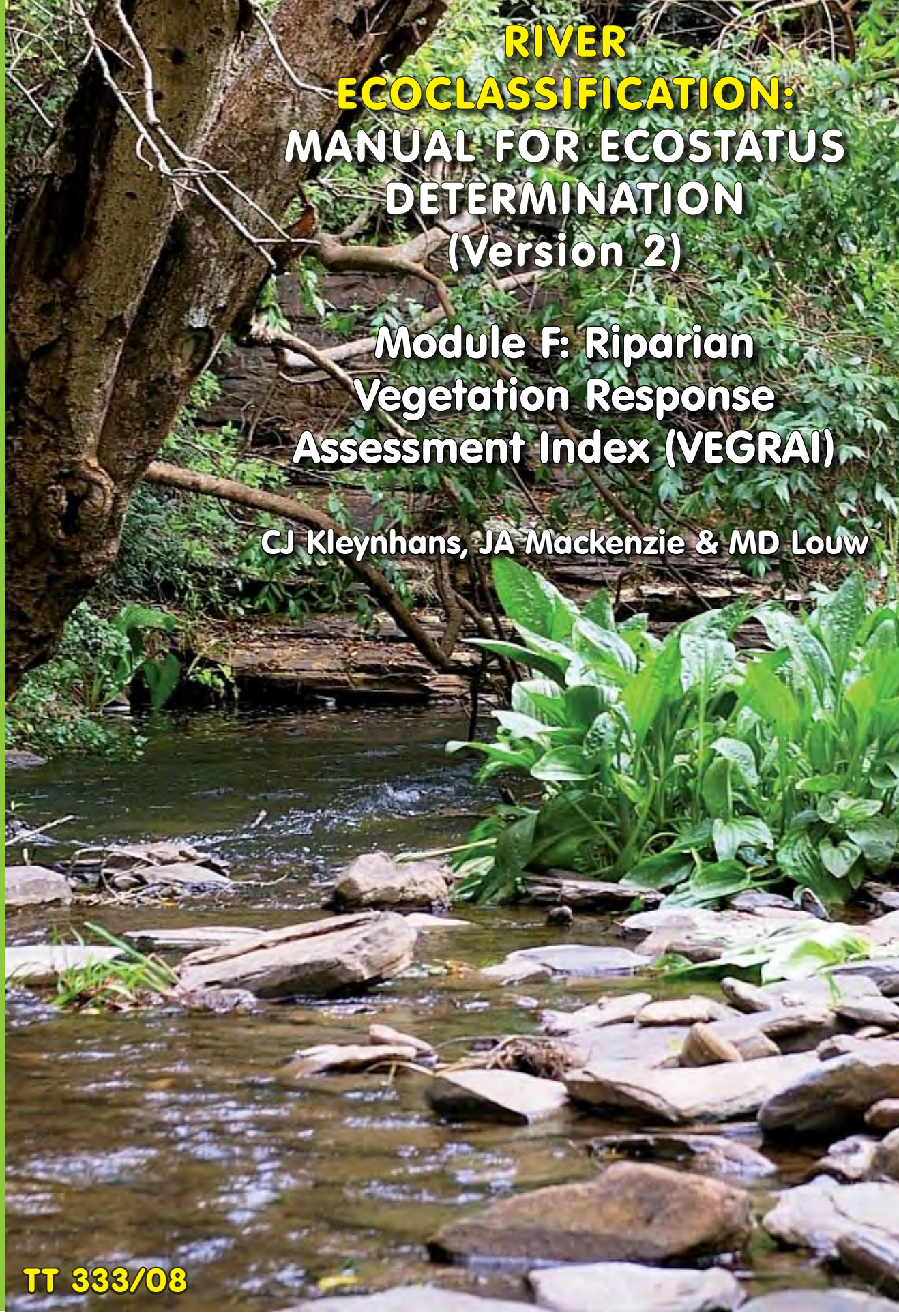
ECOCLASSIFICATION



RIVER ECOCLASSIFICATION: MANUAL FOR ECOSTATUS DETERMINATION (Version 2)

Module F: Riparian Vegetation Response Assessment Index (VEGRAI)

CJ Kleynhans, JA Mackenzie & MD Louw

TT 333/08

water & forestry

Department:
Water Affairs and Forestry
REPUBLIC OF SOUTH AFRICA

Water
Research
Commission

RIVER ECOCLASSIFICATION
MANUAL FOR ECOSTATUS DETERMINATION
(Version 2)

MODULE F: RIPARIAN VEGETATION RESPONSE ASSESSMENT INDEX (VEGRAI)

Report to the
Water Research Commission

by

CJ Kleynhans
Department of Water Affairs & Forestry,
Resource Quality Services, Pretoria
JA MacKenzie
Alexander & Llewellyn (Environmental Section), Johannesburg
MD Louw
Water for Africa, Pretoria

WRC Report No TT 333/08
April 2008

Obtainable from:

Water Research Commission
Private Bag X03
Gezina, Pretoria 0031, South Africa

orders@wrc.org.za

The manuals for ecostatus determination emanate from studies which were initiated within the WRC research consultancy, K8/619, titled: "*Designing a Riparian Vegetation Response Assessment Index as part of the existing EcoStatus determination process*".

This module is the seventh of a series. Please refer to Page iii for a list of the other publications.

ISBN **978-1-77005-680-0**
Set No **978-1-77005-676-3**

Printed in the Republic of South Africa

STRUCTURE OF THE MANUAL

The manual consists of the following modules:

- Module A: Ecoclassification and Ecostatus Models
- Module B: Geomorphological Driver Assessment Index (GAI)
- Module C: Physico-Chemical Driver Assessment Index (PAI)
- Module D: Fish Response Assessment Index (FRAI)
  (Volume 1 & 2)
- Module E: Macroinvertebrate Response Assessment Index (MIRAI)
- (Volume 1 & 2)
- **Module F: Riparian Vegetation Response Assessment Index (VEGRAI)**
- Module G: Index of Habitat Integrity

This report is Module F and consists of the VEGRAI manual and models. The module provides the background to and scientific rationale for VEGRAI. It also provides an explanation of the VEGRAI field sheets, the VEGRAI model as well as all necessary information on the different VEGRAI levels.

Modules B, C, E (Volume 2) and G will be published towards the end of 2008.

PURPOSE OF THE MANUAL: MODULE F

To provide a step by step guideline to the appropriate specialists on how to use the VEGRAI models.

WHO SHOULD APPLY THESE MODELS?

VEGRAI 4: An experienced riparian vegetation specialist
VEGRAI 3: An experienced aquatic ecologist with understanding of the responses of riparian vegetation to a range of impacts.

NOTE: It is strongly recommended that the user participates in training courses and/or contact the authors of this manual when applying the models

The manual is structured in the two sections. The first provides background information:

FIRST SECTION OF THE MANUAL

Chapter 1: Introduction: Provides background and over view detail.
Chapter 2: Description of VEGRAI structure: Provides an overview of the model structure and information on the rating and weighting procedure.

The second section is the ***'how to'*** section, that is, the more traditional manual part.

SECOND SECTION OF THE MANUAL

Chapter 3: Preparation for VEGRAI application: This provides the detail preparatory work one has to undertake prior to the field visit and the populating of the model.
Chapter 4: VEGRAI field work & field forms: Provides a step by step guidance in the actions to be undertaken during the field visit and how you populate the field form.
Chapter 5: Populating the model: Provides step by step guidance in the application of the VEGRAI models.
Chapter 6: VEGRAI: Predictive use: Discusses the way that the VEGRAI will be used when the model must be populated in a predictive manner in reaction to a range of flow scenarios for example.
Chapter 7: VEGRAI: Uses within Ecological Reserve Monitoring: Provides information on how the models can be used to set EcoSpecs and TPCs

The CD issued with this report "Riparian Vegetation Response Assessment Index (Vegrai)", Module F, (WRC Report TT 333/08), contains an electronic copy of the report as well as its supporting models. The other modules in the series are also provided. An inventory is given on the CD.

RIVER ECOCLASSIFICATION MANUAL FOR ECOSTATUS DETERMINATION (VERSION 2)

Module F: Riparian Vegetation Response Assessment Index (VEGRAI)
The manual describing the Riparian Vegetation Response Assessment Index (VEGRAI) Level 3 and 4: **VEGRAI.doc**

The Manual is supported by VEGRAI models for both level 3 and 4
(i) **VEGRAI3.xls**
(ii) **VEGRAI4.xls**

A fieldform for both VEGRAI 3 and 4 is also provided: **fieldform.doc**

DOCUMENT REFERENCE

Kleynhans CJ, MacKenzie J, Louw MD. 2007. Module F: Riparian Vegetation Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 333/08

ACKNOWLEDGEMENTS

Douglas Macfarlane for the Cover, Abundance and Alien infestation illustrations.

All the persons who participated in the development in alphabetical order:

Boucher, C	Private
Deacon, Andrew	National Parks Board
Dickens, Chris	INR
Eckardt, Holgar	National Parks Board
Engelbrecht, J	Mpumalanga Parks Board
Fouche, Paul	University of the North
Graham, Mark	Groundtruth cc
Kemper, N	Integrated Environmental Assessments
Leroy, Mark	LEDET
Lindstrom, Anton	Mpumalanga Parks Board
MacFarlane, Douglas	INR
Marnewecke, G	Wetland Consulting Services
Thirion, C	RQS, DWAF
Todd, C	RQS, DWAF

In memoriam: Nigel Kemper designed the first vegetation index for the River Health Programme, and set the baseline for the assessment of riparian vegetation for environmental flow requirements.

APPROVAL FOR RELEASE OF REPORT

Module A	EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Kleynhans CJ, Louw MD
Module D	Fish Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2) Kleynhans CJ
Module E	Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2) Thirion C
Module F	Riparian Vegetation Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2) Kleynhans CJ, Mackenzie J, Louw MD
REPORT STATUS	FINAL
DATE	April 2007

APPROVED FOR WATER FOR AFRICA

.....

MD LOUW
PROJECT LEADER

APPROVED FOR THE WATER RESEARCH COMMISSION

SA Mitchell

.....

DR SA MITCHELL
WRC DIRECTOR: WATER-LINKED ECOSYSTEMS (KSA 2)

APPROVED FOR THE DEPARTMENT OF WATER AFFAIRS AND FORESTRY: DIRECTORATE RESOURCE DIRECTED MEASURES

.....

MR B MADIKIZELA
ACTING SENIOR MANAGER: RESOURCE QUALITY SERVICES

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

TABLE OF APPENDICES

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
FRAI	Fish Response Assessment Index
GAI	Geomorphology Driver Assessment Index
HAI	Hydrology Driver Assessment Index
IFR	Instream Flow Requirements
IHI	Index of Habitat Integrity
ISP	Internal Strategic Perspective
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
NAEHMP	National Aquatic Ecosystem Health Programme

EXECUTIVE SUMMARY

1. ECOCLASSIFICATION

EcoClassification - the term used for the Ecological Classification process - refers to the determination and categorisation of the Present Ecological State (PES; health or integrity) of various biophysical attributes of rivers relative the natural or close to the natural reference condition. The purpose of the EcoClassification process is to gain insights and understanding 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 the EcoClassification process are as follows:

- Determine reference conditions for each component.
- Determine the Present Ecological State for each component as well as for the EcoStatus. The EcoStatus refers to the integration of physical changes by the biota and as reflected by biological responses.
- Determine the trend (i.e. moving towards or away from the reference condition) for each component as well as for the EcoStatus.
- Determine causes for the PES and whether these are flow or non-flow related.
- Determine the Ecological Importance and Sensitivity (EIS) of the biota and habitat.
- Considering the PES and the EIS, suggest a realistic and practically attainable 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 for the purposes of providing various scenarios

The EcoClassification process is an integral part of the Ecological Reserve determination method and of any Environmental Flow Requirement method. Flows and water quality conditions cannot be recommended without information on the predicted resulting state, the Ecological Category.

Biological monitoring for the River Health Programme (RHP) also uses the EcoClassification process to assess biological response data in terms of the severity of biophysical 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'.

In 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 that is being dealt with.

3. ECOSTATUS SUITE OF MODELS

The following index models were developed following a 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)
- Riparian Vegetation Response Assessment Index (VEGRAI)

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.

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 interpret 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 can be undertaken. Each of these relates to an Ecological Water Requirement (EWR) method with an appropriate level of detail and 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

These five levels of EcoStatus determination are associated with an increase in the level of detail required to execute them. As the EcoStatus levels become less complex, less-complex tools must be used (such as the Index of Habitat Integrity). This set of manuals explains these different tools, how they work and when they should be applied.

1 INTRODUCTION

Riparian vegetation is described in the Water Act (Act No 36 of 1998**)** as follows:

“riparian habitat" includes the physical structure and associated vegetation of the areas associated with a watercourse which are commonly characterised by alluvial soils, and which are inundated or flooded to an extent and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent land areas.

The definition of wetlands to distinguish with that of riparian vegetation habitat or zone is provided in the Act as follows:

“wetland" means land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil.

1.1 BACKGROUND

During the early phases of the River Health Programme (RHP) component of the National Aquatic Ecosystem Health Programme (NAEHMP) a riparian vegetation assessment index (RVI) was developed (Kemper, 2001). The RVI was applied during several RHP surveys. However, it was found that it represented several problems (documented in the minutes of a Riparian Vegetation Workshop held on 22 August 2002 at the CSIR, Pretoria):

- The RVI approach is too resource intensive.
- Concerns about the repeatability of results.
- The representivity of a site – does a single site adequately represent a river reach?
- Results are difficult to interpret.
- Problems with interpretation of basal and aerial cover.
- Determination and specification of reference condition is highly subjective.
- Delineation of the riparian zone is subjective.
- Marginal vegetation is not adequately dealt with.
- Strongly based on woody vegetation.
- Riparian vegetation types in different biomes may require different considerations.
- No consideration of lateral zonation.
- There appears to be a “black box” situation in the calculation and interpretation of the RVI. A lot of the data collected during the field surveys are not used in the formula calculation, assessment and interpretation.

During 2004 the EcoClassification process and EcoStatus assessment methods were developed (Kleynhans et al., 2005). It was found that the RVI did not fit into the approach and context needed for EcoStatus assessment.

1.2 INDEX REQUIREMENTS

Taking into consideration the above issues, the general requirements of the VEGRAI were specified during a number of workshops as well as testing by riparian vegetation specialists:

- It should be a practical and rapid approach to assess changes in riparian vegetation condition.
- It should consider the condition of the different vegetation zones separately but allow the integration of zone scores to provide an overall index value for the riparian vegetation zone as a unit.
- The vegetation should be assessed based on woody and non-woody components in the respective zones and according to the different vegetation characteristics which include, inter alia,
  - Cover
  - Abundance
  - Recruitment
  - Population structure
  - Species composition
- It should provide an indication of the causes for riparian vegetation degradation.
- It should be impact based. This means that the reference condition will only be broadly defined and based on the natural situation in the absence of impacts. Where possible, however, reference conditions should be derived based on reference sites or sections.
- The index is based on the interpretation of the influence of riparian vegetation structure and function on instream habitat.
- Although biodiversity characteristics are used in assessing the riparian vegetation condition, it is not a biodiversity assessment index *per se.*

Two levels of the index were proposed:

- Level 3 for application in the RHP and for rapid Ecological Reserve purposes. This level will be aimed at general aquatic ecologists.
- Level 4 for application in the intermediate and comprehensive Ecological Reserve determinations. This level will be aimed at specialist riparian vegetation ecologists (Levels 3 & 4 refer to the appropriate level of EcoStatus determination as defined in Kleynhans, *et al*. 2005 and module A of version 2).

2 DESCRIPTION OF VEGRAI STRUCTURE

It must be noted that this section describes the structure of the Riparian Vegetation Response Assessment Index (VEGRAI) component that determines the Ecological Category. The products of VEGRAI are more than a measure of Ecological Category (EC) as the process and data are valuable in and of themselves. VEGRAI is designed for qualitative assessment of the response of riparian vegetation to impacts in such a way that qualitative ratings translate into quantitative and defensible results. Results are defensible because their generation can be traced through an outlined process (a suite of rules that convert assessor estimates into ratings and convert multiple ratings into an EC).

2.1 VEGRAI MODEL

VEGRAI has a spreadsheet model component that is composed of a series of metrics and metric groups (described hereunder and illustrated in Fig 2.1), each of which is rated in the field with the guidance of data collection sheets (referred to as field forms).

The metrics in VEGRAI first describe the status of riparian vegetation in both its current and reference states (see section 3.1 for discussion of reference state) and second, compare differences between the two states as a measure of vegetation response to an impact regime.

The riparian vegetation zones (Marginal, Lower and Upper) were used as the metric groups. For the simplified Level 3 version, the Lower and Upper zones were combined to form the Non-Marginal metric group (zone).

A range of metrics for each metric group was selected of which some are essential for both Levels 3 and 4 (Abundance and Cover) and the others are optional (Species Composition, Population Structure and Recruitment). The metrics are then rated and weighted (see below) and an Ecological Category (A-F) determined which represents the Ecological Category for the riparian vegetation state (Fig 2.1).

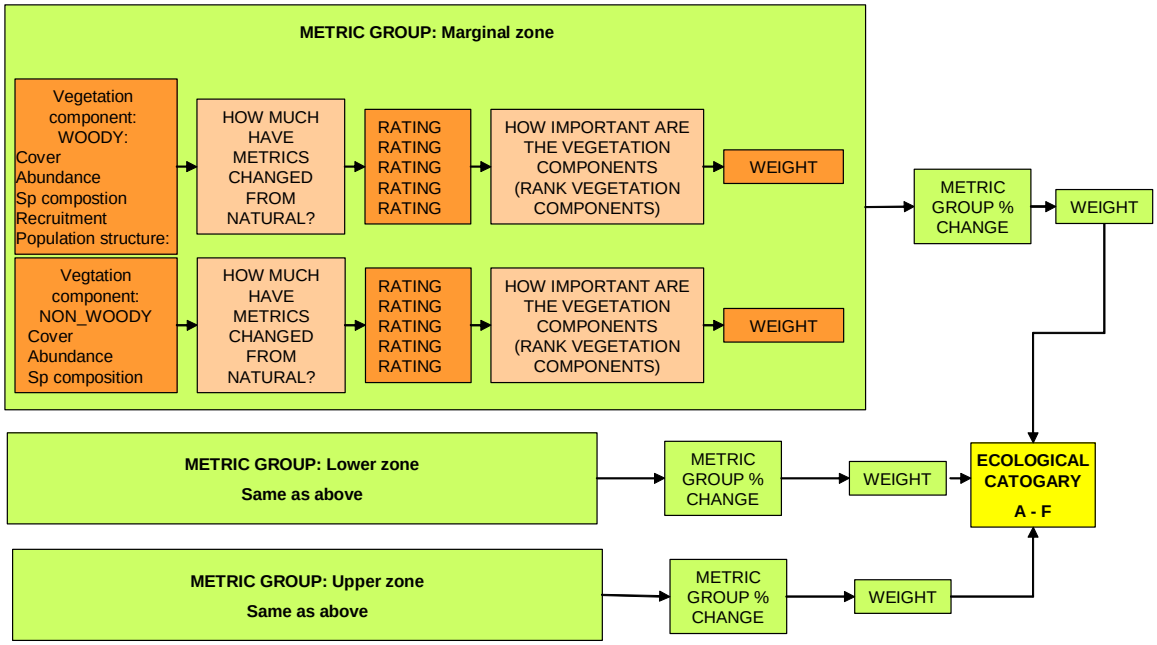


Figure 2.1 VEGRAI 4 structure

2.2 METRIC GROUPS

Metric groups were defined in order to facilitate multiple assessments of metrics for different vegetation zones within the riparian zone. This is necessary as the response of riparian vegetation to impacts is known to be a function of position within the riparian zone (Craig & Malanson, 1993). The model therefore caters for the assessment of vegetation response in different positions (zones) to capture in greater detail the actual response overall.

Two or three zones are identified and used in VEGRAI 3 or 4 assessments respectively. These zones, marginal, lower and upper, are in keeping with riparian literature and while actual terms vary, their definition is based on

- periodicity of hydrological influence (Hupp & Osterkamp, 1996; Auble & Scott, 1998);
- marked changes in lateral elevation or moisture gradients (Hupp & Osterkamp, 1996; van Coller et *al*.,1997);
- changes in geomorphic structure (Hupp & Osterkamp, 1985);
- changes in plant species distribution or community composition along lateral gradients (van Coller et *al.,* 1997).

Note that when identifying zones, a combination of geomorphic structure, elevation and vegetation distribution needs to be used. Elevation is used as a surrogate for hydrological activation, which is taken to be moistening or inundation of the substrate by water in the channel. When identifying zones, preference should be given to the physical template rather than vegetation distribution, since vegetation distribution varies or vegetation may be absent. Note that with the exception of the marginal zone, the other zones are not necessarily always present.

The marginal zone has also been referred to as active features or wet bank (Van Niekerk and Heritage, 1993). It includes the area from the water level at low flow, if present (the greenline concept may be used in the absence of base flow (Cagney, 1993), to those features that are hydrologically activated for the greater part of the year (see Figure 2.2).

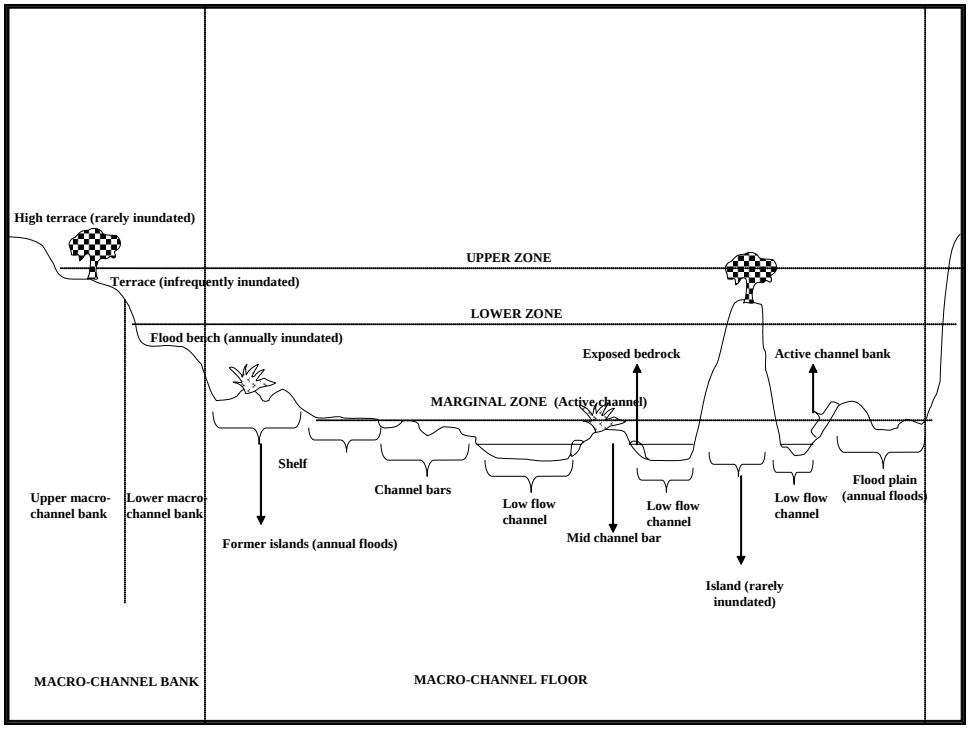


Figure 2.2 Schematic diagram illustrating an example of where the 3 zones would be placed relative to geomorphic diversity

The lower zone has also been referred to as seasonal features or wet bank (Van Niekerk and Heritage, 1993). The lower zone extends from the marginal zone and usually ends where a marked increase occurs in lateral elevation. This change in elevation may or may not be characterised by an associated change in species distribution patterns. The lower zone consists of geomorphic features that are hydrologically activated on a seasonal basis (yearly during high flow, or every 2 to 3 years).

The upper zone has also been referred to as ephemeral features (Van Niekerk and Heritage, 1993) or dry bank and extends from the end of the lower zone to the end of the riparian corridor. The upper zone consists of geomorphic features that are hydrologically activated on an ephemeral basis (less than every 3 years). The upper zone is usually characterised by steeper slopes and the presence of both riparian and terrestrial species.
The differences in the zones are summarised in Table 2.1.

Table 2.1 Description of riparian vegetation zones

	Marginal	Lower	Upper
Alternative descriptions	Active features Wet bank	Seasonal features Wet bank	Ephemeral features Dry bank
Extends from	Water level at low flow	Marginal zone	Lower zone
Extends to	Geomorphic features / substrates that are hydrologically activated (inundated or moistened) for the greater part of the year.	Usually a marked increase in lateral elevation.	Usually a marked decrease in lateral elevation
Characterized by	See above ; Moist substrates next to water's edge; water loving- species usually vigorous due to near-permanent access to soil moisture	Geomorphic features that are hydrologically activated (inundated or moistened) on a seasonal basis. May have different species than marginal zone	Geomorphic features that are hydrological activated (inundated or moistened) on an ephemeral basis. Presence of riparian and terrestrial species Terrestrial species with increased stature

Level 3 assessments are intended for use by the River Health Programme (RHP) and Ecological Reserve determination at the Rapid III level and require a simplification to the above 3 zones. Two zones only are defined and assessed: the marginal and non-marginal zone. The non-marginal zone is a combination of the above lower and upper zones.

2.3 METRICS

Several metrics are defined and used in VEGRAI to describe and rate riparian vegetation status. These are abundance, cover, recruitment, population structure and species composition. Each of these, defined and justified below, is assessed in each of the zones for both a woody and non-woody vegetation component. Not all the metrics are used in the VEGRAI 3 and the differences are shown in Table 2.2.

Table 2.2 Metrics used in Level 3 and 4

Vegetation Components	Level 3	Level 4
Woody	Cover	Cover
	Abundance	Abundance
	Species composition	Species composition
		Recruitment
		Population structure
Non-woody	Cover	Cover
	Abundance	Abundance
	Species composition	Species composition

2.3.1 Woody

The woody component is defined as a combination of trees and shrubs. Trees are

woody perennials, usually single stemmed in an undamaged state, with a distinct upper crown. Shrubs are woody perennials, with two or more stems arising from near the ground, are generally smaller than trees and without a trunk.

2.3.2 Non Woody

The non-woody component is comprised of grasses, sedges, forbs, and all other herbaceous plants. The non-woody component includes species such as *Phragmites*, Palmiet, the Restios, *Typha, Juncus*, aquatic (hydrophytic) grasses, and aquatic sedges.

2.3.3 Cover

This metric addresses the question of how much vegetation there is under present condition compared to how much there should be under reference condition. Vegetation cover is a measure of the extent to which the ground is covered by vegetation, and is measured as canopy cover (the extent to which the canopy of the plants covers the ground, as seen from above). The change in percentage cover from reference conditions is estimated without it actually being measured. Exotic vegetation does not form part of the cover assessment (see abundance).

Both abundance and cover are needed to address the question of how much vegetation there is and how this has changed, because each gives a different aspect to assessing amount, e.g. a site may have 30 small trees giving a high abundance value but low cover because they are small, while the next site may have a single large tree giving a low abundance value and high cover. Both are needed in combination to assess riparian vegetation.

2.3.4 Abundance

This metric also addresses the question of how much indigenous vegetation there is under present conditions compared to how much there should be under reference conditions. Abundance is measured in terms of density (number of stems/plants per unit area). Abundance is qualitatively assessed in terms of the extent of change in vegetation density present in the relevant zone at the site relative to reference conditions. The change from reference condition for density is estimated rather than being actually measured. Note that VEGRAI does not consider exotic vegetation in its assessment of abundance because exotic invasion is seen as an impact affecting indigenous vegetation abundance rather than being a part of its measurement. Hence exotic invasion is assessed (as an impact) elsewhere. In a scenario where exotic invasion occurs at a site, the abundance metric will give indication of this (in combination with exotic assessment) by showing a marked difference from the reference condition.

2.3.5 Population Structure

The assessment of population structure addresses the viability and sustainability of populations. It is only assessed for the woody component. Population structure is an assessment of the relative abundance of life stages within respective populations of selected indicator species. Life stages used in VEGRAI are juveniles, sub-adults and adults, and represent functionality in the life histories of selected species. A juvenile is an individual that has become dependant on its own resources, but is not yet reproductive. Juveniles are established, and can be considered the first successfully survived generation. Sub-adults are individuals who have not yet reached a maturity status of adults, are not yet fully reproductive (fruits may be minimal), but are also not juveniles. They vary in height and girth between juveniles and adults. An adult is a potentially fully reproductive individual that has reached maturity. Damaged specimens, reduced in size and possibly reproductive functionality, are included.

2.3.6 Recruitment

Recruitment is the arrival and establishment of new individuals into riparian populations / communities. Recruitment addresses the viability and sustainability of vegetation components. It is a qualitative estimate of the abundance of established juveniles for the woody component only. Recruitment excludes vegetative reproduction (coppicing, re-sprouting). Established individuals are those juveniles that have completed the process of germination (lost cotyledons) and have developed a visible amount of woodiness, but are not yet contributing reproductively. Recruitment of non-woody vegetation is not included in VEGRAI due to the difficulty of the assessment, and because non-woody plants are generally shorter-lived than woody (annuals, e.g.) and an assessment of cover and abundance is therefore sufficient.

2.3.7 Species Composition

Species composition refers to the arrangement of species in the riparian community that comprise the assemblage in the study area. Species composition refers to the presence and absence of species as well as their relative proportions in the assemblage.

The assessment should focus on the change of the indigenous riparian species assemblage. Exotic and terrestrial species are often major contributors to changes in indigenous riparian species composition. The change in species composition for each zone is assessed separately for woody and non-woody vegetation components. This assessment makes use of indicator species and records the change in relative abundance (relative to other indicator species) from present to reference conditions.

2.4 RATING, RANKING, WEIGHTING

Note:
Ranking and weighting refers to the degree of change from reference conditions.

The principle of following a ranking-weighting approach is that not all metrics and metric groups (various zones) 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 riparian zone. In another river (or a different section of the same river) in a different ecoregional context (Kleynhans et al., 2005), 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.

The basis of the assessment of the importance of the metrics in determining the EC is a simplified Multi Criteria Decision Analysis (MCDA) approach with swing weights (Joubert, 2004).

2.4.1 Rating (Scoring)

A six-point rating system is followed, where metrics are scored in terms of the degree to which they have changed compared to the natural or close-to-natural reference. If required, ratings with 0.5 intervals can be used (e.g. 1.5, 3.5):

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

2.4.2 Ranking and weighting

The principle of the VEGRAI in estimating ranks and weights should be emphasized here: The importance of both the vegetation component in a metric group and the metric group in determining the condition of the riparian vegetation, relates to **the function of the riparian vegetation in determining the instream habitat and condition.**

The vegetation component (woody and non-woody) in each vegetation zone is considered in terms of its importance in maintaining the condition of the vegetation zone under reference conditions. This means that the vegetation component that is considered to be most important in influencing the EC of the vegetation zone if it changed, is ranked 1 and awarded a weight of 100%, the next most important component is ranked 2 and is awarded a rating proportionally less than 100% based on expert judgement. Usually expert knowledge limits the resolution to 10% and

sometimes 5%. Where it is not possible to distinguish between the relative importance of vegetation components, a rank of 1 (and weight of 100%) should be awarded to both components in a zone. 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. Note should be taken here that vegetation component metrics are not ranked and carry equal weight (100%).

The weighting of metric groups (vegetation zones) follow a similar approach, e.g. the metric group considered to be most important in determining the condition of the riparian vegetation (the EC) under reference conditions is ranked 1, the next group as 2, and so on. Weights are awarded according to the principle explained above.

2.4.3 Calculation of weighted scores

2.4.3.1 Metrics within metric groups

The average response rating for respectively the woody and non-woody vegetation components are calculated based on the number of metrics assessed. The two vegetation components are combined to provide an integrated assessment for the metric group (i.e. the vegetation zone). This is achieved by following the ranking and weighting procedure indicated above. The average rating for a vegetation component is then multiplied by the weight of the component to provide a weighted rating. These two weighted ratings are then summed. The estimated weight for a vegetation group is then used to calculate the balanced weight of the group out of the maximum of 5 (i.e. the maximum rating possible). The sum of these two values is calculated, followed by calculation of the ratio of the integrated vegetation group rating. This ratio is expressed as a percentage which indicates the degree to which the metric group (vegetation zone) has changed from the estimated natural state.

2.4.3.2 Metric groups and the calculation of the Ecological Category

The following procedure is followed to integrate the condition of metric groups and to provide an estimated Ecological Category for the riparian vegetation:

- The degree to which a metric group has changed from the natural state is subtracted from 100 to provide the degree to which the metric group is still intact.
- Each metric group (vegetation zone) is ranked and weighted according to its relative importance to the functioning of the river under natural conditions (cf. above). The focus is on the instream aspect of the river in particular.
- These weights are summed and the weight for each metric group is expressed as a proportion of this total.
- This proportional weight is multiplied by the percentage of the metric group in a natural condition and summed for all metric groups. This provides an integrated value that relates to the Ecological Category for the riparian vegetation that ranges from A to F (Table 2.3).

Table 2.3 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 modified. Modifications have reached a critical level and the lotic 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

2.5 VEGRAI FORMULATION

2.5.1 Response metric impact ratings

a) Woody

Overall response of woody vegetation to impact (Wi)

$$Wi = (\sum Wir)/n$$

Where

Wir = woody vegetation response rating (0-5)

n = number of response metrics considered/rated

b) Non-woody

Overall response of non-woody vegetation to impact (Ni)

$$Ni = (\sum Nir)/n$$

Where

Nir = Non-woody vegetation response rating (0-5)

n = Number of response metrics considered/rated

2.5.2 Riparian vegetation zone condition

$$ZC=[((\sum Wi) \times Ww)+ ((\sum Ni) \times Nw)]$$

Where

ZC = Marginal or non-marginal zone (level 3),

OR

Marginal or lower or upper zone (level 4).

Ww = Woody weight

NW = Non-woody weight

2.5.3 VEGRAI EC

$$VEGRAI_3 = \sum (ZCm \times Mw) + (ZCnm \times Nmw) \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where

$VEGRAI_3$ = VEGRAI level 3
ZCm = Marginal zone condition
Mw = Marginal zone weight
ZCnm = Non-marginal zone condition
Nmw = Non-marginal zone weight

$$VEGRAI_4 = \sum (ZCm \times Mw) + (ZCl \times Lw) + (Zcu \times Uw) \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where

$VEGRAI_4$ = VEGRAI level 4
ZCm = Marginal zone condition
Mw = Marginal zone weight
ZCl = Lower zone condition
Lw= Lower zone weight
ZCu= Upper zone condition
Uw = Upper zone weight

3 PREPARATION FOR VEGRAI APPLICATION

3.1 REFERENCE CONDITIONS

The reference conditions form a benchmark against which to assess/estimate a deviation/change in riparian vegetation status. It provides a backdrop for standardising comparisons and assessing the response of riparian systems to anthropogenic impacts. Reference conditions are usually natural, i.e. conditions prior to significant human interaction with riparian structure and function. Reference conditions often do not to exist in the present state and reference conditions therefore need to be reconstructed (see section 4.6 for details).

When considering reference state conditions, it is very important not to think of it as a climax state. One must bear in mind that the riparian zone is in a state of constant flux, and that this is natural. The implication is that there is more than one state that may be/become the reference state. We have highlighted 6 possible states to guide the process of reference state reconstruction (see Fig. 3-1):

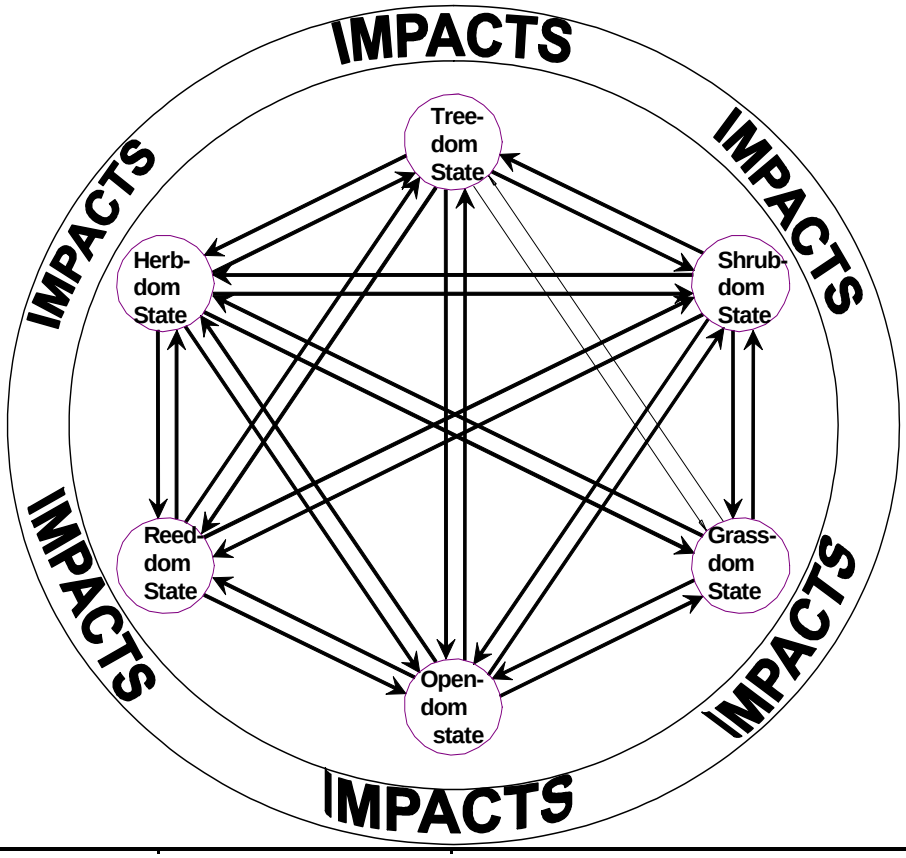
- Tree-dominated state,
- Shrub-dominated state,
- Grass-dominated state,
- Herbaceous-dominated state,
- Reed-dominated state,
- Open-dominated state (this is substrate such as sand/rock).

Arrows between states denote flux towards or away from a state. All states occur in 3-dimensional space since transition between states is not linear or progressive, but can go from any state to any other state (or remain as is). Transition between states is influenced by impacts. In order to apply VEGRAI it is essential to qualify the reference conditions before metrics are rated.

- Decide where on the diagram of states the present state of each zone is, and indicate on your field form. Taking the reference state reconstruction process into account (below), together with all available information of the site and the system that it occurs in, decide on the most likely state as a reference state for that site. Record on your field form.
- This is the state you wish to work towards, and the one against which all comparisons are made when rating model metrics.
- The reference state is not necessarily a climax state and may shift between different generic states (each with additional finer-scaled characteristics). Movement between states is dependent on the impact regime.
- Before any fieldwork takes place, as much information about the site and river system as possible must be sourced. These sources of information must be recorded. This information will help to reconstruct the reference condition.

Once all impacts have been recorded and assessed (desk and field based), a first attempt at constructing the reference state can begin:

- Start with a list of the impacts present at the site.
- Take the first impact and assess the response of riparian vegetation and the system as a whole to that impact. Query what the response would be (and what the site would look like) in the absence of that impact. Record your thoughts as step 1 in reference state reconstruction.
- Do the same with all other impacts. This will begin to form a picture of what the reference state would be like.
- Bear in mind that there will be multiple effects of all/different impacts acting in tandem. Once you have gone through the list of impacts, ask yourself what these multiple effects might be and what the response is. Now in their absence how would the riparian zone have responded? Adjust your picture of the reference state as is needed. Remember to make notes, as this will be of great help to future users/assessors.



IMPACTS TO REMOVE	RESPONSE METRIC	DESCRIPTION OF STATE CHANGE (In all descriptions try to make reference to zones and states outlined in Fig. #2)
Vegetation removal	Cover	Describe how woody (trees & shrubs) and non-woody (grass, herbs & reeds) cover would change in the absence of existing vegetation removal.
	Abundance	
	Population structure	
	Recruitment	
	Species composition	
Exotic invasion	Cover	Describe how woody (trees & shrubs) and non-woody (grass, herbs & reeds) species composition would change in the absence of existing exotic invasion.
	Abundance	
	Population structure	
	Recruitment	
	Species composition	
Water quantity	Cover	Describe how woody (trees & shrubs) and non-woody (grass, herbs & reeds) species composition would change in the absence of existing changes to flow.
	Abundance	
	Population structure	
	Recruitment	
	Species composition	
Water quality	Cover	Describe how woody (trees & shrubs) and non-woody (grass, herbs & reeds) species composition would change in the absence of existing changes to water quality.
	Abundance	
	Population structure	
	Recruitment	
	Species composition	

Figure 3.1 Deriving reference conditions

3.2 SITE SELECTION

3.2.1 Rationale

The aim of this procedure is to characterize the riparian vegetation according to the diversity of impacts in the identified Resource Unit (RU) (Louw & Hughes, 2002). For this purpose it is necessary to identify broad sections of riparian zones with relatively similar types of riparian vegetation disturbance.

A broad assessment of the land use in each RU is conducted and this provides an indication of impacts and modification of the vegetation. Where impacts and modification in a RU is not homogenous, this may indicate the necessity of a diversity of sites to provide a representative indication of riparian vegetation health or integrity. Results of the assessment can be expressed in terms of the length of the RU.

3.2.2 Broad categorization of impacts on riparian zone vegetation

The main purpose of this exercise is to determine how homogenous disturbances in the RU are. This is achieved by determining the habitat integrity of the RU (and where appropriate and significant, also the habitat integrity of upstream RUs) according to the Index of Habitat Integrity (IHI; Kleynhans, 1996). Emphasis is put on the riparian aspect of the IHI. The IHI must be representative of the RU and should enable the distinction between river sections with relatively homogenous types of

disturbance.
The scale of information required for the IHI assessment will be determined by the level of EcoStatus assessment that can vary from a site IHI determination where land cover information and other readily available data sources are used, to detailed assessments where aerial videos and photographs are used. Emphasis is placed on activities that indicate the level of disturbance of the riparian vegetation (e.g., removal and indicators of changes in characteristics such as abundance and cover). Where level 4 EcoStatus assessment is done, appropriate driver information can be used to assess the impacts on the riparian vegetation.

IHI determination is described in Kleynhans (1996 & 1999). This method is in the process of being upgraded (Module G). The results from the IHI assessment within each of the identified RUs should be interpreted according to potential changes in the condition of the riparian vegetation:

- None (natural/close to natural)
- Small
- Moderate
- Large
- Very large
- Extreme

Each of these categories of disturbance can potentially indicate a requirement for different sampling sites in order to provide a representative impression of the condition of the riparian vegetation in the RU.

Combining the categories of modification can be considered if it does not represent radically different types of disturbance (e.g. contrasting cultivated lands with urban development). This approach will decrease the number of sites required to represent riparian vegetation condition.

3.2.3 Weighting the VEGRAI values for different sections in a RU

The principle of calculating an overall VEGRAI for a RU, is that the longitudinal length of a river section is used to weight the contribution of the section's VEGRAI value based on its proportion of the total length of the RU:

The weighted contribution of the VEGRAI index value for a particular section of river is calculated by:

$$WC = (L/TL) \times C$$

Where:

WC = Weighted contribution of section's VEGRAI index value
L = Length of the river section
TL = Total length of the RU
C = Condition of the riparian vegetation (VEGRAI index value (%))

The riparian vegetation condition for the total RU is calculated by:

$$RUC = \sum WC$$

Where:

RUC = Resource unit riparian vegetation condition

3.3 IMPACT EVALUATION AND INTERPRETATION

3.3.1 Rationale

The purpose is to evaluate and interpret the observed impacts at a site in terms of its relative influence on the riparian vegetation according to vegetation removal, alien vegetation invasion, water quantity and water quality. The approach followed is that each of these four broad causes of modification relates to and is associated with particular human-related activities that would change the riparian vegetation characteristics directly or indirectly. Some of these changes may occur rapidly while others will occur gradually and only become evident through time.

This approach relates to the National Water Act which aims to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource. The protection of water resource quality[1] is essential to achieve this:

``resource quality'' means the quality of all the aspects of a water resource including,

- The quantity, pattern, timing, water level and assurance of instream flow;
- The water quality, including the physical, chemical and biological characteristics of the water;
- The character and condition of the instream and riparian habitat; and
- The characteristics, condition and distribution of the aquatic biota
- Considering the functions of the riparian vegetation, these have been summarized as (Anon. 2002):
  - Sediment trapping,
  - Nutrient trapping
  - Bank stabilization and bank maintenance,
  - Contributes to water storage,
  - Aquifer recharge,
  - Flow energy dissipation,
  - Maintenance of biotic diversity,
  - Primary production.

Most of these functions relate to instream habitat conditions and it follows that the basic consideration when assessing the condition of the riparian vegetation, is that impacts should be interpreted in terms of the influence on the instream habitat.

[1] 'resource quality' means the quality of all the aspects of a water resource

3.3.2 Causes of modification and associated impacts

3.3.2.1 Vegetation Removal

Removal of riparian vegetation can increase the amount of solar radiation reaching a stream. This increases water temperature and effects aquatic primary production while the ability of riparian areas to retain water will also be impaired (Anon, 2002):

- Physical removal for whatever purpose.

The presence of human structures, cultivated lands or clearing of vegetation for whatever reason is direct evidence that physical removal took place. Conversion of riparian vegetation to cultivated lands can decrease infiltration and increase overland flow volumes and peak runoff rates. High erosion rates can result from this and riparian vegetation may be inundated with sediment and impair the filtering functions of the riparian zone (Anon, 2002).

- Utilization by humans and animals.

Care must be taken to assess utilization in terms of "excessive" use, i.e. where vegetation is utilized beyond its ability to recover. Evidence for this is often the presence of bare and compacted soil, absence of vegetation and sheet or donga erosion.

  – Direct human use: Specific direct human uses such as cutting of trees, pruning of trees, harvesting of reeds or medicinal plants are also included.
  – Use by animals: Livestock grazing are particularly important in many areas. Trampling and removing of vegetation may lead to the compaction of soils and dispersal of exotic plant species and pathogens. Grazing can also alter hydrologic and fire disturbance regimes, accelerate erosion and reduce plant reproductive success and establishment of plants. The long-term cumulative effects of grazing include changes in the structure, composition and productivity of plants at community, ecosystem and landscape levels. Domesticated herbivores have a disproportionate effect on riparian vegetation because they concentrate in these areas due to the availability of forage and water Although native ungulates can inflict similar types of damage to riparian vegetation, their impact is generally much less than that of livestock in areas that support both (Anon, 2002).

3.3.2.2 Exotic Invasion

The introduction of plant species has a severe effect on riparian areas. This can lead to the displacement of indigenous species and subsequently to a change in ecosystem properties (Allan, 2002). The exclusion of natural riparian vegetation due to vigorous growth can cause bank instability thereby decreasing the buffering function of the riparian zone. Allachtonous organic input will also be changed and riparian habitat diversity reduced (Kleynhans, 1996).

Invasion by exotic vegetation can be due directly to the invasive capabilities of such species, or as a result of other disturbances that enables exotic species to invade

stream banks (Wohl & Rathburn, 2003).

3.3.2.3 Water Quantity

A change in the volume and seasonality of flows can have a direct impact on riparian vegetation (Kleynhans, 1996). Hydrologic changes can be caused by dams and other structures. Increased flow can also result in increased stream widths or downcutting of the streambed (Allan, 2002) that can lead to the loss of riparian vegetation.

This includes modification brought about by hydrologic changes such as caused by dams and other structures.

3.3.2.4 Water Quality

The transport of agricultural chemicals from upslope can negatively impact indigenous riparian plants (Allan, 2002). Eutrophication may cause excessive growth of exotic riparian vegetation in particular. In some situations, water abstraction from the riparian zone may cause water with high salinities to move into the riparian zone and impact on the riparian vegetation.

Water quality modification originates from point and diffuse point sources and is aggravated by a decrease in the volume of water during low or no flow conditions. It can be measured directly or possible impacts can be derived from the presence of agricultural activities, human settlements and industrial activities may indicate the likelihood of modification.

Increased or decreased sediment supply is an important aspect of water quality, and is often the component that affects riparian vegetation the most.

4 VEGRAI FIELD WORK AND FIELD FORMS

Time constraints associated with a field visit is approximately 2 hours. This depends on the complexity and size of the river, as well as whether you need an assessment for both banks.

4.1 DETERMINATION OF SITE EXTENT

When arriving at the site, the following process must be followed:

- Walk both upstream and downstream until you are confident that enough variability (biotic and abiotic) has been viewed to give an overview of the river in that area.
- Pay particular attention to flow, geomorphic morphology, substrata, elevation, vegetation structure and species, as well as impacts on each of these. Flow, geomorphic morphology, etc. have all been shown to determine riparian vegetation distribution, and as such their variability should be sufficiently covered when determining extent of the site.
- Describe the general characteristics of the site on the data sheets provided.
- If the two banks are sufficiently different in terms of riparian vegetation status, then each bank must be assessed separately as if different sites.
- Document your reasoning and description of the site delineation on page 1 of the field form (Fig 4.1) and Appendix A

Assessor:_____
River:_____
Latitutde (E): _____
Longitude (S):_____
Quaternary Catchment: _____
Date:_____

Longitudinal boundary of site
Description:
RIPARIAN VEGETATION ZONES: MARGINAL
Description
RIPARIAN VEGETATION ZONES: NON MARGINAL (split into **lower** and **upper** for level 4)
Description

Figure 4.1 Illustration of Page 1 of field forms

4.2 ZONE DEFINITION

Once sites have been selected and described on page 1 of the field form (Fig 4.1), zones need to be identified and demarcated. (See examples of Identified zones on photographs in Appendix F)

4.2.1 Marginal zone

Start at the waters edge, or if there is no flowing water, start where water would flow. If there are pools that are not backwater pools, use these to help indicate where water would flow. This is the beginning of the marginal zone and may or may not have vegetation present. Often, if vegetation is present, it will be characteristic either in its species composition or in structure or vigour. Remember to look up and downstream for additional detail and pointers, bearing in mind that vegetation, sharp changes in elevation, and geomorphic structure, all provide clues. If the site is assessed when high flows occur, it is likely that the marginal zone will be inundated. Try to assess where the waters edge would be under low flow conditions.

The marginal zone seldom extends farther than several meters along a lateral gradient. Look for sharp changes in elevation, changes in species composition, or changes in plant vigour to provide clues to where the marginal zone ends. Together with these clues, bear in mind that the marginal zone extends as far as does activation of geomorphic features by base flow water. Activation refers to wetting of the soil close to or at its surface.

4.2.2 Lower zone

The end of the marginal zone is also the beginning of the lower zone for level 4 users and the non-marginal zone for level 3 users. The lower zone usually extends further than the marginal zone.

4.2.3 Upper zone

Continue along the lateral elevation gradient and look for a sharp increase in lateral slope. If it exists, this point marks the beginning of the upper zone, and is often characterised by a change in species composition. Bear in mind that changes in elevation along and within the lower zone are usually gradual, and must be such so as for the entire zone to have seasonal activation by channel flow. This means that the soil surface will be wetted at least every 1 to 3 years.

If there is no distinct increase in lateral elevation to mark the beginning of the upper zone, use changes in species composition or substrate. The upper zone will have more terrestrial species and finer sediments than the lower zone.

Also, estimate hydrological activity, bearing in mind than the entire upper zone will have ephemeral activation by channel flow. This means that the soil surface will be

wetted less than every 3 years. The end of the upper zone may be discerned by a marked decrease in lateral slope, or where this does not occur, by the absence of fluvial sediments or riparian species, or by terrestrial species smaller in stature / vigour than those in the riparian zone.

NOTE:
Bear in mind that while physical zones may be continuous, vegetation distribution within zones is mostly patchy or fragmented

4.3 PLAN VIEW AND CROSS-SECTION SKETCH

The following must be sketched on page 2 of the field forms.

Draw the site in plan view and mark as many features as you can (date, flow direction, banks, zones, geomorphic features, water level, prominent plants or plant groups/clumps with species names if possible). An example of the sketch is provided in Fig 4.2.

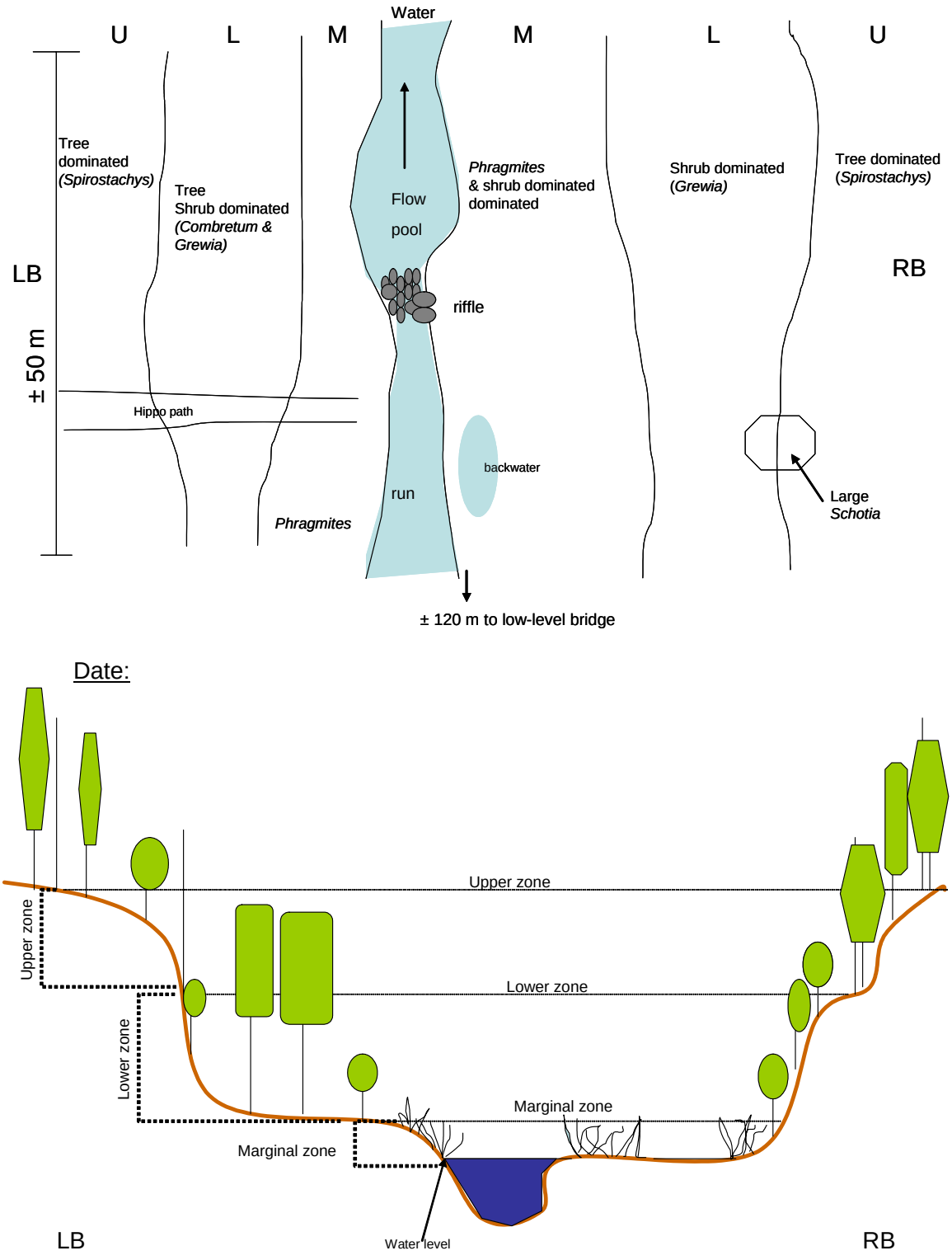


Figure 4.2 Example of a plan view and cross section sketch

4.4 SPECIES LIST

Make a list of key / indicator / dominant / or easily identifiable species on Page 3 of the Field form (See Fig 4.3). Indicate whether each is woody or non-woody and record the zone/s in which it occurred. Also indicate whether the species is exotic.

Note that this is not a biodiversity list or a comprehensive species list for the site.

NOTE ON INDICATOR SPECIES

Indicator species have been defined as organisms that only occur in areas with specific environmental conditions, and because of their narrow ecological tolerance, their presence or absence on a site is a good indicator of environmental conditions (Noss, 1990; Helms 1998). Good indicators for VEGRAI assessments would be plant species that are both reasonably common (especially under reference conditions) and sensitive to disturbance in normal riparian functionality (especially the hydrological regime and sediment dynamics). There are numerous examples of riparian species that are indicators of changes to the flow regime (MacKenzie et *al.*, 1999), geomorphological structure at different scales (Scott et *al.*, 1996), and impacts on riparian functionality and integrity (Friedman et al., 1995; Friedman & Auble., 1999). In VEGRAI, indicator species are used to assess and rate population structure and recruitment of woody vegetation, and species composition of both woody and non

SPECIES LIST

(Focus on key / indicator / dominant / easily identifiable species - maximum 10 - 15 species per zone)

L = Lower, U = Upper, W = woody, NW = Non-woody

Tick applicable zone. If non-marginal, complete only the L column

SPECIES	MARGINAL		NON MARGINAL			
	W	NW	L: W	L: NW	U: W	U: NW

Figure 4.3 Illustration of Page 3 of the field forms (Species list table)

4.5 LAND USE AND IMPACT EVALUATION

This is an assessment of the surrounding and upstream land use that has an impact (causes a vegetation response) at any VEGRAI site. Three impacts (vegetation removal, changes to water quality and quantity) are assessed for intensity (the localized severity of the impact) and extent (the proportion of the site where the impact occurs), but if other impacts are prevalent then these need to be noted and added to the assessment. Assessment of the intensity and extent of each impact is on a scale of 0 to 5 (0=None; 1= Low; 2=Moderate; 3=Large; 4=Serious; 5 =Extreme) for each listed land use.

Land use assessment must be completed on Page 4 of the field forms (Fig 4.4). A page is provided for each of the zones. Level 3 users must ignore the upper zone. A check list of land uses is provided. Space is also provided for additional land uses not identified in the checklist as well as any notes to be inserted.

Each of the land uses identified is then evaluated according to impacts on

- removal;
- quantity;
- quality.

Impacts due to exotic vegetation are addressed in a different table (cf section 4.6)

MARGINAL ZONE: SURROUNDING AND UPSTREAM LAND USE (any land use that causes an impact on the VEGRAI site)						
LANDUSE	**IMPACTS**					
	Rating: 0 (no impact) - 5 (severe impact)					
	REMOVAL		**QUANTITY**		**QUALITY**	
	INT[1]	**EXT[2]**	**INT**	**EXT**	**INT**	**EXT**
Nature reserve, game farming, natural areas						
Picnic site/recreational area						
Subsistence (rural) farming (not stock)						
Stock farming						
Firewood, reed, medicinal plant utilisation						
Forestry						
Irrigation farming (formal) crops						
Residential, urban						
Residential, rural						
Large dams						
Weirs and farm dams						
Mining, quarrying (including obsolete)						
Sewerage treatment and releases						
Infrastructure (formal roads)						
Infrastructure (vehicle tracks)						
Infrastructure (rails)						
Infrastructure (foot- and livestock paths)						
Rubbish Dumping						
Industrial						
Other: Specify						
OVERALL RATING (representative of the maximum rating above)						
CONFIDENCE						

1: Int – Intensity

2: Ext - Extent

Figure 4.4 Illustration of Page 4 of the Field Forms (Surrounding and Upstream Land use)

- Nature reserve, game farming, natural areas: This land use should not have any impact on riparian vegetation apart from infrastructure such as roads, fences, etc. Infrastructure is addressed separately. As this land use could be present, but without impact, the land use can just be ticked.
- Picnic site, recreational areas: This covers a wide range of potential impacts. Below are some possible examples which are by no means a complete list.
  - Launching site for boats (removal)
  - Clearing of vegetation for recreational areas (removal)
  - Local abstraction for lodges, chalets, etc. (quantity)
  - Sewage input in rivers and/or fertilizer input from gardens (quality)
  - 4x4 obstacle course
- Subsistence (rural) farming: This refers to small-scale farming, usually dry land farming or bucket irrigation for maize, vegetables, etc.
  - Lands in or outside of the riparian zone (Removal, quality (sedimentation))
  - Small scale irrigation (Removal - probably small impact)
  - Stock farming

  Examples of how stock farming impacts on the riparian vegetation are the following:
  - Overgrazing (sedimentation - quality)
  - Trampling from watering stock (quality, removal)
- Firewood, reed, medicinal plant utilisation: This would be direct removal of vegetation from the riparian zone. Pending on the scale of removal, this could also cause sedimentation and changes in species composition due to selective removal of species.
- Forestry: Examples of how forestry could affect the riparian vegetation by the following:
  - Removal of riparian vegetation to make place for forestry
  - Utilisation of low flows, especially in dry periods (quantity)
- Irrigation farming (formal) crops: This refers to large scale formal irrigation farming with water being directly pumped from the river or from farm dams. These dams could be in or off channel. Some of the impacts on the riparian vegetation could be the following:
  - Changes in flow regime especially the low flows that could impact on the riparian zone and result in changes in species composition. Increase of long periods of low to no flows could result in terrestrialisation. Lack of floods could also result in clogging (thick growth) of the riparian zone.
  - Farming activities result in use of fertilizers and pesticides which impacts on the riparian vegetation due to a response on water quality.
  - Lands could encroach on/in the riparian zone which results in the removal of riparian vegetation.
  - Farm dams often inundate the marginal and or other zones also resulting in removing of riparian vegetation and increasing some of the vegetation due to permanent water being present - prolific reed growth.
- Residential urban and residential rural: Impacts are often very similar although sometimes more intense and widespread in urban areas. Impacts

associated with rural housing are often similar than those associated with subsistence and stock farming. Examples of the some of the urban impacts are:

  - Sewage runoff causing enrichment and resulting in increased growth.
  - Urban runoff can result in an artificial flooding regime that also impacts on riparian vegetation (quantity).

- Large dams: Impacts of large dams depend on how they are operated. Examples are:
  - Unseasonal releases from dams could result in less dry periods, or longer dry periods. These all will have impacts on the riparian vegetation (quality).
  - No releases from the dam during certain periods can result in a no flow situation. This could result in die-off of certain flow dependant species and the increase of more terrestrial species in the riparian zones.
  - Large dams could impact on the flooding regime, especially the small (freshes) and medium sized floods. This could have a major impact on the riparian vegetation due to a lack of clearing, scouring, not providing required sediment and nutrients, etc.
- Weirs and farms dams: The difference between weirs and farm dams and large dams are in size (weirs, etc. are smaller) and lack of operational structures. Impacts are therefore mostly on low flows. If inundation extends beyond different vegetation zones, the impact gets progressively more.
- Mining, quarrying (including abandoned): Water is often abstracted for mining which impacts on the flow regime. Outflow from mines result in quality problems. Mining activities in the riparian zone could have result in removal of vegetation.
- Sewage treatment and releases: This results in a quality and quantity impact. Increased nutrients result in prolific growth. Increased flows especially in the dry season also lead to prolific growth or die-off of deciduous species.
- Infrastructure: Formal constructed / engineered roads, vehicle tracks, rails, footpaths. The resulting impacts of the above are similar but will differ in intensity. Formal roads and rails are usually well protected. The following impacts could occur
  - Removal of riparian vegetation if the infrastructure is situated in the riparian zone.
  - Sedimentation from the runoff from the infrastructure (quality)
- Rubbish dumping: Rubbish dumping could result in removal of vegetation. It may be very prominent in urban areas.
- Industrial: Impacts on the riparian vegetation depend on the type of industry. The following is some of the expected impacts:
  - Abstraction (quantity) for use in the industries
  - Releases with resulting impact on quality and quantity
  - Activities related with the industry which could occur in the riparian zone (removal.

4.6 EXOTIC VEGETATION AND INVASION

Invasion by exotic species is viewed as an impact on indigenous riparian vegetation rather than being part of riparian vegetation. The impact of exotic vegetation is measured using the COVER of exotic species

Invasion by exotic species is assessed and rated separately for each zone on Page F. A. 7 of the field forms and illustrated in Fig 4.5. Complete the field forms as follows:

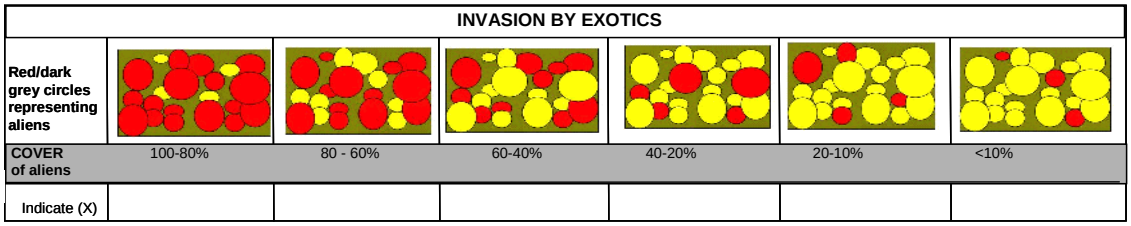


Figure 4.5 Illustration of Page 7 of field form (Invasion by exotics)

- Estimate the % **cover** of exotics in each zone as you observe it on site.
- Tick the appropriate percentage range or put in a specific percentage within the range.
- Determine the intensity of the impact by supplying a rating as follows: Percentage cover of exotic species in the reference state is always taken to be 0. Use the rating guide (Fig 4.6) provided at the end of the field forms. For example, if the present estimate is 10 - 20 %, the intensity rating will be 1 - 2. Decide whether the rating is a 1, 1.5, or 2. This usually depends on where your present estimate lies in the percentage range. If you feel that it lies close to 20%, then the rating should be a 2.
- Make a list of exotic species in the table provided, and indicate in which zone/s each occurs.

EXOTIC INVASION		REFERENCE 0%
PRESENT %	80-100	5
	60-80	4-5
	40-60	3-4
	20-40	2-3
	10-20	1-2
	<10	0-1

Figure 4.6 Illustration of Page 17 of field form (Exotic Invasion)

4.7 RECONSTRUCTION OF THE REFERENCE CONDITIONS

It is important that before any fieldwork takes place the user sources as much information about the site and river system as possible and that these sources of

information be recorded. This information will help to reconstruct the reference state.

Often a combination of two approaches can be followed to reconstruct or derive the reference condition:

- There may be rivers within the same EcoRegional context that are in a better condition. In some cases one of the banks may actually in a much less impacted condition. This information can be used as pointers to the reference condition.
- The second approach are expert knowledge based, are based on the elimination of impacts to reconstruct the reference condition and is discussed in detail below.

Once all impacts have been recorded and assessed (desktop and field based), a first attempt at reconstructing the reference state can begin:
Start with a list of the impacts and standing at the site

- Take the first impact and assess the response of riparian vegetation and the system as a whole to that impact (use appendix 1 to help understand possible responses). Ask yourself what the response would be and what the site would look like in the absence of that impact. Record your observations and interpretations in the blank table designed to assist in the reconstruction of the reference conditions. Do the same with all other impacts. This will begin to form an idea or a picture of what the reference state would be like. Use Table 4.1 to guide and record a description of what the reference state would look like.
- Bear in mind that there will be multiple effects of all/different impacts acting in tandem. Once you have gone through the list of impacts, ask yourself what these multiple effects might be and what the response is. Now in their absence how would the riparian zone have responded? Adjust your picture of the reference state as is needed. Remember to make notes, as this will be of great help to future users/assessors.
- When considering reference state conditions, it is very important not to think of it as a climax state. One must bear in mind that the riparian zone is in a state of constant flux, and that this is natural. The implication is that there is more than one state that may be/become the reference state. We have highlighted 6 possible states to guide the process of reference state reconstruction (see Fig. 3.1):
  - Tree-dominated state,
  - Shrub-dominated state,
  - Grass-dominated state,
  - Herbaceous-dominated state,
  - Reed-dominated state,
  - Open-dominated state (this is substrate such as sand/rock). Arrows between states denote flux towards or away from a state. All states occur in 3-dimensional space since transition between states is not linear or progressive, but can go from any state to any other state (or remain as is).

Transition between states is influenced by impacts.

- Decide where on the diagram of states the present state of the site is, and indicate on your field form. Taking the reference state reconstruction process into account (above), together with all available information of the site and the system that it occurs in, decide on the most likely state as a reference state for that site. Record on your field form. This is the state against which all comparisons are made when rating model metrics.

Table 4.1 Guide to reference state reconstruction. Use appendix 1 to help with descriptions.

IMPACTS TO ELIMINATE	RESPONSE METRIC IMPACTED	DESCRIPTION OF STATE CHANGE (In all descriptions try to make reference to zones and states outlined in Fig. 3.1)
Vegetation removal	Cover	Describe how woody (trees & shrubs) and non-woody (grass, herbs & reeds) cover would change in the absence of existing vegetation removal.
	Abundance	
	Population structure	
	Recruitment	
	Species composition	
Exotic invasion	Cover	Describe how woody (trees & shrubs) and non-woody (grass, herbs & reeds) cover would change in the absence of existing exotic invasion.
	Abundance	
	Population structure	
	Recruitment	
	Species composition	
Water quantity	Cover	Describe how woody (trees & shrubs) and non-woody (grass, herbs & reeds) cover would change in the absence of existing changes to flow.
	Abundance	
	Population structure	
	Recruitment	
	Species composition	
Water quality	Cover	Describe how woody (trees & shrubs) and non-woody (grass, herbs & reeds) cover would change in the absence of existing changes to water quality.
	Abundance	
	Population structure	
	Recruitment	
	Species composition	

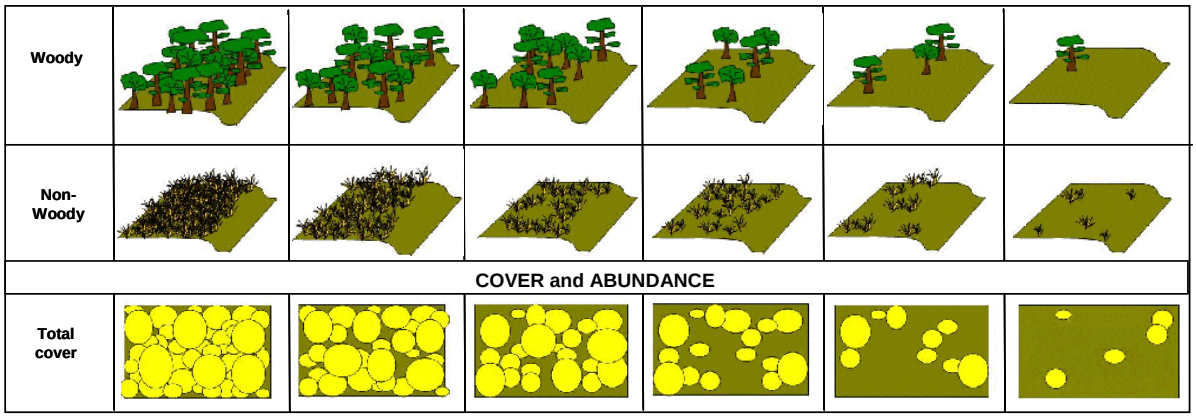
4.8 RATING RESPONSE METRICS

NOTE:
For VEGRAI (Level 3), only Abundance and Cover Response Metrics must be completed. The assessment of the other Response Metrics is optional.
For VEGRAI (Level 4), most Response Metrics must be completed, but if required some can be switched off.

4.8.1 Vegetation abundance

Abundance is rated separately for woody and non-woody vegetation in each zone, and is based on the density of indigenous vegetation (see section 2.3.4 for definition). On the field forms, the assessments for abundance and cover (see below) are recorded in the same tables (Page 8 & 9 of the field forms and Fig 4.7).

WOODY



		100 - 80%		80 - 60%		60 - 40%		40 - 20%		20 - 10%		<10%	
		Cov	Abun	Cov	Abun	Cov	Abun	Cov	Abun	Cov	Abun	Cov	Abun
Marginal	Present												
	Reference												
Lower	Present												
	Reference												
Upper	Present												
	Reference												

Figure 4.7 Cover and abundance assessment

Note the following:
The 1st row (illustration of trees) is used for woody abundance (density or number of woody plants).
The 2nd row (illustration of grasses) is used for non-woody abundance (density or amount of non-woody plants)
The 3rd row is used for both woody and non-woody cover (aerial / canopy % cover).

- Using the illustrations as a guide, tick the appropriate cell for present condition abundance of indigenous woody vegetation (this is done again in the next table for non-woody vegetation).
- Tick the appropriate cell for reference conditions (see section 4.7 to help with reconstruction of reference conditions). The rating (value that is entered into

the VEGRAI model) for woody and non-woody vegetation abundance is not determined on the field forms, but is derived using the rating table at the end of the field forms (or in the spreadsheet) at the model population stage (see section 5 for model population).

- If possible provide an indication of the % within the % range.
- Remember: The abundance rating is for indigenous vegetation only. The impact of exotic vegetation is used to derive the reference condition.

4.8.2 Vegetation cover

Cover is rated separately for woody and non-woody vegetation in each zone, and is based on the percentage aerial cover of indigenous vegetation (see section 2.3.3 for definition). The procedure for completing the field forms are the same as for abundance (4.8.1)

- Using the illustrations as a guide, (Fig 4.5) tick the appropriate cell for present condition cover of indigenous woody vegetation (this is done again in the next table for non-woody vegetation).
- Tick the appropriate cell for reference conditions (see section 4.7 to help with reconstruction of reference conditions). The rating (value that is entered into the VEGRAI model) for woody and non-woody vegetation cover is not determined on the field forms, but is derived using the rating table at the end of the field forms (or in the spreadsheet) at the model population stage (see section 5 for model population).

4.8.3 Population structure and Recruitment

Population structure and recruitment are assessed and rated for woody vegetation at level 4 only, and on separate tables for each zone. Use the blank tables provided (one for each zone) (Page 10 in field forms and Table 4.1).

- List the woody indicator species for that zone (indigenous only) in a ranked manner, i.e. the most important indicator first, the next most important second and so on.
- Assign a species weight to each indicator: the highest ranking species will carry a weight of 100, and assign a percentage less than 100 to each successive indicator species which is an estimate of its relative contribution as an indicator. Use a resolution of 5% for experienced users.
- Estimate the relative abundance (%) for each life stage (juvenile, sub-adult & adult) of each indicator species for the present state. Use a resolution of 5% for experienced users.
- Do the same for the reference condition (see section 4.7 to help with reconstruction of reference conditions). Percentage estimates for the three life stages of each species must add to 100 in both present and reference states.
- Construct two simple population curves illustrating life stage proportions for each indicator species (i.e. curve is based on percentages of juveniles, sub-adults and adults) in the present and reference states (e.g. table 4).

- The rating for population structure for each species is based on a visual assessment of the degree of difference between the population curves for present and reference states.
- Record the rating on a scale of 0 to 5 in the table as follows: 0 - Population curves do not differ; 1 - Population curves differ slightly; 2 - Population curves differ moderately; 3 - Population curves differ largely; 4 - Population curves differ seriously; 5 - Population curves differ extremely.
- Use the rating table at the end of the field forms to derive a rating for recruitment for each indicator species. This is done by comparing the % abundance of only juveniles between present and reference states for each indicator species.

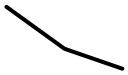
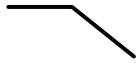
The overall rating for population structure and recruitment (the values which are entered into the model) are calculated in the model by allowing each species weight/rate combination to contribute to the overall weighted rating (see section 5 on populating the model for more detail).

Population curves

The use of population curves makes a visual assessment of population viability easier, and aids interpretation of longer-term population sustainability. For example, a negative-J shaped curve indicates consistent recruitment into the population and sufficient survival to maintain the resilience of the population. A unimodal shaped curve indicates punctuated recruitment, which could be the natural biology of the species, or could be a response to perturbations. Survival to sub-adults and adults may or may not be sufficient for the sustainability of the population. The assessment and rating will be in context of prevalent impacts. An exponential-shaped curve indicates a population that has done well historically, but is in danger of losing sustainability. (Grime, 1979).

Table 4.2 provides an example of a population structure and recruitment table with fabricated data for *Breonadia salicina*, a species used as an indicator of sedimentation of exposed bedrock areas. The population in the marginal zone (M) is shown with a negative J-shaped curve for both present and reference states (a rating of 1 indicating only a slight difference between curves) and a potential score of 0 or 1 for recruitment since present state recruitment is close to what would be expected in the reference state (50% vs 65% respectively). In the lower zone (L) the population curves differ moderately since fewer adults occur in the present state relative to what would be expected in the reference state. Recruitment however, is what it would be in the reference state. In the upper zone (U), the population in the reference state indicates adults that persist, but with relatively little and infrequent recruitment. (only 5% juveniles expected, i.e. population is dominated by adults). In the present state however, recruitment is proportionally higher and adults have not persisted as much as would be expected. The population curves differ seriously with a rating of 4 and recruitment also differs markedly with a potential rating of 3/4 (30% vs 85% for present state and reference state respectively).

Table 4.2 Example of how population structure and recruitment are assessed and measured

Indicator Species (ranked)	Zone	State	Relative abundance (%)			Example curve	Rating of population structure	Rating of recruitment
			Juvenile	Sub-adult	Adult			
1. Breonadia salicina	Marginal	Pres	50	30	20		1	0/1
		Ref	65	25	10			
	Lower	Pres	40	40	20		2	0-1
		Ref	40	30	30			
	Upper	Pres	30	40	30		4	3-4
		Ref	5	10	85			

4.8.4 Species Composition

Species composition is assessed separately for woody and non-woody vegetation as well as for each zone (i.e. 6 level 3 ratings and 6 level 4 tables). One of the Level 4 tables is illustrated in Table 4.2. The process for level 4 is as follows:

- Allow exotic species to exert an impact by listing “all exotics” as your first “species” and estimating the % of space utilized by exotics, i.e. this represents the proportion of the site that is no longer available for indigenous species, and hence impacts indigenous species composition
- List indigenous indicator species in a ranked manner as before with population structure (record the most important species as 1, the second as 2 and so on). All non-indicator species are lumped into one group called “rest” and are given the lowest rank.
- Assign a weight to each species (include the “rest” group which is treated as a species). Species 1 will always have a weighting of 100, species 2 of less than 100 and so on (range from 0 to 100). Note that the weights are not

relative and do not add to 100; they simply indicate the proportional contribution of each indicator species to overall species composition assessment of ranking and weighting considerations.

- Record the relative abundance (%) for each species (including “rest”) in the present state for the marginal zone. Note that it is relative so all scores for the present state need to add to 100.
- Estimate the relative abundance (%) for each species in the reference state. Again, scores are relative and need to add to 100. Do the same for the lower and the upper zones.
- Derive the rating (0-5 as before) for each species (including “rest”) by comparing % values for present vs reference states for each species. Use the rating table of % comparisons at the end of the field forms as a guide.
- The overall rating for woody and non-woody species composition is calculated in the model by allowing each species weight/rate combination to calculate the weighted rating.

Table 4.3 Species composition table (Level 4 only)

Species	Weight	State	Marginal %	Rating (Marginal)	Lower %	Rating (Lower)	Upper %	Upper (rating)
1. all exotics		(P)res						
		(R)ef						
2. sp 1		P						
		R						
3. sp2		P						
		R						

4.9 STORING FIELD FORM DATA

All the field form data must be transferred to the VEGRAI Excel spreadsheet (see populating the model below).

5 POPULATING THE MODEL

Model population is the transferral of data on data sheets to the VEGRAI spreadsheet model.

5.1 LEVEL 3 USERS

The VEGRAI model has various worksheets (Reference State, Marginal Zone, Non Marginal Zone, Riparian Zone EC, and Rating Guide). Worksheets are the same for the different riparian zones. Complete the marginal zone and repeat for the non-marginal zone.

5.1.1 Reference State Reconstruction

- Indicate the dominant state (using the diagram in the model) for the PRESENT conditions, for each ZONE. (any particular state may be a mix of dominant states, e.g. tree & shrub dominated state, or reed & open dominated state, etc.)
- Describe the PRESENT state for each zone. Try to be specific about observed impacts at the site, and how response metrics have been affected by these impacts, i.e. describe the vegetation state with reference to its response to impacts
- Describe what you think the REFERENCE state for each zone would be. Try to imagine what the vegetation would be like if both the impacts you observe and the vegetation response to past impacts had not taken place, i.e. were replaced with "natural" disturbance only. Try to be specific about the characteristics of response metrics when no "unnatural" disturbances have taken place, i.e. describe the vegetation state with reference to its response to regimes uninfluenced by humans
- Indicate the dominant state (using the diagram in the model) for the REFERENCE conditions, for each ZONE. (any particular state may be a mix of dominant states, e.g. tree & shrub dominated state, or reed & open dominated state, etc.

5.1.2 Impact evaluation

- Type in overall ratings for each impact (removal, exotic invasion, water quantity, water quality). This information is obtained from the field forms. Use the intensity rating in the 'overall rating' cell in the field forms.
- Record confidence levels in the applicable spaces. The scale is as follows:
  1 - Low confidence (derived / scarce data).
  2 - low to medium confidence;
  3 - medium confidence;
  4 - medium to high confidence;

5 - high confidence (observed and good ecological knowledge).

5.1.3 Response metric: Cover and abundance

- Use the rating table of % comparisons in the model or at the end of the field forms to derive ratings for both woody and non-woody vegetation as follows: Compare the reference condition % with the present condition % to obtain a rating range. For example, if the reference % falls in the 40 - 60% range (indicated in the field forms as 50%) and the present % falls in the 60 - 80% range (indicated in the field forms as 60%), the rating would be 1-2. As the actual change is only 50% to 60%, the rating would be 1. Note that ratings such as 1.5, 2.5, etc. are acceptable.
- Provide any motivation or comments in comment blocks
- Provide confidences according to the 1-5 scale

5.1.4 Response metric: Species composition

- Species composition for Level 3 users is only undertaken in terms of impacts from exotics or very obvious selective vegetation removal.
- Simply transfer ratings from the field forms to the appropriate space in the model
- Examples are when exotics have replaced most of the key species that would have occurred under reference conditions. Note that if exotics are used as the key impact for changes in species condition, then the rating used for changes in species composition must relate to the exotic rating on the field forms.
- Provide any motivation or comments in comment blocks
- Provide confidences according to the 1-5 scale

5.1.5 On-off switches

- Response metrics can be switched on or off. All response metrics are switched on by default. Each response metric may be switched off by entering “n” or “N”.
- A response metric is switched off if a rating is not possible. All n/N entries require an explanation, e.g. response metrics for non-woody vegetation may be switched off in the marginal zone because inundation prohibited assessment.
- Cover and abundance is mandatory and must be completed for both level 3 and 4.

Switching off vegetation components

If a vegetation component (woody and non-woody) exists at a site (present state) **OR** should have existed at a site (reference state) then it should NOT be switched off. If a vegetation component does not exist at a site (present) **AND** is not expected to have existed at the site (reference), then it MUST be turned off rather than rating the metrics, e.g. if the reference condition for the site is grassveld with no woodies present, then woody must be switched off as it should not be evaluated.

Switching off metrics

Metrics are switched off due to circumstances that prevent their assessment such as a lack of knowledge, available information, understanding, or inundation of a riparian zone due to flooding.

5.1.6 Vegetation components weighting process

- Consider whether either woody and non-woody vegetation components need to be switched off (both are switched on by default).
- Switching a vegetation component off will remove its contribution to the calculation of the EC, e.g. the woody vegetation component would be switched off if the site occurs on a river flowing through highveld grassland.
- Rank the woody and non-woody vegetation components (in the marginal zone) in terms of their importance to instream habitat creation and maintenance. Rank the most important component as 1. The next will be ranked as 2. Note that if components are of equal importance, they are ranked the same.
- Assign a weight of 100% to the component that was ranked as 1. Assign a weight to the 2nd ranked component (0-100) that indicates its contribution relative to the 1st ranked component. If, e.g. the 2nd ranked component is still very important, a weight of for example 90% can be allocated.

5.1.7 Determining the Riparian zone EC

- Open the worksheet labelled “RIP ZONE EC”.
- Rank the marginal and non-marginal zone in terms of their importance to instream habitat creation and maintenance (cf 2.4.2) The most important zone will be ranked as 1 and the other as 2. Assign weights in the same way as before.(cf 5.1.5)
- VEGRAI will automatically calculate the riparian zone EC once each zone has been ranked and weighted.

Ranking and weighting is important and can influence the outcome of VEGRAI. It also affords users the flexibility to over- or underplay certain components of the riparian zone. For, e.g. by ranking and weighting, the user can show that non-woody vegetation is important in the marginal zone (reeds), woody vegetation (trees and shrubs) is important in the lower zone, and that the upper zone is unimportant to the calculation of the EC under reference conditions.

5.2 LEVEL 4 USERS

The VEGRAI model has various worksheets (Reference State, Marginal Zone, Lower Marginal Zone, Upper Zone, Riparian Zone EC, Rating Guide, Pop Structure & Recruitment, Species Composition). Worksheets are the same for the different riparian zones. Complete the marginal zone and repeat for the lower and upper zones.

5.2.1 Reference State Reconstruction

- Indicate the dominant state (using the diagram in the model) for the PRESENT conditions, for each ZONE. (any particular state may be a mix of dominant states, e.g. tree & shrub dominated state, or reed & open dominated state, etc.)
- Describe the PRESENT state for each zone. Try to be specific about observed impacts at the site, and how response metrics have been affected by these impacts, i.e. describe the vegetation state with reference to its response to impacts
- Describe what you think the REFERENCE state for each zone would be. Try to imagine what the vegetation would be like if both the impacts you observe and the vegetation response to past impacts had not taken place, i.e. were replaced with "natural" disturbance only. Try to be specific about the characteristics of response metrics when no "unnatural" disturbances have taken place, i.e. describe the vegetation state with reference to its response to regimes uninfluenced by humans
- Indicate the dominant state (using the diagram in the model) for the REFERENCE conditions, for each ZONE. (any particular state may be a mix of dominant states, e.g. tree & shrub dominated state, or reed & open dominated state, etc.

5.2.2 Impact evaluation

- Type in overall ratings for each impact (removal, exotic invasion, water quantity, water quality). This information is obtained from the field forms. Use

the intensity rating in the 'overall rating' cell in the field forms.

- Record confidence levels in the applicable spaces.

The scale is as follows:

– 1 - Low confidence (derived / scarce data).
– 2 - low to medium confidence;
– 3 - medium confidence;
– 4 - medium to high confidence;
– 5 - high confidence (observed and good ecological knowledge).

5.2.3 Response metric: Cover and abundance

- Use the rating table of % comparisons in the model or at the end of the field forms to derive ratings for both woody and non-woody vegetation as follows:
- Compare the reference condition % with the present condition % to obtain a rating range. For example, if the reference % falls in the 40 - 60% range (indicated in the field forms as 50%) and the present % falls in the 60 - 80% range (indicated in the field forms as 60%), the rating would be 1-2. As the actual change is only 50% to 60%, the rating would be 1. Note that ratings such as 1.5, 2.5, etc. are acceptable.
- Provide any motivation or comments in comment blocks
- Provide confidences according to the 1-5 scale

5.2.4 Response metric: Population structure & recruitment

- Use the worksheet labelled “Population Structure & Recruitment” to capture field form data.
- Transfer species names, rankings, weightings, life stage relative abundance (%) (for juveniles, sub-adults and adults), and ratings for both population structure and recruitment from field forms to the spreadsheet.
- The overall rating (or weighted rating) for population structure and recruitment is automatically calculated from population structure data for woody and non-woody vegetation in all 3 zones.
- Provide any motivation or comments in comment blocks
- Provide confidences according to the 1-5 scale

5.2.5 Response metric: Species composition

- Allow exotic species to exert an impact by listing “all exotics” as your first “species” and estimating the % of space utilized by exotics, i.e. this represents the proportion of the site that is no longer available for indigenous species, and hence impacts indigenous species composition
- Transfer species names, rankings, weightings, relative abundance (%) and ratings from field forms to the spreadsheet.
- The overall rating (or weighted rating) is automatically calculated from species composition data for woody and non-woody vegetation in all 3 zones.

- Provide any motivation or comments in comment blocks
- Provide confidences according to the 1-5 scale

5.2.6 On-off switches

- Response metrics can be switched on or off. All response metrics are switched on by default. Each response metric may be switched off by entering "n" or "N".
- A response metric is switched off if a rating is not possible. All n/N entries require an explanation, e.g. response metrics for non-woody vegetation may be switched off in the marginal zone because inundation prohibited assessment.
- Cover and abundance is mandatory and must be completed for both level 3 and 4.

Switching off vegetation components

If a vegetation component (woody and non-woody) exists at a site (present state) **OR** should have existed at a site (reference state) then it should NOT be switched off. If a vegetation component does not exist at a site (present) **AND** is not expected to have existed at the site (reference), then it MUST be turned off rather than rating the metrics, e.g. if the reference condition for the site is grassveld with no woodies present, then woody must be switched off as it should not be evaluated.

Switching off metrics

Metrics are switched off due to circumstances that prevent their assessment such as a lack of knowledge, available information, understanding, or inundation of a riparian zone due to flooding.

5.2.7 Vegetation components weighting process

- Consider whether either woody or non-woody vegetation components need to be switched off (both are switched on by default).
- Switching a vegetation component off will remove its contribution to the calculation of the EC, e.g. the woody vegetation component would be switched off if the site occurs on a river flowing through highveld grassland.
- Rank the woody and non-woody vegetation components (in the marginal zone) in terms of their importance to instream habitat creation and maintenance. Rank the most important component as 1. The next will be ranked as 2. Note that if components are of equal importance, they are ranked the same.
- Assign a weight of 100% to the component that was ranked as 1. Assign a weight to the 2nd ranked component (0-100) that indicates its contribution relative to the 1st ranked component. If, e.g. the 2nd ranked component is still

very important, a weight of for example 90% can be allocated.

5.2.8 Determining the riparian zone EC

- Open the worksheet labelled “RIP ZONE EC”.
- Rank the marginal, lower and upper zone in terms of their importance to instream habitat creation and maintenance (cf 2.4.2). The most important zone will be ranked as 1 and the other as 2. Assign weights in the same way as before.(cf 5.1.5)
- VEGRAI will automatically calculate the riparian zone EC once each zone has been ranked and weighted.

Ranking and weighting is important and can influence the outcome of VEGRAI. It also affords users the flexibility to over- or underplay certain components of the riparian zone. For, e.g. by ranking and weighting, the user can show that non-woody vegetation is important in the marginal zone (reeds), woody vegetation (trees and shrubs) is important in the lower zone, and that the upper zone is unimportant to the calculation of the EC under reference conditions.

6 VEGRAI: PREDICTIVE USES

Using the VEGRAI spreadsheet model, it is possible to make some qualitative predictions as to how the riparian vegetation is likely to respond when changes in driver components, and specifically particular driver metrics, occur. Essentially these predictions are scenario assessments and will be of a conceptual nature, with low confidence of how close to reality they actually are.

The question could, for instance, be asked as to how the riparian vegetation in a particular river would react if flow characteristics were changed. An example scenario would be to assess the impacts of a new dam on downstream riparian vegetation status. One could provide qualitative or quantitative descriptions of altered flow due to the dam. Using VEGRAI, one would assess the differences between the present state (before the dam) and the predicted future state under scenario conditions. The reference state would remain the same and VEGRAI would be used in the same way as before, but using the predicted future state. The difference between the two outputs would give some indication of what the impacts of the dam would be for vegetation. When applying VEGRAI 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.

7 VEGRAI: USES WITHIN ECOLOGICAL RESERVE MONITORING

7.1 ECOSPECS AND THRESHOLDS OF PROBABLE CONCERN (TPC)

Ecological specifications (EcoSpecs) were initially developed and specified in terms of the Resource Quality Objectives (RQOs) as per the Resource Directed Measures (RDM) (Kleynhans & Louw, 2006).

The purpose of RQOs is the following:

- To establish clear goals relating to the resource quality of the relevant water resources.
- Where resources for instance need a high level of protection, a strict set of objectives that will represent a low risk of damage, will be set.
- There is an implicit understanding that once the management class of a water resource has been decided, the objectives for protection of basic human needs and ecological integrity take precedence in cases where the objectives for other uses, or for impacts, may conflict with the requirements for protection.

The critical components of the RQOs are:

- Requirements for water quantity, stated as flow requirements for a river reach or estuary, and/or water level requirements for standing water or ground water, and/or requirements for groundwater level in order to maintain spring flow and base flow in rivers and other ecological features.
- Requirements for water quality (chemical, physical, and biological characteristics of the water).
- Requirements for habitat integrity, which encompass the physical structure of in-stream and riparian habitats, as well as the vegetation aspects.
- Requirements for biotic integrity that reflect the health, community structure and distribution of aquatic biota. The RQOs must further be quantifiable, measurable, verifiable, and enforceable and ensure protection of all components of the resource, which make up ecological integrity.

EcoSpecs are derived from RQOs and are clear and measurable specifications of ecological attributes (e.g. water quality, flow, biological integrity) that define the Ecological Category and serve as an input to Resource Quality Objectives. EcoSpecs refer explicitly and only to ecological information whereas RQOs include economic and social objectives (Kleynhans & Louw, 2006).

Determination of EcoSpecs is based on ecological specifications for different metric groups and metrics. This means that in VEGRAI EcoSpecs will be based on vegetation cover and abundance for level 3 assessments, and on cover, abundance,

population structure, recruitment and species composition for level 4 assessments. (see Table 7.1. for examples of VEGRAI EcoSpecs)

Table 7.1. Example of Riparian Vegetation EcoSpecs and TPCs (Louw & Koekemoer, 2006)

Metric group	Metric	EcoSpecs	TPCs
Marginal zone	Vegetation cover	Maintain existing cover (between 40 and 50%) of indigenous marginal species in the marginal zone	Reduction in existing cover (<35%) of indigenous marginal species in marginal zone
		Tolerate or reduce existing cover (5%) of exotic species in marginal zone.	Increased cover (>5%) of exotic species in marginal zone.
Lower zone	Vegetation cover	Maintain existing vegetation cover (between 20 and 35%) of riparian species in the lower zone.	Reduction in existing cover (<10%) of indigenous riparian species in lower zone.
		Tolerate or reduce existing cover (5%) of exotic species in lower zone.	Increased cover (>5%) of exotic species in lower zone.
Upper zone	Vegetation cover	Maintain existing cover (10 - 15%) of indigenous riparian species in the upper zone.	Reduction in existing cover (<10 %) of indigenous riparian species in the upper zone.
		Tolerate or reduce existing cover (50 - 60%) of exotic species in upper zone.	Increased cover (>60 %) of exotic species in upper zone.

7.2 THRESHOLDS OF PROBABLE CONCERN

TPCs are upper and lower levels along a continuum of change in selected environmental indicators. When this level is reached (or when modelling predicts it will be reached), it prompts an assessment of the causes of the extent of the change. The assessment provides the basis for deciding whether management action is needed or recalibrates the TPC. TPCs provide management with strategic goals or endpoints within which to manage the system. They form the basis of an inductive approach to adaptive management, as they are invariably hypotheses of limits of acceptable change in ecosystem structure, function and composition. As such their validity and appropriateness are always open to challenge and they must be adaptively modified as understanding and experience of the system being managed increases" (Rogers & Bestbier, 1997).

TPCs are meant to provide an early warning that EcoSpecs are in a danger of being exceeded and that the REC may not be achieved or maintained. TPCs can be formulated in terms of particular metrics that have to be selected based on their information value. TPCs for VEGRAI should be measurable and quantitative as far as possible. The most sensitive indicator species should be used to assess TPC status. (see Table 7.1. for examples of VEGRAI TPCs)

8 REFERENCES

Allan, D.J (2004) Landscapes and Riverscapes. The influence of Land use on Stream Ecosystems Annu Rev Ecol Evol Syst 2004 35:257-84

Anon. (2002) Riparian Areas Functions and Strategies for management. Committee on Riparian zone functioning and strategies for management. Water Science and Technology Board. Board on Environmental Studies and Toxicology. Division on Earth and Life Studies, National Research Council, National Academy Press. Washington D.C.

Auble, G.T., Scott, M.L. (1998). Fluvial disturbance patches and Cottonwood recruitment along the upper Missouri River, Montana. *Wetlands* **18**:546-556.

Cagney, J. (1993). Riparian Area Management: Greenline riparian-wetland monitoring. Technical Reference 1737-8 U.S. Department of the Interior.

Friedman, J.M., Scott, M.L., Lewis, W.M. Jnr. (1995). Restoration of riparian forest using irrigation, artificial disturbance, and natural seedfall. *Environmental Management.* 19 (4): 547-557.

Friedman, J.M., Auble, G.T. (1999). Mortality of riparian Box Elder from sediment mobilization and extended inundation. *Regulated Rivers: Research and Management* 15: 463-476.

Grime, J.P. (1979). Plant Strategies and Vegetation Processes. Wiley, Chichester.

Haefner, J.W. (1996). *Modeling biological systems: principles and applications.* Chapman & Hall. New York.

Hupp, C.R., Osterkamp, W.R. (1985). Bottomland vegetation distribution along Passage Creek, Virginia, in relation to fluvial landforms. *Ecology* 66:670-681.

Hupp, C.R., Osterkamp, W.R. (1996). Riparian vegetation and fluvial geomorphic processes. *Geomorphology* 14:277-295.

Joubert, A, (2004) The ecostatus project and multicriteria decision analysis: Report and background. Dept of Statistics. University of Cape Town. Prepared for DWAF, RQS.

Kemper, NP (2001) RVI Riparian vegetation Index. WRC Report no 850/3/01.

Kleynhans, CJ (1996) A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu river (Limpopo system, South Africa). Journal of Aquatic Ecosystem Health 5: 41-54

Kleynhans, CJ (1999). The development of a fish index to assess the biological integrity of South African rivers. Water SA 25: 265-278

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

Kleynhans, C.J., Louw M.D. (2006). Ecological Reserve Monitoring: Preliminary Generic Guidelines. With contributions by: C Thirion, P Scherman, N Muller, D Hughes, L du Preez and K Rowntree. Draft report, DWAF, ROS and Water for Africa.

Louw, MD, Hughes, DA (2002). Prepared for the Department of Water Affairs and Forestry, South Africa. Resource Directed Measures for Protection of Water Resources: River Ecosystems - Revision of a quantity component.

Louw, MD, Koekemoer, S (2006). Kat River Determination Study – Technical component. Monitoring report. Unpublished to the WRC, IWR, Rhodes University, Grahamstown.

MacKenzie, J.A.; van Coller, A.L. & Rogers, K.H. (1999). *Rule Based Modelling for Management of Riparian Systems.* Water Research Commission, Pretoria.

Noss, R.F. (1990). Indicators for monitoring biodiversity: A hierarchical approach. *Conservation Biology* **4:**355-364.

O'Neil, R.V., Gardner, R.H. (1979). Sources of uncertainty in ecological models. In: *Methodology in Systems Modelling and Simulation.* (Eds Zeigler, B.P; Elza, M.S.; Klir, G.J. & Oren, T.I.). North-Holland Press. Amsterdam.

Scott, M.L., Friedman, J.M., Auble, G.T. (1996). Fluvial processes and the establishment of bottomland trees. *Geomorphology.* 14: 327-339.

Starfield, A.M. & Bleloch, A.L. (1991). *Building Models for Conservation and Wildlife Management*. Burgess International Group Inc. Minnesota, USA.

Van Coller, A.L.; Rogers, K.H. & Heritage, G.L. (1997). Linking riparian vegetation types and fluvial geomorphology along the Sabie River within the Kruger National

Park, South Africa. *African Journal of Ecology* **35**:194-212.

Van Niekerk, A.W., Heritage, G.L. (1993). *Geomorphology of the Sabie River: Overview and Classification.* Report No: 2/93, Centre for Water in the Environment, University of the Witwatersrand: Johannesburg.

Wohl, E., Rathburn, S, (2003). International Journal of sediment research. VOL 18: PART 2, pages 97 - 106

APPENDIX A: FIELD FORMS

Assessor:_____
River:_____
Latitude (E): _____
Longitude (S):_____
Quaternary Catchment: _____
Date:_____

Longitudinal boundary of site
Description:
RIPARIAN VEGETATION ZONES: MARGINAL
Description
RIPARIAN VEGETATION ZONES: NON MARGINAL (split into **lower** and **upper** for level 4)
Description
PLAN VIEW and CROSS SECTION

SPECIES LIST

(Focus on key / indicator / dominant / easily identifiable species - maximum 10 - 15 species per zone)

L = Lower, U = Upper,   W = woody, NW = Non-woody

Tick applicable zone. If non-marginal, complete only the L column

SPECIES	MARGINAL		NON MARGINAL			
	W	NW	L: W	L: NW	U: W	U: NW

LANDUSE AND IMPACT EVALUATION

MARGINAL ZONE: SURROUNDING AND UPSTREAM LAND USE (any land use that causes an impact on the VEGRAI site)						
LANDUSE	**IMPACTS**					
	Rating: 0 (no impact) - 5 (severe impact)					
	REMOVAL		**QUANTITY**		**QUALITY**	
	INT	**EXT**	**INT**	**EXT**	**INT**	**EXT**
Nature reserve, game farming, natural areas						
Picnic site/recreational area						
Subsistence (rural) farming (not stock)						
Stock farming						
Firewood, reed, medicinal plant utilisation						
Forestry						
Irrigation farming (formal) crops						
Residential, urban						
Residential, rural						
Large dams						
Weirs and farm dams						
Mining, quarrying (including obsolete)						
Sewerage treatment and releases						
Infrastructure (formal roads)						
Infrastructure (vehicle tracks)						
Infrastructure (rails)						
Infrastructure (foot- and livestock paths)						
Rubbish Dumping						
Industrial						
Other: Specify						
OVERALL RATING (representative of the maximum rating above)						
CONFIDENCE						

NOTES:

NON-MARGINAL OR LOWER ZONE: SURROUNDING AND UPSTREAM LAND USE (any land use that is causes an impact on the VEGRAI site)						
LANDUSE	**IMPACTS**					
	Rating: 0 (no impact) - 5 (severe impact)					
	REMOVAL		**QUANTITY**		**QUALITY**	
	INT	**EXT**	**INT**	**EXT**	**INT**	**EXT**
Nature reserve, game farming						
Natural areas						
Picnic site/recreational area						
Subsistence (rural) farming						
Stock farming						
Forestry						
Irrigation farming (formal) crops						
Residential, urban						
Residential, rural						
Large dams						
Weirs and farm dams						
Mining, quarrying (including obsolete)						
Sewerage treatment and releases						
Infrastructure (formal roads)						
Infrastructure (vehicle tracks)						
Infrastructure (rails)						
Infrastructure (foot- and livestock paths)						
Rubbish Dumping						
Industrial						
Other: Specify						
OVERALL RATING (representative of the maximum rating above)						
CONFIDENCE						

NOTES:

UPPER ZONE (LEVEL 4 ONLY): SURROUNDING AND UPSTREAM LAND USE (any land use that is causes an impact on the VEGRAI site)						
LANDUSE	**IMPACTS**					
	Rating: 0 (no impact) - 5 (severe impact)					
	REMOVAL		**QUANTITY**		**QUALITY**	
	INT	**EXT**	**INT**	**EXT**	**INT**	**EXT**
Nature reserve, game farming						
Natural areas						
Picnic site/recreational area						
Subsistence (rural) farming						
Stock farming						
Forestry						
Irrigation farming (formal) crops						
Residential, urban						
Residential, rural						
Large dams						
Weirs and farm dams						
Mining, quarrying (including obsolete)						
Sewerage treatment and releases						
Infrastructure (formal roads)						
Infrastructure (vehicle tracks)						
Infrastructure (rails)						
Infrastructure (foot- and livestock farms)						
Rubbish Dumping						
Industrial						
Other: Specify						
OVERALL RATING (representative of the maximum rating above)						
CONFIDENCE						

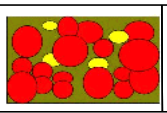
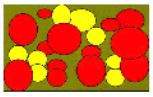
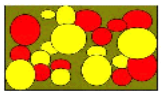
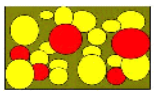
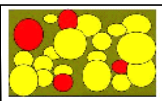
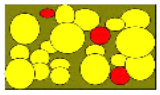
NOTES:

EXOTIC INVASION

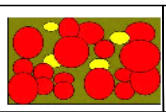
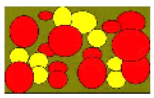
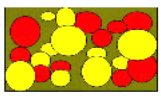
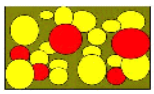
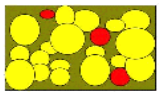
Use COVER of alien vegetation compared to indigenous vegetation to provide an estimate of the proportional invasion as a percentage according to the range below.
(Red or Dark Grey if printed on a black and white printer = exotics) (Figure Supplied by Douglas Macfarlane) check spelling

Use the rating table at the end of the field form to determine the rating. Note that the reference conditions will always be zero in this case. (delete last 2 rows in each table below and provide a single space for zone rating)

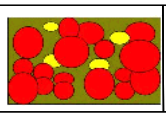
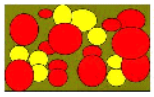
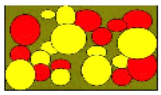
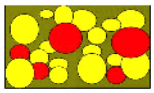
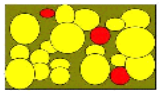
MARGINAL

INVASION BY EXOTICS						
Red/dark grey circles representing aliens						
COVER of aliens	100-80%	80 - 60%	60-40%	40-20%	20-10%	<10%
Indicate (X)						

LOWER

INVASION BY EXOTICS						
Red/dark grey circles representing aliens						
COVER of aliens	100-80%	80 - 60%	60-40%	40-20%	20-10%	<10%
Indicate (X)						

UPPER

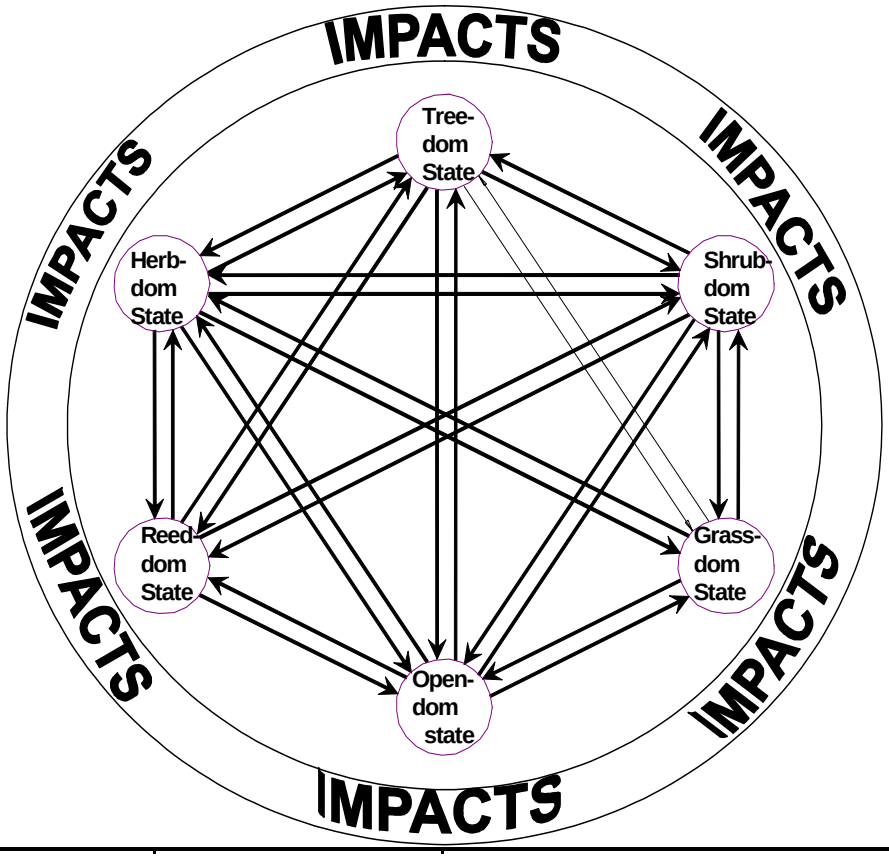
INVASION BY EXOTICS						
Red/dark grey circles representing aliens						
COVER of aliens	100-80%	80 - 60%	60-40%	40-20%	20-10%	<10%
Indicate (X)						

EXOTIC VEGETATION	Marginal		Non-marginal			
			Lower		Upper	
(indicate with a tick)						
Species:						
	Int	Ext	Int	Ext	Int	Ext
EXOTIC VEGETATION: OVERALL RATING (Use rating in figures above for Intensity)						

This Table for Level 3 users only.
User information compiled on exotic vegetation to derive the potential impact on species composition. Provide a rating of 0 – 5 in the Marginal and Non – Marginal columns and provide a motivation in the comments block.

Species Composition			
Vegetation Components	**Marginal rating**	**Non Marginal rating**	**Comment**
Woody			
Non Woody			

REFERENCE CONDITIONS

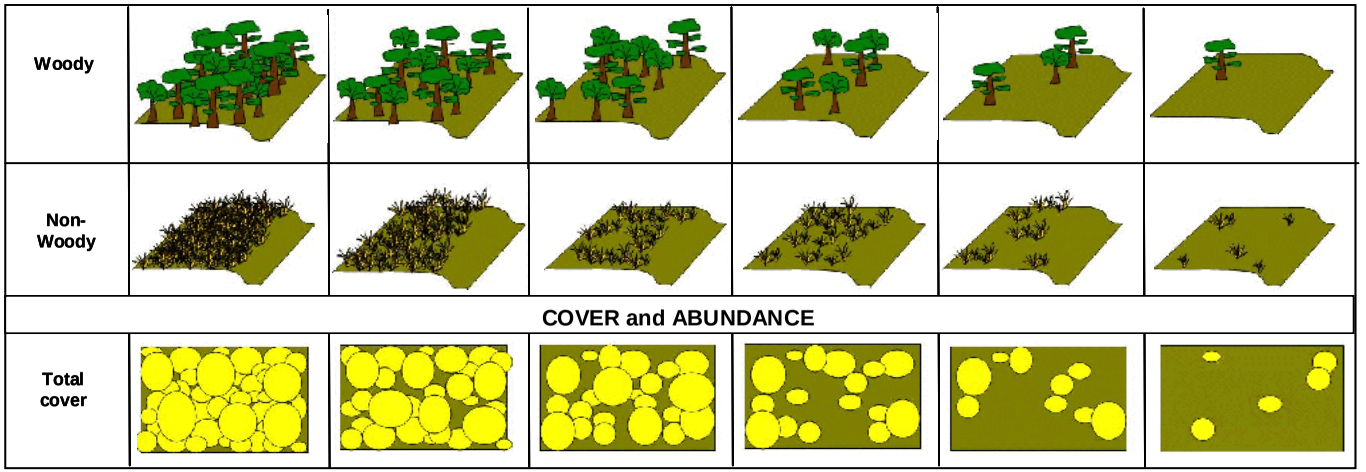


IMPACTS TO REMOVE	RESPONSE METRIC	DESCRIPTION OF STATE CHANGE (In all descriptions try to make reference to zones and states outlined in Fig. #2)
Vegetation removal	Cover	
	Abundance	
	Population structure	
	Recruitment	
	Species composition	
Exotic invasion	Cover	
	Abundance	
	Population structure	
	Recruitment	
	Species composition	
Water quantity	Cover	
	Abundance	
	Population structure	
	Recruitment	
	Species composition	
Water quality	Cover	
	Abundance	
	Population structure	
	Recruitment	
	Species composition	

ABUNDANCE AND COVER:

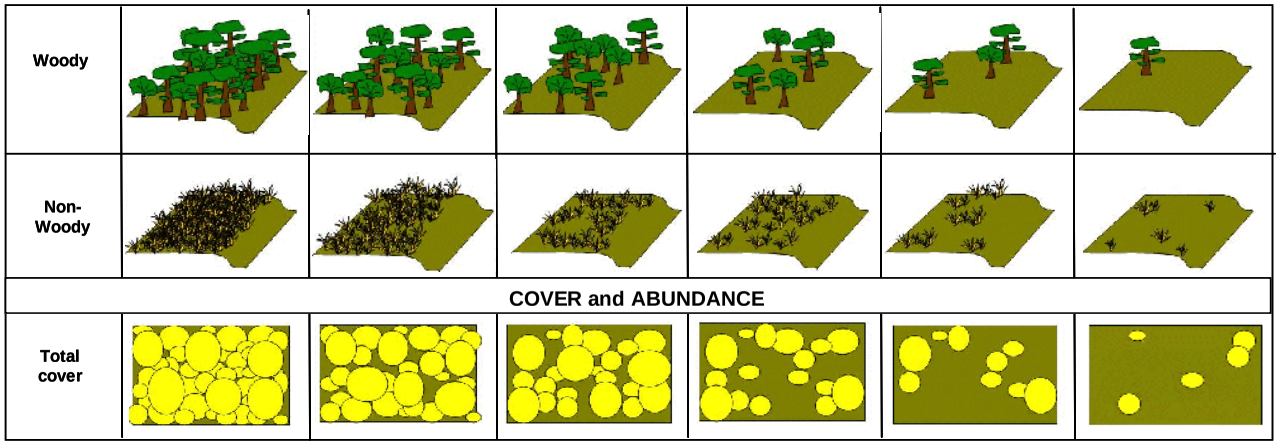
Use the top two rows (woody and non-woody) to assess abundance and the third row (circles) to assess cover Tick the appropriate cell for present condition of INDIGENOUS VEGETATION. If possible, indicate the percentage in the range where you think it lies. Then, derive reference conditions using the reference conditions guide at the end of the forms and indicate which percentage range represents reference condition. Using the rating table at the end of the document, determine the appropriate rating to populate the model. ((Figure Supplied by Douglas Macflardane)

WOODY



		100 - 80%		80 - 60%		60 - 40%		40 - 20%		20 - 10%		<10%	
		Cov	Abun	Cov	Abun	Cov	Abun	Cov	Abun	Cov	Abun	Cov	Abun
Marginal	Present												
	Reference												
Lower	Present												
	Reference												
Upper	Present												
	Reference												

NON-WOODY



		100 - 80%		80 - 60%		60 - 40%		40 - 20%		20 - 10%		<10%	
		Cov	Abun	Cov	Abun	Cov	Abun	Cov	Abun	Cov	Abun	Cov	Abun
Marginal	Present												
	Reference												
Lower	Present												
	Reference												
Upper	Present												
	Reference												

RECRUITMENT AND POPULATION STRUCTURE: MARGINAL - WOODY (Level 4 only)

0 - Population curves don't differ. 1 - Population curves differ slightly. 2 - Population curves differ moderately 3 - Population curves differ largely 4 - Population curves differ seriously 5 - Population curves differ extremely

Indicator Species (ranked)	Species weight	State	Relative abundance (%)			Population curve	Rating of population structure	Rating of recruitment
			Juvenile	Sub-adult	Adult			
1.		Pres						
		Ref						
2		Pres						
		Ref						
3.		Pres						
		Ref						
4.		Pres						
		Ref						
5.		Pres						
		Ref						
6.		Pres						
		Ref						
7.		Pres						
		Ref						
8.		Pres						
		Ref						

RECRUITMENT & POPULATION STRUCTURE: LOWER - WOODY
(Level 4 only)

0 - Population curves don't differ. 1 - Population curves differ slightly. 2 - Population curves differ moderately 3 - Population curves differ largely. 4 - Population curves differ seriously 5 - Population curves differ extremely

Species (ranked)	Species weight	State	Relative abundance (%)			Example curve	Rating of population structure	Rating of recruitment
			Juvenile	Sub-adult	Adult			
1.		Pres						
		Ref						
2		Pres						
		Ref						
3.		Pres						
		Ref						
4.		Pres						
		Ref						
5.		Pres						
		Ref						
6.		Pres						
		Ref						
7.		Pres						
		Ref						
8.		Pres						
		Ref						

RECRUITMENT & POPULATION STRUCTURE: UPPER - WOODY
(Level 4 only)

0 - Population curves don't differ 1 - Population curves differ slightly 2 - Population curves differ moderately. 3 - Population curves differ largely. 4 - Population curves differ seriously 5 - Population curves differ extremely

Species (ranked)	Species weight	State	Relative abundance (%)			Example curve	Rating of population structure	Rating of recruitment
			Juvenile	Sub-adult	Adult			
1.		Pres						
		Ref						
2		Pres						
		Ref						
3.		Pres						
		Ref						
4.		Pres						
		Ref						
5.		Pres						
		Ref						
6.		Pres						
		Ref						
7.		Pres						
		Ref						
8.		Pres						
		Ref						

SPECIES COMPOSITION: WOODY (Level 4 only)

Species	Weight	State	Marginal %	Rating (Marginal)	Lower %	Rating (Lower)	Upper %	Upper (rating)
1.		(P)res						
		(R)ef						
2.		P						
		R						
3.		P						
		R						
4.		P						
		R						
5.		P						
		R						
6.		P						
		R						
7.		P						
		R						
8.		P						
		R						
9.		P						
		R						
10.		P						
		R						
All the rest (see list)		P						
		R						
Total PRESENT								
Total REFERENCE			100		100		100	

SPECIES COMPOSITION: NON-WOODY (Level 4 only)

Species	Weight	State	Marginal %	Rating (Marginal)	Lower %	Rating (Lower)	Upper %	Upper (rating)
1.		(P)res						
		(R)ef						
2.		P						
		R						
3.		P						
		R						
4.		P						
		R						
5.		P						
		R						
6.		P						
		R						
7.		P						
		R						
8.		P						
		R						
9.		P						
		R						
10.		P						
		R						
All the rest (see list)		P						
		R						
Total PRESENT								
Total REFERENCE			100		100		100	

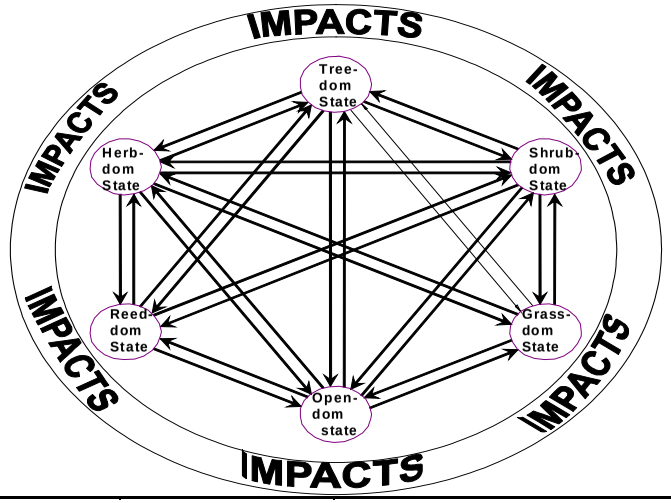
RATING GUIDE

		REFERENCE (%)					
		80-100	60-80	40-60	20-40	20-10	<10
PRESENT %	80-100	0-1	1-2	2-3	3-4	4-5	5
	60-80	1-2	0-1	1-2	2-3	3-4	4-5
	40-60	2-3	1-2	0-1	1-2	2-3	3-4
	20-40	3-4	2-3	1-2	0-1	1-2	2-3
	20-10	4-5	3-4	2-3	1-2	0-1	1-2
	<10	5	4-5	3-4	2-3	1-2	0-1

EXOTIC INVASION		REFERENCE 0%
PRESENT %	80-100	5
	60-80	4-5
	40-60	3-4
	20-40	2-3
	10-20	1-2
	<10	0-1

APPENDIX B: VEGRAI MODEL: LEVEL 3

Reference State



WHAT TO DO
1) Indicate the dominant state (using the diagram) for the PRESENT conditions, for each ZONE. (any particular state may be a mix of dominant states e.g. tree & shrub dominated state, or reed & open dominated state etc)
2) Describe the PRESENT state for each zone. Try to be specific about observed impacts at the site, and how response metrics have been affected by these impacts i.e. describe the vegetation state with reference to its response to impacts
3) Describe what you think the REFERENCE state for each zone would be. Try to imagine what the vegetation would be like if both the impacts you observe and the vegetation response to past impacts had not taken place i.e were replaced with "natural" disturbance only. Try to be specific about the characteristics of response metrics when no "unnatural" disturbances have taken place i.e. describe the vegetation state with reference to its response to regimes uninfluenced by humans
4) Indicate the dominant state (using the diagram) for the REFERENCE conditions, for each ZONE. (any particular state may be a mix of dominant states e.g. tree & shrub dominated state, or reed & open dominated state etc

Zones	Impacts	Response Metrics	Description of PRESENT STATE	Description of REFERENCE STATE
Marginal	Vegetation Removal Exotic Vegetation Water Quantity Water Quality	Cover Abundance Species Composition		
Non-marginal	Vegetation Removal Exotic Vegetation Water Quantity Water Quality	Cover Abundance Species Composition		

Marginal Zone

	MODIFICATION RATINGS			
CAUSES OF MODIFICATION	**INTENSITY**	**EXTENT**	**CONFIDENCE**	**NOTES: (give reasons for each assessment)**
REMOVAL				
EXOTIC INVASION				
WATER QUANTITY				
WATER QUALITY				
AVERAGE			#DIV/0!	

		RESPONSE METRIC RATINGS					
VEGETATION COMPONENTS	**RESPONSE METRIC**	**CONSIDER? (Y/N)**	**RATING**	**CONFIDENCE**	**NOTES: (give reasons for each assessment)**		
WOODY	COVER	Y					
	ABUNDANCE	Y					
	SPECIES COMPOSITION	Y					
			0.0	0.0			
NON-WOODY	COVER	Y					
	ABUNDANCE	Y					
	SPECIES COMPOSITION	Y					
			0.0	0.0			

VEGETATION COMPONENTS	**CONSIDER? (Y/N)**	**RANK**	**WEIGHT**	**RATING**	**WEIGHTED RATING**	**MEAN CONFIDENCE**	**NOTES: (give reasons for each assessment)**
WOODY	Y			0.0	0.00	0.0	
NON-WOODY	Y			0.0	0.00	0.0	
					0.00	0.0	

CHANGE (%) IN MARGINAL ZONE CONDITION	**#DIV/0!**

Non-Marginal Zone

	MODIFICATION RATINGS			
CAUSES OF MODIFICATION	INTENSITY	EXTENT	CONFIDENCE	NOTES: (give reasons for each assessment)
REMOVAL				
EXOTIC INVASION				
WATER QUANTITY				
WATER QUALITY				
AVERAGE			#DIV/0!	

		RESPONSE METRIC RATINGS			
VEGETATION COMPONENTS	RESPONSE METRIC	CONSIDER? (Y/N)	RATING	CONFIDENCE	NOTES: (give reasons for each assessment)
WOODY	COVER	Y			
	ABUNDANCE	Y			
	SPECIES COMPOSITION	Y			
			0.0	0.0	
NON-WOODY	COVER	Y			
	ABUNDANCE	Y			
	SPECIES COMPOSITION	Y			
			0.0	0.0	

VEGETATION COMPONENTS	CONSIDER? (Y/N)	RANK	WEIGHT	RATING	WEIGHTED RATING	MEAN CONFIDENCE	NOTES: (give reasons for each assessment)
WOODY	Y			0.0	0.00	0.0	
NON-WOODY	Y			0.0	0.00	0.0	
					0.00	0.0	

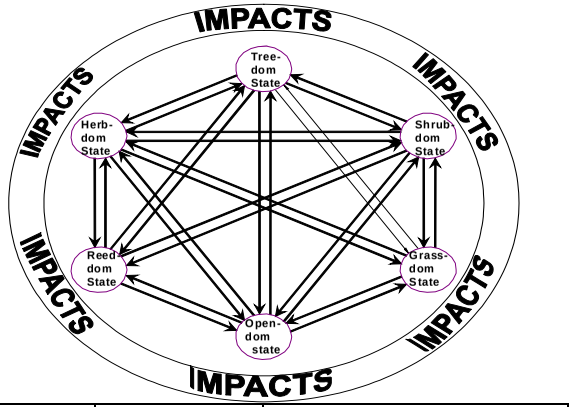
CHANGE (%) IN MARGINAL ZONE CONDITION	#DIV/0!

Riparian Zone

LEVEL 3 ASSESSMENT						
METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**% WEIGHT**	**NOTES: (give reasons for each assessment)**
MARGINAL	#DIV/0!	#DIV/0!	0.0			
NON MARGINAL	#DIV/0!	#DIV/0!	0.0			
0.0					0.0	
LEVEL 3 VEGRAI (%)				#DIV/0!		
VEGRAI EC				**#DIV/0!**		
AVERAGE CONFIDENCE				0.0		

APPENDIX C: VEGRAI MODEL: LEVEL 4

Reference State



WHAT TO DO
1) Indicate the dominant state (using the diagram) for the PRESENT conditions, for each ZONE. (any particular state may be a mix of dominant states e.g. tree & shrub dominated state, or reed & open dominated state etc)
2) Describe the PRESENT state for each zone. Try to be specific about observed impacts at the site, and how response metrics have been affected by these impacts i.e. describe the vegetation state with reference to its response to impacts
3) Describe what you think the REFERENCE state for each zone would be. Try to imagine what the vegetation would be like if both the impacts you observe and the vegetation response to past impacts had not taken place i.e were replaced with "natural" disturbance only. Try to be specific about the characteristics of response metrics when no "unnatural" disturbances have taken place i.e. describe the vegetation state with reference to its response to regimes uninfluenced by humans
4) Indicate the dominant state (using the diagram) for the REFERENCE conditions, for each ZONE. (any particular state may be a mix of dominant states e.g. tree & shrub dominated state, or reed & open dominated state etc

Zones	Impacts	Response Metrics	Description of PRESENT STATE	Description of REFERENCE STATE
Marginal	Vegetation Removal Exotic Vegetation Water Quantity Water Quality	Cover Abundance Species Composition Recruitment Population Structure		
Lower	Vegetation Removal Exotic Vegetation Water Quantity Water Quality	Cover Abundance Species Composition Recruitment Population Structure		
Upper	Vegetation Removal Exotic Vegetation Water Quantity Water Quality	Cover Abundance Species Composition Recruitment Population Structure		

Marginal Zone

	IMPACT RATINGS			
IMPACTS	**INTENSITY**	**EXTENT**	**CONFIDENCE**	**NOTES: (give reasons for each assessment)**
REMOVAL				
EXOTIC INVASION				
WATER QUANTITY				
WATER QUALITY				
AVERAGE			#DIV/0!	

		RESPONSE METRIC RATINGS			
VEGETATION COMPONENTS	**RESPONSE METRIC**	**CONSIDER? (Y/N)**	**RATING**	**CONFIDENCE**	**NOTES: (give reasons for each assessment)**
WOODY	COVER	Y			
	ABUNDANCE	Y			
	POPULATION STRUCTURE	Y	#DIV/0!		
	RECRUITMENT	Y	#DIV/0!		
	SPECIES COMPOSITION	Y	#DIV/0!		
			#DIV/0!	0.0	
NON-WOODY	COVER	Y			
	ABUNDANCE	Y			
	SPECIES COMPOSITION	Y	#DIV/0!		
			#DIV/0!	0.0	

VEGETATION COMPONENTS	**CONSIDER? (Y/N)**	**RANK**	**WEIGHT**	**RATING**	**WEIGHTED RATING**	**MEAN CONFIDENCE**	**NOTES: (give reasons for each assessment)**
WOODY	Y			#DIV/0!	#DIV/0!	0.0	
NON-WOODY	Y			#DIV/0!	#DIV/0!	0.0	
					#DIV/0!	0.0	

CHANGE (%) IN VEGETATION COMPONENTS:OVERALL	**#DIV/0!**

Lower Zone

	IMPACT RATINGS:			
IMPACTS	**INTENSITY**	**EXTENT**	**CONFIDENCE**	**NOTES: (give reasons for each assessment)**
REMOVAL				
EXOTIC INVASION				
WATER QUANTITY				
WATER QUALITY				
AVERAGE			#DIV/0!	

		RESPONSE METRIC RATINGS			
VEGETATION COMPONENTS	**RESPONSE METRIC**	**CONSIDER? (Y/N)**	**RATING**	**CONFIDENCE**	**NOTES: (give reasons for each assessment)**
WOODY	COVER	Y			
	ABUNDANCE	Y			
	POPULATION STRUCTURE	Y	#DIV/0!		
	RECRUITMENT	Y	#DIV/0!		
	SPECIES COMPOSITION	Y	#DIV/0!		
			#DIV/0!	0.0	
NON-WOODY	COVER	Y			
	ABUNDANCE	Y			
	SPECIES COMPOSITION	Y	#DIV/0!		
			#DIV/0!	0.0	

VEGETATION COMPONENTS	**CONSIDER? (Y/N)**	**RANK**	**WEIGHT**	**RATING**	**WEIGHTED RATING**	**MEAN CONFIDENCE**	**NOTES: (give reasons for each assessment)**
WOODY	Y			#DIV/0!	#DIV/0!	0.0	
NON-WOODY	Y			#DIV/0!	#DIV/0!	0.0	
					#DIV/0!	0.0	

CHANGE (%) IN VEGETATION COMPONENTS:OVERALL CHANGE	**#DIV/0!**

Upper Zone

	IMPACT RATINGS			
IMPACTS	**INTENSITY**	**EXTENT**	**CONFIDENCE**	**NOTES: (give reasons for each assessment)**
REMOVAL				
EXOTIC INVASION				
WATER QUANTITY				
WATER QUALITY				
AVERAGE			#DIV/0!	

		RESPONSE METRIC RATINGS			
VEGETATION COMPONENTS	**RESPONSE METRIC**	**CONSIDER? (Y/N)**	**RATING**	**CONFIDENCE**	**NOTES: (give reasons for each assessment)**
WOODY	COVER	Y			
	ABUNDANCE	Y			
	POPULATION STRUCTURE	Y	#DIV/0!		
	RECRUITMENT	Y	#DIV/0!		
	SPECIES COMPOSITION	Y	#DIV/0!		
			#DIV/0!	0.0	
NON-WOODY	COVER	Y			
	ABUNDANCE	Y			
	SPECIES COMPOSITION	Y	#DIV/0!		
			#DIV/0!	0.0	

VEGETATION COMPONENTS	**CONSIDER? (Y/N)**	**RANK**	**WEIGHT**	**RATING**	**WEIGHTED RATING**	**MEAN CONFIDENCE**	**NOTES: (give reasons for each assessment)**
WOODY	Y			#DIV/0!	#DIV/0!	0.0	
NON-WOODY	Y			#DIV/0!	#DIV/0!	0.0	
					#DIV/0!	0.0	

CHANGE (%) IN VEGETATION COMPONENTS:OVERALL CHANGE	**#DIV/0!**

Riparian Zone

LEVEL 4 ASSESSMENT						
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**	**NOTES: (give reasons for each assessment)**
MARGINAL	#DIV/0!	#DIV/0!	0.0			
LOWER ZONE	#DIV/0!	#DIV/0!	0.0			
UPPER ZONE	#DIV/0!	#DIV/0!	0.0			
	0.0				0.0	
LEVEL 4 VEGRAI (%)				#DIV/0!		
VEGRAI EC				**#DIV/0!**		
AVERAGE CONFIDENCE				0.0		

LEVEL 4 ASSESSMENT					
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**
MARGINAL	68.5	22.8	0.0	1.0	100.0
LOWER ZONE	68.3	22.8	0.0	1.0	100.0
UPPER ZONE	68.3	22.8	0.0	1.0	100.0
	3.0				300.0
LEVEL 4 VEGRAI (%)				68.4	
VEGRAI EC				**C**	
AVERAGE CONFIDENCE				0.0	

Rating Guide

		REFERENCE (%)					
		80-100	**60-80**	**40-60**	**20-40**	**20-10**	**<10**
PRESENT %	**80-100**	0-1	1-2	2-3	3-4	4-5	5
	60-80	1-2	0-1	1-2	2-3	3-4	4-5
	40-60	2-3	1-2	0-1	1-2	2-3	3-4
	20-40	3-4	2-3	1-2	0-1	1-2	2-3
	20-10	4-5	3-4	2-3	1-2	0-1	1-2
	<10	5	4-5	3-4	2-3	1-2	0-1

Population Structure and Recruitment

(repeated for Marginal, Lower and Upper zones)

WOODY VEGETATION: POPULATION STRUCTURE & RECRUITMENT

MARGINAL									
Indicator Species	Rank	Weight	State	Relative Abundance (%)			Population Curve	Pop Struc Rating	Recruit Rating
				Juveniles	Sub-adults	Adults			
	1		Present						
			Reference						
	2		Present						
			Reference						
	3		Present						
			Reference						
All species that were not used as indicator species	Rest		Present						
			Reference						
RATING FOR POPULATION STRUCTURE						#DIV/0!			
RATING FOR RECRUITMENT:						#DIV/0!			

Species Composition

WOODY VEGETATION: SPECIES COMPOSITION CHANGE

MARGINAL

Indicator Species	Rank	Weight	State	% Composition	Rating
All Exotic Vegetation (total)	1		Present		
			Reference		
	2		Present		
			Reference		
	3		Present		
			Reference		
	4		Present		
			Reference		
	5		Present		
			Reference		
	6		Present		
			Reference		
	7		Present		
			Reference		
	8		Present		
			Reference		
	9		Present		
			Reference		
	10		Present		
			Reference		
All species that were not used as indicator	Rest		Present		
			Reference		
Total for Present states				0.0	
Total for Reference states				0.0	
ERROR:	Sum of all Present st		Sum of all Present state percentages		
ERROR:	Sum of all Present st		Sum of all reference state percentag		
IMPACT RATING:				#DIV/0!	

LOWER

Indicator Species	Rank	Weight	State	% Composition	Rating
All Exotic Vegetation (total)	1		Present		
			Reference		
	2		Present		
			Reference		
	3		Present		
			Reference		
	4		Present		
			Reference		
	5		Present		
			Reference		
	6		Present		
			Reference		
	7		Present		
			Reference		
	8		Present		
			Reference		
	9		Present		
			Reference		
	10		Present		
			Reference		
All species that were not used as indicator species	Rest		Present		
			Reference		
Total for Present states				0.0	
Total for Reference states				0.0	
ERROR:	Sum of all Present st		Sum of all Present state percentages		
ERROR:	Sum of all Present st		Sum of all reference state percentage		
IMPACT RATING:				#DIV/0!	

UPPER

Indicator Species	Rank	Weight	State	% Composition	Rating
All Exotic Vegetation (total)	1		Present		
			Reference		
	2		Present		
			Reference		
	3		Present		
			Reference		
	4		Present		
			Reference		
	5		Present		
			Reference		
	6		Present		
			Reference		
	7		Present		
			Reference		
	8		Present		
			Reference		
	9		Present		
			Reference		
	10		Present		
			Reference		
All species that were not used as indicator	Rest		Present		
			Reference		
Total for Present states				0.0	
Total for Reference states				0.0	
ERROR:	Sum of all Present st		Sum of all Present state percentages must be 100 in upper zone		
ERROR:	Sum of all Present st		Sum of all reference state percentages must be 100 in upper zone		
IMPACT RATING:				#DIV/0!	

APPENDIX D: GUIDELINES FOR ASSESSING THE RESPONSE OF RIPARIAN VEGETATION

The purpose of this appendix is to aid the user of the VEGRAI models in the interpretation of riparian vegetation to a range of impacts.

THE ECOLOGICAL FUNCTION OF MAINTENANCE FLOWS FOR RIPARIAN VEGETATION

- Inundate and maintain marginal vegetation
- Water should reach marginal fringe to be in contact with roots of trees
- To meet transpiration and growth needs of riparian woody species
- Recharge of bank soil moisture
- Encourage successful recruitment of seedlings
- Riparian trees should not be inundated by base flows
- Water level close to reed line to prevent reed encroachment on the channel
- Roots must be able to follow the subsiding ground water

THE ROLE OF HIGHER FLOWS FOR RIPARIAN VEGETATION

- Overtopping of terraces/levees for inundation to recharge substrates, cracks in rocky areas, recharge of lower and upper zones
- Meet growth demands of riparian species with the onset of growing season
- Meet moisture and nutritional demands for increased temperatures, photoperiod and flowering of some species
- To provide for the recruitment of woody species
- To encourage germination and recruitment of woody tree species
- To create hydrological variability for additional microsite habitats
- To discourage terrestrialisation on the edges of the riparian zone (especially the lower zone) by removal/prevention of terrestrial seedlings and death of existing plants.

EXAMPLE RESPONSES TO VEGETATION REMOVAL

Vegetation removal:

- Increase in solar radiation to stream can increase water temperature or change water quality
- Decreased infiltration of lateral flow can cause erosion (sheet or donga)

Wood removal:

- Prevalence of shortened / stunted stumps, often with extensive coppice regrowth
- Increase in non-woody vegetation cover and abundance due to reduced shading
- Reduced reproduction of woody vegetation since resources are used for vegetative regrowth and an associated loss of recruitment

Reed removal (community use):

- Increase in open areas
- Reduced ability to trap sediment
- Sediment removal during higher flows

Domestic grazing

- Loss of woody vegetation recruitment due to juvenile removal
- Bank destabilization and slumping due to vegetation removal and trampling (especially in the marginal zone)
- Introduction of alien species by animal-aided dispersal

EXAMPLE RESPONSES TO EXOTIC INVASION

- Competition for resources reduce indigenous vegetation prevalence and recruitment
- Loss of understorey vegetation increases risk of sediment removal at high flows

EXAMPLE RESPONSES TO CHANGES IN WATER QUANTITY

Reduced flows:

- Terrestrialisation in the lower zone
- Shift if vegetation zonation, i.e. marginal zone expands into channel
- Die-off of riparian species in upper or even lower zones, and especially those dependent on perched water tables
- Woody population structure on lower and upper zones show loss of recruitment
- Die-off of marginal species especially at the upper end of their distribution

Regulated flows:

- Very distinct zonation in vegetation distribution and loss of patchiness (spatial variability in vegetation distribution patterns)
- Narrowing of riparian vegetation distribution in the riparian zone
- Die-off where inundation occurs at a time when flows should have receded
- Reduced vitality or vigour of riparian vegetation due to elevation flows in dry season (root rot) or decreased flow in the wet season (water stress)

EXAMPLE RESPONSES TO CHANGES IN WATER QUALITY

- Increased growth and vigour in marginal zone vegetation due to eutrophication (especially exotic species)
- Sediment trapping, e.g. reed beds when sediment load is high
- Root fanning / wads at waters edge due to increased nutrients in water.

APPENDIX E: SENSITIVITY ANALYSIS

Parameter values are a source of uncertainty in biological modelling, (O'Neil & Gardner, 1979), as the mean or variance of the population from which the parameters are taken is not always known. Uncertainty in parameter values will affect model predictions, but the effect can be investigated using parameter sensitivity analyses (Haefner, 1996).

In a sensitivity analysis, parameters, or metrics in this case, are systematically changed to determine their effect on the output (Starfield & Bleloch, 1991). The model is first run with its set of default parameters and its output is used as a benchmark against which all other runs are measured. Single or multiple parameter analyses can be performed (Haefner, 1996). In single parameter analyses, each of the parameters is changed one at a time, either uniformly or variably to determine the effect on model output. In multiple parameter analyses more than one variable is altered to assess interactions between variables. If the model is linear and deterministic, then single parameter sensitivity analyses are often sufficient (Starfield & Bleloch, 1991). If parameters are changed uniformly, all parameters are changed by the same percentage of their respective nominal values. The variable approach weights the altered interval of each parameter by the variance of the estimate of that parameter (if this is known) (Haefner, 1996).

The sensitivity index (S) derived from changes in the model output was used to compare the relative sensitivity of all parameters. S compares the change in model output to model response for a nominal set of parameters (Haefner, 1996). S is therefore the ratio of standardized change in response (model output) to standardized change in parameter values, and is given by:

$$S \approx \frac{\frac{R_a - R_n}{R_n}}{\frac{P_a - P_n}{P_n}}$$

where R_a and R_n are model output responses for altered and nominal parameters respectively, and P_a and P_n are the altered and nominal parameters respectively. The absolute value of S was used to make comparisons because parameters could then be ranked according to their S-values. Negative and positive values indicated the same level of sensitivity (e.g., an S-value of 0.379 and -0.379), but indicate a positive or negative response to changes respectively.

Examples of VEGRAI sensitivity analyses are shown in tables 1 and 2 for level 3 and 4 models respectively. Results show that both level 3 and 4 models are not sensitive in terms of their structure and functioning. Model output is more sensitive to metric ratings however, than to rankings & weightings. Sensitivity in general increases with increased variability between metric ratings, especially for rankings & weightings, i.e. the more variability there is between metric ratings the more important it is to be accurate when ranking and weighting.

Similarly, the more extreme metric ratings are, or the more metric ratings vary, the more sensitive VEGRAI output is to turning metrics off (see Table 3 for an example). This means that users should rate as many metrics as possible, especially where riparian vegetation conditions is poor.

Table E.1 Results of sensitivity analysis for level 3 VEGRAI.
Pn = nominal parameter, Pa = altered parameter, Ra/Rn = the ratio of the altered and nominal response, abs S norm to 0 = absolute Sensitivity index normalized to 0. Values with bold font indicate starting conditions, i.e. Pn = Pa. Values in grey indicate small values used in place of 0 since S cannot be calculated with 0.

Zone	Description of parameter	Pn	Pa	Ra/Rn	abs S norm to 0
marginal	non-woody species composition	1	5	0.90	4.58
non-marginal	woody cover	1	5	0.91	4.51
non-marginal	non-woody abundance	1	5	0.93	4.40
marginal	woody abundance	1	5	0.94	4.33
marginal	woody cover	1	5	0.94	4.33
marginal	non-woody species composition	1	4	0.92	3.34
non-marginal	woody cover	1	4	0.93	3.30
non-marginal	non-woody abundance	1	4	0.94	3.24
marginal	woody abundance	1	4	0.95	3.20
marginal	woody cover	1	4	0.95	3.20
marginal	non-woody species composition	1	3	0.95	2.16
non-marginal	woody cover	1	3	0.95	2.15
non-marginal	non-woody abundance	1	3	0.96	2.12
marginal	woody abundance	1	3	0.97	2.10
marginal	woody cover	1	3	0.97	2.10
marginal	Veg component rank, woody @ 3's, non-woody @ 1's, weights @ 100 & 20	1	2	0.81	1.23
marginal	non-woody species composition	1	2	0.97	1.05
non-marginal	woody cover	1	2	0.98	1.05
non-marginal	non-woody abundance	1	2	0.98	1.04
marginal	woody abundance	1	2	0.98	1.03
marginal	woody cover	1	2	0.98	1.03
marginal	Veg component rank, all comp @ 1's, weights @ 100 & 20	1	2	1.00	1.00
Rip Zone EC	change zone rank, metrics = contribution	1	2	1.00	1.00
marginal	non-woody species composition	1	0.01	1.03	0.99
marginal	woody abundance	1	0.01	1.02	0.99
marginal	woody cover	1	0.01	1.02	0.99
non-marginal	non-woody abundance	1	0.01	1.02	0.99
non-marginal	woody cover	1	0.01	1.02	0.99
Rip Zone EC	weights of 2nd ranked (all zones @ 1's)	80	40	1.00	0.50
Rip Zone EC	change zone ranks, marginal @ 4's, non-marginal @ 1's	1	2	1.14	0.43
Rip Zone EC	weights of 2nd ranked (marginal @ 3's)	80	40	0.89	0.40
Rip Zone EC	weights of 2nd ranked (all zones @ 1's)	80	50	1.00	0.38
Rip Zone EC	weights of 2nd ranked (marginal @ 3's)	80	50	0.92	0.28
Rip Zone EC	weights of 2nd ranked (all zones @ 1's)	80	60	1.00	0.25
Rip Zone EC	weights of 2nd ranked (marginal @ 3's)	80	90	1.02	0.18
Rip Zone EC	weights of 2nd ranked (marginal @ 3's)	80	60	0.95	0.16

Zone	Description of parameter	Pn	Pa	Ra/Rn	abs S norm to 0
Rip Zone EC	weights of 2nd ranked (all zones @ 1's)	80	70	1.00	0.13
Rip Zone EC	weights of 2nd ranked (all zones @ 1's)	80	90	1.00	0.13
Rip Zone EC	weights of 2nd ranked (marginal @ 3's)	80	70	0.98	0.04
marginal	non-woody species composition	**1**	**1**	**1.00**	**0.00**
Marginal	Veg component weights, all metrics @ 1's, weights @ 100 & 20	**1**	**1**	**1.00**	**0.00**
marginal	Veg component weights, woody @ 3's, non-woody @ 1's, weights @ 100 & 20	**1**	**1**	**1.00**	**0.00**
marginal	woody abundance	**1**	**1**	**1.00**	**0.00**
marginal	woody cover	**1**	**1**	**1.00**	**0.00**
non-marginal	non-woody abundance	**1**	**1**	**1.00**	**0.00**
non-marginal	woody cover	**1**	**1**	**1.00**	**0.00**
Rip Zone EC	change zone rank, zone metrics =	**1**	**1**	**1.00**	**0.00**
Rip Zone EC	change zone rank, marg @ 4's, non-marg @ 1's	**1**	**1**	**1.00**	**0.00**
Rip Zone EC	weights of 2nd ranked (all zones @ 1's)	**80**	**80**	**1.00**	**0.00**
Rip Zone EC	weights of 2nd ranked (marginal @ 3's)	**80**	**80**	**1.00**	**0.00**

Table E.2 Results of sensitivity analysis for level 4 VEGRAI.

Pn = nominal parameter, Pa = altered parameter, Ra/Rn = the ratio of the altered and nominal response, abs S norm to 0 = absolute Sensitivity index normalized to 0. Values with bold font indicate starting conditions, i.e. Pn = Pa. Values in grey indicate small values used in place of 0 since S cannot be calculated with 0.

Zone	Description of parameter	Pn	Pa	Ra/Rn	abs S norm to 0
Marginal	non-woody abundance	1	5	0.91	4.47
Lower	non-woody species composition	1	5	0.96	4.22
Lower	woody population structure	1	5	0.96	4.22
Marginal	woody cover	1	5	0.97	4.16
Upper	woody recruitment	1	5	0.97	4.14
Marginal	non-woody abundance	1	4	0.93	3.28
Lower	non-woody species composition	1	4	0.97	3.13
Lower	woody population structure	1	4	0.97	3.13
Marginal	woody cover	1	4	0.98	3.10
Upper	woody recruitment	1	4	0.98	3.09
Marginal	non-woody abundance	1	3	0.96	2.14
Lower	non-woody species composition	1	3	0.98	2.06
Lower	woody population structure	1	3	0.98	2.06
Marginal	woody cover	1	3	0.98	2.05
Upper	woody recruitment	1	3	0.99	2.04
Rip Zone EC	change rank, zone metrics equal	1	3	1.00	2.00
Rip Zone EC	change rank, marg 4's, lower 3's, upper 1's	1	3	1.20	1.29
Marginal	non-woody abundance	1	2	0.98	1.04
Lower	non-woody species composition	1	2	0.99	1.02
Lower	woody population structure	1	2	0.99	1.02
Marginal	woody cover	1	2	0.99	1.02
Upper	woody recruitment	1	2	0.99	1.01

Zone	Description of parameter	Pn	Pa	Ra/Rn	abs S norm to 0
Marginal	Veg component weights, metric ratings all 1's, weights 100 & 60	1	2	1.00	1.00
Rip Zone EC	change rank, zone metrics equal	1	2	1.00	1.00
Lower	non-woody species composition	1	0.01	1.01	0.99
Lower	woody population structure	1	0.01	1.01	0.99
Marginal	non-woody abundance	1	0.01	1.02	0.99
Marginal	woody cover	1	0.01	1.01	0.99
Upper	woody recruitment	1	0.01	1.01	0.99
Marginal	Veg component weights, woody 3's, non-woody 1's, weights 100 & 60	1	2	0.94	0.97
Rip Zone EC	change rank, marginal 4's, lower 3's, upper 1's	1	2	1.04	0.76
Rip Zone EC	weights of 2nd ranked (all zones @ 1's)	80	40	1.00	0.50
Rip Zone EC	weights of 2nd ranked (marginal @ 3's)	80	40	0.95	0.48
Rip Zone EC	weights of 2nd ranked (all zones @ 1's)	80	50	1.00	0.38
Rip Zone EC	weights of 2nd ranked (marginal @ 3's)	80	50	0.96	0.37
Rip Zone EC	weights of 2nd ranked (all zones @ 1's)	80	60	1.00	0.25
Rip Zone EC	weights of 2nd ranked (marginal @ 3's)	80	60	0.98	0.25
Rip Zone EC	weights of 2nd ranked (marginal @ 3's)	80	70	0.99	0.14
Rip Zone EC	weights of 2nd ranked (all zones @ 1's)	80	70	1.00	0.13
Rip Zone EC	weights of 2nd ranked (all zones @ 1's)	80	90	1.00	0.13
Rip Zone EC	weights of 2nd ranked (marginal @ 3's)	80	90	1.01	0.09
Lower	non-woody species composition	**1**	**1**	**1.00**	**0.00**
Lower	woody population structure	**1**	**1**	**1.00**	**0.00**
Marginal	non-woody abundance	**1**	**1**	**1.00**	**0.00**
Marginal	Veg component weightings, metric ratings all 1's, weights 100 & 60	**1**	**1**	**1.00**	**0.00**
Marginal	Veg component weightings, woody 3's, non-woody 1's, weights 100 & 60	**1**	**1**	**1.00**	**0.00**
Marginal	woody cover	**1**	**1**	**1.00**	**0.00**
Rip Zone EC	change rank, zone metrics equal	**1**	**1**	**1.00**	**0.00**
Rip Zone EC	change rank, marginal 4's, lower 3's, upper 1's	**1**	**1**	**1.00**	**0.00**
Rip Zone EC	weights of 2nd ranked (zone metrics @ 1's)	**80**	**80**	**1.00**	**0.00**
Rip Zone EC	weights of 2nd ranked (marginal @ 3's)	**80**	**80**	**1.00**	**0.00**
Upper	woody recruitment	**1**	**1**	**1.00**	**0.00**

Table E.3 Results of sensitivity analysis for level 4 VEGRAI testing the effect of turning metrics off (only the marginal woody vegetation metric is shown as an example).

Pn = nominal parameter, Pa = altered parameter, Ra/Rn = the ratio of the altered and nominal response, abs S norm to 0 = absolute Sensitivity index normalized to 0. Values with bold font indicate starting conditions, i.e. Pn = Pa. Values in grey indicate small values used in place of 0 since S cannot be calculated with 0.

Zone	Description of parameter	Pn	Pa	Ra/Rn	Abs S norm to 0
Marginal	woody cover	1	**0.01**	1.01	0.99
	1 other metric off	1	**0.01**	1.02	0.99
	2 other metrics off	1	**0.01**	1.02	0.99
	3 other metrics off	1	**0.01**	1.03	0.99
	4 other metrics off	1	**0.01**	1.07	0.99
		1	**1**	**1.00**	**0.00**
	1 other metric off	**1**	**1**	**1.00**	**0.00**
	2 other metrics off	**1**	**1**	**1.00**	**0.00**
	3 other metrics off	**1**	**1**	**1.00**	**0.00**
	4 other metrics off	**1**	**1**	**1.00**	**0.00**
		1	2	0.99	1.03
	1 other metric off	1	2	0.98	1.03
	2 other metrics off	1	2	0.98	1.04
	3 other metrics off	1	2	0.97	1.07
	4 other metrics off	1	2	0.93	1.14
		1	3	0.97	2.08
	1 other metric off	1	3	0.97	2.10
	2 other metrics off	1	3	0.96	2.14
	3 other metrics off	1	3	0.93	2.21
	4 other metrics off	1	3	0.87	2.45
		1	4	0.96	3.16
	1 other metric off	1	4	0.95	3.21
	2 other metrics off	1	4	0.93	3.28
	3 other metrics off	1	4	0.90	3.43
	4 other metrics off	1	4	0.80	3.97
		1	5	0.95	4.27
	1 other metric off	1	5	0.93	4.35
	2 other metrics off	1	5	0.91	4.47
	3 other metrics off	1	5	0.87	4.75
	4 other metrics off	1	5	0.74	5.76

APPENDIX F: EXAMPLES OF ZONE IDENTIFICATION

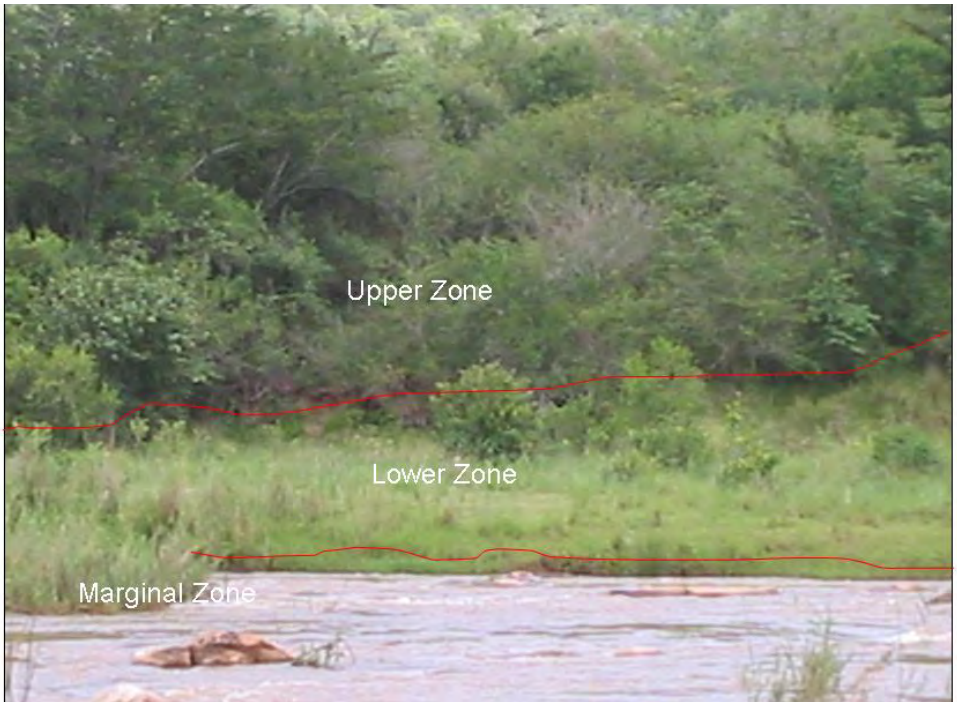
The following photographs illustrated the different vegetation zones on various rivers.

Mkhondvo River

Ngwempisi River

Nwempisi River

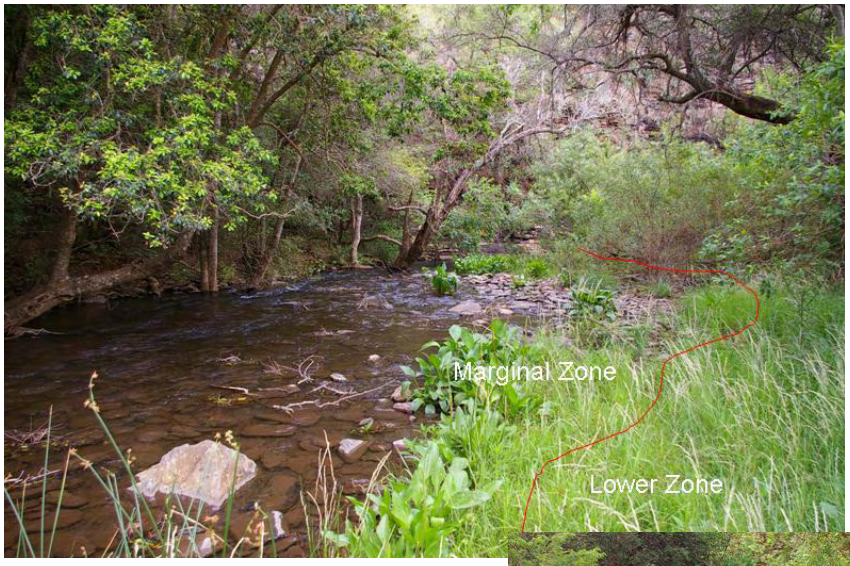
Mkondvo River



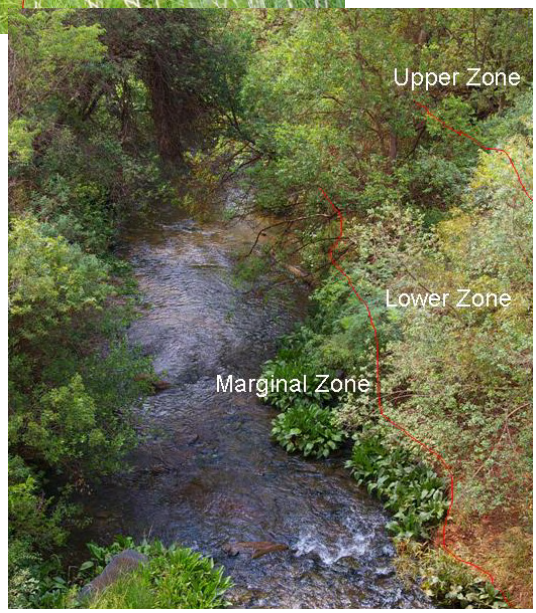
Ngwempisi River

Maputo River

Sabie River



Kaaloog se Loop



Liuwa River

Kafue River