat Integrity procedure serves as a substitute for the drivers, as well as playing a role in assessing the EcoStatus. This is necessary because the response information is of low confidence.
- To accommodate the lack of fish and invertebrate response information, the Desktop Habitat Integrity results are brought into the equation to calculate the

Instream EC. The instream EC is therefore a combination of the Desktop Habitat Integrity (not the Instream Habitat Integrity analysis as for Levels 1, 2 and 3) and the Desktop fish and invertebrate ECs.

- Riparian vegetation a response (integrity) is derived from the riparian / bank condition metrics in the Desktop Habitat Integrity. This is used instead of the Riparian Habitat Integrity assessment as in Level 1, 2 and 3.
- As the EcoStatus is primarily targeted towards the Instream integrity, and as the derived vegetation EC is inherently of lower confidence, the instream EC comprises two thirds of the EcoStatus. The model is illustrated in Figure 9.13.

DESKTOP LEVEL	
	RATING
Bed modification	2.0
Flow modification	1.0
Introduced instream biota	3.0
Inundation	1.0
Riparian/bank condition	3.0
Water quality modification	1.0
HABITAT INTEGRITY	1.8
DESKTOP INVERTEBRATE RATIN	3.0
DESKTOP FISH RATING	3.0
INSTREAM EC%	56.9
INSTREAM EC	D
DESKTOP VEGETATION	2.0
	0.7
ECOSTATUS %	60.7
ECOSTATUS EC	C
BOUNDARY EC	

Figure 9.13 EcoStatus Desktop Level

9.4.6 Comparison of different EcoStatus levels

The following table illustrates the differences between the five EcoStatus levels (Table 9.2). An additional table (Table 9.3) is supplied that illustrates the use of the different tools normally associated with the different levels. It must be emphasised that, at all levels, the best available information should always be used. More detailed tools than desktop tools can therefore be used if available from other relevant studies (such as detailed hydrology available from water resources planning studies).

To determine the Instream EC and the EcoStatus, certain rules must be followed.

These rules are illustrated in Table 9.4.

Table 9.2 Differences between EcoStatus levels

COMPONENTS	Desktop	Level 1	Level 2	Level 3	Level 4
DRIVER					
Geomorphology	Desktop HI	IHI (instream and riparian)	IHI (instream and riparian)	IHI (instream and riparian)	GAI
Water quality					PAI
Hydrology					HAI
RESPONSES					
Fish	Desktop EC (rating)	Desktop EC (rating)	None	FRAI	FRAI
Invertebrates			MIRAI	MIRAI	MIRAI
INSTREAM	Combination of Desktop fish, invert and HI	Combination of Desktop fish, invert and IHI	Comb of Desktop fish, MIRAI and IHI	FRAI & MIRAI & confidence	FRAI & MIRAI & confidence
Riparian vegetation	Derive from Desktop HI	Derive from RHI	Derive from RHI	Derive from RHI	VEGRAI
ECOSTATUS					
EcoStatus	Combination of Instream and derived riparian vegetation	Combination of Instream and derived riparian vegetation	Combination of Instream and derived riparian vegetation	Combination of Instream and derived riparian vegetation. Confidence and weights included	Combination of Instream & VEGRAI. Confidence and weights included

Table 9.3 Tools used for different EcoStatus levels

ECOSTATUS LEVELS	TOOLS											
	GAI	PAI	HAI	VEGRAI	FRAI	MIRAI	IHI	DERIVED VEG EC	DESKTOP FISH RATING	DESKTOP INVERT RATING	DESKOP HI	DERIVED VEG RATING
4	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N
3	N	N	N	N*	Y	Y	Y	Y*	N	N	N	N
2	N	N	N	N*	N	Y	Y	Y*	Y	N	N	N
1	N	N	N	N	N	N	Y	Y	Y	Y	N	N
DT#	N	N	N	N	N	N	N	N	Y	Y	Y	Y

DT: Desktop
* Once the VEGRAI has been designed and tested, it will/can be used for these levels; definitely for the RHP and will replace the derived vegetation EC.

Table 9.4 Rules to determine Instream and EcoStatus EC

Desktop	Level 1	Level 2	Level 3
INSTREAM EC			
1. If fish and invertebrate EC available then use Desktop HI. 2. If fish EC available and not invertebrates, then use fish with Desktop HI. 3. If invertebrate EC available and not fish, then use Invertebrate with Desktop HI. 4. If fish and invertebrate ECs not available, then use only Desktop HI.	1. If fish and invertebrate EC available then use with IHI. 2. If fish EC available and not invertebrates, then use fish with IHI. 3. If invertebrate EC available and not fish, then use Invertebrate with IHI. 4. If fish and invertebrate ECs not available, then use only IHI.	1. If fish EC available then use with IHI (invertebrate EC available). 2. If fish EC not available, use invertebrate EC with IHI.	Not applicable
ECOSTATUS			
1. If derived vegetation EC differs by 2 or more classes from instream, use Instream EC	1. If derived vegetation EC differs by 2 or more classes from instream, use Instream EC	1. If derived vegetation EC differs by 2 or more classes from instream, use Instream EC	1. If derived vegetation EC differs by 2 or more classes from instream, use Instream EC

9.5 ECOSTATUS FOR RIVER HEALTH PROGRAMME

EcoStatus Level 3 assessment that includes a detailed vegetation assessment using the VEGRAI (under development) is the appropriate level for the RHP.

However, there are no prescriptions and, depending on the driver information available, it may be possible to provide reasonably explicit indications of causes for particular biological responses. It is recommended that the GAI should also be used.

9.6 COMPARISON BETWEEN ECOSTATUS EC AND DRIVER ECs

As driver scores do not form part of the EcoStatus calculation it is possible that, in some cases, the EcoStatus might not reflect the actual situation. An indication of such a possible discrepancy would be if the driver ECs (or any single driver EC) differ significantly from the response ECs. Usually the ECs are summarised in the figure (Figure 9.14) following, which provides a visual indication of any problems.

When there are discrepancies, the driver summary of all the metrics (cf. 9.1) are utilised to gain insights into such a situation. Such a potential discrepancy could be explained by understanding the interaction between the drivers and the responses.

Some of the situations where a discrepancy between drivers and responses could occur are as follows -

- Instream biota is resilient and no permanently flow-dependent fish species occur. In the Thukela system for example, some of the drivers (usually hydrology) are often in a much lower PES than the instream PES. In this case, the fish and invertebrates are resilient and not very responsive to driver changes. In other rivers, however, biota may be highly sensitive and responsive to particular driver changes.
- The biota may be in a better state than would be expected based on the state of the drivers because there is a time lag in the biological responses. This means that there may be a deteriorating driver trend but that the biological responses are not yet observable. In these cases, the EcoStatus EC should not just reflect the response ECs but should consider the trend and the Driver ECs as well.
- The general state of the drivers may be closer to the reference condition than the biota. In such cases the biota may be highly intolerant to comparatively small changes in driver conditions. This situation is expected to occur in systems with highly sensitive biota, and which are adapted to physical conditions on a micro- to meso-habitat scale.

Driver Components	Component EC
HYDROLOGY	E
GEOMORPHOLOGY	E
WATER QUALITY	B/C
Response components	**Component EC**
FISH	C
AQUATIC INVERTEBRATES	D
INSTREAM	C/D
RIPARIAN VEGETATION	D
ECOSTATUS	**D**

Figure 9.14 Illustration of the summary of an EcoStatus assessment

9.7 GUIDANCE IN THE USE OF THE ECOSTATUS LEVEL 4 PROCESS

The EcoStatus model is used in various ways as follows -

- To determine the PES
- To derive the Recommended Ecological Category
- To derive an alternative Ecological Category
- To predict as an ecological consequence, the EcoStatus given certain scenarios

The rest of this section is provided as guidance for a coordinator / practitioner managing Ecological Water Requirement / Reserve studies.

9.7.1 Determination of the PES

The following provide a step-by-step guidance to apply the EcoStatus Level 3 model at a study site-

- The coordinator ensures that all specialists are aware of and understand the process (specialists should have been exposed to a training course) prior to the first site visit.
- The specialists collate the required information in the field to allow them to complete the respective rule-based models.
- The response specialists require information regarding drivers prior to finalising their rule-based model. The coordinator distributes the rule-based models and information as follows -
  - Hydrology information to be provided to all specialists.
  - Geomorphology information to be provided to the riparian vegetation, fish and invertebrate specialists.
  - Parallel to this, the physico-chemical information must be provided to the riparian vegetation, fish and invertebrate specialists.
  - The vegetation information to be provided to the fish and invertebrate specialists
  - Fish and invertebrate specialists to finalise information last and provide to coordinator.
- The aquatic ecologists apply the required weighting to the hydrology and water quality driver models.
- The coordinator obtains the answers to the instream model from the fish and invertebrate specialists as well as the confidences.
- The coordinator finalises the Instream model.
- The coordinator obtains the riparian vegetation confidence.
- The coordinator runs the EcoStatus model.

- In a workshop environment, the weightings are tested with all specialists and the EcoStatus results finalised. The final results are summarised and illustrated as indicated in Figure 9.14.
- The coordinator ensures that the trends are documented, the causes and sources, and any qualitative reasoning and explanations for ratings provided in the indices.

9.7.2 Determination of the REC

The determination of the REC is based on the EIS and the PES. If the REC is different from the PES, that is, if the REC is set to improve the PES, this implies the determination of the EcoStatus for an alternative EC. The same process will therefore be followed to determine the EcoStatus as described in 9.7.3 following.

9.7.3 Determination of the alternative ECs

A range of alternative ECs must be addressed during most Reserve studies. This most often include a category higher than the PES and one lower than the PES. The following guides the decision-making on alternative ECs (Table 9.5

Table 9.5 Guidelines for the range of ECs to be addressed (DWAF, 2004a)

PES	Range of ECs
A	A
A/B	A/B, B/C
B	B, C
B/C	B, B/C, C/D
C	B, C, D
C/D	B/C, C/D, D
D	C, D
D/E, E, E/F, F	D

The alternatives are addressed during the workshop, as this can only be done after the specialists have agreed on the PES of the system. The steps followed during the workshop to determined alternative ECs are -

- Hypothetical conditions regarding the hydrology and water quality are discussed and defined. The conditions for a lower category could be decreased low flows and increased nutrients. Future development could be considered to define a realistic hypothetical condition.

- The geomorphology specialists describe what would happen under these changed conditions.
- The models are run predictively to determine whether the required alternative ECs will be achieved.
- The EcoStatus model is then run to determine whether the alternative EcoStatus EC will be met.
- The range of ECs that must be addressed will then be summarised in a table as illustrated in (Figure 9.15).

Driver Components	PES Category	REC	Alternative EC (up)
HYDROLOGY	E	D	C
GEOMORPHOLOGY	E	D	C
WATER QUALITY	B/C	B/C	B
Response components	**PES Category**	**REC**	**Alternative EC (up)**
FISH	C	C	B
AQUATIC INVERTEBRATES	D	D	C
INSTREAM	C/D	C/D	B/C
RIPARIAN VEGETATION	D	D	C
ECOSTATUS	D	D	C

Figure 9.15 Illustration of the summary of the alternative ECs

9.7.4 Determining ecological consequences

As part of an Ecological Reserve determination study, future flow scenarios are generated to be tested with regards to the impact on the Ecological Categories. A similar process as described for 9.7.3 will be followed -

- The hydrologist will interpret the results and complete the Hydrological Driver Assessment Index (HAI);
- The water quality specialist undertakes concentration modelling and, based on that result, completes the Physico-Chemical Driver Assessment Index (PAI).
- Based on these results, the geomorphologist and then the biological response specialists complete their indices.
- The EcoStatus model is completed and the ecological consequences

summarised (Figure 9.16).

Driver Components	PES Category	REC	Alternative EC (up)	Scenario 1	Scenario 2
HYDROLOGY	E	D	C	E	D
GEOMORPHOLOGY	E	D	C	E	D
WATER QUALITY	B/C	B/C	B	C	B
Response components	**PES Category**	**REC**	**Alternative EC (up)**	**Scenario 1**	**Scenario 2**
FISH	C	C	B	C	B/C
AQUATIC INVERTEBRATES	D	D	C	D/E	C/D
INSTREAM	C/D	C/D	B/C	D	C
RIPARIAN VEGETATION	D	D	C	D/E	D
ECOSTATUS	D	D	C	D/E	C/D

Figure 9.16 Illustration of summary of ecological consequences expressed in terms of impact on EC

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11 APPENDIX A: FISH DATA SHEETS

Table 11.1 Site information (adapted from Dallas 2005)

Assessor Name(s)			
Organisation		Date	/ /

Site information - assessed at the site

RHP Site Code		Project Site Number	
River		Tributary of	
Farm Name:		Farm Reg. Code:	

Latitude and longitude co-ordinates:

Degrees-minutes-seconds	or Decimal degrees	or Degrees & decimal minutes	
S ° ' . "	S . °	S ° . '	Cape datum Clarke
E 0 ° ' . "	E 0 . °	E 0 ° . '	WGS-84 datum HBH94

Site Description							
Map Reference (1: 50 000)		Site Length (m)		Altitude (m)			
Longitudinal Zone	Source zone	Mountain headwater stream	Mountain stream	Transitional	Upper foothill	Lower foothill	Lowland river
Rejuvenated cascades (gorge)	Rejuven-ated foothill	Upland floodplain	Other:				
Associated Systems:	Wetland	Estuary	Other:	Distance:			
Additional Comments:							

Desktop / spatial information – data used for classifying a site and subsequent querying of data			
Political Region		Water Management Area	
Ecoregion I		Ecoregion II	
Secondary Catchment		Quaternary Catchment	
Water Chemistry Management Region			
Vegetation Type		Geological Type	
Contour Range (m): From:	to:		
Source Distance (km)		Stream Order	

Rainfall Region	Summer		Winter	Aseasonal	Other:				
DWAF Gauging Station	Yes	No	Code :		Distance Upstream		Or Downstream		

Table 11.2 Fish habitat. Velocity-depth classes and cover present at site.

Estimate abundance of each velocity-depth class and cover type using the scale: 0 – absent; 1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 – very abundant

SLOW-DEEP:	SLOW-SHALLOW:	FAST-DEEP:	FAST-SHALLOW:
Overhanging vegetation:	Overhanging vegetation:	Overhanging vegetation:	Overhanging vegetation:
Undercut banks & root wads:	Undercut banks & root wads:	Undercut banks & root wads:	Undercut banks & root wads:
Substrate:	Substrate:	Substrate:	Substrate:
Aquatic macrophytes:	Aquatic macrophytes:	Aquatic macrophytes:	Aquatic macrophytes:
Water Column:	Water Column:	Water Column:	Water Column:
Remarks:	Remarks:	Remarks:	Remarks:

Table 11.3 Velocity-depth classes sampled and effort.

Indicate which velocity-depth classes were sampled. Where the mosaic of velocity-depth classes makes it difficult or impossible to sample classes separately (e.g. combinations of fast-deep and fast-shallow classes), the dominant velocity-depth class should be used as the unit of reference for sampling effort, but the presence of other velocity-depth classes should also be indicated.

Sampling effort	Slow deep (SD)	Slow shallow (SS)	Fast deep (FD)	Fast shallow (FS)
Dominant velocity-depth class				
Electro shocker (min)				
Small seine (mesh size, length, depth, efforts)				
Large seine (mesh size, length, depth, efforts)				
Cast net (dimensions, efforts)				
Gill nets (mesh size, length, time)				

Remarks:

Table 11.4 **Fish caught (Indicate where velocity-depth combined)**

Habitat (velocity-depth class(es)	
Sampling method:	
Species	**Number (J = juvenile, A = abnormality)**

12 APPENDIX B: FRAI SPREADSHEETS

ASSEMBLAGE

	VELOCITY-DEPTH PREFERENCE				FLOW INTOLERANCE				COVER PREFERENCE					TOLERANCE: MODIFIED PHYSICO-CHEM			
SPECIES EXPECTED: REFERENCE	PREFERENCE: FD	PREFERENCE:FS	PREFERENCE:SD	PREFERENCE:SS	INTOLERANT: NO-FLOW (>4)	MODERATELY INTOLERANT: NO FLOW(>3-4)	MODERATELY TOLERANT: NO FLOW (>2-3)	TOLERANT: NO FLOW (1-2)	OVERHANGING VEGETATION: HIGH->VERY HIGH (>3)	BANK UNDERCUT: HIGH->VERY HIGH (>3)	SUBSTRATE: HIGH->VERY HIGH (>3)	AQUATIC MACROPHYTES: HIGH->VERY HIGH (>3)	WATER COLUMN: HIGH->VERY HIGH (>3)	INTOLERANT: MODIFIED WQ (>4)	MODERATELY INTOLERANT: MODIFIED WQ (>3-4)	MODERATELY TOLERANT (>2-3): MODIFIED WQ	TOLERANT: MODIFIED WQ (1-2)
ANAT	5.0	4.7	FALSE	FALSE	4.9	FALSE	FALSE	FALSE	FALSE	FALSE	5.0	FALSE	FALSE	4.9	FALSE	FALSE	FALSE
BNAT	4.5	4.0	FALSE	FALSE	FALSE	3.5	FALSE	FALSE	FALSE	FALSE	3.5	FALSE	3.5	FALSE	FALSE	3.0	FALSE
LRUB	3.9	FALSE	5.0	FALSE	FALSE	FALSE	2.5	FALSE	FALSE	FALSE	5.0	FALSE	FALSE	FALSE	FALSE	3.0	FALSE
AVERAGE	**4.5**	**4.4**	**5.0**	**#DIV/0!**	**4.9**	**3.5**	**2.5**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**4.5**	**#DIV/0!**	**3.5**	**4.9**	**#DIV/0!**	**3.0**	**#DIV/0!**
MEDIAN	**4.5**	**4.4**	**5.0**	**#NUM!**	**4.9**	**3.5**	**2.5**	**#NUM!**	**#NUM!**	**#NUM!**	**5.0**	**#NUM!**	**3.5**	**4.9**	**#NUM!**	**3.0**	**#NUM!**
NUMBER	**3.0**	**2.0**	**1.0**	**0.0**	**1.0**	**1.0**	**1.0**	**0.0**	**0.0**	**0.0**	**3.0**	**0.0**	**1.0**	**1.0**	**0.0**	**2.0**	**0.0**

	FLOW-DEPTH PREFERENCE				FLOW INTOLERANCE				COVER PREFERENCE					TOLERANCE: MODIFIED WQ			
SPECIES OBS: REFERENCE	PREFERENCE: FD	PREFERENCE:FS	PREFERENCE:SD	PREFERENCE:SS	INTOLERANT: NO-FLOW (>4)	MODERATELY INTOLERANT: NO FLOW(>3-4)	MODERATELY TOLERANT: NO FLOW (>2-3)	TOLERANT: NO FLOW (1-2)	OVERHANGING VEGETATION: HIGH->VERY HIGH (>3)	BANK UNDERCUT: HIGH->VERY HIGH (>3)	SUBSTRATE: HIGH->VERY HIGH (>3)	AQUATIC MACROPHYTES: HIGH->VERY HIGH (>3)	WATER COLUMN: HIGH->VERY HIGH (>3)	INTOLERANT: MODIFIED WQ (>4)	MODERATELY INTOLERANT: MODIFIED WQ (>3-4)	MODERATELY TOLERANT (>2-3): MODIFIED WQ	TOLERANT: MODIFIED WQ (1-2)
ANAT	5.0	4.7	FALSE	FALSE	4.9	FALSE	FALSE	FALSE	FALSE	FALSE	5.0	FALSE	FALSE	4.9	FALSE	FALSE	FALSE
BNAT	4.5	4.0	FALSE	FALSE	FALSE	3.5	FALSE	FALSE	FALSE	FALSE	3.5	FALSE	3.5	FALSE	FALSE	3.0	FALSE
LRUB	3.9	FALSE	5.0	FALSE	FALSE	FALSE	2.5	FALSE	FALSE	FALSE	5.0	FALSE	FALSE	FALSE	FALSE	3.0	FALSE
AVERAGE	**4.5**	**4.4**	**5.0**	**#DIV/0!**	**4.9**	**3.5**	**2.5**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**4.5**	**#DIV/0!**	**3.5**	**4.9**	**#DIV/0!**	**3.0**	**#DIV/0!**
MEDIAN	**4.5**	**4.4**	**5.0**	**#NUM!**	**4.9**	**3.5**	**2.5**	**#NUM!**	**#NUM!**	**#NUM!**	**5.0**	**#NUM!**	**3.5**	**4.9**	**#NUM!**	**3.0**	**#NUM!**
NUMBER	**3.0**	**2.0**	**1.0**	**0.0**	**1.0**	**1.0**	**1.0**	**0.0**	**0.0**	**0.0**	**3.0**	**0.0**	**1.0**	**1.0**	**0.0**	**2.0**	**0.0**

Note:

Step 1: DO not remove any columns

Step 2: Do not remove, change or fiddle with rows 1, 2, 3 as well as the average, median and number rows.

Step 3: Insert sufficient blank rows according to the expected species and copy row 3 onto blank lines.

Step 4: Remove species abbreviations in column A and enter species abbreviations expected.

Step 5: Make sure that the number of species refer to the correct range

Step 6: Copy the expected tables and delete rows of species that have not been observed.

Step 7: Use this information to complete the ratings in the various worksheets.

ABBREVIATIONS (ABBREV)

FRESHWATER SPECIES SCIENTIFIC NAME, ABBREVIATION AND COMMON NAME.
SHADED BLOCKS INDICATE SPECIES FOR WHICH NO RATINGS WERE DONE (information provided by Skelton 1997)

ABBREVIATION	SCIENTIFIC NAME	ENGLISH COMMON NAME
AAEN	*AWAOUS AENEOFUSCUS* (PETERS 1852)	FRESHWATER GOBY (M)
ABAR	*AUSTROGLANIS BARNARDI* (SKELTON, 1981)	BARNARD'S ROCK CATFISH
ABER	*ACANTHOPAGRUS BERDA* (FORSSKÅL, 1775)	RIVERBREAM (MS)
ABIC	*ANGUILLA BICOLOR BICOLOR* MCCLELLAND, 1844	SHORTFIN EEL
ABRE	*ATHERINA BREVICEPS* VALENCIENNES, 1835	CAPE SILVERSIDE
AGIL	*AUSTROGLANIS GILLI* (BARNARD, 1943)	CLANWILLIAM ROCK? CATFISH
AJOH	*APLOCHEILICHTHYS JOHNSTONI* (GÜNTHER, 1893)	JOHNSTON'S TOPMINNOW
AKAT	*APLOCHEILICHTHYS KATANGAE* (BOULENGER, 1912)	STRIPED TOPMINNOW
ALAB	*ANGUILLA BENGALENSIS LABIATA* PETERS, 1852	AFRICAN MOTTLED EEL
AMAR	*ANGUILLA MARMORATA* QUOY & GAIMARD 1824	GIANT MOTTLED EEL
AMOS	*ANGUILLA MOSSAMBICA* PETERS 1852	LONGFIN EEL
AMYA	*APLOCHEILICHTHYS MYAPOSAE* (BOULENGER, 1908)	NATAL TOPMINNOW
ANAT	*AMPHILIUS NATALENSIS* BOULENGER, 1917	NATAL MOUNTAIN CATFISH
ASCL	*AUSTROGLANIS SCLATERI* (BOULENGER, 1901)	ROCK? CATFISH
AURA	*AMPHILIUS URANOSCOPUS* (PFEFFER, 1889)	STARGAZER (MOUNTAIN CATFISH)
BAEN	*LABEOBARBUS AENEUS* (BURCHELL, 1822)	SMALLMOUTH YELLOWFISH
BAFR	*BARBUS AFROHAMILTONI* CRASS, 1960	HAMILTON'S BARB
BAMA	*BARBUS AMATOLICUS* SKELTON, 1990	AMATOLA BARB
BAND	*BARBUS ANDREWI* BARNARD, 1937	WHITEFISH
BANN	*BARBUS ANNECTENS* GILCHRIST & THOMPSON, 1917	BROADSTRIPED BARB
BANO	*BARBUS ANOPLUS* WEBER, 1897	CHUBBYHEAD BARB
BARG	*BARBUS ARGENTEUS* GÜNTHER, 1868	ROSEFIN BARB
BBIF	*BARBUS BIFRENATUS* FOWLER, 1935	HYPHEN BARB
BBRI	*BARBUS BREVIPINNIS* JUBB, 1966	SHORTFIN BARB
BCAL	*BARBUS CALIDUS* BARNARD, 1938	CLANWILLIAM REDFIN
BCAP	*BARBUS CAPENSIS* SMITH, 1841	CLANWILLIAM YELLOWFISH
BERU	*BARBUS ERUBESCENS* SKELTON, 1974	TWEE RIVER REDFIN
BEUT	*BARBUS EUTAENIA* BOULENGER, 1904	ORANGEFIN BARB
BGUR	*BARBUS GURNEYI* GÜNTHER, 1868	REDTAIL BARB
BHOS	*BARBUS HOSPES* BARNARD, 1938	NAMAQUA BARB
BIMB	*BRYCINUS IMBERI* (PETERS, 1852)	IMBERI
BKIM	*LABEOBARBUS KIMBERLEYENSIS* GILCHRIST & THOMPSON, 1913	LARGEMOUTH YELLOWFISH
BLAT	*BRYCINUS LATERALIS* (BOULENGER, 1900)	STRIPED ROBBER
BLIN	*BARBUS LINEOMACULATUS* BOULENGER, 1903	LINE-SPOTTED BARB
BMAR	*LABEOBARBUS MAREQUENSIS* SMITH, 1841	LARGESCALE YELLOWFISH
BMAT	*BARBUS MATTOZI* GUIMARAES, 1884	PAPERMOUTH
BMOT	*BARBUS MOTEBENSIS* STEINDACHNER, 1894	MARICO BARB
BNAT	*BARBUS NATALENSIS* CASTELNAU, 1861	SCALY
BNEE	*BARBUS NEEFI* GREENWOOD, 1962	SIDESPOT BARB
BPAL	*BARBUS PALLIDUS* SMITH, 1841	GOLDIE BARB
BPAU	*BARBUS PALUDINOSUS* PETERS, 1852	STRAIGHTFIN BARB
BPOL	*LABEOBARBUS POLYLEPIS* BOULENGER, 1907	SMALLSCALE YELLOWFISH
BRAD	*BARBUS RADIATUS* PETERS, 1853	BEIRA BARB
BSER	*BARBUS SERRA* PETERS, 1864	SAWFIN
BTOP	*BARBUS TOPPINI* BOULENGER, 1916	
BTRE	*BARBUS TREURENSIS* GROENEWALD, 1958	TREUR RIVER BARB
BTRI	*BARBUS TRIMACULATUS* PETERS, 1852	THREESPOT BARB
BTRV	*BARBUS TREVELYANI* GÜNTHER, 1877	
BVIV	*BARBUS VIVIPARUS* WEBER, 1897	BOWSTRIPE BARB
CANO	*CHILOGLANIS ANOTERUS* CRASS, 1960	PENNANT? TAIL SUCKERMOUTH (OR ROCK
CAUR	*CARASSIUS AURATUS* (LINNAEUS, 1758)	GOLDFISH (EX)
CBIF	*CHILOGLANIS BIFURCUS* JUBB & LE ROUX, 1969	INCOMATI SUCKERMOUTH (OR ROCK CATLET)
CBRE	*CHETIA BREVIS* JUBB, 1968	ORANGE? FRINGED LARGEMOUTH
CCAR	*CYPRINUS CARPIO* LINNAEUS, 1758	CARP (EX)
CEMA	*CHILOGLANIS EMARGINATUS* JUBB & LE ROUX, 1969	PONGOLO SUCKERMOUTH (OR ROCK CATLET)
CFLA	*CHETIA FLAVIVENTRIS* TREWAVAS, 1961	CANARY KURPER

CGAR	*CLARIAS GARIEPINUS* (BURCHELL, 1822)	SHARPTOOTH CATFISH
CIDE	*CTENOPHARYNGODON IDELLA* (VALENCIENNES, 1844)	GRASS CARP (EX)
CMUL	*CTENOPOMA MULTISPINE* PETERS, 1844	MANYSPINED CLIMBING PERCH
CPAR	*CHILOGLANIS PARATUS* CRASS, 1960	SAWFIN SUCKERMOUTH (OR ROCK CATLET)
CPRE	*CHILOGLANIS PRETORIAE* VAN DER HORST, 1931	SHORTSPINE SUCKERMOUTH (OR ROCK CATLET)
CSWI	*CHILOGLANIS SWIERSTRAI* VAN DER HORST, 1931	LOWVELD SUCKERMOUTH (OR ROCK CATLET)
CTHE	*CLARIAS THEODORAE* WEBER, 1897	SNAKE CATFISH
GAES	*GILCHRISTELLA AESTUARIA* (GILCHRIST, 1913)	ESTUARINE ROUND? HERRING
GAFF	*GAMBUSIA AFFINIS* (BAIRD & GIRARD, 1853)	MOSQUITOFISH (EX)
GCAL	*GLOSSOGOBIUS CALLIDUS* SMITH, 1937	RIVER GOBY (M)
GGIU	*GLOSSOGOBIUS GIURIS* (HAMILTON-BUCHANAN, 1822)	TANK GOBY (M)
GZEB	*GALAXIAS ZEBRATUS* CASTELNAU, 1861	CAPE GALAXIAS
HANS	*HIPPOPOTAMYRUS ANSORGII* (BOULENGER,1905)	SLENDER STONEBASHER
HCAP	*HYPORHAMPHUS CAPENSIS* (THOMINOT, 1886)	CAPE HALFBEAK (MS)
HMOL	*HYPOPHTHALMICHTHYS MOLITRIX* (VALENCIENNES, 1844)	SILVER CARP (EX)
HVIT	*HYDROCYNUS VITTATUS* CASTELNAU, 1861	TIGERFISH
KAUR	*KNERIA AURICULATA* (PELLEGRIN, 1905)	SOUTHERN KNERIA
LCAP	*LABEO CAPENSIS* (SMITH, 1841)	ORANGE RIVER LABEO
LCON	*LABEO CONGORO* PETERS, 1852	PURPLE LABEO
LCYL	*LABEO CYLINDRICUS* PETERS, 1852	REDEYE LABEO
LMAC	*LEPOMIS MACROCHIRUS* RAFINESQUE, 1819	BLUEGILL SUNFISH (EX)
LMCR	*LIZA MACROLEPIS* (SMITH, 1846)	LARGE-SCALE MULLET (MS)
LMOL	*LABEO MOLYBDINUS* DU PLESSIS, 1963	LEADEN LABEO
LRIC	*LIZA RICHARDSONII* (SMITH, 1846)	SOUTHERN MULLET (MS)
LROS	*LABEO ROSAE* STEINDACHNER, 1894	REDNOSE LABEO
LRUB	*LABEO RUBROMACULATUS* GILCHRIST & THOMPSON, 1913	TUGELA LABEO
LRUD	*LABEO RUDDI* BOULENGER, 1907	SILVER LABEO
LSEE	*LABEO SEEBERI* GILCHRIST & THOMPSON, 1911	CLANWILLIAM SANDFISH
LUMB	*LABEO UMBRATUS* (SMITH, 1841)	MOGGEL
MACU	*MICRALESTES ACUTIDENS* (PETERS, 1852)	SILVER ROBBER
MARG	*MONODACTYLUS ARGENTEUS* (LINNAEUS, 1758)	NATAL MOONY (MS)
MBRA	*MICROPHIS BRACHYURUS* BLEEKER, 1853	OPOSSUM PIPEFISH (M)
MBRE	*MESOBOLA BREVIANALIS* (BOULENGER, 1908)	RIVER SARDINE
MCAP	*MYXUS CAPENSIS* (VALENCIENNES, 1836)	FRESHWATER MULLET (M)
MCEP	*MUGIL CEPHALUS* LINNAEUS, 1758	FLATHEAD MULLET (M)
MCYP	*MEGALOPS CYPRINOIDES* (BROUSSONET, 1782)	OXEYE TARPON
MDOL	*MICROPTERUS DOLOMIEU* LACEPÈDE, 1802	SMALLMOUTH BASS (EX)
MFAL	*MONODACTYLUS FALCIFORMIS* LACEPÈDE, 1801	CAPE MOONY (MS)
MFLU	*MICROPHIS FLUVIATILIS* (PETERS, 1852)	FRESHWATER PIPEFISH (M)
MMAC	*MARCUSENIUS MACROLEPIDOTUS* (PETERS, 1852)	BULLDOG
MPUN	*MICROPTERUS PUNCTULATUS* (RAFINESQUE, 1819)	SPOTTED BASS (EX)
MSAL	*MICROPTERUS SALMOIDES* (LACEPÈDE, 1802)	LARGEMOUTH BASS (EX)
NORT	*NOTHOBRANCHIUS ORTHONOTUS* (PETERS, 1844)	SPOTTED KILLIFISH
NRAC	*NOTHOBRANCHIUS RACHOVII* AHL, 1926	RAINBOW KILLIFISH
OAUR	*OREOCHROMIS AUREUS* (STEINDACHNER, 1864)	ISRAELI TILAPIA (EX)
OMAC	*OREOCHROMIS (NYASALAPIA) MACROCHIR* (BOULENGER, 1912)	GREENHEAD TILAPIA
OMOS	*OREOCHROMIS MOSSAMBICUS* (PETERS, 1852)	MOZAMBIQUE TILAPIA
OMYK	*ONCORHYNCHUS MYKISS* (WALBAUM, 1792)	RAINBOW TROUT (EX)
ONIL	*OREOCHROMIS NILOTICUS (LINNAEUS, 1758)*	NILE TILAPIA (EX)
OPER	*OPSARIDIUM PERINGUEYI* (GILCHRIST & THOMPSON, 1913)	SOUTHERN BARRED MINNOW
OPLA	*OREOCHROMIS PLACIDUS* (TREWAVAS, 1941)	BLACK TILAPIA
PAFE	*PSEUDOBARBUS AFER* (PETERS, 1864)	EASTERN CAPE REDFIN
PAMP	*PROTOPTERUS AMPHIBIUS* (PETERS, 1844)	EAST COAST LUNGFISH
PANN	*PROTOPTERUS ANNECTENS BRIENI* POLL,1961	LUNGFISH
PASP	*PSEUDOBARBUS ASPER* (BOULENGER, 1911)	SMALLSCALE REDFIN
PBUG	*PSEUDOBARBUS BURGI* (BOULENGER, 1911)	BERG RIVER REDFIN
PBUR	*PSEUDOBARBUS BURCHELLI* SMITH, 1841	BURCHELL'S REDFIN
PCAT	*PETROCEPHALUS CATOSTOMA* (GÜNTHER, 1866)	CHURCHILL
PFLU	*PERCA FLUVIATILIS* LINNAEUS, 1758	EUROPEAN PERCH (EX)
PPHI	*PSEUDOCRENILABRUS PHILANDER* (WEBER, 1897)	SOUTHERN MOUTHBROODER

PPHL	*PSEUDOBARBUS PHLEGETHON* (BARNARD, 1938)	FIERY REDFIN
PQUA	*PSEUDOBARBUS QUATHLAMBAE* (BARNARD, 1938)	DRAKENSBERG MINNOW
PRET	*POECILIA RETICULATA* PETERS, 1859	GUPPY (EX)
PTEN	*PSEUDOBARBUS TENUIS* (BARNARD, 1938)	SLENDER REDFIN
RDEW	*REDIGOBIUS DEWAALI* (WEBER, 1897)	CHECKED GOBY (M)
SBAI	*SANDELIA BAINSII* CASTELNAU, 1861	EASTERN CAPE ROCKY
SCAP	*SANDELIA CAPENSIS* (CUVIER, 1831)	CAPE KURPER
SFON	*SALVELINUS FONTINALIS* (MITCHILL, 1815)	BROOK CHARR (EX)
SINT	*SCHILBE INTERMEDIUS* RÜPPELL, 1832	SILVER CATFISH
SMER	*SERRANOCHROMIS MERIDIANUS* JUBB, 1967	LOWVELD LARGEMOUTH
SSIB	*SILHOUETTEA SIBAYI* FARQUHARSON, 1970	SIBAYI GOBY (M)
STRU	*SALMO TRUTTA* LINNAEUS, 1758	BROWN TROUT (EX)
SZAM	*SYNODONTIS ZAMBEZENSIS* PETERS, 1852	BROWN SQUEAKER
TREN	*TILAPIA RENDALLI* (BOULENGER, 1896)	REDBREAST TILAPIA
TSPA	*TILAPIA SPARRMANII* SMITH, 1840	BANDED TILAPIA
TTIN	*TINCA TINCA* (LINNAEUS, 1758)	TENCH (EX)
VNEL	*VARICORHINUS NELSPRUITENSIS* GILCHRIST & THOMPSON, 1911	INCOMATI CHISELMOUTH
XHEL	*XIPHOPHORUS HELLERI* HECKEL, 1848	SWORDTAIL (EX)

VELOCITY DEPTH METRICS (VELDEPTH)

CHANGE IN COMMONNESS OF VELOCITY-DEPTH CLASSES			
VELOCITY-DEPTH CLASSES METRICS WITH REFERENCE TO FLOW MODIFICATIONS AND CHANGES IN SEDIMENT MOVEMENT, WHAT ARE THE CHANGES TO THE FOLLOWING OBSERVED OR EXPECTED TO BE?	RATINGS	COMMONNESS ORDER UNDER REF COND	%WEIGHT
Commonness of FAST-DEEP conditions	-3.0	2	100
Commonness of FAST-SHALLOW conditions	-3.0	1	100
Commonness of SLOW-DEEP conditions	-3.0	3	100
Commonness of SLOW-SHALLOW conditions	-3.0	1	100
Absolute sum		4	
Absolute overall weighed % velocity-depth change	**60.0**		

CHANGES IN COMMONNESS OF SPECIES WITH HIGH TO VERY HIGH PREFERENCE FOR VELOCITY DEPTH CLASSES			
VELOCITY-DEPTH CLASSES METRICS BASED ON OBSERVED AND DERIVED DATA, AND WITH WITH REFERENCE TO VELOCITY-DEPTH CLASS PREFERENCES, HOW DID THE FOLLOWING CHANGE?	RATINGS	RANK	%WEIGHT
Response of species with high to very high preference for FAST-DEEP conditions	2.0	2	100
Response of species with high to very high preference for FAST-SHALLOW conditions	1.0	1	100
Response of species with high to very high preference for SLOW-DEEPconditions	0.5	3	100
Response of species with high to very high preference for SLOW-SHALLOW conditions	1.0	1	100
Absolute sum		4	
Absolute overall weighed % assemblage change	**22.50**		

COVER METRICS (COVER)

CHANGE IN COMMONNESS OF FISH COVER FEATURES			
COVER METRICS: CHANGES IN FISH COVER FEATURES IN COMPARISON TO THE REFERENCE CONDITION	RATINGS	COMMONNESS ORDER UNDER REF COND	%WEIGHT
Commonness of overhanging vegetation	2.0	1	100
Commonness of undercut banks and root wads	2.0	3	100
Commonness of substrate types that can serve as cover	2.0	1	100
Commonness of instream vegetation	2.0	3	100
Commonness of sufficient water column depth that can serve as cover	2.0	2	100
Absolute sum		5	
Absolute overall weighed % velocity-depth change	**40.0**		

CHANGE IN COMMONNESS OF SPECIES WITH PREFERENCE FOR SPECIFIC COVER FEATURES			
COVER METRICS: WITH REFERENCE TO CHANGES IN FISH COVER FEATURES, WHAT ARE THE CHANGES TO THE FOLLOWING OBSERVED OR EXPECTED TO BE?	RATINGS	RANK	%WEIGHT
Response of species with a very high to high preference for overhanging vegetation	0.0	1	100
Response of species with a very high to high preference for undercut banks and root wads	0.0	3	100
Response of species with a high to very high preference for a particular substrate type	0.0	1	100
Response of species with a high to very high preference for instream vegetation	0.0	3	100
Response of species with a very high to high preference for the water column	0.0	2	100
Absolute sum		5	
Absolute overall % assemblage change	**0.0**		

FLOW MODIFICATION METRICS (FLOWMOD)

FLOW MODIFICATIONS			
FLOW MODIFICATION METRICS: WHAT IS THE CHANGES TO THE FOLLOWING OBSERVED OR EXPECTED TO BE? (CARRIED OVER FROM DRIVER ASSESSMENT)	RATINGS	RANK	%WEIGHT
Increase or decrease in no-flow conditions	2.0	2	100
Increase or decrease in low-flow conditions	2.0	1	90
Change in seasonality	2.0	3	80
Increase or decrease in moderate events	2.0	2	70
Increase or decrease in events (high flow, floods)	2.0	2	60
Absolute sum		5	
Absolute overall weighed % change in flow metrics	**32.0**		

FLOW DEPENDANCE METRICS: BASED ON OBSERVED AND DERIVED DATA, AND WITH WITH REFERENCE FLOW DEPENDANCE, HOW DID THE FOLLOWING CHANGE?	RATINGS	RANK	%WEIGHT
Response of species intolerant of no-flow conditions	1.0	2	100
Response of species moderately intolerant of no-flow conditions	2.0	1	100
Response of species moderately tolerant of no-flow conditions	1.0	3	100
Response of species tolerant of no-flow conditions	1.0	1	100
Absolute sum		4	
Absolute overall % assemblage change	**25.0**		

MIGRATORY SPECIES METRICS (MIGSPP)

CHANGES IN SYSTEM CONNECTIVITY	
MIGRATION METRICS: WHAT IS THE EXTENT OF THE FOLLOWING	RATINGS
Weirs and causeways	1.00
Impoundments	0.50
Physico-chemical barriers	1.50
Flow modifications	1.50

IMPACT ON SPECIES WITH DIFFERENT LEVELS OF MIGRATORY REQUIREMENTS			
MIGRATION METRICS: BASED ON OBSERVED AND DERIVED DATA, AND WITH REFERENCE TO CHANGES IN SYSTEM CONNECTIVITY, HOW DID THE FOLLOWING CHANGE?	RATINGS	RANK	%WEIGHT
Response in terms of distribution/abundance of spp with catchment scale movements	0.5	1	100
Response in terms of distribution/abundance of spp with requirement for movement between reaches or fish habitat segments	0.5	2	100
Response in terms of distribution/abundance of spp with requirement for movement within reach or fish habitat segment	1.0	3	100
Absolute sum		3	
Absolute overall % change in assemblage longitudinal continuity	**13.3**		

HEALTH CONDITION METRICS (HEALTH COND)

PHYSICO-CHEMICAL CONDITIONS			
PHYSICO-CHEMICAL METRICS: WHAT IS THE CHANGES TO THE FOLLOWING OBSERVED OR EXPECTED TO BE? (CARRIED OVER FROM PHYSICO-CHEMICAL DRIVER ASSESSMENT)	RATINGS	RANK	%WEIGHT
pH	2.0	5	100
SALTS	2.0	2	100
NUTRIENTS	2.0	2	100
TEMPERATURE	2.0	3	100
TURBIDITY	2.0	4	100
OXYGEN	2.0	3	100
TOXICS	2.0	1	100
Absolute sum		7	
Absolute overall % change in physico-chemical conditions	**40.0**		

IMPACT ON SPECIES WITH DIFFERENT INTOLERANCE LEVELS TO CHANGE IN PHYSICO-CHEMICAL CONDITIONS			
PHYSICO-CHEMICAL METRICS: BASED ON OBSERVED AND DERIVED DATA, AND WITH REFERENCE TO INTOLERANCE TO MODIFIED PHYSICO-CHEMICAL CONDITIONS, HOW DID THE FOLLOWING RESPOND IN TERMS OF FISH HEALTH AND CONDITION?	RATINGS	RANK	%WEIGHT
Response of species intolerant of modified physico-chemical conditions	1.0	1	100
Response of species moderately intolerant of modified physico-chemical conditions	0.5	2	100
Response of species moderately tolerant of modified physico-chemical conditions	0.0	3	100
Response of species tolerant of modified physico-chemical conditions	0.0	4	100
Absolute sum		4	
Absolute overall % impact on assemblage	**7.5**		

INTRODUCED SPECIES METRICS (INTRODUC)

INTRODUCED SPECIES IMPACT			
INTRODUCED SPECIES METRICS: WITH REFERENCE TO THE TYPES OF INTRODUCED SPECIES, THE CHARACTERISTICS OF THE HABITAT AND THE NATIVE SPECIES, WHAT IS THE FOLLOWING OBSERVED OR EXPECTED TO BE?	RATINGS	RANK	%WEIGHT
The impact/potential impact of introduced competing/predaceous spp?	0.0	1	100
How widespread (frequency of occurrence) are introduced competing/predaceous spp?	0.0	1	100
The impact/potential impact of introduced habitat modifying spp?	0.0	2	100
How widespread (frequency of occurrence) are habitat modifying spp?	0.0	3	100
Absolute sum		4	
Absolute overall potential % assemblage change	**0.0**		

ECOLOGICAL CATEGORY (EC)

FISH EC METRIC GROUPs	METRIC GROUP: CALCULATED RATING	WEIGHTED RATING FOR GROUP	RANK OF METRIC GROUP	% WEIGHT FOR METRIC GROUP
VELOCITY-DEPTH METRICS	77.50	15.50	1	100
COVER METRICS	100.00	20.00	1	100
FLOW MODIFICATION METRICS	75.00	15.00	4	100
MIGRATION METRICS	86.67	17.33	3	100
PHYSICO-CHEMICAL METRICS	92.50	18.50	5	100
IMPACT OF INTRODUCED SPP (NEGATIVE)	0.00	0.00	0	0
	5.00			500.00
FRAI (%)			86.33	
EC: FRAI			B	
BOUNDARY EC			N/A	

13 APPENDIX C INVERTEBRATE DATA SHEETS

Table 13.1 Taxa with specific velocity preferences

Very Fast (>0.6 m/s)	Moderately Fast (0.3-0.6 m/s)	Slow (0.1-0.3 m/s)	Very Slow (<0.1 m/s)
Perlidae	Elmidae	Ecnomidae	Machadorythidae
Oligoneuridae	Naucoridae	Haliplidae	Veliidae
Glossosomatidae	Gomphidae	Tipuliudae	Lestidae
Hydropsalpingidae	Coenagrionidae	Hydroptilidae	Belostomatidae
Psephenidae	Libellulidae	Calopterygidae	Gerridae
Polycentropodidae	Barbarochthonidae	Lepidostomatidae	Hydrometridae
Blepharoceridae	Ephemeridae	Pisuliidae	Nepidae
Ceratopogonidae	Hydraenidae	Chironomidae	Notonectidae
Muscidae	Amphipoda	Chlorocyphidae	Pleidae
Simuliidae	Potamonautidae	Corduliidae	Dipseudopsidae
Notonemouridae	Heptageniidae	Corixidae	Calamoceratidae
Hydropsychidae	Pyralidae	Tabanidae	Ephydridae
Telagonodidae	Leptoceridae	Corbiculidae	Syrphidae
Dryopidae	Sericostomatidae	Sphaeridae	Dytiscidae
Elmidae	Corydalidae	Platycnemidae	Sialidae
Trichorythidae		Protoneuridae	Culicidae
Petrotrhincidae		Unionidae	Psychodidae
Paleomonidae		Limnichidae	Bulinae
Polymitarcyidae			Hydrobiidae
Gyrinidae			Lymnaeidae
Prosopistomatidae			Physidae
Philopotamidae			Planorbinae
Psychomyiidae			Thiaridae
Xiphocentronidae			Viviparidae
			Chlorolestidae
			Caenidae
			Dixidae
			Leptophlebiidae

Table 13.2 Taxa with specific habitat preferences

Bedrock	Cobbles	Vegetation	Gravel, Sand, Mud	Water
Petrothirincidae	Hirudinea	Nepidae	Gomphidae	Veliidae
Psychomyiidae	Libellulidae	Belostomatidae	Syrphidae	Gerridae
Xiphocentronidae	Glossosomatidae	Peidae	Machadorythidae	Culicidae

Bedrock	Cobbles	Vegetation	Gravel, Sand, Mud	Water
Polycentropodidae	Chlorocyphidae	Lestidae	Dipseudopsidae	Dixidae
Porifera	Perlidae	Chlorolestidae	Sialidae	Gyrinidae
Ancylidae	Prosopistomatidae	Atyidae	Oligochaeta	Hydrometridae
	Notonemouridae	Protoneuridae	Ephemeridae	Notonectidae
	Heptageniidae	Coenagrionidae	Unionidae	Muscidae
	Telagonodidae	Haliplidae	Corbiculidae	Naucoridae
	Dryopidae	Hydrophilidae	Sphaeridae	Corixidae
	Empididae	Hydraenidae	Ephydridae	Psychodidae
	Elmidae	Calopterygidae	Polymitarcyidae	
	Trichorythidae	Helodidae	Tabanidae	
	Athericidae	Platycnemidae	Limnichidae	
	Philopotamidae	Pyralidae	Tipulidae	
	Psephenidae	Dytiscidae	Caenidae	
	Corydalidae	Hydrobiidae	Corduliidae	
	Paleomonidae	Physidae	Hydracarina	
	Potamonautidae	Thiaridae	Calamoceratidae	
	Aeshnidae	Viviparidae	Amphipoda	
	Sericostomatidae	Hydroptilidae		
	Leptophlebiidae	Bulinae		
	Blepharoceridae	Lymnaeidae		
	Oligoneuridae	Planorbinae		
	Hydropsychidae			
	Ceratopogonidae			
	Pisuliidae			
	Ecnomidae			
	Hydropsalpingidae			
	Simuliidae			
	Barbarochthonidae			

Table 13.3 Taxa with specific water quality preferences

High	Moderate	Low	Very Low
Helodidae	Veliidae	Gyrinidae	Culicidae
Pyralidae	Gerridae	Pleidae	Notonectidae
Blepharoceridae	Dixidae	Porifera	Belostomatidae
Polycentropodidae	Hydrometridae	Ancylidae	Nepidae
Hydropsychidae >2spp	Petrothrincidae	Viviparidae	Coelenterata
Sericostomatidae	Chlorolestidae	Hydropsychidae 1sp	Hydrobiidae
Hydropsalpingidae	Psychomyiidae	Hydropsychidae 2spp	Physidae
Barbarochthonidae	Xiphocentronidae	Simuliidae	Thiaridae
Perlidae	Platycnemidae	Naucoridae	Bulinae
Prosopistomatidae	Paleomonidae	Haliplidae	Lymnaeidae
Notonemouridae	Aeshnidae	Coenagrionidae	Planorbinae
Heptageniidae	Leptophlebiidae	Dytiscidae	Turbellaria

High	Moderate	Low	Very Low
Telagonodidae	Ecnomidae	Hydroptilidae	Muscidae
Oligoneuridae	Chlorocyphidae	Libellulidae	Corixidae
Baetidae >2spp	Dryopidae	Empididae	Potamonautidae
Amphipoda	Elmidae	Hydrophilidae	Hirudinea
Ephemeridae	Trichorythidae	Baetidae 1sp	Psychodidae
	Psephenidae	Baetidae 2spp	Chironomidae
	Hydraenidae	Leptoceridae	Syrphidae
	Calopterygidae	Ceratopogonidae	Ephydridae
	Lestidae	Tabanidae	Oligochaeta
	Atyidae	Tipulidae	Sphaeridae
	Protoneuridae	Caenidae	
	Corydalidae	Sialidae	
	Glossosomatidae	Unionidae	
	Athericidae	Corbiculidae	
	Philopotamidae	Gomphidae	
	Lepidostomatidae		
	Pisuliidae		
	Hydracarina		
	Polymitarcyidae		
	Limnichidae		
	Corduliidae		
	Calamoceratidae		
	Dipseudopsidae		

5. SASS Version 5 Score Sheet -

Version date: Feb 2005

Date:	/ /		(dd.ddddd)	**Biotopes Sampled**	**Rating (1 - 5)** / **Time (min)**
RHP Site Code:	-	**Grid reference (dd mm ss.s) Lat:**	S	**Stones In Current (SIC)**	
Collector/Sampler:		**Long:**	E	**Stones Out Of Current (SOOC)**	
River:		**Datum (WGS84/Cape):**		**Bedrock**	
Level 1 Ecoregion:		**Altitude (m):**	m	**Aquatic Veg**	
Quaternary Catchment:		**Zonation:**		**MargVeg In Current**	
	Temp (°C):	**Cond (mS/m)**		**MargVeg Out Of Current**	
Site Description:	**pH:**	**Clarity (cm):**		**Gravel**	
	DO (mg/L):	**Turbidity:**		**Sand**	
	Flow:	**Colour:**		**Mud**	
	Riparian Disturbance:			**Hand picking/Visual observation**	
	Instream Disturbance:				

Taxon		S	Veg	GSM	TOT	Taxon		S	Veg	GSM	TOT	Taxon		S	Veg	GSM	TOT
PORIFERA	5					**HEMIPTERA**						**DIPTERA (Flies)**					
COELENTERATA	1					Belostomatidae* (Giant water	3					Athericidae	10				
TURBELLARIA	3					Corixidae* (Water	3					Blephariceridae (Mountain	15				
ANNELID						Gerridae* (Pond skaters/Water	5					Ceratopogonidae (Biting	5				
Oligochaeta	1					Hydrometridae* (Water	6					Chironomidae	2				
Hirudinea (Leeches)	3					Naucoridae* (Creeping water	7					Culicidae*	1				
CRUSTACE						Nepidae* (Water	3					Dixidae* (Dixid	10				
Amphipoda	13					Notonectidae*	3					Empididae (Dance	6				
Potamonautidae*	3					Pleidae* (Pygmy	4					Ephydridae (Shore	3				
Atyidae (Shrimps)	8					Veliidae/M...veliidae* (Ripple	5					Muscidae (House flies, Stable	1				
Palaemonidae	10					**MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)**						Psychodidae (Moth	1				
HYDRACARINA (Water	8					Corydalidae (Fishflies &	8					Simuliidae	5				
PLECOPTERA						Sialidae (Alderflies)	6					Syrphidae* (Rat tailed	1				
Notonemouridae	14					**TRICHOPTERA**						Tabanidae (Horse	5				
Perlidae	12					Dipseudopsidae	10					Tipulidae (Crane	5				
EPHEMEROPTERA						Ecnomida	8					**GASTROPODA**					
Baetidae 1sp	4					Hydropsychidae 1 sp	4					Ancylidae (Limpets)	6				
Baetidae 2 sp	6					Hydropsychidae 2 sp	6					Bulininae*	3				
Baetidae > 2 sp	12					Hydropsychidae > 2 sp	12					Hydrobiidae*	3				
Caenidae	6					Philopotamida	10					Lymnaeidae* (Pond	3				
Ephemerida	15					Polycentropodida	12					Physidae* (Pouch	3				
Heptageniidae (Flatheaded	13					Psychomyiidae/Xiphocentronida	8					Planorbinae* (Orb	3				
Leptophlebiidae	9					**Cased caddis:**						Thiaridae*	3				
Oligoneuridae (Brushlegged	15					Barbarochthonidae	13					Viviparidae* ST	5				
Polymitarcyidae (Pale	10					Calamoceratidae	11					**PELECYPODA**					
Prosopistomatidae (Water	15					Glossosomatidae	11					Corbiculidae	5				
Teloganodidae	12					Hydroptilidae	6					Sphaeriidae (Pills	3				
Tricorythidae (Stout Crawlers)	9					Hydrosalpingidae	15					Unionidae (Perly	6				
ODONATA (Dragonflies & Damselflies)						Lepidostomatida	10					**SASS Score**					
Calopterygidae	10					Leptoceridae	6					**No. of Taxa**					
Chlorocyphidae	10					Petrothrincidae	11					**ASPT**					
Synlestidae	8					Pisuliidae	10					**Other biota:**					
Coenagrionidae (Sprites and	4					Sericostomatidae	13										
Lestidae (Emerald	8					**COLEOPTERA**											
Platycnemidae (Brook	10					Dytiscidae/Noteridae* (Diving	5										
Protoneuridae	8					Elmidae/Dryopidae* (Riffle	8										
Aeshnidae (Hawkers &	8					Gyrinidae* (Whirligig	5										
Corduliidae	8					Haliplidae* (Crawling water	5										
Gomphidae	6					Helodidae (Marsh	12										
Libellulidae	4					Hydraenidae* (Minute moss	8					**Comments/Observations:**					
LEPIDOPTERA (Aquatic						Hydrophilidae* (Water scavenger	5										
Crambidae	12					Limnichidae	10										
						Psephenidae (Water	10										

Procedure: Kick SIC & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock for 1 min. Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg $1m^2$. Stir & sweep gravel, sand, mud for 1 min total. * = airbreathers

Hand picking & visual observation for 1 min - record in biotope where found (by circling estimated abundance on score sheet). Score for 15 mins/biotope but stop if no new taxa seen after 5 mins.

Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000 S = Stone, rock & solid objects; Veg = All vegetation; GSM = Gravel, sand, mud SWC = South Western Cape, T = Tropical, ST = Sub-tropical

Rate each biotope sampled: 1=very poor (i.e. limited diversity), 5=highly suitable (i.e. wide diversity)

14 APPENDIX D MIRAI SPREADSHEETS

Taxon	Reference	Abundance	Frequency	<0.1	0.1-0.3	0.3-0.6	>0.6	BEDROCK	COBBLES	VEG	GSM	WATER	QUALITY
Perlidae	B			1	1	1	5	1	4	1	0	0	HIGH
Psephenidae	B	AA	50	0	1	3	4	1	4	1	0	0	MODERATE
Glossosomatidae	B			0	2	3	4	1	4	0	1	0	MODERATE
Turbellaria	A	AA	50	1	2	3	4	1	4	0	0	0	NONE
Empididae	A			0	0	2	4	1	4	1	1	0	LOW
Telagonodidae	B			0	0	2	4	1	4	1	0	0	HIGH
Notonemouridae	B			1	1	2	4	1	4	1	0	0	HIGH
Hydropsychidae 2spp		AABB	100	0	1	2	4	2	3	1	0	0	LOW
Hydropsychidae >2spp	B			0	1	2	4	2	3	1	0	0	HIGH
Muscidae	A	1	25	2	2	2	4	1	1	1	1	4	NONE
Ceratopogonidae	A	11A	75	2	2	2	4	2	3	2	2	0	LOW
Simuliidae	B	A1	50	0	2	2	4	2	3	2	0	0	LOW
Petrothrincidae	A			0	0	1	4	4	1	0	0	0	MODERATE
Trichorythidae	B	1AAB	100	0	1	1	4	1	4	1	0	0	MODERATE
Philopotamidae	A			0	1	2	3	1	4	1	1	0	MODERATE
Prosopistomatidae	A			1	1	2	3	1	4	1	0	0	HIGH
Gyrinidae	B	AAA1	100	1	2	2	3	0	0	0	0	5	LOW
Elmidae	B			0	0	4	2	1	4	1	0	0	MODERATE
Corydalidae	B			0	0	3	2	0	3	0	1	0	MODERATE
Leptoceridae	B			0	1	3	2	2	2	2	2	0	LOW
Potamonautidae	A	AAAA	100	1	1	3	2	0	3	1	1	0	NONE
Sericostomatidae	B			0	1	3	2	0	3	2	0	0	HIGH
Heptageniidae	B	11AB	100	1	1	3	2	1	4	1	0	0	HIGH
Hydraenidae	A			2	2	3	2	0	1	3	1	2	MODERATE
Ephemeridae				2	2	3	2	0	1	0	4	0	HIGH
Amphipoda	A	1	25	1	2	3	2	0	2	2	3	0	HIGH
Athericidae	B	111	75	0	1	2	2	1	4	1	1	0	MODERATE
Baetidae 2spp		B	25	2	2	2	2	2	2	2	2	1	LOW
Baetidae >2spp	B	CAA	75	2	2	2	2	2	2	2	2	1	HIGH
Aeshnidae	B	AA1	75	1	2	2	2	0	3	2	0	0	MODERATE
Porifera	B			2	2	2	2	3	2	1	0	0	LOW
Chironomidae	B	AAA	75	1	3	2	2	2	2	2	2	0	NONE
Hydroptilidae	A	1	25	0	3	2	2	1	2	3	1	0	LOW
Coenagrionidae	B	AAAA	100	1	2	3	1	0	1	4	1	0	LOW
Libellulidae	B	11	50	1	2	3	1	1	4	0	1	0	LOW
Barbarochthonidae	B			0	2	3	1	2	3	2	0	0	HIGH
Oligochaeta	B	AA1A	100	2	2	2	1	0	1	0	4	0	NONE
Helodidae	B			2	2	2	1	0	2	3	0	0	HIGH
Leptophlebiidae	B	AAAB	100	3	2	2	1	1	3	2	0	0	MODERATE
Ancylidae	B	A1AA	100	1	2	2	1	3	2	1	0	0	LOW
Pisuliidae	B			1	3	2	1	2	3	2	2	0	MODERATE
Lepidostomatidae	A			1	3	2	1	2	2	2	2	0	MODERATE
Caenidae	B	11AB	100	3	2	1	1	0	2	1	3	0	LOW
Hirudinea	A	1	25	2	2	1	1	0	4	1	1	0	NONE
Protoneuridae	A			2	3	1	1	0	1	4	1	0	MODERATE
Platycnemidae	A			2	3	1	1	0	2	3	0	0	MODERATE
Tipulidae	A			3	4	1	1	1	2	0	3	0	LOW
Naucoridae	B	AA	50	2	2	3	0	1	1	1	1	4	LOW
Gomphidae	B	1BAA	100	0	2	3	0	0	1	0	5	0	LOW
Dixidae	A	1	25	3	2	2	0	0	0	0	0	5	MODERATE
Hydrophilidae	B	1	25	0	2	2	0	0	0	3	2	2	LOW
Hydracarina	B	A1	50	0	2	2	0	1	1	2	3	1	MODERATE
Veliidae	B	BAB	75	5	1	1	0	0	0	0	0	5	MODERATE
Dytiscidae	B	AAA	75	4	2	1	0	1	2	3	1	2	LOW
Chlorolestidae	A			3	2	1	0	0	1	4	0	0	MODERATE
Corixidae	B	ABBA	100	2	3	1	0	1	1	1	1	4	NONE
Corbiculidae	A			2	3	1	0	0	2	0	4	0	LOW
Corduliidae	A	1	25	2	3	1	0	0	2	1	3	0	MODERATE
Tabanidae	A	A21	75	2	3	1	0	0	2	0	3	0	LOW
Culicidae	B	11	50	3	1	0	0	0	0	0	0	5	NONE
Gerridae	B	1A	50	4	1	0	0	0	0	0	0	5	LOW
Notonectidae	B	1	25	4	1	0	0	0	0	2	0	4	NONE
Hydrometridae	A			4	1	0	0	0	0	2	0	4	LOW
Psychodidae	A			3	1	0	0	1	1	1	2	3	NONE
Ephydridae	A			4	1	0	0	0	1	1	4	1	NONE
Belostomatidae	A			4	1	0	0	0	0	4	0	1	NONE
Pleidae	B			4	1	0	0	0	0	4	0	1	LOW
Syrphidae	A	1	25	4	1	0	0	0	0	0	4	0	NONE
Lestidae	A			4	1	0	0	0	1	4	1	0	MODERATE
Nepidae	A			4	1	0	0	0	0	5	0	0	NONE
Lymnaeidae	B			3	2	0	0	2	2	3	0	0	NONE
Planorbinae	B	A1	50	3	2	0	0	2	2	3	0	0	NONE
Physidae	B	1	25	3	2	0	0	1	2	3	0	0	NONE
Ecnomidae	B			1	5	0	0	2	3	2	0	0	MODERATE

FLOW MODIFICATION METRICS (FM)

FLOW MODIFICATION METRICS. **WITH REFERENCE TO VELOCITY PREFERENCES, WHAT ARE THE CHANGES TO THE FOLLOWING OBSERVED OR EXPECTED TO BE?**	**RATING**	**RANKING OF METRICS**	**% Weight**
Presence of taxa with a preference for very fast flowing water	2	3	80
Abundance and/or frequency of occurrence of taxa with a preference for very fast flowing water	1	4	70
Presence of taxa with a preference for moderately fast flowing water	2	1	100
Abundance and/or frequency of occurrence of taxa with a preference for moderately fast flowing water	0.5	2	95
Presence of taxa with a preference for slow flowing water	2.5	3	80
Abundance and/or frequency of occurrence of taxa with a preference for slow flowing water	1	4	70
Presence of taxa with a preference for standing water	1.5	5	30
Abundance and/or frequency of occurrence of taxa with a preference for standing water	1.5	5	30
		8	
Overall % change in flow dependance of assemblage			

HABITAT MODIFICATION METRICS (H)

HABITAT MODIFICATION METRICS. **WITH REFERENCE TO INVERTEBRATE HABITAT PREFERENCES, WHAT ARE THE CHANGES TO THE FOLLOWING OBSERVED OR EXPECTED TO BE?**	**RATING**	**RANKING OF METRICS**	**%WEIGHT**
Has the occurrence of invertebrates with a preference for bedrock/boulders changed relative to expected?	0.5	5	10
Has the abundance and/or frequency of occurrence of any of the taxa with a preference for bedrock/boulders changed?	0.5	5	10
Has the occurrence of invertebrates with a preference for loose cobbles changed relative to expected?	2.5	1	100
Has the abundance and/or frequency of occurrence of any of the taxa with a preference for loose cobbles changed?	1	1	100
Has the occurrence of invertebrates with a preference for vegetation changed relative to expected?	2	2	95
Has the abundance and/or frequency of occurrence of any of the taxa with a preference for vegetation changed?	2	2	95
Has the occurrence of invertebrates with a preference for sand, gravel or mud changed relative to expected?	0.5	4	50
Have the abundance of any of the taxa with a preference for sand, gravel or mud changed relative to expected?	1	4	50
Has the occurrence of invertebrates with a preference for the water column or water surface changed relative to expected?	0.5	3	8
Has the abundance and/or fequency of occurrence of any of the taxa with a preference for the water column/water surface changed?	1	3	80
		10	
Overall % change in flow dependanceof assemblage			

[**WSR:** Cannot edit,… abundance and/or frequency … not consistent in third-last line]

WATER QUALITY METRICS

WATER QUALITY METRICS. WITH REFERENCE TO WATER QUALITY REQUIREMENTS, WHAT ARE THE CHANGES TO THE FOLLOWING OBSERVED OR EXPECTED TO BE?	RATING	RANKING OF METRICS	% WEIGHT
Have the number of taxa with a high requirement for unmodified physico-chemical conditions changed?	2	4	60
Have the abundance and/or frequency of occurrence of the taxa with a high requirement for unmodified physico-chemical	2	4	60
Have the number of taxa with a moderate requirement for unmodified physico-chemical conditions changed?	1.5	3	85
Have the abundance and/or fequency of occurrence of the taxa with a moderate requirement for modified physico-chemical	1.5	3	85
Have the number of taxa with a low requirement for unmodified physico-chemical conditions changed?	2	2	90
Have the abundance and/or frequency of occurrence of the taxa with a low requirement for unmodified physico-chemical conditions	1.5	2	90
Have the number of taxa with a very low requirement for unmodified physico-chemical conditions changed?	0.5	3	85
Have the abundance and/or frequency of occurrence of the taxa with a very low requirement for unmodified physico-chemical	1	3	85
How does the total SASS score differ from expected?	3	1	100
How does the total ASPT score differ from expected?	3	1	100
		10	
Overall change to indicators of modified water quality			

[**WSR:** Cannot edit: "number" is singular - use has instead of have]

SYSTEM CONNECTIVITY AND SEASONALITY

Based on observed and derived data, with reference to migration and seasonality, how did the following change?	RATING	RANKING OF METRICS	% Weight
Impact on distribution of migratory taxa			
Impact on abundance and/or frequency of occurrence of migratory taxa			
Impact on occurrence of taxa with seasonal distribution	2	1	100
Impact on abundance and/or frequency of occurrence of taxa with seasonal distribution	1.5	2	80
		2	
Overall % change in flow dependance of assemblage			

[**WSR:** Cannot edit: Draw separating lines between descriptions for clarity ???]

ECOLOGICAL CATEGORY

INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC	%WEIGHT FOR METRIC
FLOW MODIFICATION	**FM**	79.1	*0.278*	21.9618	1	100
HABITAT	**H**	82.0	*0.250*	20.505	2	90
WATER QUALITY	**WQ**	69.3	*0.194*	13.4653	3	70
CONNECTIVITY & SEASONALITY	**CS**	68.0	*0.278*	18.8889	1	100
						360
INVERTEBRATE EC				74.821		
INVERTEBRATE EC CATEGORY				C		

>89=A; 80-89=B; 60-79=C; 40-59=D; 20-39=E; <20=F

15 GEOMORPHOLOGY CHANGE & SITE EVALUATION DATASHEETS

GEOMORPHOLOGY CHANGE DATASHEET

POTENTIAL FOR GEOMORPHOLOGICAL CHANGE

SCORING GUIDELINES

GEOMORPHOLOGY DRIVERS						
COMPONENTS	**RANK**	**RELATIVE WEIGHTING (%)**	**RATING**	**WEIGHT**	**Weighted score**	**CONFIDENCE**
BED MOBILITY	1.00	100.00	1.00	0.42	0.42	4.00
BANK STABILITY	2.00	90.00	3.00	0.38	1.13	3.00
CHANNEL CONFINEMENT	3.00	50.00	2.00	0.21	0.42	4.00
TOTALS		240.00		1.00	**1.96**	
POTENTIAL FOR FLOW RELATED CHANGE					**1.96**	**3.63**

SITE EVALUATION SHEET

	GOOD	BAD	DON'T KNOW	SCORE
How well does the morphology of the site represent that of the reach?	5	1	2	4
To what extent does the site include critical geomorphological feature characteristic of the reach?	5	1	2	3
To what extent is the condition of the site as good as or better than that of the reach?	5	1	2	5
Are there good morphological clues that can be related to flood levels?	10	2	4	7
Add total score and divide by 5				**3.8**