Wetland Health and Importance Research Programme

6

WET-Sustainable Use

A System for Assessing the Sustainability of Wetland Use

Author: D Kotze
Series Editor: H Malan

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WETLAND HEALTH AND IMPORTANCE RESEARCH PROGRAMME

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WET-SUSTAINABLE USE

A SYSTEM FOR ASSESSING THE SUSTAINABILITY OF WETLAND USE

Report to the

Water Research Commission

by

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Front Cover: Livestock grazing, Mkuze floodplain, KwaZulu-Natal, South Africa
Photograph: D Kotze

PREFACE

This report is one of the outputs of the Wetland Health and Importance (WHI) research programme which was funded by the Water Research Commission. The WHI represents Phase II of the National Wetlands Research Programme and was formerly known as "Wetland Health and *Integrity*". Phase I, under the leadership of Professor Ellery, resulted in the "WET-Management" series of publications. Phase II, the WHI programme, was broadly aimed at assessing wetland environmental condition and socio-economic importance.

The full list of reports from this research programme is given below. All the reports, except one, are published as WRC reports with H. Malan as series editor. The findings of the study on the effect of wetland environmental condition, rehabilitation and creation on disease vectors were published as a review article in the journal Water SA (see under "miscellaneous").

An Excel database was created to house the biological sampling data from the Western Cape and is recorded on a CD provided at the back of Day and Malan (2010). The data were collected from mainly pans and seep wetlands over the period of 2007 to the end of 2008. Descriptions of each of the wetland sites are provided, as well as water quality data, plant and invertebrate species lists where collected.

An overview of the series

Tools and metrics for assessment of wetland environmental condition and socio-economic importance: handbook to the WHI research programme by E. Day and H. Malan. 2010. (This includes "*A critique of currently-available SA wetland assessment tools and recommendations for their future development"* by H. Malan as an appendix to the document).

Assessing wetland environmental condition using biota

Aquatic invertebrates as indicators of human impacts in South African wetlands by M. Bird. 2010.

The assessment of temporary wetlands during dry conditions by J. Day, E .Day, V. Ross-Gillespie and A. Ketley. 2010.

Development of a tool for assessment of the environmental condition of wetlands using macrophytes by F. Corry. 2010.

Broad-scale assessment of impacts and ecosystem services

A method for assessing cumulative impacts on wetland functions at the catchment or landscape scale by W. Ellery, S. Grenfell, M. Grenfell, C. Jaganath, H. Malan and D. Kotze. 2010.

Socio-economic and sustainability studies

Wetland valuation. Vol I: Wetland ecosystem services and their valuation: a review of current understanding and practice by Turpie, K. Lannas, N. Scovronick and A. Louw. 2010.

Wetland valuation. Vol II: Wetland valuation case studies by J. Turpie (Editor). 2010.

Wetland valuation. Vol III: A tool for the assessment of the livelihood value of wetlands by J. Turpie. 2010.

Wetland valuation. Vol IV: A protocol for the quantification and valuation of wetland ecosystem services by J. Turpie and M. Kleynhans. 2010.

WET-SustainableUse: A system for assessing the sustainability of wetland use by D. Kotze. 2010.

Assessment of the environmental condition, ecosystem service provision and sustainability of use of two wetlands in the Kamiesberg uplands by D. Kotze, H. Malan, W. Ellery, I. Samuels and L. Saul. 2010.

Miscellaneous

Wetlands and invertebrate disease hosts: are we asking for trouble? By H. Malan, C. Appleton, J. Day and J. Dini (Published in Water SA 35: (5) 2009 pp 753-768).

EXECUTIVE SUMMARY

WET-SustainableUse has been developed to assist in assessing the ecological sustainability of wetland use, focusing on grazing of wetlands by livestock, cultivation of wetlands and harvesting of wetland plants for crafts and thatching. WET-SustainableUse asks to what extent the use of the wetland has altered the following five components of the wetland's environmental condition: (1) the distribution and retention of water, (2) the erosion of sediment, (3) the accumulation of Soil organic matter (SOM), (4) the retention of nutrients and (5) the natural species composition of the vegetation in the wetland. WET-SustainableUse assists the user in answering these questions by providing a set of indicators for each of the five components, and a structured way of scoring these indicators and deriving an overall score for each component.

Wetlands that do not have sustainable management systems will be vulnerable to unsustainable use. Therefore, although focusing on ecological sustainability, WET-SustainableUse encourages the user to describe the broad socio-economic and institutional context within which the wetland is used. To assist, WET-SustainableUse provides a simple framework to identify the key factors (operating from a household level to an international level) that may be influencing the use of the wetland. It also provides a set of key questions relating to governance. Next, WET-SustainableUse requires that the perspectives of the users be sought regarding how they see their land-use activities affecting the wetland's condition.

Users of WET-SustainableUse should preferably be qualified in physical sciences and have field experience. The system can be used to assess the environmental impacts of both current and possible future uses of a particular wetland resource. This helps guide the use of wetlands, plan and monitor sustainable-use projects, develop policy dealing with the use of wetlands, education, awareness and research. The assessment process in WET-SustainableUse is presented as a linear sequence of interconnected assessment components, but users can also "dip in" to WET-SustainableUse to obtain specific information using the index provided.

For assessing the impact of wetland use (e.g. grazing of wetlands by livestock, cultivation of wetlands or harvesting of wetland plants for crafts and thatching) on the environmental condition of a wetland, two levels of assessment are provided, depending on the level of detail required by the user. Level 1 is less detailed and rests upon several generalizations regarding each of the land-uses considered. Level 2 is more detailed,

and its approach and structure is derived from WET-Health (Macfarlane *et al.,* 2008). Level 2 consists of a series of models each comprising a set of metrics that are combined in a simple algorithm to represent how a key component of environmental condition (e.g. accumulation of SOM) in the wetland is affected by use. The models used depend on which type of wetland use (grazing, cultivation or harvesting) is being considered. In the case of accumulation of SOM, some of the metrics are as follows:

- altered level of wetness (e.g. as a result of artificial drainage), with desiccation exposing the soil to more aerobic conditions, thereby increasing the rate of SOM decomposition;
- extent, frequency and depth of disturbance of the soil as a result of tillage, which increases the exposure of the SOM to air and hence increases the rate of decomposition;
- level of soil cover, with the high temperature fluctuations associated with poorly-covered soil resulting in increased SOM decomposition.

The rationale behind the selection of each of the metrics is also provided, together with the rationale for combining the scores of the different metrics into a single score. A description of a Level 2 application of WET-SustainableUse to two wetlands in the Kamiesberg, Northern Cape is given in Kotze *et al.* (2010).

Once the five components of the environmental condition of the wetland have been assessed, the next step is to examine the consequences of this for the livelihoods of those that use the ecosystem. This requires that the specific use patterns and preferences of local users be considered as well as the context of the wetland in the broader catchment and landscape. The following general relationships apply.

1. Reduced distribution and retention of water in the wetland often results in greater opportunities for cultivation in wetland areas, but it impacts negatively on water supply, growth of plants for craft production, and on cultivation during dry periods (when drains may prevent the storage of water in the wetland).
2. Erosion in the wetland impacts negatively on wetland productivity, which in turn impacts on most provisioning services and on water quality for downstream water users.
3. Increased breakdown of SOM may result in short term benefits for crop production as the breakdown of SOM releases nutrients for crops. However, in the long term the impacts are negative, resulting in reduced levels of both nutrient retention and soil water holding capacities.

4. Reduced retention of, and internal cycling of, nutrients in the wetland results in (a) reduced wetland productivity, which in turn will impact negatively on the supply of provisioning services (including cultivated food), and (b) reduced water quality for downstream areas.
5. A loss of native plant species generally reduces the resource base for medicine, crafts and thatching and livestock grazing, although the opportunistic species that replace the lost species may also have some resource value.

Next, guidance is provided for setting “Thresholds of Potential Concern” (TPCs) for each of the five components of environmental condition. These thresholds define what are considered to be the limits of sustainable use for the wetland. It is recognized that differences of opinion may exist amongst the different role-players about the effects of particular use practices, and therefore dialogue is encouraged to help to build a common understanding. Finally, WET-SustainableUse provides general guidance to assist in identifying appropriate actions required to improve sustainability of use in the light of the above assessments and dialogue. Recommendations are also provided for further research, which highlight the need for detailed, process-based research on selected reference sites.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

It is gratefully acknowledged that the development of WET-SustainableUse took place as part of a broader research programme on wetland environmental condition that was coordinated by the University of Cape Town and funded by the Water Research Commission. The following individuals and organizations are also thanked for their contributions.

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ABBREVIATIONS

AWARD – Association for Water and Rural Development

CEC – Cation Exchange Capacity

DEAT – Department of Environmental Affairs and Tourism

DWAF – Department Of Water Affairs and Forestry

HGM – Hydrogeomorphic

HPUE – Harvest per Unit Effort

MAP – Mean Annual Precipitation

NEMA – (South African) National Environmental Management Act

NGO – Non-Governmental Organization

PET – Potential Evapotranspiration

SOM – Soil Organic Matter

TPC – Threshold of Potential Concern

UN – United Nations

WCPA – World Commission on Protected Areas

WHI – Wetland Health and Importance (Research Programme)

WRC – Water Research Commission

PART 1: AN OVERALL DESCRIPTION OF WET-SUSTAINABLE USE

1. RATIONALE, PURPOSE AND SCOPE OF THE SYSTEM

In many areas of South Africa, people are directly dependent on wetlands for subsistence use. At the same time, resources such as water and land are becoming increasingly scarce. Therefore there is a great need to assess and predict the sustainability of different land-use options in wetlands. This, however, is a difficult task because of the complex nature of wetlands. Complexity arises given that wetlands are:

- located at the transition between terrestrial and aquatic systems, and are therefore strongly influenced by both of these systems;
- complex ecosystems in which several key processes (e.g. nutrient retention and accumulation of Soil organic matter [SOM]) affect the overall environmental condition of the system;
- influenced by factors occurring locally (e.g. artificial drainage channels in the wetland) and more broadly (especially in the catchment upstream of the wetland), and at different time scales (e.g. daily, seasonally or over much longer time periods); and
- supply a broad spectrum of ecosystem services, both locally and to distant beneficiaries (e.g. water users downstream).

To assist in assessing sustainability in the midst of this complexity, a framework comprising a set of metrics was developed, and is termed WET-SustainableUse. Whilst it is recognized that sustainability comprises three dimensions, namely ecological, social and economic, the specific focus of WET-SustainableUse is on ecological sustainability. The social and economic dimensions can be explored in much more detail using other systems such as Turpie (2010) and Pollard *et al.* (2009).

WET-SustainableUse has been developed with the following purpose: **To assist in assessing the ecological sustainability of wetland use,** focusing on the following three land-uses:

- grazing of wetlands by livestock;
- cultivation of wetlands, particularly annual crops by small-scale and non-mechanized cultivation (generally associated with subsistence farmers);
- harvesting of wetland plants for crafts and thatching.

These three uses were chosen because they are amongst some of the most widely applied to South African wetlands, and are of particular relevance to the livelihoods of those dependent on wetlands. Water is another widely used renewable resource supplied by wetlands, but this is not included in WET-SustainableUse as the ecological sustainability of its use is covered by WET-Health (Macfarlane *et al.,* 2008). Other renewable natural resources not covered are included in the following list.

- Fish. In South Africa, harvestable fish resources are found in lakes (restricted mainly to the coastal plain), some rivers, dams, and in a few inland wetlands such as the Phongolo floodplain (Heeg and Breen, 1982; 1994). However, most inland South African wetlands lack harvestable fish resources. Kyle (1995) provides a useful case study description of the utilization of fish in the Kosi Bay lakes, and Pitcher (1999) provides a technique for assessing the sustainability of a fishery based on easily scored attributes.
- Medicinal plants. Some hydric species, e.g. *Gunnera perpensa* and *Ranunculus multifidus*, have medicinal value. Guidelines for assessing sustainability of these resources are given in Cunningham (2001).
- Wood. This is provided by swamp forests, which are restricted in their distribution (also covered in Cunningham, 2001).

Thus, WET-SustainableUse certainly does not attempt to answer all potential questions relating to use, and it does not cover all of the different uses of wetlands. However, it is anticipated that the general approach can be adapted and applied to a broad range of uses of wetland natural resources.

Wetlands that do not have sustainable management systems will be vulnerable to unsustainable use. Therefore, although focusing on ecological sustainability, the framework assists the user in placing the assessment in a broader socio-economic and governance context.

2. THE KEY PRINCIPLES AND PHILOSOPHIES UNDERPINNING WET-SUSTAINABLE USE (WITH INPUT FROM CHARLES BREEN)

The Ramsar Convention Secretariat (2006) defines the wise use of wetlands in terms of the maintenance of their ecological character (environmental condition), achieved through the implementation of ecosystem approaches, within the context of sustainable development.

Sustainable development comprises three mutually reinforcing pillars: economic development, social development and environmental protection — at the local, national, regional and global levels (UN, 2002). In broad terms, the concept of sustainable development is an attempt to combine concerns about environmental issues with socio-economic issues (Hopwood *et al.,* 2005). The South African National Environmental Management Act (NEMA, 2008) defines sustainable development as the integration of social, economic and environmental factors into planning, implementation and decision-making so as to ensure that development serves present and future generations. Sustainable development is also enshrined within South Africa's Constitution, which makes the following provision within Section 24 of the Bill of Rights:

> *Everyone has the right to an environment that is not harmful to their health and well-being; and to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that prevent pollution and ecological degradation, promote conservation, and secure sustainable development and use of natural resources, while promoting justifiable economic and social development.*

The concept of sustainable development has proved useful, and a wide range of non-government and government organizations have embraced it as the new paradigm of development. However, Lélé (2002) cautions that although the all-encompassing nature of the concept gives it political strength, its formulation by the mainstream of sustainable development thinking contains significant weaknesses. These include an incomplete perception of the problems of poverty and environmental degradation, and confusion about the role of economic growth (Lélé, 2002, Hopwood *et al.,* 2005). Too much focus is on "well-having" rather than "well-being" (Hopwood *et al.,* 2005) and the term sustainable development is open to misuse in situations where the economic dimension predominates over the social and environmental. It is suggested that if sustainable development is to have a fundamental impact, politically expedient fuzziness will have to be given up in favour of more rigour and clarity of meaning (Lélé, 2002).

Given the conflicting interpretations that are likely to arise around sustainable development and the need for greater clarity of meaning, more specific guidance and criteria are required to measure attainment of sustainable development (Sunderlin, 1995; Lawrence, 1997). WET-SustainableUse provides a set of specific criteria for assessing how the environmental condition[1] of a wetland has been altered from the natural condition, and it therefore contributes primarily to the environmental pillar of sustainable development. It does not provide specific criteria for assessing the social and economic dimensions of sustainable development. Nevertheless, it should be seen as a tool to be used in the context of sustainable development that is clearly defined.

The "ecosystem approach" referred to earlier in this section explicitly considers the effects of use on the ecosystem, whether the ecosystem is in a transformed or an untransformed state. A key philosophy underpinning WET-SustainableUse is agro-ecology, and at the heart of agro-ecology is the idea that a crop field is an ecosystem in which ecological processes (e.g. nutrient retention, predator/prey interactions, competition and successional changes) found in other vegetation formations also occur (Altieri, 1987a and 1987b; Hecht, 1987). "Implicit in some agro-ecological work is the idea that by understanding these processes and relations, agro-ecosystems can be manipulated to produce better, with fewer negative environmental and social impacts, more sustainably and with fewer external inputs" (Hecht, 1987).

Where a wetland is being used in a natural or near-natural state, assessment of sustainable use primarily involves assessing the sustained yield of the particular resource(s) being used (e.g. reeds harvested for thatching). However, where use involves transformation of the system (i.e. altering its environmental condition), assessment is more complex. Besides assessing sustained yield, an assessment is required to determine how far a system can be modified before the environmental condition is no longer being maintained, as indicated by the Ramsar Convention. It may be, for example, that the cultivation of an area is sustainable from the perspective of sustained yield and soil and water conservation (e.g. if the erosion hazard is low and a perennial crop is grown, requiring infrequent tillage) but it may have a very high impact on the environmental condition of the wetland (e.g. because all of the natural vegetation of the wetland has been removed and replaced with crops).

[1] "Environmental condition" is taken to be synonymous with the terms "ecosystem integrity" and "ecosystem health".

Another concept that is closely linked with that of sustainability is “resilience”. This refers to the ability of a system to maintain its functionality when it is subject to perturbations or shocks (e.g. a major drought), or to maintain the elements needed to renew or reorganize if a large perturbation radically alters structure and function (Walker *et al.,* 2002). It is not that a resilient system resists change, but rather that it is able to recover by renewing or reorganizing itself if a large perturbation radically alters the structure of the system.

Table 2.1: The five key environmental components considered in assessing the extent to which use of a wetland alters the environmental condition of the wetland

Key components	Rationale
1. The distribution and retention of **water** in the wetland	Hydrology is the primary determinant of wetland functioning. The hydrological conditions in a wetland affect many abiotic factors, including soil anaerobiosis (waterlogging), availability of nutrients and other solutes, and sediment fluxes (Mitsch and Gosselink, 1986). These factors in turn strongly affect the fauna and flora that are present in a wetland.
2. The retention (or erosion) of **sediment** in the wetland	Wetlands are generally net accumulators of sediment, which affects the landform of the wetland, and this in turn has a feedback effect on how water is distributed and retained (i.e. hydrology). Sediment retention is also important for maintaining the wetland’s on-site agricultural productivity, as well as being potentially important for downstream water users by enhancing nutrient retention.
3. The accumulation of **soil organic matter** (SOM) in the wetland	SOM makes a significant contribution to wetland functioning and productivity, and contributes to (1) enhanced water holding capacity of the soil; (2) the physical strength of sandy soils, which increases their resistance to erosion, and (3) enhanced Cation Exchange Capacity (CEC) of the soil, which increases the proportion of nutrients held in the soil potentially available for uptake by plants (Miller and Gardiner, 1998; Mills and Fey, 2003; Sahrawat, 2004).
4. The retention and internal cycling of **nutrients** in the wetland	Wetlands are generally effective in retaining and cycling nutrients, which is important for maintaining the wetland’s on-site productivity in terms of growth of natural vegetation and crops, as well as being potentially important for downstream water users by enhancing nutrient retention and thus improving water quality (Mitsch and Gosselink, 1986).
5. The natural composition of the wetland **vegetation**	The particular composition of wetland vegetation is of significance in itself for biodiversity, and in addition provides habitat for a range of fauna. Particular plant species may also have direct economic importance (e.g. for use in craft production).

WET-SustainableUse assists in determining the effect that use of a wetland has on its environmental condition, based on an assessment of the extent to which five key inter-related components of the wetland have been altered. These key components are based on the elements assessed in WET-Health[2] (Macfarlane *et al.,* 2008), and together with the rationale for using them, are listed in Table 2.1.

Thus, WET-SustainableUse asks to what extent has the use of the wetland altered: (1) the distribution and retention of water, (2) the retention (or erosion) of sediment, (3) the accumulation of SOM, (4) the retention and cycling of nutrients, and (5) the natural species composition of the vegetation in the wetland? As explained in Section 4, WET-SustainableUse assists the user in answering these questions by providing a set of indicators and a structured way of scoring these indicators and deriving an overall score.

WET-SustainableUse does not prescribe what is considered to be sustainable (e.g. "to be sustainable, the environmental condition must not be reduced by more than 30%"). Instead, it provides some guidelines for assessing the sustainability of use based on the particular catchment, landscape and socio-economic context of the wetland. It may be, for example, that the environmental condition of two similar wetlands have both been reduced by the same amount, but the first is in a catchment where the cumulative impacts on wetlands are considerably higher than for the second wetland. Therefore, although reduced by the same amount, use of the first wetland is considered less sustainable in the context of the overall catchment than the second wetland.

WET-SustainableUse recognizes that sustainability can be assessed across different spatial levels (Adey, 2007), from the plot level to the level of an individual wetland, to the landscape comprising several interconnected wetlands. Even so, the primary focus of WET-SustainableUse is on the level of an individual wetland. Cumulative impacts on wetlands at a landscape level are examined specifically in another sub-component of the research programme (Ellery *et al.,* 2010).

As indicated, the focus of WET-SustainableUse is on assessing the effect of use on the environmental condition of a wetland, for which fairly detailed recommendations are provided. At the same time it is recognized that a change in environmental condition has implications for livelihoods (dealt with in Section 11) and the delivery of ecosystem

[2] WET-Health provides guidelines for scoring the health of a wetland in relation to its natural state in terms of three components: hydrology, geomorphology and vegetation. It assists in determining the wetland's Present Ecological State (environmental condition) in terms of DWAF categories: A to E. It also helps identify the wetland's trajectory of change and diagnose the causes of degradation. Scoring can be done at Level 1, based mainly on aerial photograph interpretation, or at Level 2, based on a field assessment of indicators of degradation (e.g. presence of alien plants).

services, for which users are referred to WET-EcoServices[3] (Kotze *et al.,* 2008b) and to the Millennium Ecosystem Assessment (2005).

Central to sustainability is an examination of people's 'needs' and people's 'options', and therefore by definition, the term is value-laden (Adey, 2007). Thus, when assessing sustainability, in addition to the technical/biophysical issues that must be addressed (e.g. what is the erosion hazard of the site?) there are socio-economic and institutional issues that must also be addressed (Kotze, 2002; Erenstein, 2003; Anderies *et al.,* 2004). Ecosystem use (and protection) is by definition a social and political process (Brechin *et al.,* 2002). As such, use and protection are dynamic, scale-related activities playing themselves out in complex ways within and between social and ecological systems. The resultant pressures and feedbacks are therefore difficult to predict and control. This complexity needs to be acknowledged and a holistic view of socio-ecological systems adopted (Walker *et al.,* 2002; Pollard *et al.,* 2008). Therefore, hope for the long-term protection and wise use of wetlands must lie in our acknowledgement of the inadequacies of current approaches, and confronting complexity using adaptive approaches to management that integrate within and across social, political, economic and ecological boundaries (Nyambe and Breen, 2002).

It is helpful to construct a framework that depicts the relationships between the actors and issues, and that exposes assumptions that underpin present understanding (Senge, 1990). It is people's needs, perceptions and desires that manifest in actions, which in turn affect the condition of wetlands. Some of these actions have direct consequences, for example harvesting resources such as water and food from a wetland by members of a household. Others arise indirectly as actions taken in response to political and policy decisions made remotely from any particular wetland, for example economic and structural reform, and signing conventions such as the Ramsar and Biodiversity Conventions. In this way actors and issues are connected across a range of scales from global to household through direct and indirect interactions and feedbacks (Figure 2.1). The conceptual framework given in Figure 2.1 is an adaptation of the Drivers-Pressure-State-Impact-Response model of the OECD (1993) framework, but makes much greater explicit reference to scale.

[3] WET-EcoServices provides guidelines for scoring the importance of a wetland in delivering each of 15 different ecosystem services (e.g. flood attenuation, sediment trapping, provision of livestock grazing). The first step is to characterize wetlands according to their hydro-geomorphic setting (e.g. floodplain). Ecosystem service delivery is then assessed either at Level 1, based on existing knowledge, or at Level 2, based on a field assessment of key descriptors (e.g. flow pattern through the wetland).

Because the system (Figure 2.1) is a complex interconnected network, downward pressure originating from government actions are propagated through the system, often with unpredicted outcomes, as has been shown on the Phongolo and Zambezi River floodplains (Nyambe and Breen, 2002). On the Phongolo River floodplain, flow regulation led to emergence of powerful new groups (notably, local cotton growers supported by a multinational seed company) who manipulate flow releases from an upstream impoundment in ways that alter patterns of resource use, favouring some households and putting others at a disadvantage (for more detail see Appendix 1). It becomes clear that inhabitants of developing countries are increasingly forced to adjust their livelihoods in response to many pressures which arise remotely from their locations, and at the same time weaken their abilities to adjust. As livelihoods lose their self-sustaining properties, so feedback effects are felt in government and even in global civil society, leading to further feedback effects which weaken local people further.

Kotze and Breen (2008) provide a framework for assessing the effectiveness of the management system of an individual wetland, referred to as WET-EffectiveManage. The framework consists of 15 questions each addressing an important element of management effectiveness (e.g. a management plan). For each question, the respondent assigns a score of 0, 1, 2 or 3, based on which of the criteria descriptions best fits the situation at the site being assessed. In addition, for each question, the respondent is invited to provide any additional comments. The questionnaire, which includes an explanation of each question and its underlying assumptions, is underpinned by the following three foundation elements required for effective management.

- It should be **strategic** (Box 1), in the sense that it is guided by a vision and objectives and the implementation of actions necessary to achieve these, and is explicit about defining what needs to be done, how, by whom and why (Rogers and Bestbier, 1997; Rogers and Biggs, 1999; Pollard and Du Toit, 2007).
- It should be **adaptive** (Box 1), in the sense that there is an ongoing process of monitoring and evaluation and adjustment to account for the lessons learnt (Holling, 1978; Mackenzie *et al.,* 2003).
- It should be **inclusive** of the key stakeholders that affect and are affected by the ecosystem, and responsibilities for allocating and using resources should be shared amongst multiple parties (Olsson *et al.,* 2004; Ramsar Convention on Wetlands, 2004; Plummer and Armitage, 2007).

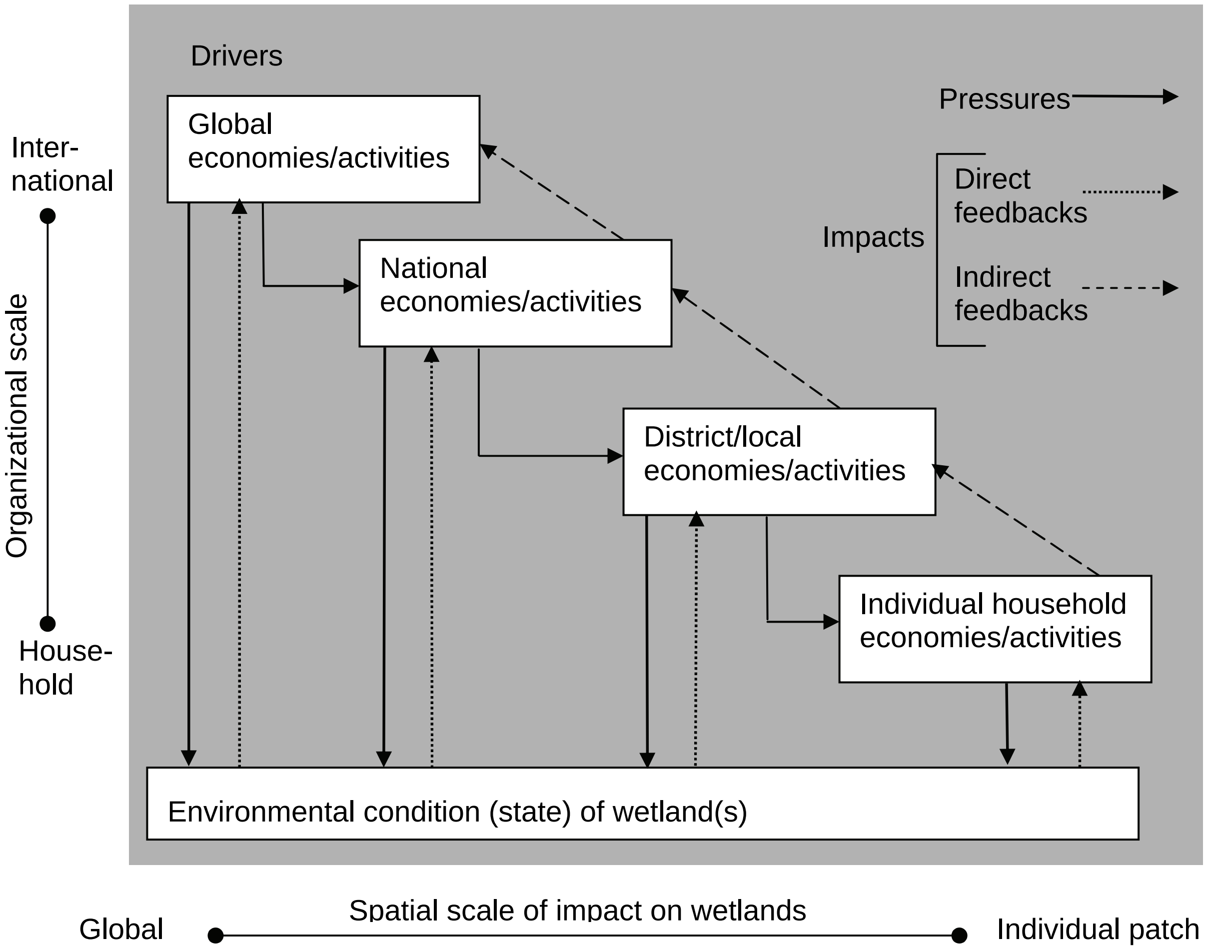


Figure 2.1: Human-wetland interactions and interrelationships at different spatial scales

These foundation elements, which are described further by Kotze and Breen (2008), are encapsulated in what can be referred to as Strategic, Adaptive Co-management (SAC) (Appendix 4). A key underlying assumption is that a management system that is strategic, adaptive and inclusive will be more sustainable than one which is not. For more detailed guidance on assessing how different institutional and management arrangements affect the robustness of a socio-ecological system see Anderies *et al.* (2004), Plummer and Armitage (2007) and Pollard *et al.* (2008 and 2009).

Box 1: Strategic adaptive management (adapted from Kotze and Breen, 2008)

In response to failures in the command-and-control approach to ecosystem management, which tended to try to maintain the stability of inherently dynamic systems, an adaptive approach is now being widely advocated (Rogers and Bestbier, 1997). Adaptive management is a structured process of ongoing "learning by doing" (also described as "management by experiment") where management actions are treated as potential learning opportunities (Walters, 1997; Rogers and Biggs, 1999; Mackenzie *et al.,* 2003). This is achieved through monitoring the outcomes of management actions, reflecting on these outcomes and then adjusting future actions accordingly. Successive cycles of action, monitoring, reflection, and modified action (i.e. a reflexive approach) thus lead to a progressive improvement in management competency. Adaptive management allows for flexibility in response not only to the dynamics of ecosystems but also to uncertainties and changes in the interests of stakeholders, the political climate and in resources available to management (Ramsar Convention on Wetlands 2004). Environmental issues are value-laden, and an understanding of the issues is shaped by the different, often conflicting, interests of society. Thus, a critical approach is required, where, during each reflection, issues and assumptions are questioned, which allows one to remain responsive to different contexts (Taylor, 2007).

Models are widely used in strategic adaptive management to make predictions of the effects of alternative scenarios of action (Walters, 1997). By investigating the effects of a number of scenarios in relation to the management objectives, management becomes strategic rather than reactive. Models do not have to be complex and numerical – they can be based on a few simple rules reflecting observed empirical relationships between management tools (e.g. timing of burning) and management outcomes (e.g. habitat suitability for a particular species).

Flowing from the management vision is a hierarchy of objectives, which, through increasing levels of detail, is ultimately linked to clear, auditable endpoints called Thresholds of Potential Concern (TPCs) (Rogers and Bestbier, 1997; Pollard and Du Toit, 2007). A TPC defines the threshold along a continuum of change in a particular environmental indicator or element. When assessment indicates that the threshold has been exceeded or is close to being exceeded then this highlights the need for specific management intervention and/or further investigation. The TPCs act as hypotheses that are adjusted as new learning is brought to bear (Rogers and Bestbier, 1997; Rogers and Biggs, 1999; Pollard and Du Toit, 2007).

For a description of the practical application of strategic adaptive management to management of the rivers of the Kruger National Park, see Pollard and Du Toit (2007).

3. WHO CAN USE WET-SUSTAINABLE USE AND FOR WHAT PURPOSES?

Users of WET-SustainableUse should preferably have a degree or diploma in physical sciences or agriculture or several years' experience as a field worker dealing with natural resource management, and at least two years' field experience with wetlands. WET-SustainableUse may be useful for assisting in the following purposes:

- creating simple models of socio-ecological systems, by drawing on the described general relationships (e.g. between tillage and SOM accumulation) and metrics and the examples that are provided;
- assessing how current use(s) of a particular wetland resource is/are impacting upon the environmental condition of a wetland (based on a qualitative scoring system that attempts to represent the relationships between land-use activities and components of environmental health);
- predicting how future use(s) of a particular wetland resource may potentially impact upon the environmental condition of a wetland;
- providing advice on the use of wetlands within the context of the long-term sustainable management of the wetland;
- planning and implementing individual projects promoting the sustainable use of wetlands, where guidance may be required in selecting which particular uses to promote and which need to be particularly strongly controlled and/or discouraged;
- developing policy dealing with the use of wetlands, particularly subsistence use;
- education and awareness relating to the use of wetlands, particularly in local contexts where users are adaptively managing a wetland resource;
- providing a framework for conducting research on the sustainable use of wetlands, by drawing from the described relationships and metrics as well as being directed by the knowledge gaps highlighted by WET-SustainableUse.

It is important to also emphasize what WET-SustainableUse is *not* designed to do, because users of the system must be fully aware of the limitations of the system, together with other tools that will assist them in dealing with issues that are beyond the scope of WET-SustainableUse.

- WET-SustainableUse focuses on land-uses taking place in the wetland itself, and does not cover in any detail the effect of land-uses in the catchment upstream of the wetland. Nevertheless, catchment effects are recognized as being potentially great, and users are referred to WET-Health (Macfarlane *et al.,* 2008) for assistance in dealing with the detailed assessment of such effects, and to Pollard *et al.* (2009), which provides a set of simple indicators that can be used with farmers and practitioners to assess the sustainability of use of the uplands surrounding the wetland.

- The system is insufficiently detailed to *quantify* the specific level of impact of a particular use on specific characteristics of the wetlands (e.g. accumulation of SOM). This requires specialist input and a more detailed, long-term investigation than that undertaken at the rapid assessment level of this system.
- Related to the above, the system does not quantify in economic terms the consequences of different use options of a wetland. Turpie (2010) and Turpie and Kleynhans (2010) provides frameworks to assist in carrying this out.
- Although WET-SustainableUse assists in assessing and scoring the impact of different uses (e.g. cultivation) on key process (e.g. accumulation of SOM), and it highlights the specific practices (e.g. tillage) which are contributing to the impacts (therefore suggesting possible ways of improving environmental sustainability), it does not provide prescriptive management guidelines for addressing these impacts and it also does not provide guidelines for the rehabilitation of wetlands. These are provided by Kotze and Breen (2000) and Kotze *et al.* (2008a) respectively.
- WET-SustainableUse does not provide any guidance on assessing the dependency of local users on the resources harvested from wetlands and on their livelihoods. Turpie (2010) provides an index for assessing the level of dependence of surrounding communities on the wetland, which has two components. The first is for assessing the benefits derived from wetlands by the local community, and the second is for assessing the vulnerability of that community to poverty. The assessment is based on field studies or on existing data in conjunction with estimates of the supply and demand relationships. Pollard *et al.* (2009) provide practical indicators that can be used by local communities for assessing the contribution of wetlands to their own nutritional, financial and social security. For more information about the concept of sustainable livelihoods, practical tools for assessing livelihoods and their sustainability (e.g. sustainable livelihoods guidance sheets) and case study reports refer to: www.livelihoods.org, and for a useful discussion on the link between sustainable livelihoods and adaptive co-management see Plummer and Armitage (2007).
- Although WET-SustainableUse assists in revealing some key issues relating to governance and to highlighting superficially some important strengths and weaknesses in terms of the long term sustainability of the governance system, it does not provide specific guidance for describing governance arrangements or indicators

for assessing and monitoring the long term sustainability of the governance system. This is specifically addressed by Pollard *et al.* (2009).

- WET-SustainableUse does not provide information on legislation relating to the use of wetlands, but this is covered by Hoffmann (2008), Armstrong (2008) and DWAF (2008).

Both WET-SustainableUse and the indicators of Pollard *et al.* (2009) deal with the sustainability of use of wetlands, and it is therefore useful to highlight key differences between the two tools in order to try and avoid confusion in their application. WET-SustainableUse focuses strongly on the *ecological* sustainability of practices taking place *within* the wetland, for which several indicators are provided. The system of Pollard *et al.* (2009) is considerably broader in the elements for which it provides indicators. Although it contains much less detail relating to ecological sustainability, it also includes indicators of the sustainability of practices in the wetland's upstream catchment, indicators of the sustainability of the governance system, and indicators of the livelihood contribution of the wetland. In addition, there is a greater emphasis on indicators that farmers themselves can use.

4. THE STRUCTURE OF THE WET-SUSTAINABLE USE FRAMEWORK

The sustainability framework and metrics were developed based on a review of the literature relating to the use of wetlands, and an examination of existing wetland assessment protocols. In addition, the framework was refined by applying it to a variety of case studies from several different biomes in South Africa (Appendix 2).

The assessment process in WET-SustainableUse is presented as a linear sequence of interconnected assessment components to be carried out in a step-by-step process (Figure 4.1) and users are encouraged to follow these steps. Having implemented actions informed by the assessment, users may need to determine if the desired outcomes have been achieved, in which case they would need to return to the first step in the sequence, and repeat the steps (i.e. the system can be applied in an adaptive management cycle: see Box 1).

Some users may not need to follow all of the steps and may require a more flexible approach, e.g. where they draw on selected elements of WET-SustainableUse to create their own models which represent their own understanding of the situation. Other users may have a very specific and narrow interest (e.g. are particular cultivation practices in a wetland likely to impact greatly on SOM levels in a wetland?). In such cases, the user can “dip in” to WET-SustainableUse to obtain this specific information, using the index of topics covered in the document (Section 16). It is important to emphasize that WET-SustainableUse serves as a guideline rather than something to be followed in a rigid ‘recipe-book’ fashion. Finally, as elaborated upon in Section 5, WET-SustainableUse is an imperfect representation of reality, which can undoubtedly be improved through further application to real world problems.

For assessing the impact of land-uses taking place within a wetland on the environmental condition of the wetland, two levels (1 and 2) of assessment are provided, depending on the level of detail required by the user. For both levels, the extent of the wetland affected by the land-use is estimated and expressed as a percentage of the overall area of the wetland.

Level 1 is less detailed, and involves a two-step process. Firstly, a preliminary assessment of the intensity of impact is undertaken, based on very broad assumptions about the land-use, which is given as a range of impacts (e.g. intermediate to high). Next, the preliminary assessment is fine-tuned by briefly describing practices associated with the land-use at the site, to determine where in the impact range given in the preliminary assessment the site is likely to lie (e.g. minimum tillage and mulching might result in soil erosion scoring intermediate rather than moderately high or high).

Level 2 is more detailed, and its approach and structure is derived from that given in WET-Health (Macfarlane *et al.,* 2008). In fact, it is designed to be applied as a "plug-in" module to use along with WET-Health. Before undertaking a Level 2 assessment, users are encouraged to read through Level 1 in this document in order to obtain a quick overview of how the three land-use types (i.e. cultivation, grazing and harvesting) compare with each other generally in terms of environmental impact.

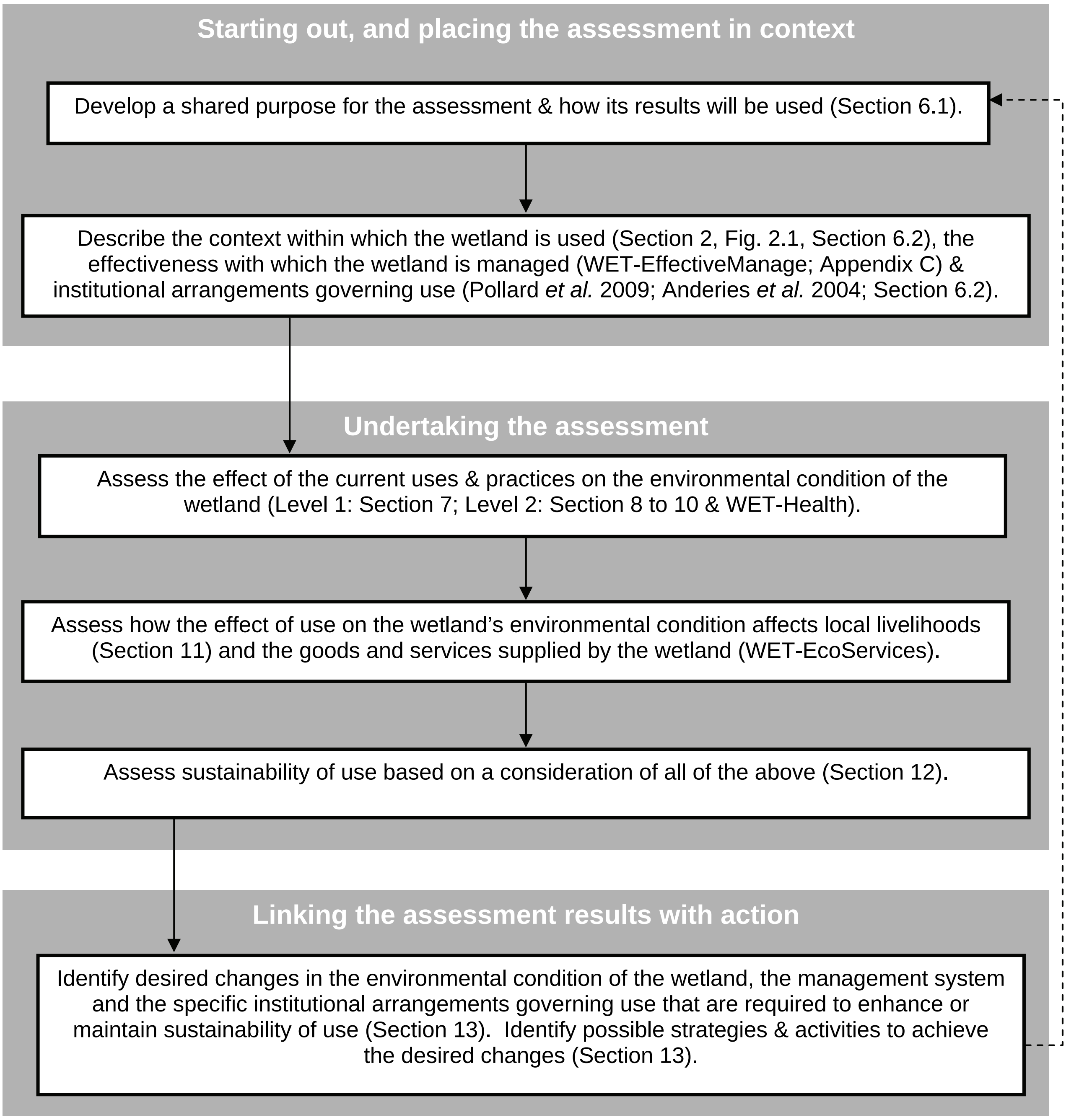


Figure 4.1: A framework for assessing the sustainability of wetland use

Level 2 consists of a series of models each comprising a set of metrics that are combined in a simple algorithm to represent how a key component of the wetland's environmental condition (e.g. sediment accumulation/erosion) is affected by use. The intensity of impact on the component being considered is determined by scoring each metric in the component's model. The scores are then arithmetically combined in the model to provide an overall index of the intensity of impact on the particular component, ranging from 0 (no impact) to 10 (critical impact). The extent and intensity are then combined to determine an overall *magnitude* of impact (Appendix 3). As in the case of the hydro-geomorphic

(HGM) method (Brinson and Rheinhardt, 1996), the algorithms are not simulation models but are designed to generate an index that reflects the extent of departure from the reference unimpacted condition.

The rationale behind the selection of each of the metrics is also provided, together with the rationale for combining the individual scores of the different metrics into a single score. The metrics are combined in a way that represents current understanding of their relative importance. In working out a combined score, it is recognized that not all factors need to score high for the overall impact to be high, and to base the overall impact on a simple average of all factors considered would “dilute” the impact. Thus, the overall score is generally based on the average of, for example, the five or six highest scoring metrics out of total of the eight to ten metrics considered. A description of a Level 2 application of WET-SustainableUse to two wetlands in the Kamiesberg, Northern Cape (together with an assessment of environmental condition using WET-Health and of the ecosystem services using WET-EcoServices), is given in Kotze *et al.* (2010).

Each model prescribes the factors to be assessed, how to score these factors and how to combine these scores to produce an overall sustainability score. This prescriptive structure is useful for standardization and for promoting consistency of assessments across different wetlands and by different assessors. However, its disadvantage is that it does not allow flexibility in accounting for some of the complexities of individual wetlands and their particular contexts and the way in which the wetland is used. Thus, the assessor may adjust the score, provided that full written justification is given. This follows the same approach as that given in WET-Health (Macfarlane *et al.,* 2008). Some general reasons prompting an adjustment include the following:

- an important site-specific factor may be missing from the model;
- the relative importance ascribed by the model to the particular factors and how they relate to one another may not be well represented;
- interactions between different impacts may not be well accounted for (e.g. how the impact of craft plant harvesting interacts with grazing and burning).

The greater the extent to which a land-use affects key ecological drivers, the greater will be the need to examine *how* they have been affected. Cultivation has the potential to affect key drivers far more than harvesting of wetland plants for crafts, and therefore requires a greater number of models to assess its impact (four models compared with one model). Livestock grazing is intermediate between these two.

Although WET-SustainableUse does not provide a comprehensive method for assessing the impacts of wetland use on biodiversity based on individual wetland-dependent species, the assessment provided by WET-SustainableUse is directly relevant to biodiversity in as far as the key ecological drivers that profoundly affect the biodiversity of a wetland are assessed. In addition, WET-SustainableUse explicitly assesses a key component of biodiversity, namely the natural species composition of the vegetation, which has further relevance to other taxa (e.g. birds and insects) for which vegetation provides essential habitat (Samways, 1993). Furthermore, the impacts of vegetation cutting on wetland-dependent birds are dealt with in the section on vegetation harvesting and a general review of the impacts of human use of wetlands on birds is given in Appendix 8.

5. CONCLUSION

5.1 Engaging complexity into the future

WET-SustainableUse has been developed with the intent that users of the system will seek ways to sustain or enhance sustainability. As has been highlighted, factors affecting the ecological sustainability of a socio-ecological system arise at different scales, and therefore these factors needs to be addressed at the appropriate scale(s). Another key issue raised by WET-SustainableUse is that sustainability of use is specific to the particular context in which it takes place. It is not appropriate to state (in no specific context) that a particular practice is (or is not) sustainable. It must be seen in relation to the particular context being assessed, and taking into account the particular vulnerabilities of the wetland. Therefore if sustainability is to be meaningfully engaged, there is no way of avoiding the complexity of each particular situation. This does not mean that we should be overwhelmed by the complexity of the multiple factors which constitute the functioning and use of ecosystems, and the interactions between these factors (H Biggs, 2008, pers. comm., SANParks, Kruger National Park; Pollard *et al.,* 2008).

WET-SustainableUse provides a set of models to help engage with this complexity and to develop a “picture” of “how the world works”. It is recognized that this “picture” will inevitably be something of a “cartoon” of reality. Nonetheless, it provides a starting point for defensible management decisions, and ultimately serves as a focus for co-learning and improving understanding. Furthermore, it is a tool that can be used in an adaptive and reflexive process (see Box 1). At the same time that the WET-SustainableUse framework is contributing to improved practice, it is recognized that its application will expose weaknesses and flawed assumptions in the framework itself, which will hopefully be addressed in the future, thereby improving the system. In a sense, the assessments carried out using WET-SustainableUse provide hypotheses for further testing within an adaptive management process (Box 1).

In the context of South Africa and other countries in Africa, there will seldom be the luxury of describing the social and ecological processes affecting a particular system in great depth. Instead, it will generally be necessary to start with a shallower (but preferably broad) understanding of the situation based on indicators or surrogates of key processes rather than quantitatively describing the processes themselves. This indicator approach is one of the central features of WET-SustainableUse. As valuable as this may be, it is also very important to recognize the limitations of this approach and not to treat the outputs of a WET-SustainableUse assessment as if they were derived through detailed, quantitative means.

5.2 Recommendations for further research

Detailed process-based research

As emphasized in Section 3, WET-SustainableUse is insufficiently detailed to *quantify* the specific level of impact of a particular use on specific characteristics of the wetlands (e.g. accumulation of SOM). A key reason for this is that WET-SustainableUse relies upon indicators of processes rather than describing the process itself. Therefore, there is a need for detailed, process-based descriptions of a few carefully selected reference wetlands. These would provide useful points of reference against which to validate systems such as WET-SustainableUse and WET-Health. Such wetlands could also serve as reference sites for future rapid assessments undertaken as other comparable sites (e.g. for the purposes of an environmental impact assessment, or EIA).

Research on the impacts of livestock grazing

As explained in Section 9, of the three uses of wetlands, livestock grazing is the least well understood, and yet it is the most widely applied use to the wetlands of South Africa. Therefore it has the greatest need for further research. Given the fact that the natural grazing regime under which a wetland evolved varies greatly according to biome, this research will need to be conducted across a diversity of different biomes in order to be nationally relevant. Furthermore, the interactive effects of fire with grazing will need to be included, given the fact that fire is often a key tool used by livestock managers.

Further testing of the application of WET-SustainableUse

As indicated in Appendix 2, WET-SustainableUse has been applied at different sites in four different biomes, and involving different individuals in the application. The author of WET-SustainableUse was involved in all of the assessments. While this provided the author with very valuable first-hand insights, it means that the system has not been independently applied. It would therefore be useful to formally solicit comment from those applying WET-SustainableUse more widely, without the input of the author. Formal testing of the precision of the outputs of the system's application to a wetland by independent operators would also be valuable.

PART 2: THE INDIVIDUAL COMPONENTS OF WET-SUSTAINABLE USE

6. INITIATING THE ASSESSMENT AND PLACING THE WETLAND USE IN CONTEXT

6.1 Developing a shared purpose for the assessment, and how the results will be used

Individual cases will vary; sometimes the need for an assessment is identified by an outside party (e.g. an extension worker), and the concept of undertaking an assessment will therefore need to be introduced to the users in an appropriate way. In other situations, wetland users themselves will request an assessment, which tends to be easier from the perspective of engaging users.

Generally, the first step in undertaking a sustainability assessment is to engage the users and other stakeholders (e.g. those that have the responsibility for regulating use). If wetland users (and extension and regulatory staff) are involved in the assessment process then it is assumed that they are more likely to consider (and later act upon) the issues that were raised in the assessment. This in turn provides opportunity to engage in dialogue about the issues, which may potentially contribute to more sustainable practices[4]. Furthermore, the local users are able to provide key information about their own practices, much of which would not be apparent during a single site visit by an outside assessor.

Once there is general agreement about undertaking a sustainability assessment, it is useful for the different parties to consider how the results will be used. If an effective and well institutionalized management system is in place with clearly defined management objectives, then the question will usually concern how the results will be used to assess achievement (or otherwise) of management objectives.

[4] Although it is readily acknowledged that increased awareness about the issues alone will often not lead to a change in practice.

6.2 Describing the context of the wetland use

Before examining the broad context of the wetland, it is necessary to delineate the boundary of the wetland and the upstream catchment area that supplies the wetland with water (surface and sub-surface; see DWAF, 2006; Kotze *et al.,* 2008b). In order to place the specific use(s) of a wetland in a broad context, the following steps are recommended for both Level 1 and Level 2 assessments.

1. Briefly describe the wetland in question, including its hydro-geomorphic (HGM) type(s) (floodplain, hill-slope seep, depression, etc.; see Kotze *et al.,* 2008b), any other key features of the wetland, and its context within the overall catchment (Hoffmann, 2008).
2. Identify key pressures and threats to the environmental condition of the wetland (including those which arise from direct use of the wetland and those which do not). WET-Health Level 1 provides a useful framework for carrying this out.
3. Describe the key drivers influencing use of (and the pressures and threats to) the wetland, based on the framework given in Figure 2.1 (the application of this framework to two examples is given in Appendix 1). Drivers influencing the use of wetlands are generally connected across a range of scales from global to household, through direct and indirect interactions and feedbacks.
4. Undertake a rapid assessment of the management effectiveness of the wetland (WET-EffectiveManage, included as Appendix 4) and briefly describe the governance arrangements that are in place, based on current understanding (Box 2). It is recognized that these and the above assessments are preliminary, and may need to be reviewed in more detail and refined later in the assessment.
5. Identify which specific uses of the wetland need to be assessed, and decide whether this should be a Level 1 (Section 7) or a level 2 (Sections 8 to 10) assessment for the specific use. A Level 1 assessment (more rapid) would generally be appropriate where several wetlands are being assessed (e.g. within a catchment) and the resources that can be allocated to individual sites are very limited, and a level 2 assessment (more detailed) would generally be appropriate for individual sites, particularly where some understanding is required of how the specific circumstances of the site are influencing the sustainability of use.
6. Identify the need for assessment of other aspects, which may potentially include one or more of the following:
   - **health/environmental condition** (using WET-Health: Macfarlane *et al.,* 2008) if there are other impacts and threats (e.g. abstraction of water in the wetland's

upstream catchment) besides those associated directly with the use, that need to be better understood and assessed;

- **ecosystem services** (using WET-EcoServices: Kotze *et al.,* 2008b; Ellery *et al.,* 2010) if the use of wetland resources is identified as potentially impacting upon any key ecosystem services delivered by the wetland in addition to the resources being used by local users;
- **institutions and governance** (Pollard and Cousins, 2007; Mitchell and Breen, 2007; Pollard *et al.,* 2009) if the influence of institutions and governance on the sustainability of the socio-ecological system needs to be better understood; this applies particularly to communal areas, which are often very complex;
- **economics** (Turpie, 2010) and Turpie and Kleynhans (2010) if the economic dimension of sustainability needs to be better understood (e.g. there may be a need to determine the economic value of different land-use options amongst which users need to decide);
- **policy and legal factors** (Pollard and Cousins, 2007; Hoffmann, 2008; Armstrong, 2008; and DWAF, 2008) if a need has been highlighted for improved understanding of the policy and legal dimensions of sustainability (e.g. some of the stakeholders may highlight that legal compliance is a key issue affecting long term sustainability).

Finally, when applying the assessment guidelines in Sections 7 to 10 it is important to remember to obtain the perspectives of the users themselves. Several of the metrics relate to specific information regarding particular practices (e.g. extent of fertilizer application) and the users can make a useful contribution by supplying this information. However, it is important to also obtain their perspective on how they see their land-use activities affecting the wetland’s condition, rather than simply “extracting” information from farmers to be “plugged into” the models given in Sections 7 to 10. For example, to an outside assessor the overwhelming significance of a raised bed is the effect that it has in drying out the wetland. However, a local farmer may see a key role of the bed as conserving soil as a result of the fact that most storm-flows pass between the raised beds in the vegetated furrows rather than washing over the tilled beds. Box 3 provides a few leading questions to facilitate this interaction.

Box 2: Governance of natural resources

Governance refers to the socio-political structures and processes by which societies share power, through exercising their rights, meeting their obligations, and mediating their differences. Governance includes laws, regulations, debates, negotiation, mediation, conflict resolution, elections, public consultations, protests, and other decision-making processes (Lebel *et al.,* 2006). Governance is not the same thing as government and it is not confined to the state, but involves many actors, including the private sector, community based organizations and NGOs. "It can be formally institutionalized or expressed through subtle norms of interaction or even more indirectly by influencing the agendas and shaping the contexts in which actors contest decisions and determine access to resources" (Lebel *et al.,* 2006).

Wise and effective governance is necessary for the sustainable use of natural resources. Governance of natural resources is exceedingly complex and dynamic (Peters, 2000; Pollard *et al.,* 2009), and it is beyond the scope of WET-SustainableUse to provide guidelines for assessing the effectiveness and sustainability of the governance arrangements. However, in order to note, very generically, some of the most salient aspects of the governance at the site, the following questions adapted from Cousins and Pollard (2008) and Pollard *et al.* (2009b) are provided.

- Is there clarity on who holds rights to which natural resources, where, when, how and on what basis?
- Are there clear processes for applying, transferring and adjudicating these rights?
- Do these processes result in fair distribution of benefits and costs between people and prevent unfair discrimination (e.g. against women, the poorest in the community or future generations of users)?
- Is it clear where responsibility and authority lie, and are these authorities known and accessible to resource users?
- Are the authorities responding promptly and effectively to problems that arise?

A generic assumption is made that the greater the level of positive response to the above four questions, the greater the likelihood that the governance system will be sustainable. WET-SustainableUse does not provide guidance on *how* these questions should be addressed, and does not account for much of the complexity that exists at a wetland site. In order to better account for this complexity, users are referred to the assessment framework of Pollard *et al.* (2009b) which provides detailed guidelines for answering these questions and building an understanding of a range of issues relating to governance (e.g. enforcing principles and rules that regulate land-use).

In communal areas in particular there is often confusion regarding governance. Not only are the statutory and customary governance systems operating in parallel, but within the statutory system, there are many laws which overlap to different extents. Addressing this confusion, Pollard and Cousins (2007) provide a comprehensive review of community-based governance of freshwater resources in southern Africa, aimed towards integrating community-based governance of water resources with the statutory frameworks for Integrated Water Resources Management.

Box 3: Leading questions to assist in soliciting the users' perspectives on the sustainability of their land-use practices

Six leading questions are given below, each of which could be probed further:

- How do you see the way you use this wetland affecting how water moves through and is retained in the wetland?
- How do you see the way you use this wetland affecting how sediment is lost through erosion or trapped in the wetland?
- How do you see the way you use this wetland affecting how nutrients are trapped and recycled in the wetland?
- How do you see the way you use this wetland affecting the plants (and animals) living in the wetland?
- How do you see the way you use this wetland affecting other uses of the wetland (e.g. if you use the wetland for cultivation and others use it for harvesting plants for crafts, your use of it may potentially affect theirs)?
- How do you see other land-uses affecting your use of the wetland?

7. THE LEVEL 1 ASSESSMENT

Identify the HGM type of the wetland (valley bottom with a channel, valley bottom without a channel, floodplain, hill-slope seepage, depression). For definitions of HGM types see the Glossary to this document, and for more information see Kotze *et al.* (2008b). If the wetland consists of more than one HGM type then it is preferable to carry out a separate assessment for each of those present.

For each of the three land-uses covered in this document (cultivation, grazing and harvesting) found to be present in the HGM unit, estimate (as a percentage of the area of the HGM unit) the **extent** of the HGM unit affected by it. Aerial photograph interpretation and GIS can be used for an accurate estimate of the extent of the land-use, otherwise, a less accurate estimate can be made by eye. For more information on assessing extent, see Macfarlane *et al.* (2008).

Next, as described in Appendix 3, the intensity of impact within the area affected by the land-use must be assessed. For a Level 1 assessment, this is assessed based on two main steps.

1. An initial assessment, as given in Table 7.1, based on the type of land-use (cultivation, livestock grazing or cutting of vegetation) and assumed general features thereof. The initial assessment gives a coarse impact range based on generic assumptions (e.g. the level of impact of annual crop cultivation on hydrology is likely to range from intermediate to high).
2. Refinement of the initial assessment, based on key features of the wetland and specific practices associated with use of the HGM unit, as given in Table 7.2. This table assists in determining approximately where the impact at the specific site is likely to lie within the impact range given in Table 7.1. It may be, for example, that a cultivated area has few and shallow artificial drainage channels in an HGM unit with a moderate vulnerability to artificial drainage (e.g. moderate permeability of soils), and that SOM is not greatly diminished (e.g. because of minimum tillage practices), in which case it is likely to have an intermediate impact (Example A: see Table 7.1). Alternatively, if there is a dense network of artificial drainage channels, which very effectively intercepts flow in an HGM unit with a high vulnerability to artificial drainage (e.g. high permeability of soils), then this is likely to have a high impact, particularly if accompanied by greatly diminished SOM levels (Example B: see Table 7.1).

From Table 7.1 it can be seen that harvesting plants for crafts and thatching has the least effect on the components of environmental condition considered (generally a low to moderate impact). While grazing may also be low to moderately low in its impact, it may also have a much higher impact, depending on the factors given in Table 7.2. Cultivation clearly has the highest impact on all of the components of environmental condition considered, particularly on the vegetation component; its impact is generally moderately high to high.

Table 7.1: Potential levels of impact of the three types of land-use on the environmental condition of the wetland, in terms of the five components of environmental condition: hydrology (water distribution and retention), erosion (sediment retention/erosion), SOM (soil organic matter) accumulation, nutrient retention and vegetation species composition*

Key components of environmental condition	Likely level of negative impact on the key component				
	Low	Mod. low	Intermediate	Mod. high	High
	Harvesting of plants for crafts and thatching				
1 Hydrology		(See Table 7.2, which lists for each of 1 to 15, the key features to consider in order to decide where along the impact range represented by the double-headed arrow a particular site lies)			
2 Erosion					
3 SOM accumulation					
4 Nutrients					
5 Vegetation comp.					
Overall					
	Livestock grazing				
6 Hydrology					
7 Erosion					
8 SOM accumulation					
9 Nutrients					
10 Vegetation comp.					
Overall					
	Cultivation of annual crops		Example A**		Example B
11 Hydrology					
12 Erosion					
13 SOM accumulation					
14 Nutrients					
15 Vegetation comp.					
Overall					

*The double-headed arrows represent the likely range in impacts, e.g. harvesting of plants for crafts and thatching is likely to have a low to moderately low impact on hydrology, whereas cultivation of annual crops is likely to have a moderately low to high impact on hydrology.

**Examples A and B are described in the text preceding Table 7.1

Table 7.2: Key features to consider when deciding where in the impact range given in Table 7.1 a particular site lies for the three different land-uses and five components of environmental condition: hydrology (water distribution and retention), erosion (sediment retention/ erosion), SOM (soil organic matter) accumulation, nutrient retention and vegetation species composition

Impact of harvesting of plants for crafts and thatching (for more information on the impact of harvesting, and for the rationale and supporting references for the guidelines given below, see Section 10)
[1]**Hydrology:** impact is likely to be greatest where cutting takes place: (1) within the main flooding season, (2) during the plants' growing season, (3) annually or more frequently (not allowing adequate time for recovery), and/or where mats of discarded material suppress new growth. Overall, the impact will be limited because wetland plants are generally highly resilient to cutting, and cutting is not accompanied by artificial drainage. [2]**Erosion:** impact is generally low, given that cutting does not disturb the soil or roots of the plants, which then rapidly re-grow. [3]**SOM accumulation:** Impact is likely to be greatest when harvesting is annual or more frequent (not allowing adequate time for recovery). However, SOM contributed by roots and discarded material, and the lack of soil disturbance, limit the level of impact. [4]**Nutrients:** impact is generally low, given that cutting does not disturb the soil or roots of the plants, which rapidly re-grow. In addition, nutrients are removed in the harvested material which, in fact, enhances the capacity of the wetland to assimilate nutrients. [5]**Vegetation:** impact is likely to be greatest where cutting takes place: (1) during the plants' growing season, (2) annually or more frequently (not allowing adequate time for recovery) and (3) in vegetation with a mix of different species, where cutting may potentially favour those species not selected, rather than in a single-species stand. However, impact is often limited by the high resilience of the wetland plants.
Impact of livestock grazing (for more information on the impact of livestock grazing, and for the rationale and supporting references for the guidelines given below, see Section 9)
[6]**Hydrology:** impact is likely to be greatest where grazing leads to high levels of erosion (see below), which in turn concentrates flow and may dry out the wetland. In the absence of high levels of erosion, impact is likely to be intermediate where inherently tall vegetation is grazed uniformly short and livestock paths (which modify the flow of water) are abundant in the wetland, and impact is likely to be low where grazing does not greatly change vegetation height and there are few paths in the wetland. [7]**Erosion:** impact is likely to be greatest where: (1) some of the following factors apply:- (a) reduction in vegetation cover is high, (b) inherently tall vegetation is grazed uniformly short, (c) livestock paths are abundant in the wetland and (d) the extent of poaching (disruption of soil structure caused by the repeated penetration of hooves into wet soil) is high; and (2) the site is vulnerable to erosion (e.g. because of its steep slope, high erodability of the soil type, and/or location within a major storm-flow path). [8]**SOM accumulation:** impact is likely to be greatest when hydrology and/or erosion impact is high and least when both hydrology and erosion impact is low. High levels of erosion result in SOM being physically carried away, and high levels of hydrological impact (causing a lower level of wetness) increase the decomposition rates of SOM. [9]**Nutrients:** impact is likely to be greatest when hydrology, erosion and SOM impact is high and least when these are low. High levels of erosion result in nutrients adsorbed to soil particles being removed with SOM being physically carried away. High levels of impact to SOM reduce the CEC of the soil, which affects its capacity to hold nutrients. [10]**Vegetation:** heavy grazing pressure may result in an increased abundance of opportunistic pioneer species such as *Eragrostis plana*. The high resilience of wetland vegetation in general (particularly that dominated by one or a few species such as *Cynodon dactylon* or *Phragmites australis)* limits the

potential impact of high grazing pressure. Moderate grazing pressure may have a low impact or even a positive effect on the vegetation composition, given that most wetlands evolved under conditions of some grazing.

Impact of cultivation of annual crops (for more information on the impacts of annual cultivation, and for the rationale and supporting references for the guidelines given below, see Tables 7.3 and 7.4, and Section 8).

[11]**Hydrology:** impact is likely to be greatest where there is a high density of (usually deep) artificial drains, which effectively drain water from the wetland (wetland areas with a steep slope, permeable soil and naturally high level of wetness are most vulnerable to artificial drainage). Highest impact usually also results from artificial drains effectively intercepting flows entering the wetland. In addition to artificial drainage, reduced SOM and disrupted soil structure (as a result of tillage) lowers water holding capacity and may also reduce water infiltration and the lateral movement of water through the soil. Crops with high water use contribute further to the impact.

[12]**Erosion:** impact is likely to be greatest where: (1) some of the following factors apply:- (a) the frequency, extent and depth of tillage is high (especially if mechanized), (b) tillage occurs during the main flooding season, (c) SOM has been reduced (applies particularly to sandy soils), (d) vegetation cover is significantly reduced, (e) the roughness of the vegetation (which offers frictional resistance to water flow) is significantly reduced, and (f) water flows are concentrated (e.g. by artificial drainage channels); and (2) the site is vulnerable to erosion (e.g. because of its steep slope, high erosion hazard of the soil, and/or location within a major storm-flow path or near an existing erosion feature).

[13]**SOM accumulation:** Impact is likely to be greatest when hydrology and/or erosion effects are strong and least where both hydrology and erosion effects are weak. Furthermore, a high level of tillage and low soil cover by plants and/or mulch, besides contributing to erosion, also directly lowers SOM by increasing decomposition rates. Impact is further increased where crop residues and weeds are removed rather than being returned to the soil.

[14]**Nutrients:** Impact is likely to be greatest when effects on hydrology, erosion and SOM are strong and least when these are weak. In addition, impact is likely to be increased if the nutrient availability is out of synchrony with the time when the crops are actively growing, and if no soil building crops (e.g. legumes) are grown.

[15]**Vegetation:** cultivation of annual crops generally involves the complete removal of the native vegetation, and therefore there is little that can be done to prevent a high level of impact on the vegetation in the cultivated area. It is, however, acknowledged that once the cultivation is abandoned then the vegetation often recovers partially, and can return to close to the original species composition.

Given the potentially very high impacts associated with cultivation, a further two tables, Tables 7.3 and 7.4, are included to provide further assistance in scoring impacts at Level 1. All of the factors included in Table 7.3 and 7.4 are covered in Section 8 in greater detail, but in Tables 7.3 and 7.4 the factors are grouped from the perspective of the user, and therefore these tables are likely to be particular useful for extension workers.

Table 7.3 consists of two sets of questions:

1. the first set of questions deals with the location chosen by the farmer in which to cultivate in relation to sensitive features of the wetland;
2. the second set of questions deals with the specific cultivation practices in the cultivated area, and the environmental impacts associated with these practices.

The following rules of thumb can be used for interpreting the results:

1. if more than half of the factors score high then the overall impact on the environmental condition of the wetland is likely to be high;
2. if most factors score low, then the overall impact is low;
3. situations in between 1 and 2 have an intermediate overall impact;
4. in some cases, however, a few individual factors may have an overriding impact, resulting in a high overall impact.

Table 7.3 is useful for highlighting, at a glance, those specific aspects/practices that are contributing positively to achieving sustainability (and farmers can be encouraged to continue with these practices), as well as those contributing negatively (and here, work could be done with farmers to explore alternative practices that would have less impact). From Table 7.3 it can be seen that the type of crop has an important effect on the specific environmental impacts of cultivation (Box 4).

Table 7.4 interprets the relevance of the factors given in Table 7.3 in terms of the five different components of environmental condition. For example, the tolerance of the crop to waterlogging is directly relevant to hydrology (because it determines the need for artificial drainage) and indirectly relevant to SOM accumulation and nutrient retention (through any altered hydrology that may result from planting of the crop).

Table 7.3: Guidelines indicating how the location of the cultivated area and different cultivation practices may generally impact upon the environmental condition of a wetland

Location of the cultivated areas in relation to:	**Likely intensity of impact**			**Rationale**
	Low	**Inter-mediate**	**High**	
Vulnerability to erosion	Cultivation is in an area that has a low risk of erosion		Cultivation is in an area that has a high risk of erosion (e.g. immediately upstream of an erosion head-cut)	Cultivation exposes an area to erosion, and therefore if cultivation takes place where there is a high risk of erosion then the likelihood is high that this will contribute to erosion.
Level of wetness	Cultivation is in an area with a naturally low level of wetness		Cultivation is in an area that has a naturally high level of wetness	The higher the level of wetness, the greater the likely need for artificial drainage, given that most crops have a low tolerance to waterlogging. However some, such as madumbes, have a higher tolerance, requiring less drainage.
Sensitivity of the natural vegetation	Cultivation is in an area where the natural vegetation is dominated by species that are well adapted to quickly colonizing disturbed areas		Cultivation is in an area where the natural vegetation is dominated by species that are poorly adapted to quickly colonizing disturbed areas	Shifting cultivation in vegetation that is dominated by species that are poorly adapted to quickly colonizing abandoned cultivated plots is likely to result in the loss of sensitive species over time, causing high impacts. Conversely, vegetation well adapted to re-colonizing will generally recover, thereby reducing the impacts.

Table 7.3 continued.

Practices concerned with the cropping system:	Likely intensity of impact			Rationale
	Low	Inter-mediate	High	
Crop type	High tolerance to waterlogging		Low tolerance to waterlogging	The lower the tolerance to waterlogging, the greater the need for artificial drainage.
	Perennial / Aerial crop		Annual / Root crop	Annual crops and root crops require a greater level of soil disturbance than perennial crops and aerial crops.
	Low transpiration rate		High transpiration rate	The higher the transpiration rate, the greater the loss of water from the wetland.
	Inherently high cover		Inherently low cover	The lower the cover, the lower the protection provided against erosion.
	Inherently low surface roughness		Inherently high surface roughness	The lower the surface roughness, the less effective the vegetation in slowing down the flow of water.
	Soil building properties high		Limited soil building properties	The higher the soil building properties, the greater the contribution to plant production and erosion control.
	Multiple crop types		Single crop type	A multiple crop system is generally more resilient to extreme events (e.g. particularly wet or particularly dry periods).
Timing of planting	Outside the main flood season		Within the main flood season	Planting in the main flood season is most likely to result in crop damage and soil erosion.
Weed management	Weeds suppressed with mulch or cover /alley crops		Tillage	Tillage is much less favourable for controlling erosion than mulch or cover/alley crops.
Artificial drainage	Low level of drainage (e.g. few, shallow, & with low gradient)		High level of drainage (e.g. many drains, deep, & with high gradient)	The higher the level of drainage, the greater will be the impact on the natural retention of water in the wetland.
Tillage	Limited extent / Low intensity (e.g. minimum tillage)		Extensive area tilled / High intensity (e.g. mechanized deep plowing)	Tillage reduces soil strength and soil organic matter content, leading to greater levels of erosion and loss of nutrients.
Utilization of crop/weed residues	Incorporated or mulched (most preferred) in the plot		Livestock fodder, cleared and discarded and/or burnt	Crop residues returned to the wetland soil (e.g. through mulching) contribute to SOM, which promotes nutrient retention.

Bands/border of natural vegetation	Present and running at right angles to the direction of water flow (high surface roughness most preferred)		Absent	Bands of natural vegetation promote the binding of soil, and if the surface roughness of the vegetation is high, the flow velocity of water is reduced.

Table 7.4: Relevance of the factors given in Table 7.3 to the five different components of environmental condition

Factors given in Table 7.3	Components of environmental condition				
	Hydrology	**Sediment retention/ erosion**	**SOM accumulation**	**Nutrient retention**	**Vegetation composition**
Vulnerability to erosion	*	***			
Level of wetness	***				
Sensitivity of vegetation					***
Tolerance to waterlogging	***		*	*	
Annual vs. perennial		***	***		
Aerial vs. root crop		***	***		
Transpiration rate	***				
Aerial cover		***			
Soil building properties				***	
Number of crop types				***	
Timing of planting relative to flooding season	***				
Mode of weed management		***	***		
Artificial drainage	***	*			
Tillage intensity	*	***	***	*	
Utilization of crop/weed residues				***	
Bands/border of natural vegetation	***			***	

* indirect relevance

*** Direct relevance

Box 4: The effect that the choice of crop has on the likely intensity of impact of cultivation on the ecological condition of a wetland

Three crops commonly grown in wetlands are shown below.

Maize ▲ Madumbe ● Pumpkin ○

Likely intensity of impact		
Low	**Intermediate**	**High**
High tolerance to waterlogging ●	○	Low tolerance to waterlogging ▲
Perennial		Annual ○●▲
Aerial crop ○▲		Root crop ●
Low transpiration rate	○	High transpiration rate ●▲
Inherently high cover	▲●○	Inherently low cover
Soil building properties high	○	Limited soil building properties ●▲

From the above it can be seen that although madumbes are "wetland friendly" from the perspective of their high tolerance to waterlogging, there are other aspects about the crop (e.g. the fact that it is a root crop, which requires a high level of soil disturbance) which are "environmentally unfriendly".

Potentially negative aspects of a crop can be compensated for to some extent by other components (e.g. the impact of an annual crop on soil disturbance could be mitigated in the case of aerial crops, such as maize and pumpkin, by adopting minimum tillage). However, other potentially negative impacts would be very difficult to mitigate (e.g. if a crop which had a very low tolerance for waterlogging was chosen for cultivation in the wetland, that would dictate that a relatively high level of drainage would be required if the wetland was inherently very wet).

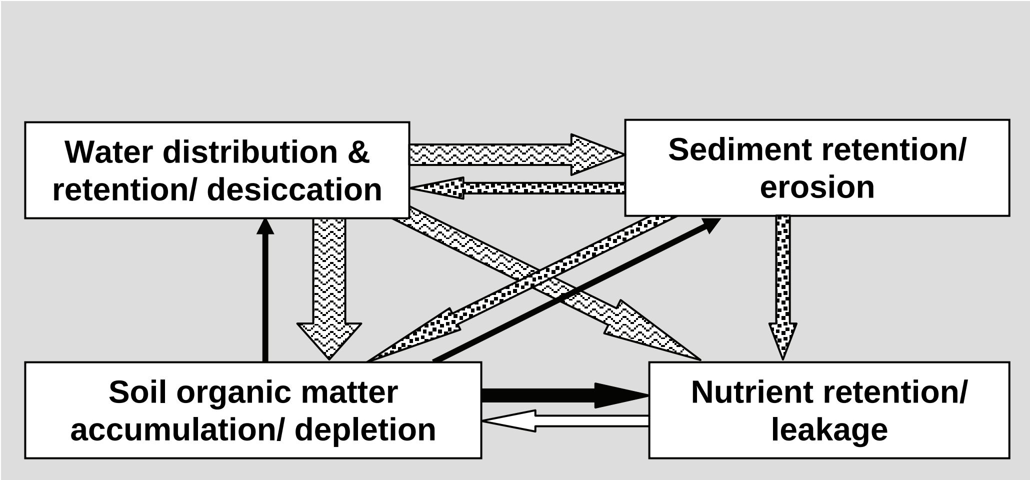
8. THE LEVEL 2 ASSESSMENT FOR CULTIVATION OF WETLANDS

Plate 8.1: A plot of the root crop madumbes (*Colocasia esculenta*) being cultivated in a wetland. Madumbes are widely cultivated by small scale farmers, particularly in KwaZulu-Natal. Madumbes are generally cultivated by hand in raised beds.

8.1 The general approach used to assess the effects of cultivation

A Level 2 assessment for cultivation is based on the same considerations as those in Table 2.1 and in the Level 1 assessment given in the previous section, but examines these factors more deeply. It considers the following: (1) the distribution and retention of water in the wetland, (2) the retention (or erosion) of sediment in the wetland, (3) the accumulation of SOM in the wetland, (4) the retention and internal cycling of nutrients in the wetland and (5) the natural composition of the wetland vegetation.

The first four items listed above can be described as hydro-geomorphic processes, and cultivation can profoundly affect all of them. Given that these processes closely affect each other, it is useful to start by gaining a general overview of how they are interlinked (Figure 8.1). Water retention has the most influence on, and is the least affected by, the other processes, and can therefore be considered the primary driving process; it is thus assessed first. Conversely, nutrient retention is the most affected by, and has the least influence on, the other factors, and should therefore be considered last. The main influence of nutrient retention is indirect, through plant growth and the organic matter accumulation that results from this growth, i.e. it influences the other factors indirectly through organic matter accumulation. Sediment retention and SOM accumulation are intermediate between water retention and nutrient retention in terms of their influence on the other processes.



Note: thickness of the line indicates the general magnitude of influence

Figure 8.1: Inter-relationships and causal links amongst four key hydrogeomorphic processes occurring in a wetland that are affected by wetland cultivation practices, which in turn, affect agricultural production and the goods and services supplied by a wetland.

The strength of the relationships represented in Figure 8.1 refer to the general situation, although it is acknowledged that it may vary considerably depending on the particular circumstances at the wetland site. For example, if the texture of the soil at the site is very sandy then the influence that organic matter accumulation has on sediment retention (by increasing the cohesiveness of the soil) is greater than if the soil was clay, which is inherently more cohesive and therefore more resistant to erosion than sand. The influence on nutrient retention (by increasing CEC) would also be greater, given that CEC is inherently lower in sandy soils than in clay.

Each of the four main processes given in Figure 8.1 is represented by a separate model in this assessment procedure (given as Tables 8.1, 8.3, 8.6 and 8.7). As explained in Section 4, each table contains a set of indicators that are scored, and the scores are aggregated in order to derive an overall score that reflects the extent to which the process has been disrupted, ranging from zero (no effect) to ten (highly/critically disrupted). The linkages between the four models are captured by the fact that if one process affects another then its output is included amongst the factors influencing the other process. For example, because water retention is a key factor affecting SOM, the level of impact on water retention (as indicated by its overall score) is taken as one of the factors considered in assessing organic matter accumulation/depletion.

Impacts on vegetation composition are assessed separately from the four components given in Section 8.1. The vegetation assessment is based primarily on the framework given in WET-Health, and involves determining the extent to which the vegetation composition has deviated from its reference state (e.g. through increased abundance of weedy species or invasion by alien species). An important impact of cultivation, particularly where its extent is high, is to fragment native habitat. The impacts may be particularly severe when the resulting fragments are smaller than the minimum size required for wetland dependent species. WET-SustainableUse does not provide specific indicators for assessing this particular impact, but the topic is reviewed in relation to wetland dependent birds in Appendix 8, which includes information on the minimum habitat size required by different wetland dependent bird species.

8.2 A set of questions to help guide discussions with farmers

WET-SustainableUse is primarily arranged according to the underlying processes in the wetland (i.e. from the perspective of the wetland). In addition, guiding questions are provided which are arranged more from the perspective of the farmer, starting with the particular types of crops that are grown (Box 5). It is recommended that the questions in Box 5 are followed with the few questions given in Box 3. You may in fact find that in discussing cultivation practices with the farmer, guided by the questions in Box 5, most of the questions in Box 3 would have already been answered. Much of the information gained from the questions in Boxes 3 and 5 will have relevance to assessing the impacts of cultivation on the wetland's environmental condition (i.e. Sections 8.2 to 8.7).

Box 5: A set of questions to help guide discussions with farmers about their cultivation practices within wetlands

1. What crops do you grow in the wetland?
2. (a) For each individual crop, when do you plant? (b) Why do you plant at these particular times?
3. (a) How do you prepare the land for planting? (b) Why do you use these methods?
4. If you use a hoe, how deep do you till?
5. How often do you need to weed?
6. What method do you use to weed (hoe, pull by hand, cut, etc.)?
7. (a) What do you do with the crop residues and weeds (burn, compost, mulch, feed to livestock, etc.)? (b) Why?
8. Do you apply manure or other fertilizers?
9. Is there anything that you do specifically to conserve soil?
10. Which of your crops provide good cover to the soil?
11. Do any of your crops help to improve soil fertility?
12. Which of your crops consume a lot of water? (It is recognized that some farmers may not be able to answer this question.)
13. Is there anything that you do specifically to conserve water?
14. Do you have any artificial drains (furrows) in your wetland plot?
15. Do you cultivate in a permanent plot, or do you shift your cultivated plot after a few years?
16. (a) If you practise shifting cultivation, after how many years you generally shift? (b) And after how many years is your original plot generally ready to cultivate again?
17. (a) If you cultivate in a permanent plot, do you ever rest any part of your plot? (b) Why? (c) If so, how much of the plot do you rest? (d) For how long do you rest it?
18. Do you leave areas of natural vegetation in your plot?
19. How do you change your practices in a very dry year?
20. How do you change your practices in a very wet year?

8.3 Impact of cultivation on hydrology within the wetland

Artificial drainage channels (drains) are generally the most important way in which within-wetland agriculture impacts on a wetland's hydrological condition. Therefore, this section focuses specifically on the extent to which artificial drainage channels and other measures (e.g. ridge and furrowing or raised beds) associated with cultivation result in reduced water retention and therefore increased desiccation of a wetland. This section is based on the procedures given in Section 3 of WET-Health for assessing artificial drains. However, it is important to emphasize that in addition to artificial drainage channels, several other human activities linked with cultivation may impact upon a wetland's hydrological condition, including the following:

- alteration of the surface roughness of the vegetation (e.g. by replacing tall robust reeds with a lawn);
- abstraction of water directly from the wetland (e.g. for irrigation);
- obstruction of flow through the wetland (e.g. as a result of a farm dam constructed in the wetland);
- introduction of plants (e.g. bananas or eucalypt trees) that may have a higher water usage than the indigenous vegetation;

- alteration of water inputs (i.e. volume) to the wetland from its upstream catchment (e.g. as a result of plantation forestry in the wetland's upstream catchment);
- alteration of the pattern of water inputs to the wetland from its upstream catchment (e.g. as a result of increased hardened surfaces in the wetland's upstream catchment).

These activities are not dealt with in WET-SustainableUse. If they are encountered in a wetland and need to be assessed then this can be done using WET-Health, which includes specific guidelines for assessing all of these activities. In addition, Allen *et al.* (1998) provide a useful reference for undertaking coarse estimates of the water use of different crops.

To undertake an assessment of artificial drains use Table 8.1, which can also be used to assess the desiccating effect of erosion gullies. Eight factors that influence the desiccating effect of drains (or gullies) are given in the table. Each should be scored with reference to the appropriate rationale, which is given below the table. As indicated in Section 4, the assessor may adjust the scores of individual factors provided that full written justification is provided.

A useful cross-check when assessing the impact of drains is the tolerance to waterlogging of the crops which are grown, relative to the natural level of wetness of the cultivated area. If the difference between these two is great (a low tolerance to waterlogging in an area with a naturally high level of wetness) then one would expect a high level of artificial drainage, although this may not always be so. Madumbes, bananas and tall fescue are three crops widely grown in South African wetlands which generally have a moderately high tolerance of waterlogging, but most other crops grown in South African wetlands have a low to moderately low tolerance for waterlogging.

Table 8.1: Factors affecting the impact of artificial drainage channels on the distribution and retention of water in the HGM unit

Extent of HGM unit affected by artificial drainage channels	ha	%

Factors	Low impact				High impact	Score
	0	2	5	8	10	
Features of the wetland						
(1) Slope of the wetland	<0.5%	0.5-0.9%	1-1.9%	2-3%	>3%	
(2a) Texture of mineral soil, if present*	Clay	Clay loam	Loam	Sandy loam	Sand/ loamy sand	
(2b) Degree of humification of peat soil, if present*	Completely amorphous (like humus)	Somewhat amorphous	Inter-mediate	Somewhat fibrous	Very fibrous	
(3) Natural level of wetness in the cultivated area	Permanent & seasonal zones lacking (i.e. only the temporary zone present)	Seasonal zone present but permanent zone absent	Permanent & seasonal zones both present but collectively <30%	Seasonal & permanent zone both present & collectively 30-60%	Seasonal & permanent zone both present & collectively >60% of total HGM unit area	
Features of the artificial drains						
(4) Depth of the drains**	<0.20 m	0.20-0.50 m	0.51-0.80 m	0.81-1.10 m	>1.10 m	
(5) Density of drains (metres of drain per hectare of wetland)	<25 m/ha	26-100 m/ha	101-200 m/ha	201-400 m/ha	>400 m/ha	
(6) Location of drains in relation to flows into and through the wetland. Drains are located such that flows are:	Very poorly intercepted	Moderately poorly intercepted	Inter-mediate	Moderately well intercepted	Very well intercepted	
(7) Obstructions in the drains	Complete obstruction	High obstruction	Moderate obstruction	Low obstruction	No obstruction	
Calculate the mean score for factors 1, 2a or 2b, 3, 4 and 5						
Multiply the score for factor 6 by the vulnerability factor (Table 8.2)						
Take the mean of the above two scores						
Intensity of impact for canalization: divide the score for factor 7 by ten and multiply this by the mean score derived in the previous step						
Multiplying the above score by factor 8 from Box 6 below, which reflects the lowered capacity of the soil to hold water						
Magnitude of impact of canalization: **extent of impact/100 × intensity of impact calculated in the row above**						

*Soil texture in mineral soils or humification in organic soils is used as a coarse surrogate for hydraulic conductivity, with zero = low conductivity and ten = high conductivity. See Rationale for Table 8.2 for field guidance for recognizing whether the soil is organic, and for distinguishing between the different texture and humification classes.

**In some circumstances, a wetland may be artificially drained by tilling the soil and piling it up onto raised beds rather than digging a drainage channel down below the soil surface. Both methods, however, serve to dry out the area. In the case of raised beds, the height of the bed above the low ground between the beds (furrow areas) is taken as the “depth of the drains”.

Box 6: Accounting for the reduced capacity of the soil to hold water (factor 8; not included in WET-Health)

Two further factors, not included in Table 8.1, which affect the capacity of the soil to hold water at a plot scale, also need to be accounted for.

- The extent to which SOM is depleted, which would reduce the water holding capacity of the soil (see Table 8.6, overall score).
- The depth to which the structure of the soil has been disrupted, which limits the height above the water table to which the soil is maintained at close to saturation point (i.e. the height of the capillary fringe). Deep tillage will tend to have a much greater impact than shallow tillage. See average score for metrics 6 to 8 of Table 8.3.

From the above two items, take that which scores highest.
If ≤ 2 then adjustment factor = 1.00
If >2 and ≤ 8 then adjustment factor = 1.05
If >8 then adjustment factor = 1.10

For example, if the SOM depletion score is 5 (from Table 8.6) and the disruption of soil structure (metrics 6 to 8 of Table 8.3) scores 6 then factor 8 would be 1.05.

8.3.1 Rationale for Table 8.1

The logic of the above scoring system is as follows. Canalization (through deliberate construction of canals, insertion of pipes, or through the formation of erosion gullies) can desiccate an area of wetland by draining the wetland more quickly than would naturally occur, i.e. by reducing the retention of water in a wetland (accounted for by factors 1 to 4), and by intercepting flow entering the wetland (accounted for by factor 5). The vulnerability factor is included based on the ratio of Mean Annual Precipitation to Potential Evapotranspiration (MAP:PET – see Table 8.2), and the lower this ratio, the smaller will be the contribution of direct precipitation falling onto the wetland and the more dependent the hydrology of the wetland will be on inflows from its upstream catchment, and therefore the more vulnerable it will be to intercepted inflows. Both the draining and intercepting effects of canalization may be negated to varying degrees by obstructions in the canals, such as vegetation or rehabilitation plugs (accounted for by factor 7). At one extreme, a minimum score, there are no obstructions, and at the other extreme, a maximum score, the obstructions are completely negating the effect of the canalization. Box 7 provides a worked example.

Box 7: A worked example including all of the factors given in Table 8.1

For example, where the factors score as follows: factor 1-2, factor 2-5, factor 3-5, factor 4-2, factor 5-8, factor 6-5, and factor 7-5, the vulnerability factor is 0.9, the adjustment factor from Box 6 is 1.05, and the canalized area occupies 60% of the wetland.

- The mean score for factors 1 to 4 is 3.5 ((2+5+5+2)/4).
- Factor 5 (score of 8) multiplied by the vulnerability factor (0.9) is 7.2 (8 X 0.9).
- The mean score for the two above factors is 5.35 ((3.5+7.2)/2).
- To account for obstructions, the above mean score (5.35) is multiplied by the score of factor 7 divided by ten, and gives an impact intensity of 2.68 (5.35 X (5/10)).
- To account for the reduced water holding capacity of the soil (Box 6), the above score is multiplied by 1.05, which gives 2.81.
- The **magnitude** of the impact is 60/100 X 2.81 = 1.69 (which is moderately low, given that the magnitude of impact ranges from zero [no impact] to ten [critical impact]).

Each of the factors that affects the final outcome (score) from Table 8.1 is discussed below.

Slope of the wetland

The steeper the slope of the wetland, the more efficiently the water is removed from the wetland by the artificial drains.

Texture of mineral soil and the degree of humification of organic soil

The greater the hydraulic conductivity of the wetland soils, the more effective the drains are in removing sub-surface water from the wetland. If the wetland has **mineral soil** then the hydraulic conductivity is approximated based on soil texture. If the HGM unit has **peat (organic) soil**, then the hydraulic conductivity is based on the degree of humification of the soil. The finer the texture of the soil, the smaller the pore spaces between the particles, and the slower the water moves through the soil. Similarly, the more humified the peat, the finer the particles of organic matter, and the slower the water moves through the soil. However, it is important to add that root channels and other pores may increase the hydraulic conductivity of fine textured soils by providing pathways along which water can easily travel.

For **mineral soil**, take a teaspoon-sized piece of soil and add sufficient water to work it in your hand to a state of maximum stickiness, breaking up any lumps that may be present. Now try to form the soil into a coherent ball. If this is impossible or very difficult (i.e. the ball collapses easily) then the soil is sand or loamy sand. If the ball forms easily but collapses when pressed between the thumb and the forefinger then the soil is sandy loam. If the soil can be rolled into a thread but this cracks when bent then the soil is loam. If the thread can be bent without cracking and it feels slightly gritty then the soil is clay loam, but if it feels very smooth then it is clay. For **organic soils**, if the soil consists of large (>5 mm) fragments of identifiable plant material (e.g. of leaves, wood fibres, etc.) then the soil is very fibrous. If it consists predominantly of small fragments (<5 mm) of plant material, but these are still identifiable, then the soil is somewhat fibrous. If it consists of a mixture of identifiable plant fragments and amorphous material (which has the feel of humus or clay), but neither predominates, it is intermediate. If it consists of a mixture of fibrous and amorphous material, with amorphous material predominating, then it is somewhat amorphous. If no fibres can be identified and the material feels like humus or clay, then the soil is amorphous.

Natural level of wetness

The greater the natural level of wetness of the wetland prior to any artificial drainage or gully erosion, the greater the potential for the area to be rendered much drier by artificial drains or erosion gullies. The natural level of wetness in a wetland can be described according to three broad classes of wetness: temporary, seasonal and permanent, using soil morphological indicators (notably soil chroma, and intensity and depth of mottling; see DWAF, 2006; Kotze *et al.,* 1996). The natural level of wetness can generally be estimated by referring to the soil and vegetation in a comparable unaltered area of wetland, but this may not always be possible. If aerial photographs taken prior to modification of the wetland are available, they may also provide some clues regarding the natural level of wetness of the wetland. Wetter areas generally appear darker, but there are exceptions to this, e.g. when a dense growth of reeds in a permanently wet area gives the area a light tone.

Depth of drains

The deeper the drains in the affected area, the greater the potential of the drain network to intercept sub-surface flow and to lead all intercepted flow (both sub-surface and surface) out of the wetland.

Drain density

The greater the density of drains, the more effective they are likely to be in desiccating the section of wetland in which they occur.

Location of drains and gullies in relation to flows into and through the wetland

The interception of water in the wetland by drains is affected by the location of the drains relative to the location of water inputs. To calculate the level of interception of water by the drains, it is necessary to examine how the flow naturally enters and passes through the wetland, and in particular *where* the flow is entering the wetland. In situations where water enters the wetland diffusely from the surrounding catchment, cut-off drains constructed around the margins of the wetland may successfully intercept a large proportion of the flow that would naturally have entered the wetland. Note that it cannot be assumed that because a drain extends around the entire margin of the wetland that all of the inflow will be intercepted. In high rainfall events, the capacity of the channel may well be exceeded. In addition, some subsurface inflows may pass beneath the channel or some water may seep through the walls of the channel (the coarser the texture of soil, the greater this seepage is likely to be).

The lower the MAP:PET ratio, the more dependent the wetland is on inflows from its upstream catchment (as explained further in the rationale for Table 8.2), and therefore the more vulnerable the wetland is to any interception of these flows.

It is important to note that a dam wall may work together with an artificial drainage channel to effectively intercept flow through an HGM unit. This applies particularly to situations where the dam wall spans the width of the unit and the outlet of the dam feeds directly into an artificial drainage channel.

Obstructions in the drains

Obstructions (e.g. earth “plugs” or dense vegetation) reduce the effectiveness of drains to remove water and the ability of artificial drains to effectively lower the water table in the affected area. Obstructions may potentially override the effect of all other features of a drain, and substantially reduce its ability to re-direct water through the wetland. The permanency of the obstructions needs to be considered when assigning the score to this factor. Earth plugs may sometimes be temporarily placed in the drains during dry periods in order to reduce their draining effect. Permanent obstructions (e.g. concrete weirs) are commonly found in wetland areas that have been rehabilitated.

Table 8.2: Hydrological vulnerability factor based on the MAP:PET ratio

MAP:PET ratio	>0.6	0.50-0.59	0.40-0.49	0.30-0.39	<0.3
Vulnerability factor	0.9	0.95	1.0	1.05	1.1

8.3.2 Rationale behind Table 8.2

One of the most important aspects of climate affecting a wetland’s vulnerability to desiccation is the ratio of Mean Annual Precipitation (MAP) to Potential Evapotranspiration (PET). Over most of South Africa, the MAP is lower than the PET, and there is a general trend of decreasing MAP and increasing PET from east to west across the country. The lower the MAP:PET ratio, the smaller will be the contribution of direct precipitation falling onto the wetland and the more dependent the hydrology of the wetland will be on inputs (surface and sub-surface) from its upstream catchment, and therefore the more vulnerable it will be to reduced inflows (e.g. as a result of the diversion of flows by drains).

8.4 Impacts of cultivation on erosion within the wetland

Wetlands are subject to both inputs and outputs of sediment. Under undisturbed conditions, inputs generally occur, but there is seldom substantial output of sediment. Wetlands are thus generally characterized by the net accumulation of sediment. An increase in sediment output from a wetland threatens a wetland's natural structure and functioning, particularly as this invariably takes place through incision that leads to gullying, which is one of the most serious problems facing South African wetlands (Macfarlane *et al.,* 2008). Erosion is one of the principal processes affecting the geomorphic condition of a wetland. Furthermore, it is recognized that there are strong feedback effects between geomorphology, hydrology and vegetation, with geomorphic processes controlling and shaping wetland architecture and dynamics, which in turn, strongly affect water distribution and therefore ecosystem structure and function (Macfarlane *et al.,* 2008).

The accumulation or loss of sediment from within a wetland fundamentally affects the three-dimensional structure of the wetland surface, particularly its longitudinal and lateral slopes. Thus, geomorphic processes fundamentally control how water flows through the wetland. The deposition or erosion of sediments also creates variation in substratum characteristics and a disturbance regime that in their own right affect the biota and biotic heterogeneity found within a wetland (Macfarlane *et al.,* 2008).

If gullies are present in the wetland then WET-Health (Macfarlane *et al.,* 2008) should be used to assess their geomorphic impact. WET-Health relies on direct indicators of erosion, which is considered appropriate for macro-level changes occurring through gully erosion. However, WET-Health does not account for sheet and rill erosion (i.e. finer-level changes taking place at plot scale), which is probably the predominant form of erosion resulting from cultivation in wetlands. Hence, a need was identified to account for erosion occurring at plot scale using indirect indicators, and this is given in Table 8.3.

Table 8.3: Factors contributing to the intensity of erosion within cultivated plots in a wetland

Extent of HGM unit affected by cultivation	ha	%

Factor	Low impact				High impact	Score
	0	2	5	8	10	
Features of the wetland						
(1) Erosion hazard of the soil type (see Table 8.4)	Low	Moderately low	Inter-mediate	Mod-erately high	High	
(2) Soil depth	>1.2 m		0.3-1.2 m		<0.3 m	
(3) Vulnerability of the site to erosion (given slope & discharge, see Appendix 5)	Low	Moderately low	Inter-mediate	Mod-erately high	High	
(4) Location in relation to storm-flow paths	Outside of storm-flow paths		In an inter-mediate position		Directly within storm-flow path	
(5) Location in relation to an existing erosional feature	Distant		Inter-mediate		Close	
Features of the land-use						
(6) Frequency of tillage	None	Less frequent than every 3 years	Every 2 or 3 years	Annually	Twice annually or more	
(7) Extent of tillage in the cultivated area	None / No till	Considerably reduced tillage	Moderately reduced tillage	Slightly reduced tillage	Com-plete tillage	
(8) Depth of tillage	<0.05 m	0.05-0.1 m	0.11-0.2 m	0.21-0.4 m	>0.4 m	
(9) Impact associated with traffic of implements		By hand	Animal traction	Me-chanized		
(10) Timing of tillage in relation to timing of flooding		Outside of the main flooding season	Partly within the main flooding season	Within the main flooding season		
(11) Reduction in SOM (for loamy to sandy soils; if high clay content then omit this factor; see Table 8.6)	Low	Moderately low	Interme-diate	Mod-erately high	High	
(12) Level of soil cover (with vegetation and/or mulch)	High	Moderately high	Interme-diate	Mod-erately low	Low	

(13) Level of reduction of surface roughness (see Table 8.5 for description of roughness classes) [1]	Rough-ness increased or un-changed[1]	Decrease in roughness is moderate (i.e. by 1 class)	Decrease in roughness is high (i.e. by 2 classes)	Decrease in rough-ness is very high (i.e. by >2 classes)		
(14) Concentration & direction of water flow (includes the orientation of drains / furrows)	Low inter-ception	Moderately low interception	Inter-mediate interception	Mod-erately high inter-ception	High inter-ception	
Overall intensity score: [Average of the 3 highest scores of (1) to (5)]/10 x [Average of (6) to (14)]						
Magnitude of impact of erosion within cultivated plots: extent of impact/100 × intensity of impact calculated in the row above						

[1]A decrease in surface roughness may be mitigated to some extent by retaining bands of permanent vegetation with high surface roughness across the main direction of water flow.

8.4.1 Rationale behind Table 8.3

Erosion hazard of the soil type

The higher the erosion hazard of the soil type in an area, the greater is the erosion that is likely to occur if the area is cultivated. To determine the erosion hazard of the soil, it is necessary to first identify the form of the soil according to the South African soil classification system (Soil Classification Working Group 1991). The different soil forms commonly associated with wetlands vary according to their erosion hazards (Table 8.4).

Depth of the soil

For a given depth of soil lost to erosion (e.g. the upper 10 cm), the shallower the soil the greater will be the proportion of soil lost. Furthermore, in a naturally shallow soil, the danger is much greater that the majority of the soil may be lost, making any recovery much more difficult.

Vulnerability of the site to erosion

This is assessed by considering the vulnerability of the HGM unit in which the cultivation site is located. The greater the vulnerability, the greater is the likely erosion under cultivation. The vulnerability of the overall HGM unit is determined based on the steepness of the longitudinal slope of the wetland and its size, which is the same approach used in the geomorphology component of Macfarlane *et al.* (2008).

Table 8.4: Erosion hazards of the main soil forms associated with wetlands in South Africa

Soil form	Erosion hazard	Notes
Champagne	Moderately high	
Katspruit	Intermediate to moderately high	Tends to be intermediate under high rainfall conditions (>800 mm p.a.) and moderately high under low rainfall conditions.
Rensburg	Moderately high	
Willowbrook	Moderately high	
Estcourt	High	
Kroonstad	High	
Longlands	Intermediate to moderately high	Tends to be intermediate under high rainfall conditions (>800 mm p.a.) and moderately high under low rainfall conditions.
Westleigh	Intermediate to moderately high	

Location in relation to storm-flow paths

A cultivated area located in the path of regular storm-flows will be subject to much more erosive conditions than an area located outside of this path. In order to establish if a cultivated area is located in a storm-flow path, it is best to visit the site in the wet season, observe whether any flood debris is present, and speak to people with local knowledge.

Location in relation to an existing erosion feature

If cultivated land is located immediately adjacent to an existing erosion feature (notably the head-cut of an erosion gully) then the disturbance associated with the cultivation could potentially increase the likelihood of the erosional feature expanding into the area where cultivation is taking place. This risk is particularly high if it is located upstream of the feature. As an approximate rule of thumb, <10 m is considered close and >100 m is considered distant.

Frequency of tillage

The greater the frequency of tillage, the greater will be the risk of erosion, given that each time the soil is tilled, its structure is disrupted and plant roots contributing to the strength of the soil are destroyed. Whether a crop is annual or perennial, or a root or aerial crop, affects the scoring of frequency of tillage. As highlighted in Section 5, annual crops required more frequent tillage than perennial or biennial crops, and root crops require tillage at both planting and harvesting (i.e. the highest frequency of tillage).

Extent of tillage

The greater the horizontal extent of tillage, the greater will be the risk of erosion, particularly if the erosion hazard of the site is high, given that tillage disrupts soil structure and destroys plant roots which would otherwise contribute to the strength of the soil. The impact associated with traffic of implements (e.g. from animal hooves or wheels) during the tillage process add further to the disturbance associated with tillage. In conventional till the extent of tillage within a cultivated area is high, whereas in minimum tillage the extent is low.

Depth of tillage

The greater the depth to which tillage takes place, the greater the volume of soil rendered more susceptible to erosion, given the effects of tillage described above. In severe cases, the entire depth of soil that has been tilled may be removed in major storm events.

Timing of tillage in relation to timing of flooding.

Soils are most susceptible to erosion immediately following tillage and then become progressively less susceptible as vegetation establishes itself and becomes more developed. If tillage takes place during the main flooding season, the chances are much higher that a major flood will occur soon after tillage than if tillage occurs outside of the main flood season.

Reduction in SOM

Soil organic matter enhances the physical strength of soils, especially sandy to loamy soils, by promoting aggregate stability. This in turn increases the resistance of the soil to erosion (Miller and Gardiner, 1998). Clay soils are, however, less positively affected by SOM. The level of reduction of SOM is assessed in Table 8.6, and the overall score from Table 8.6 is used (as factor 11) in Table 8.3.

Level of soil cover

Soil may be covered by living and/or dead organic material. The positive effect that soil cover has on controlling erosion has been well demonstrated. The cover protects the soil against rain-splash erosion as well as providing some measure of protection against erosion from the flow of water over the soil surface. A practice often leading to a dramatic reduction in cover is slash-and-burn agriculture (Box 8). Cover may be provided by the crop itself, by mulch or by weeds. Different crops vary according to the cover that they provide, with some such as pumpkins providing good cover, which has the added advantage of suppressing weeds (Anaya *et al.,* 1987; Fujiyoshi, 1998).

Box 8: Some long term soil impacts commonly associated with the practice of slash-and-burn

In terms of short term crop production, slash-and-burn has several potential positive effects: the immediate availability of phosphorus (P), control of weeds, and control of some pests and diseases. However, the long term negative effects on wetland environmental condition and long term production potential may be substantial. Fire is often responsible for large nutrient losses due to volatilization (particularly of nitrogen [N]; Juo and Mann, 1996; Kleinman *et al.,* 1996).

The removal of vegetation cover and surface litter following the burn exposes the soil to greater rain-splash erosion and reduces control over runoff, which may greatly increase the amount of sediment lost from the field due to erosion (Lal, 1990; Alegre and Cassel, 1996; Rodenburg *et al.,* 2003). Vegetation protects soil from rain-splash erosion by the covering it provides, and limits rill erosion by slowing the movement of any water flow on the soil surface (Lal, 1990). Soil run-off and sedimentation processes at field and landscape scale can cause a net soil loss and can also affect spatial variability of soil fertility within a field or landscape (Rodenburg *et al.,* 2003). Soil run-off is most severe on sloping lands and occurs mainly in the first year after burning, particularly if slash-and-burn is followed by high intensity rainfall (Rodenburg *et al.,* 2003).

Severe burns (e.g. resulting from abundant plant material piled on the soil surface) also alter the structure of the soil and reduce its infiltration capacity (Parsons, 2003), rendering it even more susceptible to erosion.

Surface roughness

Surface roughness has a significant influence on the velocity of water flow across the surface of the ground. The greater the surface roughness (Table 8.5), the greater the frictional resistance to the movement of water and the greater will be the level to which flow velocity is reduced (Reppert *et al.,* 1979; Adamus *et al.,* 1987).

Table 8.5: Classes used to estimate the surface roughness of an HGM unit or a channel (from Macfarlane *et al.,* 2008)

Class	Descriptor
Low	Smooth surface with little or no vegetation to offer resistance to water flow
Moderately low	Vegetation is present but short (i.e. < 500 mm) and not robust (e.g. rye grass)
Moderate	Vegetation offering slight resistance to water flow, generally consisting of short plants (i.e. < 1 m tall)
Moderately high	Robust vegetation (e.g. dense stand of reeds) or hummocks offering high resistance to water flow
High	Vegetation very robust (e.g. dense swamp forest with a dense under-storey), offering high resistance to water flow

Note: Where roughness varies across the channel or HGM unit, take the average condition, and where roughness varies over time (e.g. areas which are regularly cut short), take the *average* condition during the *wet season*. Harvesting at the end of the wet season will often have little effect on the surface roughness for the following wet season.

Concentration of storm-flows

For a given volume of water flowing through the wetland, the more concentrated the flow, the lower the wetted perimeter, the higher the velocity, and therefore the greater the capacity to erode. The long-term effect of artificial drains or raised beds (with furrows in between) on reducing the natural level of wetness of the soil is dealt with in Table 8.1. These drains or beds may also act to increase the speed of storm-flows through the wetland. The long-term and short term effects are related, but if the drains/beds are very effective in reducing the level of wetness, it does not automatically mean that they will also be effective in concentrating storm-flows and reducing storm-flow retention in the wetland. Sub-surface drains, in particular, make very little contribution to carrying storm-flows. In the case of raised beds, they may be raised very high to greatly reduce the level of wetness, but if they are oriented across the direction of storm-flows and are staggered, then storm-flows are likely to pass through the wetland much less rapidly than if the beds are all oriented with the direction of flow and are not staggered.

However, it is important to highlight that focusing flow in well vegetated, or otherwise protected, “waterways” may serve to keep water off the tilled lands, and would therefore have a positive effect in controlling erosion, provided that the waterways remain protected against erosion. If this is the case, then leave out the concentration of flows descriptor (factor 14, Table 8.3).

The relative importance of features of the wetland (factors 1 to 5) compared with features of the land-use (factors 6 to 14)

In terms of erosion, the features of the wetland can have an overriding influence on the features of the land-use. For example, even though the land-use factors may be at their worst in terms of causing erosion, if the features of the wetland are such that the inherent vulnerability of the site to erosion is very low, then erosion levels are likely to be low to moderately low rather than intermediate. The land-use factor score is therefore given as a *multiplier* that is applied to the score for the features of the wetland to give the final score, rather than deriving the final score as a simple average of the two.

8.5 Impacts of cultivation within the wetland on the accumulation of SOM

Soil organic matter makes a significant contribution to wetland functioning and productivity, and its accumulation can also be profoundly affected by different land-use practices. According to Miller and Gardiner (1998), Mills and Fey (2003) and Sahrawat (2004), SOM contributes to the following:

- enhanced water holding capacity of the soil, particularly important for sandy soils, which have inherently low water holding capacities;
- increased storage of plant nutrients, particularly nitrogen;
- enhanced soil CEC, which increases the amount of nutrients held in the soil potentially available for uptake by plants; this is particularly important for sandy soils, as they have an inherently low CEC;
- the supply, through microbial action, of the major soil aggregate-forming cements; this contributes to the physical strength of sandy soils in particular, which increases their resistance to erosion;
- a reduction of the hardening of plinthite soils, which are rich in soluble iron and aluminium, through the formation of humate complexes with iron and aluminium, and through maintaining more uniform temperature and moisture conditions; plinthite soils are common in wetlands with fluctuating water tables (i.e. seasonally wet areas).

Sahrawat (2004) argues that when compared with upland soils, wetland soils are “better endowed in maintaining fertility, especially their organic matter status”. Nevertheless, cultivation of wetlands still leads to a decline in SOM (e.g. Grant, 1994; see Box 9), particularly if it involves artificial drainage. Thus, just as it is important to minimize erosion and desiccation when cultivating a wetland, it is also important to minimize the depletion of SOM.

The extent to which SOM declines depends on several influencing factors (e.g. the extent to which the level of wetness of the wetland is maintained). Table 8.6 provides a means of scoring what are considered the most important and readily described of these.

Table 8.6: Cultivation-related factors affecting the accumulation of SOM[1]

Factor	Low impact				High impact	Score
	0	2	5	8	10	
(1) Reduction in plant inputs (plant growth)	Low	Moderately low	Intermediate	Moderately high	High	
(2) Decreased level of wetness (see Section 8.3)	None	Moderately low	Intermediate	Moderately high	High	
(3) Level of erosion (see Table 8.3)	Low	Moderately low	Intermediate	Moderately high	High	
(4) Frequency of tillage	None	Less frequent than every 3 years	Every 2 or 3 years	Annually	Twice annually or more	
(5) Depth of tillage	<0.05 m	0.05-0.1 m	0.11-0.2 m	0.21-0.4 m	>0.4 m	
(6) Level of soil cover	High	Moderately high	Intermediate	Moderately low	Low	
(7) Removal of whole plants or plant parts, e.g. through burning	Low	Moderately low	Intermediate	Moderately high	High	
(8) Level of physical removal of organic sediment (e.g. through peat mining or ground fires)	Low	Moderately low	Intermediate	Moderately high	High	
Overall intensity score: {Score for (1) + [Average of factors (2) to (8)]}/2						

[1] Several factors given in Table 8.6 also appear in some of the other tables, since these factors directly influence more than one of the hydro-geomorphological processes.

8.5.1 Rationale behind Table 8.6

Reduction in plant growth

The primary input to the SOM pool is from *in situ* plant growth, including roots and above-ground material (Jenkinson, 1990; Mills and Fey, 2003). It stands to reason, therefore, that the greater the reduction of *in situ* plant growth (e.g. as a result of desiccation of the wetland) the greater will be the decline in inputs. The amount of *in situ* plant growth may be restricted through the clearing of weeds or as a result of desiccation and/or reduced levels of plant nutrients. In connection with the resting of an area of cropland, it can be appreciated that in order to get the most benefit out of this practice, a high level of plant growth is required during the rest period to provide the organic matter inputs. If the area does not support effective plant growth (e.g. because it has been severely desiccated and eroded) then there will be little input of organic matter into the soil, and the rest would have been of little benefit (A Manson, 2004, pers. comm., Department of Agriculture and

Environmental Affairs, Cedara) and could, in fact, have a negative effect on SOM (Grant, 1994).

It is important to remember that reduced *in situ* plant growth may be compensated for to some extent by inputs of mulch or manure from an external source. These additions therefore need to be considered when scoring ‘reduction in plant growth inputs’.

Decreased level of wetness

Prolonged soil saturation or flooding results in the development of anaerobic soil conditions. This, in turn, promotes the accumulation of SOM by impeding its decomposition. Thus for a given wetland, the greater level of wetness (i.e. the more prolonged the saturation of flooding) the greater will be the amount of SOM (Tiner and Veneman, 1988). It therefore stands to reason that the greater the desiccation of previously saturated soils, the greater will be the extent to which the soils are subject to aerobic conditions, and therefore the greater the potential loss of SOM previously accumulated under the wetter conditions.

The level of desiccation needs to be considered during cultivation and resting times, if rests are included. It may be, for example, that during resting times drains are temporarily blocked, resulting in lower levels of desiccation than during periods of active cultivation.

Level of erosion

The greater the level of erosion, the greater will be the physical loss of SOM, given that much of it is concentrated in the upper levels of the soil (Mills and Fey, 2003).

Frequency of tillage

The greater the frequency of tillage, the greater will be the reduction in SOM through microbial decomposition. Tillage affects decomposition through several mechanisms (Box 9).

Box 9: Mechanisms through which tillage and other forms of soil disturbance reduce SOM content

One of the key mechanisms by which the rate of decomposition of organic matter is reduced is through the organic matter being physically protected within soil aggregates (Six *et al.,* 2002). Tillage acts to increase the rate of organic matter decomposition by disrupting (breaking down) soil aggregates. This takes place directly through the physical disturbance of the tillage process and exposure of new soil at the soil surface. Tillage also reduces the abundance of soil fauna and microbes, particularly fungi (Jenkinson, 1990; Stayley *et al.,* 1988), and this appears to operate indirectly by reducing the amount of various binding agents contributed by the fauna and microbes (Six *et al.,* 2002). These agents, which assist in binding soil particles together, include earthworm mucus that helps bind earthworm casts, which are typically high in organic matter; fungal hyphae that entrap soil particles, and certain fungal and bacterial exudates that operate as "glues" (Six *et al.,* 2002).

Although the results reported above were not specifically for wetland soils, a similar trend is anticipated for wetlands. For example, Grant (1994) found a 23% reduction in organic matter of wetland soils cropped to maize for four years in comparison with adjacent virgin soil. A further example is of annually cultivated hygrophilous grassland which had less than half the SOM levels of virgin hygrophilous soil in floodplain wetlands of the KwaZulu-Natal Drakensberg (1.7% compared with 3.5; Walters *et al.,* 2006). A commonly used measure of the rate of breakdown or loss of SOM is the mean residence time (MRT) of organic matter in the soil. In a review article, Six *et al.* (2002) examined all published MRT values and found that on average the MRT of non-tilled soils was 1.5 times longer than tilled soils.

Depth of soil tillage

The greater the depth of tillage, the greater will be the volume of soil subject to disturbance, which in turn will lead to reduced SOM levels, through the same mechanisms described for frequency of disturbance (Box 9).

Level of soil cover

The greater the exposure of the soil, the greater the extent to which the soil is subject to temperature fluctuations, which in turn contributes to increased levels of SOM depletion (Six *et al.,* 2002).

Removal of plants or plant parts

Removal of whole plants or plant parts may be through export with the harvested crop, removal by grazing livestock or by burning (Box 8).

Physical removal of organic sediment

The greater the physical removal of organic sediment (e.g. through peat mining or ground fires) the greater will be the depletion of the SOM store.

Rationale behind the algorithm for calculating the overall intensity score for the impact to SOM

In Table 8.6, there are seven factors influencing loss of SOM, whilst only a single factor deals with gains in organic matter. Thus, if a simple average is used for calculating the overall intensity score then losses would carry much more weight than gains. However, the collective losses should count equally strongly as the collective inputs. Therefore in the algorithm for calculating the overall intensity score, factor 1 (which deals with the inputs) has the same importance as the average of all of the factors dealing with losses.

8.6 Impact of cultivation in the wetland on retention of nutrients

Wetlands are characteristically sinks for nutrients and other elements, but their capacity to hold nutrients and cycle them internally rather than allowing the elements to "leak" from the system is affected by the inherent properties of the wetland (Mitsch and Gosselink, 1986) and the manner in which the wetland is utilized (e.g. for crop production; Kotze, 1999; Walters *et al.,* 2006).

The situation is very complex, and involves several different nutrients. The two primary nutrients considered here are nitrogen (N) and phosphorus (P), globally the most limiting of nutrients for the production of annual food crops (Buresh and Giller, 1998). Owing to the different chemical properties of these two elements and the manner in which they are cycled, the primary means by which they leak from the system is quite different (Appendix 6). Excluding off-take of nutrients in the crop itself, in the case of N, there are three primary "leakage routes", namely: volatilization, denitrification and leaching. In the case of P, "leakage" is primarily through particles lost via erosion (given that P is much more strongly bound to soil particles than N). Phosphorus is generally much less readily leached than N. An exception to this is in farming systems where fertilizer application rates are very high, a situation very seldom found amongst subsistence farmers.

Inorganic N is much more mobile than inorganic P, and unless taken up by plants it is easily leached from the system or lost to the atmosphere, which under wetland conditions is mainly through ammonia volatilization and denitrification. From the perspective of water quality enhancement, denitrification is advantageous, as it reduces the amount of N potentially entering the water column. However, from the perspective of agricultural production, denitrification is undesirable, because it represents N that is lost from the system and consequently unavailable for plant growth.

Table 8.7 provides a framework for assessing the extent to which cultivation practices diminish nutrient retention (including N and P). It provides specific guidance for assessing the extent to which the capacity of the wetland for retaining nutrients (e.g. through reduced SOM) has been diminished. It is important to emphasize that it does *not* provide guidelines for assessing the inherent fertility of a wetland (i.e. the size of the pool of nutrients contained in the wetland), or for determining the extent to which this pool has been "drawn down" through the off-take of nutrients removed in the crop itself. This is an important question, and further guidance for addressing it is given in Pollard *et al.* (2009b).

Wetland soils are often inherently more fertile than associated non-wetland soils. The pH values, organic content and nutrient levels are generally higher, and aluminium toxicity is seldom a problem. Although some peat soils may be very acid, lime and fertilizer requirements are generally lower in wetlands (Scotney and Wilbey, 1983). Nevertheless, in landscapes that are inherently very poor in nutrients, wetlands may be deficient in some essential plant nutrients, even though wetland soils may be higher in nutrients relative to the non wetland areas. For example, the granitic sandy landscapes of Zimbabwe are typically low in nutrients (Mugwira and Murwira, 1998; Grant, 1970) although the cropping potential of wetlands in these landscapes are high, these wetlands are also typically low in N, P and S, as is the case for the corresponding non-wetland areas (Grant, 1994). Many of these wetlands are also acidic (Grant, 1994), and thus they are also susceptible to nutrient deficiencies even where there has been adequate application of nutrients. Grant (1994) recommends that in order to obtain the benefit of the *dambo* (wetland) moisture, fertilizers or manure must be applied. Grant (1994) also draws attention to the fact that the wetlands of these landscapes may also be deficient in micronutrients such as boron and zinc, which are commonly needed for maize on granite sandveld soils.

Table 8.7: Cultivation factors impacting upon the retention of nutrients in the wetland

Factor	Low impact				High impact	Score
	0	2	5	8	10	
(1) Level of artificial drainage (see Table 8.1)	Low (level)	Moderately low	Intermediate	Moderately high	High	
(2) Level of erosion (see Table 8.3)	Low	Moderately low	Intermediate	Moderately high	High	
(3) Level of SOM depletion (see Table 8.6)	Low	Moderately low	Intermediate	Moderately high	High	
(4) Texture of the soil[1]	Clay	Clay loam	Loam	Sandy loam	Sand/ loamy sand	
(5) Synchronization of nutrient availability and plant uptake	High	Moderately high	Intermediate	Moderately low	Low	
(6) Export of nutrients in harvested or burnt plant material	Low	Moderately low	Intermediate	Moderately high	High	
(7) Addition of nutrients	Low	Moderately low	Intermediate	Moderately high	High	
(8) Extent of soil building crops	High	Moderately high	Intermediate	Moderately low	None	
(9) Diversity of crop types &/or varieties		Three or more types	Two types	One type		
Overall intensity score: Average of the 7 highest of factors (1) to (9)						

[1] This factor has an important influence on the ultimate effect of SOM depletion on nutrient retention (see rationale below).

8.6.1 Rationale behind Table 8.7

Level of drainage

Artificial drainage of a wetland affects how water is distributed across the wetland (channelled flow vs. diffuse flow) as well as its retention in the wetland. Much of the assimilation of nutrients by wetlands, particularly those nutrients, such as nitrates, which are not carried predominantly by sediment, takes place during low flow periods. At these times, waters are shallower and residency times in the wetland longer, which affords the wetland greater opportunity to assimilate nutrients contained in the water (Kadlec and Kadlec, 1979; Hammer, 1992). Some wetlands naturally experience diffuse flow during both low flow and high flow periods, allowing for considerable contact between water and soil, unless flow is concentrated through artificial drainage channels. Conversely, other wetlands may experience diffuse flow under storm-flow conditions but under low flow conditions water is naturally contained within a small part of the wetland in a stream channel, allowing for little contact between wetland and water. The greater the contact between water and soil, the greater is the opportunity for plants and microbes to assimilate nutrients carried in the water.

Artificial drainage tends to reduce the retention time in a wetland. However, this impact may be mitigated to some extent by controlled drainage, in which the depth of the water table is controlled. This reduces loss of nutrients through leaching, by increasing opportunities for storage of water in the field for utilization by the crop. Field studies in North Carolina and Ontario, for example, have shown substantial reductions in losses of nitrates from sub-surface drainage where controlled drainage has been employed (Randall and Goss, 2001) and Drury *et al.* (1996) found that controlled drainage reduced nitrate loss by 43%. Thus, it can be concluded that generally, the greater the intensity of artificial drainage, the greater will be the extent of nutrient leaching.

In the short term, the effect of drainage depends strongly on precipitation, which has a key effect on drainage flow volume, and therefore potential losses through leaching. In commercial agriculture operations, Randall and Goss (2001) report annual nitrate losses ranging from zero in dry years to over 100 kg/ha in wet years. Leaching is also influenced by the preceding conditions, with greatest losses occurring in wet years following dry years. According to Randall and Goss (2001), “A substantial proportion of the annual nitrate loss may occur within only a few days when soils are saturated and very large precipitation events happen.”

Level of erosion

The greater the level of erosion, the greater will be the loss of nutrients adsorbed to the mineral particles lost through erosion, which applies particularly to P and other elements bound to the mineral particles in the soil. The strong relationship between soil erosion and loss of P has been widely demonstrated (Pierzynski *et al.,* 2005). In the extensive literature relating to P-use efficiency in flooded rice cultivation, it has been shown that, in general, loss of P in both upland and flooded cultivation is predominantly through the loss of particulates, except in situations where fertilizer application rates are very high. Therefore, any of the factors influencing erosion (e.g. soil cover) potentially have a considerable influence over the loss of P. The loss of organic particles through erosion will also affect the loss of both N and P, as explained in the following paragraph.

Level of SOM depletion

The greater the depletion of organic matter (e.g. through drying out of the area), the greater will be the loss of the pool of nutrients contained within the organic matter. This applies particularly to N (Craft and Chiang, 2002; Sahrawat, 2004) but also to P (Tiessen, 2005; Pierzynski *et al.,* 2005; Turner, 2006).

As discussed under “synchronization of nutrient availability and uptake by plants”, minimizing the loss of N depends on nutrient availability and uptake by plants occurring at the same time. However, if mineralization levels are very high (e.g. in a drained and rapidly mineralizing peat soil), then it will make it difficult for plants to take up all of the available N, even if this is well synchronized.

Soil organic matter also contributes to increasing the CEC of the soil, and therefore the ability of the soil to retain nutrients which would then be available for plant uptake. In the case of P, the soil organic carbon forms complexes with iron (Fe) and aluminium (Al), which increases the amount of amorphous Al and Fe relative to crystalline Fe and Al oxides. This in turn increases the surface area available for sorption of P, since the amorphous form has a greater surface area than the crystalline form (D’Angelo *et al.,* 2005).

Texture of the soil

Generally, the coarser the texture of the soil, the greater will be the relative contribution of the SOM to the CEC of the soil, and therefore the more severely it will be affected by a decline in SOM. Table 8.6 covers those factors affecting the depletion of SOM, e.g. through mineralization.

Synchronization of nutrient availability and uptake by plants

Tillage and exposure of the soil promotes the mineralization of SOM, which transforms the N present in the organic matter into a much more mobile form which, in turn, is readily leached from the system unless it is taken up by plants. Thus, the longer the time between tillage and nutrient demand and uptake by the crop, the more intense the tillage and the more exposed the soil is during the intervening period, and the greater will be the leakage of nutrients from the system. This is especially important in areas where precipitation is high. In temperate areas, this may not lead to short term problems, but the negative effects accumulate with time. In the humid tropics to sub-tropics, leaching is more intense and the negative effects of tillage may be manifested rapidly (Sanchez, 1976).

The greater the level of interruption of actively growing vegetation (between harvesting/ senescence of one crop and the full establishment of the next crop), the lower will be the capacity of the plants to take up mobile nutrients and prevent them from being leached (Randall and Goss, 2001). This interruption therefore undermines the capacity of the system for internal retention of nutrients[5]. Where the period of time from the harvest of one crop to the planting of the next is extended, the weeds growing on the area in the interim may limit the disruption of actively growing vegetation and prevent leaching of plant nutrients. Alternatively, cover crops referred to as “catch crops” may be planted during this period specifically to fulfil this role. Note though, for a catch crop to be useful, the residues from the crop must be returned to the field, rather than being removed or burnt. Nevertheless, nutrient losses are still often substantially higher than under continuous perennial crops where growth (and hence nutrient uptake) is uninterrupted (see Appendix 6). The benefits for soil fertility of dense vegetation during a rest period are widely reported by smallholder wetland farmers (e.g. Kotze, 1999; Dixon and Wood, 2003).

The more closely synchronized plant growth and nutrient uptake is with organic matter mineralization, the lower will be the leakage of N from the field. The implication is that the greater the level of mineralization taking place at a time of limited active uptake of nutrients by plants, the greater will be the pool of nutrients (particularly those that are mobile) available for leaching. The longer this situation remains (i.e. the longer it takes for active uptake to commence) and the higher the level of artificial drainage, the greater will be the level of leaching.

Export of nutrients in harvested, grazed or burnt material

The harvesting of a crop results in the removal of some nutrients, although the quantity of nutrients removed varies greatly amongst different crops (See Appendix 6, Box A6.1) and depends on the off-take level at the site. As explained previously in Box 8 (Section 8.4), fire is often responsible for high N losses due to volatilization (Juo and Mann 1996; Kleinman *et al.,* 1996).

[5] It would also have an indirect effect through reduced inputs to the SOM pool, as explained in Table 8.6.

Addition of nutrients

The greater the rate of fertilizer application, the more difficult it is for the system to recycle most of the incoming nutrients, and the greater will be the extent of leakage. It has been widely demonstrated that nitrate losses increase as the rate of N application increases, particularly when application rates are greater than needed by the crop and in wetter-than-normal years (Randall and Goss, 2001). These authors highlighted that a significant proportion of the N leached from the system is from mineralization of the previous crop rather than direct leaching of applied fertilizer.

It should be highlighted, however, that fertilizer application rates are generally very low in the case of subsistence and small-scale farmers, and typically involve small quantities of manure precision-placed in the planting holes rather than being broadcast over the plot.

Soil building crops

The most important soil building crops are those that fix gaseous nitrogen (N_2). Tropical grain legumes in particular may fix large quantities of N_2, and some of these, such as cow pea and pigeon pea, return a large proportion of this to the soil (Appendix 6, Box A6.1). Deep rooted crops (e.g. pigeon peas) may also contribute to the building of soil by taking up some nutrients from the deeper layers, and when plant litter falls to the ground this may become incorporated into the topsoil.

It should be emphasized again that the retention and cycling of nutrients is very complex. Whilst some generalizations have been made in the model given in Table 8.7, different nutrients may respond quite differently depending on the particular conditions and land-use practices in a wetland, and this is not captured by the simple model given in Table 8.7. An introduction is provided in Appendix 6 to the two most important plant growth limiting nutrients, N and P in cultivated wetlands.

Diversity of crop types and/ or varieties

A system with several crop types and/or varieties is likely to be more resilient than a system with only a single crop (Altieri, 1987a and 1987b; Richards, 1995). This, in turn is likely to enhance the capacity of the system for retaining nutrients. A multiple crop system is generally more resilient to extreme events (e.g. in particularly wet periods, those crops better adapted to waterlogging will do better, whilst in particularly dry periods those crops better adapted to droughts will do better). A greater variety also allows the system to adapt more readily to the spatial variability of a wetland. This is illustrated by the traditional rice farmers of central Sierra Leone, who cultivate up to ten different varieties on the same farm in small stream-fed swamps, an environment with considerable variability. Through their rich knowledge of the soil moisture requirements of each variety, individual farmers are able to match the different varieties with the soil moisture variation along the soil catena (Richards, 1985; 1995). Thus, the need for artificial drainage is minimized.

8.7 Impacts of cultivation in the wetland on vegetation species composition

Few native wetland plant species, except for some generalist, weedy species, are able to persist in any abundance in cultivated plots. Therefore the impact of currently cultivated areas on indigenous vegetation is high (usually an intensity score of 8 to 10). If the extent of this cultivation within the HGM unit is large, then the magnitude of impact will be high. Refer to Table 8.8 for guidance in assigning an intensity score. For more information on assessing the current impact on vegetation species composition refer to WET-Health (Macfarlane *et al.,* 2008).

Besides assessing the current impact on vegetation, it is important also to consider the recovery of abandoned lands, which applies particularly to shifting agriculture. If the cultivated areas are abandoned then over time some of the native species re-colonize the area, and the vegetation species composition may gradually recover, in some cases to close to its original composition. But it is important to recognize that some vegetation types recover much more readily than others. Areas dominated by a single species (usually in areas with a high level of wetness) generally recover well, but vegetation dominated by several co-occurring species (usually in areas with a moderate to low level of wetness) generally has a much lower potential for recovery (Walters *et al.,* 2006).

Table 8.8: Categories of intensity of impact on vegetation composition (adapted from WET-Health, Macfarlane *et al.,* 2008)

DESCRIPTION	Impact intensity score
Vegetation composition appears natural	0-0.9
A very minor change to vegetation composition is evident at the site	1-1.9
Vegetation composition has been moderately altered but introduced alien and/or ruderal species are still clearly less abundant than characteristic indigenous wetland species	2-3.9
Vegetation composition has been largely altered and introduced alien and/or ruderal species occur in approximately equal abundance to the characteristic indigenous wetland species	4-5.9
Vegetation composition has been substantially altered but some characteristic species remain, although the vegetation consists mainly of introduced, alien and/or ruderal species	6-7.9
Vegetation composition has been totally or almost totally altered, and if any characteristic species still remain, their extent is very low	8-10

9. THE LEVEL 2 ASSESSMENT OF THE IMPACT OF GRAZING OF WETLANDS BY LIVESTOCK

Plate 2: The *Echinochloa*-dominated wet grasslands of the Mkuze floodplain in KwaZulu-Natal, which support large numbers of cattle during the drier times of the year.

9.1 Background information on the impact of livestock grazing on wetlands

Although some plants may be uprooted during grazing, the major impact of grazing involves the removal of mainly the aerial portions of the plant and trampling of the soil surface by the grazing animal. The principal potential effects of this are on (1) erosion and loss of sediment from the wetland, (2) structure of the wetland vegetation (cover and height) and (3) vegetation composition (measured in terms of vegetation species composition). A key consideration when assessing the effect of livestock grazing on wetlands is to remember that southern African wetlands evolved under the influence of indigenous grazers such as elephant and buffalo. Where these indigenous grazers no longer graze a wetland, grazing livestock would partly simulate the effect of the indigenous grazers. The assumption is that the closer the grazing regime is to what would be expected naturally, the lower will be the deviation from the natural vegetation structure and composition. It is suggested that under natural conditions, wetlands in sweetveld[6] areas would tend to be grazed more heavily than in sourveld, particularly

[6] The quality of forage provided by veld is generally not constant throughout the year, and declines during the non-growing season. In sweetveld this decline is slight, but in sourveld it is far more significant, as the plants withdraw most of the nutrients from their leaves down into their roots for storage during the non-growing season. Sourveld generally occurs in high rainfall areas, especially where the climate is cool and/or the parent material of the soil is lacking in nutrients (e.g. sandstone). Sweetveld, on the other hand, generally occurs in areas receiving low rainfall.

during the dry season (Figure 9.1). Jacobs *et al.* (2007) note that the effect of herbivory in mesic areas (which are predominantly sourveld) is less pronounced than in semi-arid areas (which are predominantly sweetveld).

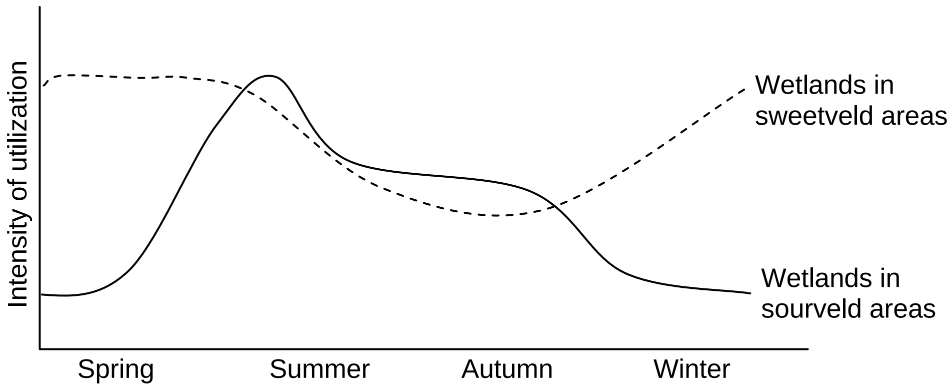


Figure 9.1: Suggested intensity of utilization by indigenous grazers of wetlands across the seasons in sweetveld areas compared with sourveld areas for summer rainfall conditions

Appendix 7 shows an example of how indigenous grazers in a sweetveld area in the Kruger National Park act to reduce the vegetation cover in wetlands. Thus, if indigenous grazers are absent, wetlands in sweetveld areas would require more intense use by livestock to simulate a natural grazing regime (Figure 9.2). Based on the underlying assumption given above, therefore, indicators of utilization (e.g. density of paths) would be higher in sweetveld than in sourveld areas for a natural wetland. It is important to note, however, that the natural state of a wetland, particularly in sweetveld areas, may often not be the optimal condition from a soil and water conservation perspective.

9.2 Assessing the impact of livestock grazing within wetlands

As indicated in Section 7, grazing potentially affects all of the components of wetland condition, but particularly erosion and vegetation composition. The main impact of livestock grazing on hydrology is through its effect on vegetation structure (Tables 9.1 to 9.3). Impacts of grazing on erosion are covered in Table 9.4. Impacts on SOM accumulation and nutrient retention are likely to be very closely linked to erosion and are not dealt with in any specific tables. Tables 9.5 and 9.6 assist in assessing impact on vegetation composition.

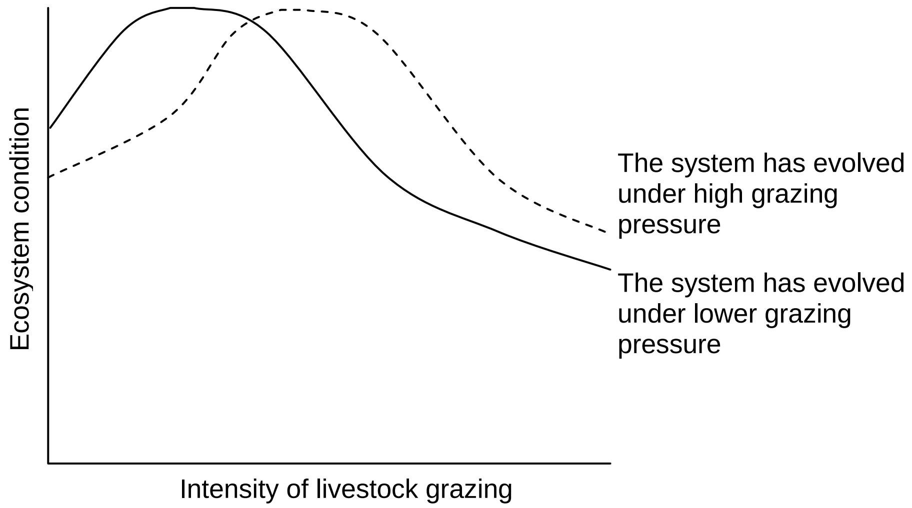


Figure 9.2: Suggested relationship between environmental condition and intensity of livestock grazing in a wetland with minimal grazing by indigenous herbivores.

When applying Tables 9.1 to 9.6, it is important to remember that the metrics described can be strongly influenced by the timing of the assessment visit. This applies particularly where grazing animals use the wetland for a short duration, but at a very high intensity for that period. If the wetland is visited during, or shortly after, the utilization period, the impacts may potentially appear far more severe than if the wetland was visited several months after the grazing period. If possible, the assessor should also try and visit the wetland at least twice during the year, at times of contrasting levels of utilization.

The effect of grazing on wetland indicators may also be affected strongly by the conditions in that particular year. For example, it may be a particularly dry year, resulting in animals utilizing the wetland much more intensively than in a wetter year.

Thus, it is important to draw on local knowledge as to how utilization is affected by the seasons and by variability between years, and then to place what is observed during the field assessment in the context of this pattern of utilization. A basic understanding of the effect of livestock grazing upon the vegetation and soil resources is also useful. Those who are unfamiliar with this topic are referred to an easily accessible booklet by Morris and Kotze (2006) that outlines some key principles relating to livestock grazing of natural vegetation and its potential impacts.

Table 9.1: Factors contributing to the intensity of impact of grazing on wetland environmental condition in terms of change to vegetation structure

Factors	Impact score: Low impact				High impact	Score
Sourveld:	**2**	**0**	**2**	**5**	**10**	
Sweetveld:	**3**	**1**	**0**	**3**	**8**	
(1) Aerial cover*	Abundant moribund material	>80% but little moribund material	60-80%	40-60%	<40%	
(2) Effects of grazing on height of vegetation (excluding those vegetation types having a low grazing value)	Uniformly at potential maximum height	Shortly grazed patches within potential maximum height	Approximately equal mix of shortly grazed and maximum height patches	Predominantly shortly grazed with maximum height patches	All uniformly shortly grazed	
(3) Density of paths	<50 m/ha	51-100 m/ha	100-200 m/ha	201 -500 m/ha	>500 m/ha	
(4) Extent of poaching**	No poaching	<10 m^2/ha	11-100 m^2/ha	101-1000 m^2/ha	>1000 m^2	
Overall intensity score for vegetation structure: Average of the three highest scores of (1) to (4)						

* It is recognized that aerial cover is potentially affected by several different factors, including the particular type of vegetation, burning regime, etc. and not just grazing alone.

** This applies primarily to seasonally and permanently wet areas. Poaching refers to the disruption of soil structure as a result of the repeated penetration of hooves into wet soil (Wilkins and Garwood, 1986).

Finally, it is important to highlight that although a concerted effort was made to capture the current understanding of the effect of grazing on southern African wetlands, the livestock grazing model (Tables 9.1 to 9.4) is recognized as being more preliminary than the models for the other two land-use types. The effects of livestock grazing are potentially more wide-ranging than those of vegetation cutting, and are often more subtle (and therefore more difficult to characterize) than those of cultivation. Furthermore, investigations of the effects of livestock grazing on southern African wetlands are limited. Therefore, the livestock grazing models have the most urgent need for further testing and refinement.

9.2.1 Rationale behind Table 9.1

Aerial cover

Aerial cover refers to the cover provided by standing plant material. Aerial cover contributes to protecting a wetland against soil erosion and provides habitat to wetland fauna, although it is recognized that different species have different cover requirements (Appendix 8). Diminished cover may therefore have wide ranging negative effects. However, a lack of any defoliation of the vegetation may result in the development of moribund vegetation, which refers to the situation where much of the standing plant material is dead. This has a negative effect on vegetation by ‘smothering’ new growth as well as generally diminishing the habitat value for fauna. Some vegetation types (e.g. tussock-forming plants) appear to be much more prone to this than other vegetation types (e.g. clonal growth plants such as *Phragmites australis)* which are less prone to becoming moribund.

Aerial cover can also be taken as a coarse indicator of above- and below-ground living biomass. The greater the biomass, the greater will be the provision of microhabitat and organic matter critical for soil microbes involved in the assimilation of N, P and toxicants. In addition, the greater the vegetation biomass, the greater will be the potential of the wetland to assimilate N and P through direct uptake by the plants. It is recognized, however, that at the end of the growing season significant amounts of the nutrients taken up by the plants may be lost through litter-fall and subsequent leaching, although this is limited by the translocation of nutrients to the below-ground storage portions of the plant prior to litter-fall (Hemond and Benoit, 1988).

Vegetation height

The height of the vegetation has an important influence over the type of habitat provided by a wetland; the greater the diversity of vegetation heights represented, the greater will be the diversity of microhabitats provided.

Density of paths

Indigenous grazers would have created paths in wetlands before the introduction of domestic grazers. When present to a limited extent, paths add to the habitat diversity of a wetland. The extent to which plants are able to grow in the paths may be limited, owing to the high level of trampling that occurs along the path. Paths can contribute greatly to erosion, particularly when they run in the direction of the flow of water. In some cases, erosion along a path may develop into severe gully erosion.

Extent of poaching

The poaching of soil results in damage to plants and decreased herbage production, and also increases susceptibility to erosion. However, it favours certain wetland dependent species, such as the African Snipe (Appendix 8).

As it stands, Table 9.1 does not account for the interactive effect of grazing with burning and cutting (harvesting). These interactions are likely to be complex and vary from site to site. In some cases they would have a compensating effect, while in other cases their effect would be synergistic. It may be, for example, that a wetland that evolved under regular burning has been protected from burning (e.g. because it is in an urban area). The defoliation associated with grazing would to some extent compensate for the lack of defoliation from burning. Alternatively, a wetland may be burnt much more frequently than the situation under which it evolved. If, in this case, the wetland was also heavily grazed by livestock, then the frequent burning regime may serve to amplify the negative effects of the grazing. A further complication is the fact that burning is often used to facilitate a greater intensity of use for grazing by stimulating early season growth. Burning is not dealt with as a specific use, but its impact is assessed in Table 9.2. The effect of vegetation cutting which, like burning, also reduces vegetation cover, is assessed in Section 10. Once burning and cutting (if it also occurs) have been assessed based on Table 9.2, an adjustment to the grazing score can be made if required. This adjustment, with the accompanying explanation, is recorded in Table 9.3.

Table 9.2: Criteria for assessing possible impacts to wetland vegetation arising from burning regimes

Grassland/savanna sweetveld Factors	Impact score					
	1	**0**	**2**	**5**	**8**	
(1) Frequency of burning	Every 6^{th} year or more	Every 4^{th} - 5^{th} year	Every 3^{rd} year	Every 2^{nd} year	Annual	
(2) Timing of burning	Late winter/early spring	Winter		Summer / autumn		
Overall score: (factor(1) x 3 + factor (2) x 2) ÷ 5						

Grassland/savanna sourveld Factors	Impact score					
	6	**3**	**0**	**5**	**8**	
(1) Frequency of burning	Every 8^{th} year or more	Every 5^{th}- 8^{th} year	Every 2^{nd}- 4^{th} year	Annual		
(2) Timing of burning		Late winter / early spring	Winter	Summer / autumn		
Overall score: (factor(1) x 3 + factor (2) x 2) ÷ 5						

Fynbos/interface between fynbos & succulent karoo Factors	Impact score					
	8	**3**	**0**	**3**	**6**	
(1) Frequency of burning	Every 40^{th} year or more	Every 21^{st}- 40^{th} year	Every 9^{th}- 20^{th} year	Every 2^{nd}- 8^{th} year	Annual	
(2) Timing of burning		Autumn / summer	Late winter / early spring	Winter		
Overall score: (factor(1) x 3 + factor (2) x 2) ÷ 5						

Note: this table does not account for the great diversity of situations that may be encountered within a region and *must be seen as preliminary and very general*, particularly for the fynbos and the interface between the fynbos and succulent karoo. It is recommended that advice be sought from local nature conservation extension services regarding the favoured burning regime for a particular site.

9.2.2 Rationale for Table 9.2

Lightning-induced fires have long been a feature of the southern African landscape. However, the frequency of burning in this region has been increased through the influence of humans for many tens of thousands of years at least, and probably longer. Identifying the natural burning regime is therefore problematic. A few generalizations can, however, be made. Owing to the higher fuel loads associated with sourveld areas, the incidence of fires is generally higher in these areas than in sweetveld areas. In both sweetveld and sourveld areas, a summer or autumn fire is most likely to detrimentally affect the growth of wetland plants, as it falls within the non-dormant period of many wetland dependent plants, and is also more likely to fall within the breeding period of wetland fauna (Kotze and Breen, 2000). Winter to early spring burning is generally more favoured because it falls within the dormant period, and early spring is most favoured because it results in the least exposure to the soil and to animal species requiring cover. It is recognized however, of course, that under natural conditions some fires would have occurred at “unfavourable times”.

Burning, and particularly the timing thereof, also has an important potential impact on the SOM content. Leaf litter input makes a significant contribution to SOM in the top few centimetres of soil, and its removal by fire therefore potentially reduces the SOM content of the top soil layer. In a long term burning and mowing trial running over a 50 year period in a mesic grassland, Fynn *et al.* (2003) found that annual and biennial spring burning did not result in a decrease in organic carbon (C) in the top 2 cm of soil, yet autumn and winter burning on an annual and biennial basis, and even autumn burning on a triennial basis, did cause a decrease. This highlights the importance of the timing of burning. It is suggested that in summer rainfall areas, when spring burning is practised, the opportunity exists during the preceding winter for litter to be incorporated into the soil, whereas with autumn burning there would be no such opportunity. Burning has a negligible effect on the SOM of deeper soil layers, because most of the organic matter here originates from root turnover. Even the treatment having the greatest impact on the uppermost 2 cm of soil (autumn burning) did not affect the SOM content in the 2-4 cm layer (Fynn *et al.,* 2003). Research on mesic grasslands has shown that by removing standing dead material and increasing primary production, burning can in fact act to increase root production, and the increased organic matter from roots offsets the reduced input from litter-fall. These results are also likely to be applicable to hygrophilous grassland wetland. Furthermore, Mook and Van der Troon (1982) and Thompson and Shay (1985) showed that below-ground production of the reed *Phragmites australis* was stimulated by fire.

Table 9.3: Adjusted grazing score

Adjusted grazing score from Table 9.1 based on consideration of interaction with cutting and/or burning (Table 9.2)	
Record justification here:	

Table 9.4: Factors contributing to the intensity of impact of grazing on wetland environmental condition in terms of the potential for causing erosion

Factors	Low impact				High impact	Score
	0	2	5	8	10	
Features of the land-use						
(1) Aerial cover*	Abundant moribund material	>80% but little moribund material	60-80%	40-60%	<40%	
(2) Effects of grazing on height of vegetation (excluding those vegetation types having a low grazing value)	Uniformly at potential maximum height	Shortly grazed patches within potential maximum height	Approximately equal mix of shortly grazed and maximum height patches	Pre-dominantly shortly grazed with maximum height patches	All uniformly shortly grazed	
(3) Density of paths	<50 m/ha	51-100 m/ha	100-200 m/ha	201-500 m/ha	>500 m/ha	
(4) Extent of poaching**	No poaching	<10 m^2/ha	11-100 m^2/ha	101-1000 m^2/ha	>1000 m^2	
Features of the wetland						
(5) Vulnerability of the site to erosion (given discharge & slope; see WET-Health, Fig. 3.8)	Low	Moderately low	Intermediate	Moderately high	High	
(6) Erosion hazard of the soil type	Low	Moderately low	Intermediate	Moderately high	High	
(7) Soil depth			>1.2 m	0.3-1.2 m	<0.3 m	
(8) Location in relation to storm-flow paths	Outside of storm-flow paths		In an intermediate position		Directly within major storm-flow path	
(9) Location in relation to an existing erosional feature	Distant		Nearby		In the immediate advancing path	
Overall intensity score for erosion: Average of the three highest scores of (1) to (4) and the three highest of scores of (5) to (9)						

* It is recognized that aerial cover is potentially affected by several different factors, including the particular type of vegetation, burning regime, etc., and not grazing alone.

** This applies primarily to seasonally and permanently wet areas. Poaching refers to the disruption of soil structure as a result of the repeated penetration of hooves into wet soil (Wilkins and Garwood, 1986).

Note: the rationale for metrics (1) to (4) is given in the rationale for Table 9.1, and the rationale for metrics (5) to (9) is given in the rationale for Table 8.3.

9.2.3 Rationale for Table 9.4

Features of the land-use (e.g. density of paths): see rationale for Table 9.1

Features of the wetland (e.g. erosion hazard of the soil): see rationale for Table 8.3

The effect of grazing on species composition is determined based on a two-step process given in Table 9.5. The extent to which the vegetation has deviated from its natural composition is determined by referring to Table 8.8, and scoring the deviation from zero (pristine) to ten (critically altered). Several different factors may be responsible for this deviation. The next step is therefore to assess the specific contribution that livestock grazing has made to this deviation, usually based on knowledge of how the site has been used in the past. This contribution is scored as a multiplier (from 0 to 1) in Table 9.5. The deviation score is multiplied by the multiplier score to give a final score of the effect of grazing on vegetation composition. For example, if the vegetation was found to have an abundance of ruderal (weedy) species approximately equal to that of characteristic indigenous wetland species, it would therefore score five in terms of the impact classes described in Table 8.8. If knowledge of the site's past history revealed that the wetland had been heavily grazed for many years and there were no other human disturbances, with reference to Table 9.5, the multiplier would be scored 0.9 because grazing is considered responsible for most of the change. If cultivation was considered to be responsible for all of the deviation then the multiplier score would be zero.

Table 9.5: Extent to which livestock grazing is responsible for the deviation in vegetation species composition from its natural state

(1) Deviation (impact) score (0 to 10) based on intensity of impact on vegetation composition (see Table 8.8 for guidance in assigning this score)	

Level of responsibility held by grazing:	**None**	**A small part**	**some**	**most**
(2) Multiplier score:	0	0.3	0.6	0.9

Combined score ((1) x (2))	

9.2.4 Rationale for Table 9.5

As elaborated upon in Section 9.1, grazing may have a considerable impact on the plant species composition of a wetland. However, it is important to account for the fact that grazing is often one of several factors influencing the deviation of the vegetation from its natural composition.

It is recognized that some vegetation types are naturally very resilient to compositional change resulting from grazing, e.g. the *Cynodon dactylon* lawns of the Phongolo floodplain (where the reasonably palatable *C. dactylon* is well adapted to heavy grazing pressure through its low-growing, creeping growth-form). Others, e.g. *Merxmauellera macowanii*, are resilient as a result of the very low palatability of the species. Secondary vegetation in old croplands dominated by *Eragrostis* spp. is also very resilient to change, although it should be added that sustained heavy grazing may retard, to some extent, the recovery of the natural species composition.

10. THE LEVEL 2 ASSESSMENT FOR HARVESTING OF PLANTS FOR CRAFT PRODUCTION (adapted from Kotze and Traynor, 2007)

Plate 3: Two harvesters from Craigieburn, Mpumalanga Province, with *Schoenoplectus brachyceras* culms that they have harvested from a local wetland.

As indicated in Section 7, harvesting of wetland plants (for crafts and thatching) generally has minimal negative impacts on hydrology, erosion and nutrient retention. Therefore, the primary focus of this assessment is on potential impacts to the selected plants, which would generally affect vegetation composition (Table 10.1). However, in severe cases, harvesting may have an impact on hydrology, through the long term reduction of the surface roughness of the wetland, as opposed to a brief reduction immediately following harvesting and before the vegetation rapidly recovers. Reduced roughness reduces the effectiveness of the vegetation in slowing down water flows. In such cases, refer to Table 8.5.

Fibre-producing wetland plant species are generally suited to sustainable harvesting and cope well with regular and intensive levels of cutting, as they are generally fast growing and have a high capacity to recover (Cunningham, 1987; 2001). Nevertheless, the potential still exists for this activity to impact negatively on the harvested plants (e.g. Tarr *et al.,* 2004), depending on factors relating to: (i) the particular area of vegetation being harvested, (ii) the particular species being harvested, (iii) the method and intensity of the harvesting and (iv) other disturbances.

Table 10.6: Factors contributing to intensity of impact of plant harvesting on the harvested species

Factors		**Low impact**				**High impact**	**Score**
		0	**2**	**5**	**8**	**10**	
(1) The mix of species growing in the area*		The harvested species completely dominates the cover of the stand	Moderately high pre-dominance of the harvested species	Intermediate	Moderately low	The harvested species has a low cover amongst a matrix of other species in the stand	
(2) Height of harvesting in relation to basal growth points of the plants		All above meristematic growth		Intermediate		Mainly below the meristematic growth	
(3) Discarded material		Little discarded material &/or no suppressing effect		Intermediate		Forms thick layer of surface litter, suppressing growth	
(4) Frequency of harvesting of individual plants:	Sedges, grasses, rushes	Every third year or more		Every year		Three or more times a year	
	Restios	Every fifth year or more		Every second year		Every year	
(5) Timing of harvesting in relation to the growing season		Harvesting towards the end of the growing season		Intermediate		Harvesting towards the beginning of the growing season	
(6) Proportion of the vegetation that is harvested		<40% harvested (of the available material)	40-65% harvested	66-90% harvested	>90% harvested		
Factors relating to other disturbances		**0.5**	**0.7**	**0.9**	**1.0**	**1.2**	
(7) Level of grazing		None	Low	Intermediate	Moderately high	High	
(8) Level of burning		See Table 9.2					
(9) Impact on the harvested plant species: **Average of the 4 highest scoring factors of (1) to (5) x Highest of weighting factors (7) and (8)**							
(10) Impact through disturbance to fauna: **Average of factors (5) and (6) x Highest of weighting factors (7) and (8)**							

*This assumes that harvesting concentrates on the selected species, while generally leaving the other species uncut. If harvesting is non-selective (i.e. all of the plant material in the stand is cut) then omit this factor from the assessment.

Table 10.1 assists in accounting for the factors contributing to the intensity of impact of plant harvesting on the harvested species, based on features that can be readily described in the field. The scores are then combined, accounting for other disturbances – notably grazing and burning – to provide an overall index of impact ranging from zero (impact low and thus sustainability likely to be very high) to ten (impact high, and thus sustainability likely to be very low). Sustainability is scored for two main aspects: (i) the primary effect on the sustained production of the species that is being harvested and (ii) the secondary impact on fauna inhabiting the harvested area.

10.1 Rationale for Table 10.1

The mix of species growing in the site

If the species being harvested has a low cover relative to other species occurring in the stand of vegetation then the selective cutting back of this species could be to its competitive disadvantage. This favours the other species, which have not been cut back and which could quickly expand their cover, closing the canopy gap long before the re-growth of the cut species has reached its full height. Thus, re-growth could potentially have to take place under very shaded conditions (unless harvesting was non-selective, in which case all species would have to re-grow together). Conversely, if the species harvested dominates the cover, then there is little else growing that could potentially capitalize on the cutting back of the harvested species. Many wetland plants used for crafts occur in dense, almost completely mono-specific stands, but may also occur mixed with other species.

Height of harvesting in relation to the growing points

Clearly, if harvesting takes place above the growing points of the plant then re-growth can readily take place. Conversely, if harvesting takes place below the meristematic growing points of the plant, then re-growth will be severely impaired. The growing points can be recognized as those places where the very youngest shoots or leaves grow out of the stem. In the case of a rhizome this will be underground. In addition, the higher the harvesting takes place in relation to the ground, the less will be the short term impact of reducing the surface roughness of the vegetation.

Discarded material

If discarded material is piled thickly on top of the growing points of the harvested plants, re-growth can be smothered. For example, buds of *Phragmites australis* are suppressed by thick layers of litter (Cowie *et al.,* 1992). However, it is also disadvantageous to remove all the discarded material from the harvested area, as this reduces the return of nutrients to the soil, which supports further growth. Thus, the most favourable condition is to have a minimal amount of discarded material, or to have the discarded material thinly spread, and preferably in the open spaces between the plants.

Frequency of harvesting

The grasses and sedges (including rushes) that are commonly harvested in wetlands (e.g. *Phragmites australis*, *Cyperus marginatus*, *C. latifolius*, and *Juncus kraussii*) are well adapted to harvesting, and re-grow vigorously following cutting (Cunningham, 1987; McKean, 2001; 2002). Thus, a harvest frequency of every second year or more should allow adequate time between harvests for individual plants to build up reserves. If individual plants are being harvested twice or more in one year then they are unlikely to be able to build up their reserves between harvests, and will ultimately weaken. If plants are harvested every year then they would have more opportunity to build up reserves, but, depending on the circumstances, this may also be insufficient time. It is important to note that it may happen that the wetland is harvested several times in the year, but if a different area is harvested each time, then no individual plant would be harvested more than once a year.

Members of the Restionaceae (“restios”) are robust plants that are also generally well adapted to harvesting (Rourke, 1974; Linder, 1990; Ball, 1995), although harvestable material accumulates more slowly than in grasses and sedges. However it also remains suitable for harvesting for a longer period (i.e. its quality does not deteriorate significantly in the year following growth, which is the case for sedges and grasses). The intervening period between harvests, therefore, needs to be longer than for grasses and sedges. In addition, the main wetland restio species which is harvested, *Condropetalum tectorum*, is vulnerable to fire (which may sometimes kill most of the plants), and depends strongly on seeds for regenerating (Linder, 1991). This contrasts with the sedge, grass and rush species which are harvested, and the non-wetland restio (*Thamnochortus erectus*), of which the adult plants are well adapted to surviving fires. These would all be described as re-sprouters.

Timing of harvesting

If leaves are harvested early in the growing season then they would have had very little opportunity to photosynthesize and contribute to the plant’s store of reserves. It should be noted, however, that this may be complicated to some extent by the timing of harvesting in relation to the plant's pattern of transport of reserves to its storage organs (Box 10). McKean (2001) recommended that *Phragmites australis* harvesting should be done during the dormant period (autumn and winter). However, this is generally not practical for sedges and rushes because the quality of the material for crafts starts to decline towards the end of summer.

Box 10: Timing of harvesting in relation to plant resource translocation and storage characteristics

The majority of the wetland species harvested for fibres are perennial plants with rhizomes or stolons. The common reed *Phragmites australis* can be used as an example to illustrate how resources are generated, transported and stored within the plant during its annual growth cycle. In spring, at the start of the growing season, reserves from the rhizomes are transferred to above-ground parts and new shoots are rapidly produced. As a result, the reserves stored within the rhizomes decrease and reach their lowest level approximately ten weeks after initial shoot emergence. Harvesting early in the growing season stresses the plant because only very limited resources would have been transported back to the rhizomes before harvesting. Harvesting towards the end of the growing season allows time for the plant to transport resources back into the rhizomes.

Although most of the wetland species exhibit similar growth patterns to those described above for *P. australis,* these patterns are also influenced by climatic conditions. Thus, under warm conditions with mild winters, such as occur along the coast, some species do not display a pronounced dormancy, for example culms of *Juncus kraussii* are produced continuously, and mature and die throughout the year (Heinsohn, 1991). Further inland, in areas with cold winters in which frosts occur, there is generally a well-defined translocation of resources below-ground prior to dormancy of plants during the winter.

10.2 Rationale for the weighting factor to account for the interactive effect between grazing and burning

It is assumed that in the past the majority of wetlands would have been subjected to both grazing and burning, which result in defoliation, and the majority of wetland plant species therefore evolved to withstand these disturbances. Thus, wetland plants are generally favoured by at least some defoliation. The effects of vegetation cutting cannot be assessed in isolation from the effects of grazing and burning, since they all contribute towards defoliation. Current management may exclude such disturbances, and where this is the case, a limited level of cutting would be beneficial to wetland plants, and hence the weighting factor in Table 10.1 is less than one (i.e. it reduces the impact score). Where grazing or burning is low or moderate, the weighting is one (i.e. the impact score remains the same), but where the level of grazing/burning is moderately high or high, the weighting factor is more than one (i.e. it increases the impact score).

The assumption underlying the above weighting factors is that adult plants will survive fires and grazing. However, as explained earlier and in Appendix 9, there are likely to be occasions when this does not apply to restios. Currently, *Chondropetalum tectorum* is the only wetland restio species harvested to any great extent, and the adults of this species may suffer high mortality in fire (Appendix 9). Therefore frequent, recurrent fires will probably reduce the frequency with which this plant can be harvested sustainably far more than is reflected in the weighting factors. Although no research has been done on harvesting of *C. tectorum*, Ball (1995) recommends waiting seven years following a burn before harvesting *T. insignis*, which is another species vulnerable to fire. This allows the abundant seedlings that appear after the fire to reach sufficient maturity for harvesting (Appendix 9).

10.3 A supplementary check of the effect of harvesting on the sustained yield of the harvested species

A further check on the sustainability of harvesting is to question harvesters if they have noticed, over the years, whether the amount of material available for harvesting has increased, remained stable or declined. When posing this question it is important to ask harvesters to think of long term changes rather than short term changes occurring as a result of wet and dry years. In a few sites, some data on harvest per unit effort may be available, which can be very valuable for assessing sustainability (Box 11). If harvesters have noticed a long term decline, question them as to why they think this has occurred.

Box 11: Harvest per unit effort
Harvest per unit effort (HPUE) examines the relationship between effort and yield, i.e. within a specified area, the time and the number of harvesters it takes to collect a given weight of reeds, sedges or grasses. It can be used to monitor the relative abundance of a resource within or between locations. HPUE for timber, fuel-wood and agriculture has been suggested as a global indicator for ecosystem environmental condition, and for "goods and services" for the Convention on Biological diversity's 2010 target (Balmford *et al.,* 2005). Harvest per unit effort can be applied to the harvesting of wetland plants, where effort relates to the total number of harvesters, total number of days spent harvesting, and area harvested.

HPUE = weight/number of harvesters/number of days spent harvesting/area

Assuming that other factors are constant, a rise in either the number of harvesters, days or area can decrease the HPUE. Comparison of yearly differences in HPUE can indicate the status of a resource. A constant HPUE suggests a stable resource, whereas if it is decreasing it suggests that the resource is declining. For example, one harvester might collect 300 kg of *iNcema* over five days in a one hectare area (HPUE = 300 kg/1/5/1 ha = 60), and ten years later that harvester may collect 200 kg over five days in a one hectare area (HPUE = 200 kg/1/5/1 ha = 40). Thus, over ten years the HPUE has declined, suggesting a declining *iNcema* population. It is important to remember, however, that a population may fluctuate naturally between wetter and drier years. This comparison should therefore be made between years with similar conditions. Harvest per unit effort is an indicator that could be effectively used within *protected areas*, where relatively reliable values for the factors assessed can be determined.

In association with Steve McKean, Ezemvelo KwaZulu-Natal Wildlife.

10.4 Sustainability in terms of impacts on wetland fauna

Timing of harvesting

Most wetland dependent bird species breed in the growing season, and therefore harvesting during the growing season is more likely to disturb their breeding activities than harvesting at the end of the growing season. It is recognized that the criteria used here for assessing impacts on fauna are simplistic and do not necessarily account for the requirements of all species. Information may be available on specific species that are known to occur in the harvested area and how these species are likely to be affected by the particular timing and intensity of harvesting. If so, then the scores for factors 5 and 6 can be assigned based on this more detailed information rather than using the prescribed scores given for these factors, provided that written justification is provided.

Proportion of the vegetation that is harvested

Faunal species respond differently to the habitat disturbance associated with plant harvesting. Some species, such as the Sedge Warbler (*Acrocephalus schoenobaerus*; Trnka and Prokop, 2006) and the Purple Heron (*Ardea purpurea*; Barbraud *et al.,* 2002), favour undisturbed wetlands. However, species such as the Great Bittern (*Botaurus* *stellaris*) favour young vegetation beds, which can be produced by harvesting activities (Puglisi *et al.,* 2005). Within a wetland, a mosaic of cut and uncut stands of different ages may provide habitat heterogeneity for fauna. Harvesting the entire stand of wetland plants will remove the cover for secretive wetland dependent birds such as rails (Aves: Rallidae; Taylor, 1994) and habitat for arthropods (Schmidt *et al.,* 2005), and this type of impact on wetland fauna may be unsustainable in the long term. Therefore it is recommended that a proportion of the vegetation type containing the harvested species is left *un*-harvested each year (for more detail see Appendix 8).

11. THE IMPACTS ON LIVELIHOODS OF THE ALTERED ENVIRONMENTAL CONDITION OF THE WETLAND

Sections 7 to 10 provide a means of assessing the impact of land-use activities (wetland cultivation, grazing and harvesting of vegetation) on the environmental condition of a wetland. The next question to be addressed is what are the consequences of this altered condition for the livelihoods of local wetland users and other stakeholders? Table 11.1 describes some general consequences of alterations to the different elements of ecological health on specific provisioning services. However, it does not provide detailed prescriptions for conducting this assessment, except to describe some possibilities to consider. Table 11.1 also highlights the fact that the greater the community's dependence on these services and the more limited their alternatives, the greater will be the impact on people's livelihoods (see Turpie, 2010).

Dependency is likely to be strongly influenced by the social context of the socio-ecological system. It may be, for example, that two wetlands are equally severely affected by a high level of artificial drainage, which in the short term provides a positive contribution to cultivated food but causes the drying up of a perennial spring in both wetlands. In the first wetland, the only other available source of water for local people is 10 km away, while in the second wetland local people are provided with piped water. Clearly, the direct negative impact on local people's livelihoods is likely to be much greater in the case of the first wetland than in the second.

Importantly, it is not just local people who benefit from wetlands and who may be affected by the altered environmental condition of a wetland. There may be many people some distance away from the wetland that are benefiting from some of the services that it provides (e.g. potable water users downstream of the wetland who benefit from the wetland assimilating nutrients, thereby enhancing water quality). WET-EcoServices (Kotze *et al.,* 2008b) provides a framework for rapidly screening the importance of a wetland for providing a range of services, including provisioning services (e.g. livestock grazing and cultivation land) which generally benefit local people, well as regulatory and supporting services (e.g. assimilation of nutrients) which generally benefit local people as well as people much further away. The goal is generally to optimize the supply of benefits, which are shared equitably. This is unlikely to be achieved if the focus is only on a single land-use, especially where impacts on the environmental condition of the wetland are high. An optimal supply of benefits is much more likely under a multiple-use system.

Table 11.1: Characteristic livelihood impacts resulting from alterations to the five key elements determining the environmental condition of a wetland

Key elements considered	**Likely impact on the livelihoods of local people using the wetland**
Hydrology (the distribution and retention of water in the wetland)	The reduced extent and duration of flooding/saturation in the wetland potentially allows for greater opportunities for the cultivation of wetland areas that were naturally too wet for cultivation. From a livelihoods perspective, this is positive. However, these alterations may also have negative effects on local livelihoods, particularly where important resources (e.g. the fish of the Phongolo floodplain or the reeds of Mbongolwane) are dependent on a close-to-natural flooding regime. An artificial drying out of the wetland is also likely to reduce the value of the wetland as a source of water for domestic and livestock use and small-scale irrigation, particularly during dry years. Over-drainage of a wetland may also directly reduce the crop production potential of a wetland during dry years by subjecting crops to desiccation[1].
The retention (or erosion) of sediment in the wetland	Reduced retention of mineral sediment (usually as a result of erosion) will almost always have a negative impact on wetland productivity, which in turn will impact negatively on the supply of provisioning services[1] and the livelihoods that these sustain. This might be expressed rapidly (e.g. if soils are inherently shallow or the intensity of erosion is very high) or slowly (e.g. if erosion intensity is low). Erosion may also impact on water quality downstream, by increasing sediment and nutrient loads.
The accumulation of SOM in the wetland	Reduced organic matter leads to both reduced nutrient retention and water holding capacities, which in turn result in reduced productivity and provisioning services. In the short term, increased mineralization of SOM (e.g. as a result of desiccation from artificial drainage) is likely to increase nutrient availability for crops, which is potentially positive for livelihoods. However, as the SOM store is depleted, this release of nutrients will come to an end and the soil will often be left both depleted of nutrients and with a poor capacity to hold any nutrients that may enter the system. This in turn will impact negatively on the capacity of the wetland for producing crops[1]. The time taken for this point to be reached may vary greatly from one wetland to the next, and will depend on the size of the SOM store, which may be very large in peatlands with deep peat deposits or very small in some seasonally saturated mineral soils.
The retention and internal cycling of nutrients in the wetland	As in the case of erosion, reduced nutrient retention and internal cycling will almost always have a negative impact on wetland productivity, which in turn will impact negatively on the supply of provisioning services[1] and the livelihoods that these sustain. A reduction in this capacity is also likely to impact negatively on the water quality of downstream areas, thereby affecting those that depend on this water.
The natural composition of the vegetation	A decline in the richness of native species reduces the resource base of wild plants, including medicinal plants and plants for crafts and thatching[1]. Plants of value for grazing livestock may also potentially be lost[1].

[1]The greater the community's dependence on these resources/services and the more limited their alternatives, the greater will be the impact on people's livelihoods (see Turpie, 2010).

12. ASSESSING SUSTAINABILITY BASED ON A CONSIDERATION OF ALL OF THE PREVIOUS ASSESSMENTS

Some users of WET-SustainableUse may choose to define sustainability very narrowly, as simply relating to the level of impact that the land-use has on the five components of ecological condition considered (i.e. those given in Table 2.1). If this was the case then the level of sustainability would be inversely related to the level of impact, as shown in Table 12.1.

Table 12.1: A comparison of the level of impact and resulting level of sustainability

Level of impact on the condition of the wetland and its delivery of ecosystem services	**Low**	**Moderately low**	**Moderate**	**Moderately high**	**High**
Resulting level of sustainability	High	Moderately high	Moderate	Moderately low	Low

In other cases sustainability may be defined more broadly, and the impacts on environmental condition may be considered together with other factors, such as the level of dependency of the users on the wetland (see Turpie, 2010) and the cumulative impact on wetlands in the broader catchment and landscape in which the wetland is located (see Ellery *et al.,* 2010). As highlighted in Section 2, WET-SustainableUse does not prescribe, in rigid terms, what is considered sustainable or not (e.g. “to be sustainable, the environmental condition must not be reduced by more than 30%”). It is up to the users to decide what constitutes sustainability, given the above features.

To expand on the example given in Section 2, it may be, for example, that the environmental condition of two similar wetlands has been reduced by the same amount, let us say 40%. However, the context of the two wetlands is entirely different: the first is in a catchment where the cumulative impacts on wetlands are already considerable (see Ellery *et al.,* 2010) and maintenance of the environmental condition of wetlands is a very high priority, while the second wetland is in a catchment where the priority for maintaining the environmental condition of the wetlands is much lower. It is conceivable, therefore, that although reduced by the same amount, use of the first wetland is considered less sustainable than the second wetland, given their contrasting contexts. Similarly, the first wetland may be in the context of an affluent commercial user with abundant alternative options, while the second wetland is in the context of subsistence users who have very little alternative area available for cultivation and a very high level of dependency on the wetland (see Turpie, 2010). Again, it is conceivable that although the environmental condition has been reduced by the same amount, use of the first wetland might be considered to be less sustainable than that of the second wetland.

As suggested in Section 2, it is useful to place the assessment of sustainability within a strategic adaptive management context. An important element of adaptive management is setting TPCs (Thresholds of Potential Concern) that define the threshold along a continuum of change (Rogers and Bestbier, 1997; Rogers and Biggs, 1999). When the threshold has been exceeded, or is close to being exceeded, then this highlights the need for specific management intervention and/or further investigation.

It is recommended that TPCs be set for the assessed wetland site for each of the five key elements that determine a wetland's environmental condition (Table 11.1). These TPCs, which define what are considered to be the limits of sustainable use for the wetland, would need to be tailored to the specific management objectives and circumstances of the site. However, as a starting point, TPCs are suggested for three general management objectives (Table 12.1). As can be seen from Table 12.1, the thresholds vary according to the health element considered and the primary management objectives. For example, in the case of retention and internal cycling of nutrients, a more stringent threshold is set (>1 compared with >3) if the primary objective is catchment management for water quality than if the primary objective is livelihood support. In the case of vegetation composition, a stringent threshold is set for biodiversity conservation but a much more lenient threshold is set for catchment management for water quality (>2 compared with >6). The rationale for the different thresholds is given in Table 12.1.

It is likely that the assessor will need to adjust the "default" TPCs suggested in Table 12.1 in order to account for the circumstances at a particular site. For example, if the primary objective is biodiversity conservation, and a key species contributing to the biodiversity value of a wetland requires that the retention of sediment be minimally affected, then a more stringent threshold may be appropriate (e.g. >1 rather than >2). Alternatively, if all of the important biodiversity features that have been identified have a moderate resilience to altered/reduced sediment retention then a more lenient threshold may be appropriate (e.g. >3 rather than >2).

As indicated, the TPCs in Table 12.2 are set for the five components that determine environmental condition of a wetland. An alternative approach would be to set thresholds for each of the indicators making up a component of environmental condition. For example, one of the indicators for the accumulation of SOM is “the frequency of tillage”; an example of a TPC for this indicator might be “a frequency greater than annual”, in which case any tillage frequency greater than annual would be of potential concern. Pollard *et al.* (2009) provide a practical example of the application of TPCs at the indicator level. If the option of setting TPCs at the indicator level is taken, it is important to emphasize that the indicators do not operate independently in affecting a particular component of environmental condition. Thus, the effect of a particular indicator value may be dampened or amplified by another indicator value. For example, the effect of a high frequency of tillage may be dampened to some extent by maintaining a high level of soil cover (through mulching). These relationships need to be borne in mind when setting TPCs for individual indicators.

Table 12.2: Thresholds of Potential Concern (TPCs) for the five key elements considered by WET-SustainableUse and for three different management objectives

Key elements considered by WET-Sustainable-Use that determine wetland environmental condition	**Threshold impact value for different primary management objectives (The continuum of impact values ranges from 0 [no impact] to 10 [critical impact])**			
	Biodiversity conservation	Catchment water quality management	Livelihood support	**Rationale for the choice of threshold values**
Hydrology *(the distribution and retention of water in the wetland)*	>1	>2	>4	Hydrology is the most important determinant of wetland structure and function, and therefore the level of disruption to the hydrology should generally be minimal in order to maintain wetland biodiversity. The capacity of a wetland to enhance water quality is also dependent on a low level of disruption to the hydrology. An important way in which wetlands generally support livelihoods is through wetland cultivation, which, by its nature, generally disrupts hydrology. If livelihood support is the primary objective then the threshold is set at a moderate level of disruption, unless there is direct dependency on the wetland for water supply, in which case a much more stringent threshold may be required.
The retention (or erosion) of ***sediment*** *in the wetland*	>2	>2	>3	Impacts on sediment retention should be kept low in order to maintain wetland biodiversity, and the capacity of a wetland to enhance water quality is also dependent on low impacts to sediment retention. Cultivation of wetlands will generally lead to some erosion impacts, but these should not exceed a moderately low level, otherwise sustained production is likely to be under threat.
The accumulation of ***SOM*** *in the wetland*	>2	>2	>3	Impacts on the accumulation of SOM should be kept low in order to maintain wetland biodiversity and the capacity of a wetland to enhance water quality. Cultivation of wetlands will generally lead to some impacts on SOM, but these should not exceed a moderately low level, otherwise sustained production is likely to be under threat.
The retention and internal cycling of ***nutrients***	>2	>1	>3	Impacts on nutrient retention should be kept low in order to maintain wetland biodiversity. This factor is the most critical in terms of the capacity of the wetland to maintain a high water quality, so impacts should be minimal. Cultivation of wetlands will generally lead to some nutrient retention impacts, but these should not exceed a moderately low level, otherwise sustained production is likely to be under threat.
Natural ***vegetation*** *composition in the wetland*	>2	>6	>5	In order to maintain wetland biodiversity, impacts on the natural vegetation should be kept low, given that vegetation is an important part of biodiversity and provides habitat for many other taxa. Provided that plant production is maintained, the retention and internal cycling of nutrients may be little diminished (or may even be enhanced) by a change in vegetation composition. Livelihood support generally does not require that vegetation is minimally impacted. However if there is direct dependency on resources which are only present when the vegetation is minimally impacted, then a much more stringent threshold may be required.

Note: the threshold values given in Table 12.2 are preliminary and require validation in the field. In addition, the table assumes a simple linear relationship between health score and the delivery of management objectives. In reality this relationship is likely to be more complex.

13. EXPLORING OPPORTUNITIES FOR ENHANCING THE SUSTAINABILITY OF WETLAND USE

This section is relevant if, after having found that the sustainability of use is below what is desired, the role-players wish to enhance sustainability. One of the first steps to enhancing sustainability is to check whether the different role-players share understanding about the sustainability of utilization practices. It may be that different role-players see things very differently (see Box 3), in which case it will be important to facilitate dialogue around the main points of disagreement.

Exploring opportunities for enhancing sustainability should be informed by all of the preceding assessments, including the socio-economic context, which highlights those factors most likely to affect utilization. These factors arise at different scales, and they need to be addressed at the appropriate scale(s). At the local scale, a good understanding of land-use practices is central to exploring the potential for enhancing sustainability of use. Some land-use practices may appear straightforward but are not a single practice and are more complicated than they seem. Mulching, for example, is a complex “basket” of interrelated practices, and the adoption of mulching typically involves adapting the entire farm production system in several ways (Erenstein, 2003). Adaptations often need to account for several constraints: (1) farm level constraints, (2) institutional constraints and (3) socio-economic constraints (Erenstein, 2003). Some practices may be very environmentally sustainable, but to be sustainable overall, they also need to be institutionally and economically sustainable.

13.1 Farm level considerations

Any land-use practice or technology generally affects the flow of resources in the existing farming / natural resource system. Because of these effects, other complementary practices may be required to ensure the successful functioning of the whole system. For example, when applying mulching, adaptations are often required to sowing, nutrient management and weed, pest and disease management. The relative complexity associated with the adoption of new technologies, and the learning costs associated with this may be problematic for farmers.

Certain practices may be incompatible with elements of the farming system. For example, mulching is incompatible with consumption of crop residues by livestock, as the animals leave little behind to use for mulching. Addressing these incompatibilities requires examining the reasons the existing practices were adopted. For example, a farmer with a fenced plot may be able to physically exclude livestock from the plot but chooses not to, because the livestock are an important part of the overall farming system and depend strongly on crop residues during the non-growing season.

Besides adjusting individual components of the farming system, an adjustment to the overall approach or philosophy of the farming system may be required (e.g. adjusting the mindset from ‘clean’ farming to ‘trash’ farming in order to be able to apply mulching). This may present a further obstacle.

13.2 Institutional considerations

How access to land and resources are controlled in a community may have a critical effect on the local farming systems and the particular technologies used. For example, the practice of mulching is affected fundamentally by how the rights to crop residues are defined and respected. In many of South Africa’s communal areas, the crop residues on maize fields are usually regarded as common property for livestock grazing during the dry season. An individual farmer in such a community is likely to encounter resistance if he/she wishes to retain the residue as mulch.

Security of tenure also influences the extent to which a farmer is willing to invest in long term conservation measures, with poor security of tenure serving as a disincentive to long term investment.

13.3 Economic considerations

The lower the economic costs of implementing a technology or practice in relation to the benefits that accrue to the household, the more economically sustainable that practice is likely to be (Boehm and Burton, 1997). Start-up costs of implementing a new practice are often the greatest and thereafter costs generally decline considerably. Nevertheless, start-up costs may act as a critical obstacle to the adoption of the new technology. If, for example, a farmer has an unfenced plot and finances are very limited, the cost of fencing a plot to exclude livestock may constitute a critical obstacle to the adoption of mulching.

Finally, it is important to highlight that choices affecting the environment are often not based on economic considerations as strongly as “economic rationalism” would suggest, and are influenced by other factors (both cultural and social; J Taylor, 2006, pers. comm., Wildlife and Environment Society, Howick). Therefore, land-users will not necessarily select what appears from a purely economic perspective to be the most favourable land-use option.

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15. GLOSSARY[7]

Adaptive management: A systematic process for continually improving management policies and practices by learning from the outcomes of management actions.

Aerobic: Having molecular oxygen (O_2) present.

Alien species: Plant or animal species that does not occur naturally in an area.

Anaerobic: Not having molecular oxygen (O_2) present.

Biodiversity: The variety of life in an area, including the number of different species, the genetic wealth within each species, and the natural areas where they are found.

Capillary fringe: The zone just above the water table that remains almost saturated. This varies from approximately 10 cm in sandy soils to about 30 cm in some clay soils.

Catchment: All the land area from mountaintop to seashore which is drained by a single river and its tributaries. Each catchment in South Africa has been sub-divided into secondary catchments, which in turn have been divided into tertiary catchments. Finally, all tertiary catchments have been divided into interconnected quaternary catchments. A total of 1946 quaternary catchments have been identified for South Africa. These sub-divided catchments provide the main basis for integrated catchment planning and management.

Chroma: The quantitative measure of the relative purity of the spectral colour of a soil, which decreases with increasing greyness. A Munsell colour chart is required to measure chroma.

Collaboration: The most complex organizational behaviour, where the goals and aims of every party are focused on a common vision of what is desired. A greater level of interdependence than cooperation, often involving a combination of human and financial resources and the development of a new, common identity.

[7] Glossary terms are consistent with those of Kotze *et al.* (2008b) and Macfarlane *et al.* (2008).

Co-management: Where the responsibilities for allocating and using resources are shared amongst multiple parties, often including local communities and a relevant government agency.

Depression: A basin shaped area with a closed elevation contour that allows for the accumulation of surface water (i.e. it is inward draining). It may also receive sub-surface water. An outlet is usually absent, and a depression is therefore usually isolated from the stream channel network.

Delineation (of a wetland): The determination of the boundary of a wetland based on soil, vegetation and/or hydrological indicators (see definition of a wetland).

Ecosystem services: The *direct and indirect benefits* that people obtain from ecosystems. These benefits may derive from outputs that can be consumed directly; indirect uses which arise from the functions or attributes occurring within the ecosystem; or possible future direct outputs or indirect uses (Howe *et al.,* 1991). Synonymous with ecosystem 'goods and services'.

Floodplain: Valley bottom areas with a well defined stream channel, gently sloped and characterized by floodplain features such as oxbow depressions and natural levees and the alluvial (by water) transport and deposition of sediment, usually leading to a net accumulation of sediment. Water inputs from main channel (when channel banks overspill) and from adjacent slopes.

Governance: The socio-political structures and processes by which societies share power, through exercising their rights, meeting their obligations, and mediating their differences. (Lebel *et al.,* 2006). Governance is not confined to the state, but involves many actors, including the private sector and Non-Governmental Organizations. "It can be formally institutionalized or expressed through subtle norms of interaction or even more indirectly by influencing the agendas and shaping the contexts in which actors contest decisions and determine access to resources" (Lebel *et al.,* 2006).

Groundwater: Sub-surface water in the zone in which permeable rocks, and often the overlying soil, are saturated under pressure equal to or greater than atmospheric (Soil Classification Working Group, 1991).

Head-cut: The upper-most entrance into an erosion gully. The point where the head-ward extension of a gully is actively eroding into undisturbed soil.

Hill-slope seepage: Wetland (seepage areas) situated on a slope or hillside, which is characterized by the colluvial (transported by gravity) movement of materials. Water inputs are mainly from sub-surface flow and outflow is via a well defined stream channel or via diffuse flow.

Hydric soil: Soil that in its undrained condition is saturated or flooded long enough during the growing season to develop anaerobic conditions, favouring the growth and regeneration of hydrophytic vegetation (vegetation adapted to living in anaerobic soils).

Hydro-geomorphic (HGM) type: Classification of wetlands or portions of wetlands on the basis of their hydrological and geomorphological characteristics. It encompasses three key elements of (1) geomorphic setting (i.e. the landform, its position in the landscape and how it evolved, e.g. through the deposition of river-borne sediment); (2) water source (i.e. where does the water come from that is maintaining the wetland?), of which there are usually several, including precipitation, groundwater flow and stream-flow, but their relative contributions will vary amongst wetlands; and (3) hydrodynamics, which refers to how water moves through the wetland.

Hydrology: The study of the properties, distribution, and circulation of water on the earth.

Hydrophyte: Any plant that grows in water or on a sub-stratum that is at least periodically
deficient in oxygen as a result of soil saturation or flooding; plants typically found in wet habitats.

Infilling: Dumping of soil or solid waste onto the wetland surface. Infilling generally has a very high and permanent impact on wetland functioning and is similar to drainage in that the upper soil layers are rendered less wet, usually so much so that the area no longer functions as a wetland.

Institutions: The formal rules, conventions and laws (e.g. marriage), as well as the informal codes of behaviour that constrain and direct societal activities and interactions.

Integrated Environmental Management (IEM): An internationally accepted procedure for promoting better planned development by ensuring that the environmental consequences of development are understood and adequately considered in planning and implementation.

Invasive species: A species, generally not indigenous to the area, which has the capacity to out-compete and dominate the indigenous species.

Inventory: Wetland inventory is the process of determining and recording where wetlands are, how many wetlands are in a given area, and their characteristics.

Livelihood: The capabilities, assets and activities required to make or gain a living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base (Chambers and Conway, 1991). Assets include natural, physical, social, human and financial capital.

Management: The implementation of actions aimed at achieving a goal. It may encompass planning, organizing, staffing, directing and controlling. Management is not the same as governance.

Management effectiveness: Effective management is strategic in the sense that it is guided by a vision and objectives and the implementation of actions necessary to achieve these, adaptive in the sense that there is an ongoing process of monitoring and evaluation and adjustment to account for the lessons learnt, and inclusive of the key stakeholders who affect and are affected by the ecosystem.

Marsh: A wetland dominated by emergent herbaceous vegetation (usually taller than 1 m), such as the common reed (*Phragmites australis*). Marshes may be seasonally wet but are usually permanently or semi-permanently flooded or saturated to the soil surface.

Minimum tillage: Keeping disturbance of the soil to a bare minimum when cultivating crops (e.g. by avoiding ploughing and ripping entirely and planting in small holes in the soil just big enough for the seeds). Minimum tillage is almost always linked with the practice of maintaining a covering on the soil of plants and/or plant residues referred to as mulch.

Mitigate: To take actions to reduce the impact of a particular proposal or activity.

Monitoring: The regular, systematic gathering of information based on observations and measurement of change in wetland characteristics in relation to a pre-defined state, in order to provide the data for evaluation.

Mottles: Soils with variegated colour patters are described as being mottled, with the 'background colour' referred to as the matrix and the spots or blotches of colour referred to as mottles.

Mulch: A protective cover placed over the soil, usually consisting of organic material (e.g. crop residues) that serves several regulating functions, including erosion control and moisture conservation, and suppresses weeds.

Munsell colour chart: A standardized colour chart which can be used to describe hue (i.e. its relation to red, yellow, green, blue, and purple), value (i.e. its lightness or darkness) and chroma (i.e. its purity). Munsell colour charts show that portion commonly associated with
soils, which is about one fifth of the entire range.

Open water: Permanently or seasonally flooded areas characterized by the absence (or low occurrence) of emergent plants.

Palustrine (wetland): All non-tidal wetlands dominated by persistent emergent plants (e.g. reeds), emergent mosses or lichens, or shrubs or trees (see Cowardin *et al.,* 1979).

Pan: Endorheic (i.e. inward draining; lacking an outlet) depressions, typically circular, oval or kidney shaped, with a flat bottom, and usually intermittently to seasonally flooded.

Participation: A process through which stakeholders influence and share control over development initiatives and the decisions and resources which affect them.

Peat: Organic soil material with a particularly high organic matter content which, depending on the definition of peat, usually has at least 20% organic carbon by weight.

Perched water table: The upper limit of a zone of saturated soil, separated from the main body of groundwater by a relatively impermeable unsaturated zone.

Permanently wet soil: Soil which remains saturated to the soil surface throughout the year.

Poaching: The disruption of soil structure as a result of the repeated penetration of the hooves of livestock into wet soil (Wilkins and Garwood, 1986).

Ramsar Convention on Wetlands: An intergovernmental treaty which provides the framework for international cooperation for the conservation of wetland habitats.

Red Data species: All those species included in the categories of endangered, vulnerable or rare, as defined by the International Union for the Conservation of Nature (IUCN).

Rehabilitation (wetland): The process of assisting in the recovery of a wetland that has been degraded, or of maintaining a wetland that is in the process of degrading, so as to improve the wetland's capacity for providing services to society.

Resilience: The ability of a system to maintain its functionality when it is subject to perturbations or shocks (e.g. a major drought), or to maintain the elements needed to renew or reorganize itself if a large perturbation radically alters its structure and function (Walker *et al.,* 2002).

Restios: Plants belonging to the family Restionaceae, also known as Cape reeds. They resemble rushes and sedges, and are perennial and generally of a tufted growth form. Restios grow predominantly in the south western Cape, and constitute one of the three main elements of the fynbos.

Riparian: "The physical structure and associated vegetation of areas associated with a watercourse which are commonly characterized 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" (National Water Act 1998). Riparian areas which are saturated or flooded for prolonged periods would be considered wetlands, and could be described as riparian wetlands. However, some riparian areas are not wetlands (e.g. an area where alluvium is periodically deposited by a stream during floods, but which is also well drained).

Roughness coefficient: An index of the roughness of a surface; a reflection of the frictional resistance offered by the land's surface to water flow.

Runoff: Total water yield from a catchment, including surface and sub-surface flow.

Seasonally wet soil: Soil that is flooded or waterlogged to the soil surface for extended periods (>1 month) during the wet season, but is predominantly dry during the dry season.

Sedges: Grass-like plants belonging to the family Cyperaceae, sometimes referred to as nutgrasses. Papyrus is a member of this family.

Sediment: Solid material transported by moving water, which typically comprises sand-, silt- and clay-sized particles.

Seepage: Wetland area that is created by the presence of soil or rock of low permeability near the soil surface, which forces subsurface flow to emerge on the surface of the earth and slowly flow down-slope in a diffuse manner before draining into a stream or re-entering the ground.

Soil saturation: Soil is considered saturated if the water table or *capillary fringe* reaches the soil surface (Soil Survey Staff 1992).

Stakeholder: In the context of a wetland, a stakeholder is taken to mean any individual, group or community living within the area affected by the wetland site, and any individual, group or community likely to influence the management of the site.

Stocking rate: The number of animal units (AUs) per unit of land for a specified period of time; it may be expressed in terms of number of land units per AU. An AU is taken as equivalent to a 450 kg animal that consumes 10 g of dry matter per day.

Sustainable development: The integration of social, economic and environmental factors into planning, implementation and decision-making so as to ensure that development serves present and future generations (The South African National Environmental Management Act [NEMA], 1998).

Sustainable use (of wetlands): The maintenance of a system's ecological character (environmental condition), achieved through the implementation of ecosystem approaches, within the context of sustainable development (Ramsar Convention Secretariat, 2006). Sustainable use of a specific natural resource requires that utilization be within the resource's capacity to renew itself, i.e. it should not be beyond the resource's biological limits.

Swamp: Wetland dominated by trees or shrubs (U.S. definition). In Europe, permanently flooded, reed-dominated wetlands may also be referred to as swamps.

Temporarily wet soil: The soil close to the soil surface (i.e. within 50 cm) is wet briefly but long enough for anaerobic conditions to develop, usually at least two weeks, during the wet season in most years. However, it is seldom flooded or saturated at the surface for longer than about a month.

Tillage: The preparation of the soil by ploughing, ripping, hoeing or otherwise disturbing the soil for agricultural purposes.

Toxicant: An agent or material capable of producing an adverse response in a biological system at low concentrations, seriously injuring structure and/or function of the system and its organisms, or causing death.

Transpiration: The transfer of water from plants into the atmosphere as water vapour.

Valley bottom with a channel: Valley bottom areas with a well defined stream channel but lacking characteristic floodplain features. May be gently sloped and characterized by the net accumulation of alluvial deposits, or may have steeper slopes and be characterized by the net loss of sediment. Water inputs originate from the main channel (when channel banks overflow) and from adjacent slopes.

Valley bottom without a channel: Valley bottom areas with no clearly defined stream channel, usually gently sloped and characterized by alluvial sediment deposition, generally leading to a net accumulation of sediment. Water inputs originate mainly from the channel entering the wetland, and also from adjacent slopes.

Vlei: A colloquial South African term for wetland.

Water quality: The purity of the water, determined by the combined effects of its physical attributes and its chemical constituents.

Waterlogged: Soil or land saturated with water long enough for anaerobic conditions to develop.

Wetland: “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 in normal circumstances supports or would support vegetation typically adapted to life in saturated soils” (National Water Act 1998). Land where an excess of water is the dominant factor determining the nature of the soil development and the types of plants and animals living at the soil surface (Cowardin *et al.,* 1979); land that is sometimes or always covered by shallow water, or has saturated soils for long enough each year to support plants adapted for life in wet conditions.

Wetland’s catchment: The area, up-slope of the wetland, from which water flows (surface and sub-surface) into the wetland, and the wetland itself.

Wise use: Synonymous with sustainable use.

16. INDEX OF TOPICS COVERED IN THE DOCUMENT

APPENDIX 1: APPLICATION OF THE FRAMEWORK IN FIGURE 2.1, REPRESENTING HUMAN-WETLAND INTERACTIONS AND INTERRELATIONSHIPS AT DIFFERENT SPATIAL SCALES

In order to elaborate further on the framework given in Figure 2.1, we now describe how it was applied to two different examples, Mbongolwane wetland (Figure A1.1) and Phongolo (previously referred to as Pongola) floodplain (Figure A1.2). Traditionally, the Phongolo floodplain has supplied local households with a rich diversity of resources, including fish, livestock grazing and flood recession agriculture (Heeg and Breen, 1982; 1994). The state owned and constructed Jozini Dam, upstream of the floodplain, allowed for the regulation of water-flow onto the floodplain. This in turn led to the emergence of new power groups (most recently, local cotton growers represented by a local farmers' association and supported by a multinational company) who manipulate flow releases from an upstream impoundment in ways that alter patterns of resource use, favouring some households (particularly those with strong interests in cotton) and putting others at a disadvantage.

Mbongolwane and Phongolo are similar in that local users exert important direct pressures on the wetland and are influenced by a range of different organizations operating on different scales. However, Mbongolwane differs from the Phongolo floodplain in three important respects. Firstly it can be seen from Figures. A1.1 and A1.2 that government departments have affected the Phongolo floodplain both directly (through the strong negative influence of Jozini Dam) and indirectly through their influence over more locally based groups, which in turn have potentially strong controlling influences over utilization by individual households. Thus, the direct pressures on the Phongolo floodplain originate from the upstream dam as well as from the use of the floodplain by local households. In contrast, the direct pressures on the Mbongolwane wetland result almost entirely from the use of the wetland and its catchment by local households (Kotze *et al.,* 2002), and the influence of government departments on the state of the wetland is primarily indirect, through their influence on local users. Although there are non-local reed harvesters, both from the district and from further afield, exerting some pressure on Mbongolwane wetland, at current rates they are having very little impact on the state of the wetland and there is little competition with local users. Secondly, the combined pressures on the Phongolo floodplain are much greater than at Mbongolwane, resulting in much greater alterations to the ecological state of the system. Thirdly, although both sites are affected by agricultural industries (sugar in the case of

Mbongolwane and cotton in the case of Phongolo) there are no explicit feedbacks to the industry influencing the Phongolo floodplain, whereas there are such feedbacks at Mbongolwane (e.g. mechanisms to encourage and prevent local farmers from growing sugar cane in the wetland).

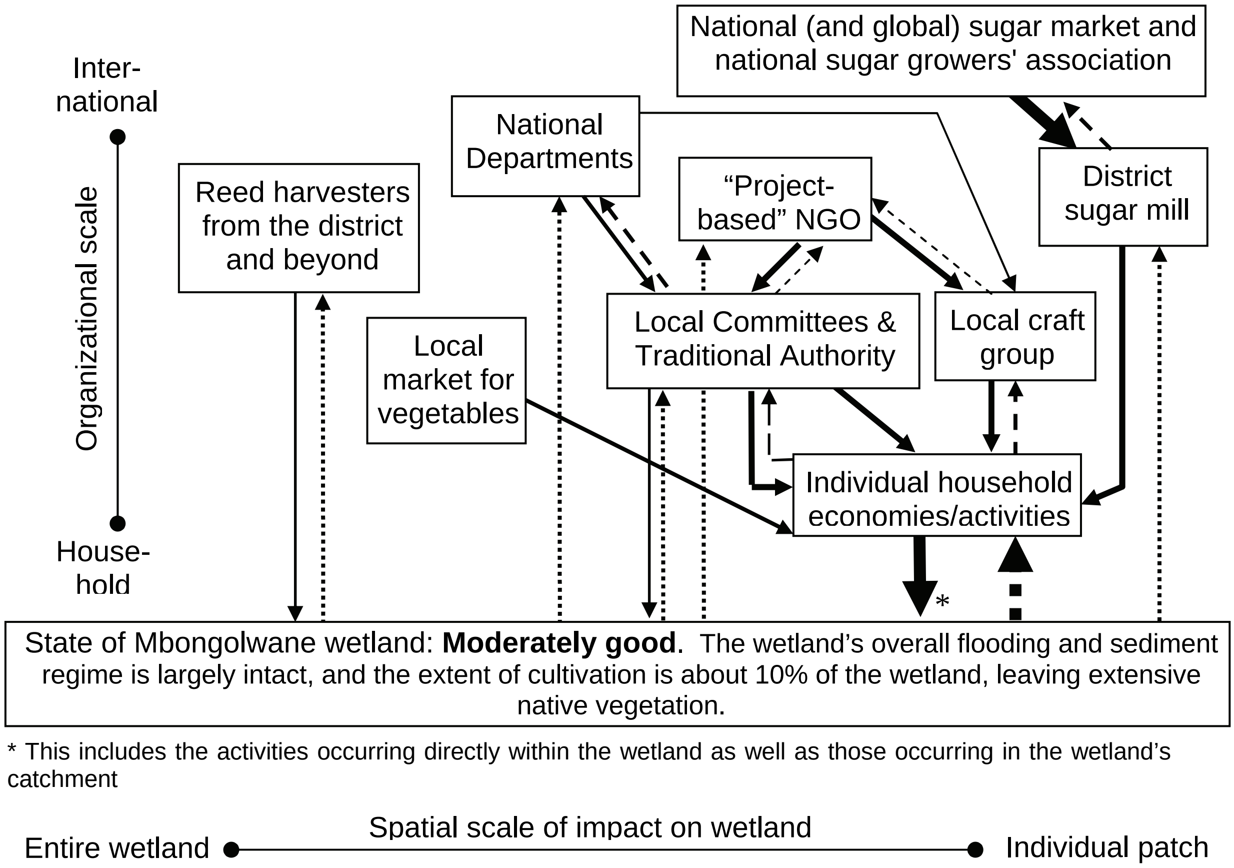


Figure A1.1: A preliminary representation of human-wetland interactions and interrelationships at different spatial scales for Mbongolwane wetland, as observed in 2003. The thickness of the arrow represents the strength of the effect. See Fig. 2.1 for legend.

It is important to add that the situations represented in Figures. A1.1 and A1.2 are as observed in 2003, but this is likely to be dynamic and could potentially change dramatically in a matter of a few years, resulting in new relationships and configurations of the elements. At both Mbongolwane and the Phongolo floodplain, global climate change is acknowledged as a potentially import influence, but at present changes in the state of the respective systems have not yet been linked to climate change. Currently, the primary impacts are from land-use activities at the sites and their upstream catchments. Thus, global climate change is not represented in Figures. A1.1 and A1.2, but it is acknowledged that in the future it is likely to become an increasingly important pressure, as is predicted for aquatic systems in general (IPCC, 2008).

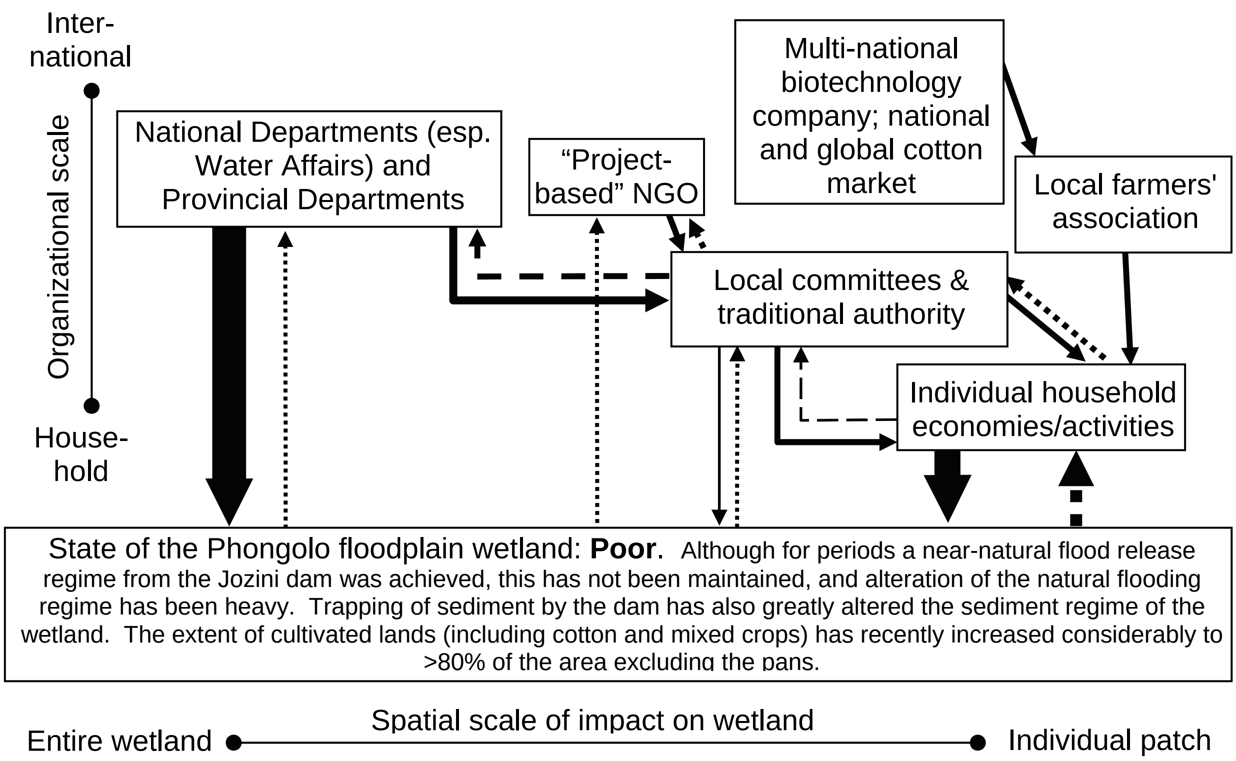


Figure A1.2: A preliminary representation of human-wetland interactions and interrelationships at different spatial scales for the Phongolo floodplain, as observed in 2003. The thickness of the arrow represents the strength of the effect. See Fig. 2.1 for legend.

The conceptual diagrams of Figures. 2.1, A1.1 and A1.2 do not represent in any depth the specific relationships between different actors in the socio-ecological system, or how the actors relate to each other. Furthermore, the diagrams do not represent the various institutions and governance mechanisms through which a wetland is managed, and by which use of a wetland is controlled. All of these issues, however, are critical to the sustainability and resilience of the socio-ecological system, and they are addressed in detail by Pollard and Cousins (2007), Mitchell and Breen (2008) and Pollard *et al.* (2009a).

An examination of the factors contributing to the need for individuals to use the wetlands is recommended, as this is relevant to achieving sustainability (see Figure. A1.3). The example given in Figure. A1.3 highlights the point that there may be much that can be done to improve production in terrestrial areas surrounding the wetland as well as making existing wetland plots more productive, which would act to reduce the overall pressure on the wetland. Thus, in many cases it may be possible to reduce the extent of cultivation in the wetlands while maintaining, and even increasing, the overall agricultural production and associated food security. Addressing the "bigger picture" factors may even result in an increase in general production so dramatic that it is no longer necessary to cultivate in the wetlands, although this is not likely to be a common occurrence. For further information on assessing the user's need or dependency on wetland resources see Turpie (2010).

It is recognized that some of these factors may be very difficult to address (e.g. institutional factors), while others may be far more readily addressed (e.g. manure storage and application practices).

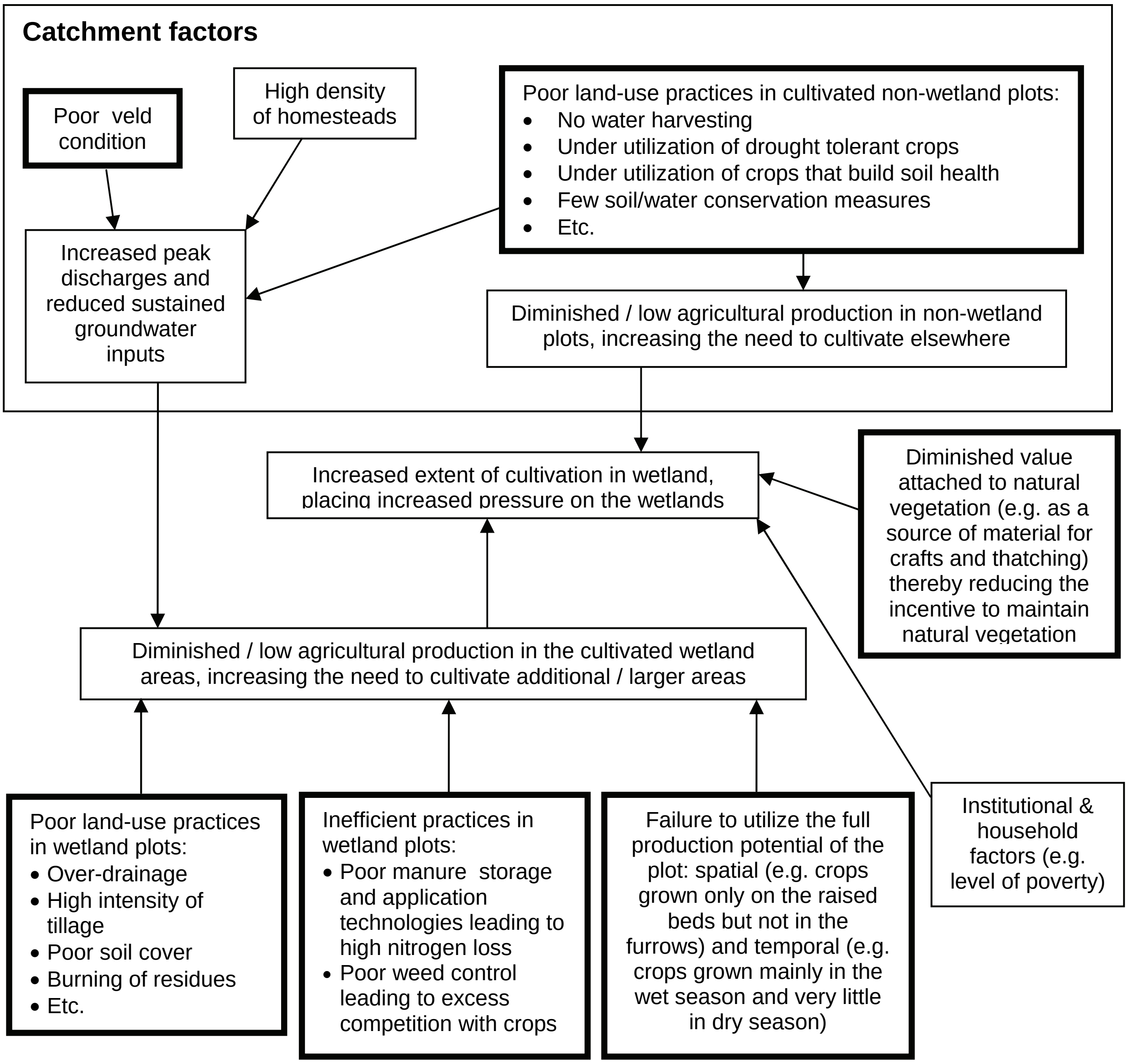


Figure A1.3: Factors that may be contributing to the extent of cultivation in Craigieburn wetland, Mpumalanga province (modified from Pollard *et al.* 2004). Land-use factors that could be directly addressed in a rehabilitation plan are shown with a **bold border** and include practices such as minimizing the level of drainage, promoting minimum tillage and mulching/cover-cropping and avoiding burning of residues. Note: such a plan would be designed to decrease the extent of wetland cultivation while at the same time increasing overall agricultural production.

APPENDIX 2: THE APPROACH USED TO DEVELOP WET-SUSTAINABLE USE

Many methods have been developed for evaluating the functioning of wetlands, e.g. Wetland Evaluation Technique (Adamus *et al.,* 1987), Method for the Comparative Evaluation of Nontidal Wetlands in New Hampshire (Ammann and Stone, 1991) and the HGM Method (Brinson, 1993; Brinson and Rheinhardt, 1996). Although these methods have some relevance to the situation in South Africa, they are of little direct help in predicting the impact of particular land-uses or guiding the use of wetlands (Adamus, 1991), and they take little account of human populations that rely on wetlands for immediate resource needs (Maltby, 1991). Although a new system tailored for South African conditions has been developed, called WET-EcoServices, which accounts for the resource provisioning services of wetlands, this system does not provide specific guidelines for assessing the impact of utilization on the underlying processes that drive a wetland.

More explicit attention to utilization is given in the system WETLAND-USE (Kotze and Breen, 2000), which is a tool to assist agricultural and nature conservation extension staff, working closely with local resource users and managers, in promoting the wise use of wetlands. The focus of WETLAND-USE is on providing guidance for making ongoing management decisions for particular land-use options (e.g. livestock grazing). Although sustainability of use is an implicit underlying element of WETLAND-USE, it gives very little explicit attention to *measuring* the sustainability of utilization. Thus there was a need for a specific tool to be developed, which has been termed WET-SustainableUse.

Based on the recognition that the sustainability of a land-use is strongly linked to the environmental condition of a wetland, WET-SustainableUse was aligned very closely with WET-Health (Macfarlane *et al.,* 2008). WET-Health provides comprehensive guidelines for measuring the condition of a wetland in relation to its natural state, and currently consists of 3 modules: hydrology, geomorphology and vegetation. It assists in determining the wetland's Present Ecological State in terms of DWA (formerly DWAF) categories: A to E. WET-Health also helps the user to identify the wetland's trajectory of change and diagnose the causes of degradation. Scoring can be done at Level 1, based mainly on aerial photograph interpretation, or at Level 2, based on a field assessment of indicators of degradation (e.g. the presence of alien plants). However, important gaps in WET-Health were identified when assessing the impact of land-use activities. It accounts well for major impacts at the level of the HGM unit (e.g. gully erosion), but some impacts taking place at the level of the individual plot are poorly accounted for (notably sheet and rill erosion). In addition, WET-Health does not address nutrient retention or internal cycling in wetlands, and impacts on SOM are only covered in as far as they occur in peat deposits (i.e. it does not account for impacts on SOM in mineral soils, which constitute the bulk of the wetland area in South Africa). Thus several specific models, contained within WET-SustainableUse, were developed to account for these gaps.

WET-SustainableUse was produced through a process of progressive refinement. Firstly, a prototype was developed (Kotze, 2007) based on a review of the literature relating to the use of wetlands (e.g. Cowie *et al.,* 1992; Grant, 1994; Drury *et al.,* 1996; Dixon and Wood, 2003; Sahrawat, 2004; Walters *et al.,* 2006) and an examination of existing wetland assessment protocols (e.g. Brinson, 1993; Smith *et al.,* 1995; Brinson and Rheinhardt, 1996; Kotze, 1999; Kotze and Breen, 2000; Hailu *et al.,* 2000; Pollard *et al.,* 2004; Walters and Kotze, 2004; Kotze and Traynor, 2007; Macfarlane *et al.,* 2008) and general frameworks for describing socio-ecological systems (e.g. OECD, 1993; Walker *et al.,* 2002; Anderies *et al.,* 2004; Plummer and Armitage, 2007).

The prototype was then refined by applying it to eight different wetland sites, Sambandou and Nyahalwe (Mutale River catchment, Limpopo Province), Ramkamp and Langvlei (Kamiesberg, Northern Cape), Moddervlei (Agulhas plain, Western Cape), and three wetlands in the Dwangwa catchment (Kusungu, Malawi). The sites included a variety of different land-uses. Most of the wetlands are used for cultivation, plant harvesting and livestock grazing, but Moddervlei was assessed only in terms of plant harvesting.

WET-SustainableUse has been developed and applied across a diverse range of biomes. The prototype system (Kotze, 2007) drew extensively from research on wetlands in the Grassland and Savanna biomes (e.g. Kotze, 1999; Kotze and O'Connor, 2000; Pollard *et al.,* 2004; Walters *et al.,* 2006), and the wetland sites to which the prototype was applied were from the Fynbos, Succulent Karoo, and Savanna biomes. These represent a very wide range of the conditions potentially encountered across South Africa.

The application of WET-SustainableUse to the various case study wetlands was extremely useful in highlighting specific elements that required attention, which led to several revisions and additions to the system, as the following three examples illustrate.

- The plant harvesting model, which in the first draft accounted only for grasses, sedges and rushes, was revised to account for the specific requirements of restios (slower recovery and accumulation of new material following harvesting). This was based on the Agulhas Plain case study and a review of the relevant literature (Appendix 9).

- The first draft did not provide explicit guidelines for discussing cultivation practices with farmers. Thus, a set of leading questions to guide such discussions was developed and added to the revised draft (Box 5).
- The first draft did not provide any guidance for describing the specific link between impacts on environmental health and livelihoods. Ellery *et al.* (2009) was also of limited help in this regard. Therefore, specific guidance has now been provided to help the user establish this link (Section 11).

In addition, comment was solicited from practitioners and experts, which contributed further to highlighting areas that need to be refined. For example, some found the initial version of the Level 1 assessment difficult to "navigate", and it was therefore re-structured completely.

Pollard *et al.* (2009) provide sustainability indicators for communal wetlands and their catchments, which were developed following the first draft of WET-SustainableUse. The indicators of Pollard *et al.* (2009) arise out of a range of action research projects undertaken by AWARD in the Craigieburn area, aimed at supporting and enhancing the sustainability of wetland use by the local community. A central question that arises from this work is 'what indicators, meaningful to the users themselves, can be used to assess the situation, to track change and to evaluate impacts?' As indicated in Section 2, WET-SustainableUse focuses strongly on the *ecological* sustainability of land-use practices taking place *within* the wetland, while the system of Pollard *et al.* (2009) is much broader in the range of elements for which it provides indicators, including indicators for the wetland's upstream catchment, the governance system, and the livelihood contribution of the wetland. There is also a greater emphasis on indicators that farmers can use themselves.

APPENDIX 3: THE APPROACH USED IN WET-HEALTH AND WET-SUSTAINABLE USE FOR SCORING IMPACTS ON WETLAND ENVIRONMENTAL CONDITION

Across all of the components of environmental condition being examined (e.g. hydrology or geomorphology) the overall approach used in WET-Health and WET-SustainableUse is to score the impacts of human activity, or clearly visible impacts on wetland health, using a standardized approach. This takes the form of assessing the spatial *extent* of impact of individual activities and then separately assessing the *intensity* of impact of each activity in the affected area. The extent and intensity are then combined to determine an overall *magnitude* of impact. Extent, intensity and magnitude of impact are defined as follows.

Extent – The proportion of the wetland and/or its catchment affected by a given activity (expressed as a percentage).

Intensity – The degree to which wetland characteristics have been altered within the affected area. Throughout the module, intensity of impact is measured on a scale of 0-10, with a score of 0 representing no impact or deviation from natural, and a score of 10 representing complete transformation from the natural state (Table C1).

Magnitude – The overall impact of a particular activity or suite of activities on the component of wetland health being evaluated. This is determined by calculating an area-weighted impact score such that the intensity of impact is scaled by its extent. The magnitude of impact is expressed on a scale of 0-10 by multiplying intensity by extent of impact as follows:

Magnitude = (Extent / 100) x Intensity

For example: If a given activity was affecting 25% of the wetland and its intensity was 4 (on a scale of 0-10) then the magnitude of the impact would be (25/100) x 4 = 1.0. However, if the same activity (intensity of 4) was affecting 75% of the wetland, then the magnitude of impact would be (75/100) x 4 = 3.0.

Table A3.1: Guideline for assessing the magnitude of impact on wetland environmental condition

IMPACT CATEGORY	DESCRIPTION	IMPACT SCORE RANGE
None	No discernible modification or the modification is such that it has no impact on wetland environmental condition.	0-0.9
Small	Although identifiable, the impact of this modification on wetland environmental condition is small.	1-1.9
Moderate	The impact of this modification on wetland environmental condition is clearly identifiable, but limited.	2-3.9
Large	The modification has a clearly detrimental impact on wetland environmental condition. Wetland environmental condition has declined by approximately 50%.	4-5.9
Serious	The modification has a clearly adverse effect on this component of wetland environmental condition. Wetland environmental condition has declined by well over 50%.	6-7.9
Critical	The modification is present to such an extent that the ecosystem processes of this component of wetland health have been totally / almost totally destroyed.	8-10

APPENDIX 4: WET-EFFECTIVE MANAGE, A FRAMEWORK FOR RAPIDLY ASSESSING THE EFFECTIVENESS OF MANAGEMENT OF INDIVIDUAL WETLANDS

A wetland may currently be used in a sustainable manner, with minimal negative environmental impacts, but this does not provide assurance that this situation will be maintained in the future. However, if an effective management system is in place to plan, monitor and control utilization, future sustainable use is more likely.

In recognizing the need for a generic approach to assessing management effectiveness, the World Commission on Protected Areas (WCPA) developed an evaluation framework (Hockings *et al.,* 2000). Assessing management effectiveness requires the inclusion of a number of components, which are applied in the following sequence (Hockings *et al.,* 2000; 2001):

1. a component to check that management is being placed in its broader policy/legislative context;
2. a component to ensure that a baseline description of the system (e.g. an individual wetland) has been undertaken and that the key issues relevant to management have been identified;
3. a component for setting management objectives;
4. a component for developing and implementing an action plan for achieving the objectives;
5. a component to ensure that the meaningful participation in management by local communities and other stakeholders is achieved, and finally,
6. a component for monitoring and evaluating all of the above (i.e. both outputs and outcomes).

Based on the recommendations given in Hockings *et al.* (2001) a scoring system, referred to as WET-EffectiveManage, was developed for rapidly assessing the effectiveness of management. WET-EffectiveManage is simply a structured questionnaire with 15 questions, each including an explanation of the question and its underlying assumptions (Table A4.1). It aims to be as transparent as possible and to emphasize that the researcher is open to dialogue and reflection – thus inviting participation from respondents. An important aspect of the questionnaire is that it is not designed simply to extract information from participants, but also to promote learning by both the researcher and the respondents as they work through the questionnaire together.

For each question, the respondent assigns a score of 0, 1, 2 or 3 based on which of the criteria descriptions best fits the situation at the site being assessed. In addition, for each question, the respondent is invited to provide additional comments.

It must be emphasized that WET-EffectiveManage deals with management effectiveness at a shallow level. While it is considered useful in providing a rapid assessment (including highlighting certain elements of management that require improvement), in situations where resources are very limited, it does not provide a detailed analysis.

Table A4.1: WET-EffectiveManage: a set of indicators and criteria for scoring management-effectiveness

Indicators	Criteria	Score
1. Protection status (*Context)* What is the wetland's protection status?	The wetland has no protection status.	0
	The wetland has limited protection status but it is not legally binding (e.g. Natural Heritage Site), or in the case of multiple ownership only a small portion of the wetland is protected.	1
	The wetland has partial protection status (e.g. protection is written into the site's deed of sale), or in the case of multiple ownership, only some of the wetland is protected.	2
	The entire wetland has been legally gazetted as a protected area.	3
2. Setting of management objectives (*Planning*) Have explicit management objectives been set that represent stakeholder interests?	No explicit management objectives have been set for the wetland.	0
	Some explicit management objectives have been set but they do not well represent the interests of stakeholders.	1
	Explicit management objectives have been set that represent the interests of stakeholders moderately well.	2
	Explicit management objectives have been set that represent the interests of stakeholders very well.	3
3. Management plan (*Planning*) Is there a management plan for achieving the objectives?	There is no management plan for the wetland.	0
	A management plan exists but it is very seldom used.	1
	A management plan exists and is occasionally used but is seldom, if ever, revised.	2
	A management plan exists and is being regularly used and periodically revised to incorporate new learning and altered circumstances.	3
4. Allocation of resources to the management of the wetland (*Inputs*) Is the current allocation of resources meeting the management needs of the wetland?	There are no resources allocated specifically for management of the wetland.	0
	The available resources are inadequate for management needs (as specified in the management plan, if present).	1
	The available resources are acceptable, but could be further improved to fully achieve effective management.	2
	The available resources meet the full management needs of the wetland.	3
5. Capacity for management of the wetland (*Inputs/capacity*) Is the human capacity meeting the needs for management of the wetland?	The capacity for managing the wetland is very low.	0
	There is some capacity present but it is inadequate for basic management needs.	1
	The capacity is reasonable but could be further improved to fully achieve effective management.	2
	The capacity meets the full management needs of the wetland.	3
6. Commitment from the managers (*Process*)	There is little or no commitment to meeting the management needs of the wetland.	0

Is there a commitment to the management of the wetland?	Some commitment demonstrated, but this is limited or fluctuates.	1
	A high level of commitment demonstrated most of the time.	2
	A high level of commitment demonstrated even under difficult circumstances.	3
7. Breadth of stakeholder involvement (*<u>Process</u>*) Is there involvement with key stakeholders, particularly those from local communities?	There is no contact between managers and other stakeholders.	0
	There is involvement with one or a few of the stakeholders but several stakeholders are not involved.	1
	There is involvement with most of the stakeholders except for a few key stakeholders.	2
	There is involvement with the majority of stakeholders and good account is taken of stakeholder issues.	3
8. Co-operation amongst the parties involved (*<u>Process</u>*) What is the level of co-operation between the different parties contributing to the management of the wetland?	Different parties work independently and are poorly informed of each other's work.	0
	Different parties are reasonably well informed of each other's work but co-operation is limited.	1
	The different parties are well informed of each other's work and seek opportunities for co-operation.	2
	The different parties are well informed of each other's work and achieve effective collaboration.	3
9. Addressing pressures & threats (*<u>Process</u>*) Is the wetland managed for the threats and pressures it faces?	The pressures and threats facing the wetland are unknown.	0
	The pressures and threats facing the wetland are known but are not being addressed.	1
	The pressures and threats facing the wetland are being addressed but insufficiently to meet the management objectives of the wetland.	2
	The pressures and threats facing the wetland are being well addressed, so as to meet the management needs of the wetland.	3
10. Mechanisms for controlling inappropriate activities (*<u>Process</u>*)	There are no mechanisms for controlling inappropriate land-use and activities in the wetland.	0
	Mechanisms for controlling inappropriate land-use and activities in the wetland exist but there are major problems in implementing them effectively.	1
	Mechanisms for controlling inappropriate land-use and activities in the wetland exist but there are some problems in implementing them effectively.	2
	Mechanisms for controlling inappropriate land-use and activities in the wetland exist and are being effectively implemented.	3
11. Benefits to local people (*<u>Outcomes</u>*)	The existence of the wetland has reduced the options for economic development for the local communities.	0
	The existence of the wetland has neither damaged nor benefited the local economy.	1

Is the wetland providing economic benefits to local communities?	There is some flow of economic benefits to local communities from the existence of the wetland but this is of minor significance to the regional economy.	2
	There is a significant or major flow of economic benefits to local communities from activities in and around the wetland (e.g. employment of locals, locally operated commercial tours etc.).	3
12. Achievement of management objectives (*Outcomes*) How well are the management objectives being achieved?	Poorly	0
	Somewhat poorly	1
	Fairly well	2
	Very well	3
13. State of health of the wetland (*Outcomes*) What is the state of health of the wetland?	Poor	0
	Fair	1
	Good	2
	Very good (natural)	3
14. Monitoring (*Planning/Process*) Is effective monitoring of management and its outcomes taking place?	There is no monitoring of the wetland.	0
	There is some *ad hoc* monitoring, but no overall strategy and/or no regular collection of results.	1
	There is a well-planned and implemented monitoring system but the results are not used systematically for management.	2
	There is a well-planned and implemented monitoring system and the results are used systematically for evaluation of management.	3
15. Evaluation and learning (*Process*) Are managers reflecting on how effectively management objectives are being achieved?	Managers very seldom reflect on how effectively the management objectives are being achieved.	0
	Managers occasionally reflect on how effectively the management objectives are being achieved.	1
	Managers regularly reflect on how effectively the management objectives are being achieved, and are moderately effective in identifying areas for improvement.	2
	Managers regularly reflect on how effectively the management objectives are being achieved, and are very effective in identifying areas for improvement.	3

Table A4.1 continued

Assumptions and further explanations for each of the 15 questions
1. Protection status: A wetland with a protected status would reduce the likelihood of inappropriate activities within the wetland, thereby contributing to effectiveness of its management. Protection is not confined to documented agreements but also includes local protection measures (e.g. those enacted through traditional authorities). Even if this protection is not legally binding, it helps give status to the wetland and increase interest in maintaining the wetland in as good a state as possible. It is also recognized that a high protection status is by no means a guarantee that the state of health of the wetland will be maintained, particularly when harmful off-site activities take place (e.g. water abstraction upstream of the wetland).
2. Setting of management objectives: Clear and agreed-upon management objectives that reflect stakeholder interests provide a critical point of reference against which management can be assessed to determine its effectiveness. It is recognized, however, that setting management objectives provides no guarantee that the actions required to meet the objectives will be identified and implemented.
3. A management plan: While management objectives are very useful (see indicator 2) they do not provide explicit management actions. A management plan therefore provides a valuable means of assisting in translating the objectives into practical management actions. It is further assumed that a management plan that is regularly used and periodically updated to account for new understanding will make a greater contribution to management than a static management plan that is seldom referred to. It is nonetheless recognized that effective management systems may be in place (e.g. traditional floodplain grazing systems that are responsive to seasonal and inter-annual variation in the hydrological state of the floodplain) without a formally documented plan. These are equally valid, although more difficult for an outsider to evaluate.
4. Allocation of resources for management of the wetland: If sufficient resources are allocated to carry out the actions specified in the management plan then this will increase the likelihood of effective management. It is, of course, recognized that many other factors also impinge on the effectiveness of management. If the plan itself is poor, an abundance of resources may be of little help.
5. Capacity for management of the wetland: The greater the available human capacity, the greater the likelihood of effective management. Again, it is recognized that many other factors (e.g. available resources, commitment, etc.) also have a bearing on the effectiveness of management.
6. Commitment from the managers: The greater the commitment from managers, the greater the likelihood of effective management. This recognizes that management is a human process, and if there is a high level of commitment then much can be achieved even with limited available resources. Nonetheless, commitment alone will not be enough in itself to ensure effective management.
7. Breadth of stakeholder involvement: The greater the extent to which stakeholders are involved in the management of the wetland, the broader will be the base of support for the management and health of the wetland. If the wetland is being managed in the interests of one or a few stakeholders, and key stakeholders, particularly local communities, are excluded, then the future state of the health of the wetland could be under significant threat. It is recognized, however, that the quest for broad and extensive participation can shift the focus away from the management of the wetland itself.
8. Co-operation between the parties involved: The management of many wetlands requires the input of different organizations, and if their level of co-operation is high then the likelihood of effective management will be increased. It is recognized, however, that achieving collaboration (e.g. through establishing a special forum) may divert attention away from the management of the wetland itself.

9. Addressing pressures and threats: If pressures and threats are adequately accounted for then the likelihood of effective management is increased. This may be through the implementation of rehabilitation measures (e.g. blocking artificial drains and halting the advance of gully erosion into a wetland) or through better control of land-use activities. Addressing threats (potential future pressures) implies that the wetland will be more likely to remain in a healthy state for at least some time into the future. It is recognized, however, that this assumption may not hold where there are pressures and threats which are present but have been overlooked. Pressures refer to human impacts currently impacting negatively on the health status of an ecosystem, while threats refer to such impacts potentially occurring in the future.
10. Mechanisms for controlling inappropriate activities: An increase in the extent to which inappropriate land-uses are controlled would increase the likelihood of effective management. It is recognized, however, that this assumes that the harmful activities are known.
11. Benefits to local people: If the wetland is a liability from the perspective of local communities then its future state of health is likely to be far less assured than if the wetland was contributing significant and positive economic benefits to local communities (i.e. conservation through beneficiation). Local communities are particularly important because they are most directly positioned to influence the state of health of the wetland, either positively or negatively, and they must, therefore, be considered. It is recognized, however, that in promoting particular benefits for local communities (e.g. access to certain natural resources) the state of health of the wetland may be compromised to some extent.
12. Achievement of management objectives: It is assumed that if the management objectives are being achieved then management is effective. It is recognized that this depends on the extent to which the management objectives address factors impacting negatively on the wetland. If key factors are not addressed in the management objectives then achievement of the objectives would be no guarantee that management is effective.
13: State of health of the wetland: Improving or maintaining the state of health of the wetland is the objective of management. If the wetland is being managed towards a natural state, then this will be the ultimate test of management effectiveness. It is, however, recognized that a wetland may be in a good state of health not because of any specific way in which it is managed but largely because it "falls outside the path of any developments". It is important to also emphasize that management of a wetland may be towards a transformed rather than natural state. In such cases, it would be possible for management to be effective (e.g. as reflected in achieving the objective of controlling erosion) but for the wetland to be in a poor state of health.
14. Monitoring: If monitoring is carried out and used in the context of adaptive management then this serves the critical function of directing management in such a way as to keep it aligned to its objectives and, if required, to also adjust objectives. This in turn will promote effective management. It is assumed that monitoring is generally most effective when the results, interpretations and adjustments are documented. It is nonetheless recognized that the process of monitoring may be undertaken in an effective manner but without formal documentation (e.g. by a farmer who closely observes the response of his/her wetland's vegetation structure to livestock grazing). Such a non-documented process is, however, much more difficult to evaluate "from the outside" but should at least be carried out using some form of structured process.
15. Evaluation and learning: Wetlands and the factors which affect wetland health generally change over time, as does understanding of a particular wetland and its response to these factors. Thus, management that involves reflecting on the effects of management actions in relation to the management objectives, and which is open to a changing situation, is more likely to be effective than management that is closed and fixed.

APPENDIX 5: ASSESSING THE VULNERABILITY OF A WETLAND TO EROSION (FROM WET-HEALTH: MACFARLANE *ET AL.,* 2008)

One of the key factors affecting the sustainable use of a wetland is erosion. The extent of erosion, and the rate of head-cut erosion, is dependent upon many factors (such as soil type, vegetation cover and type, rainfall events etc.) but one of the most critical and overriding factors is slope. For any given discharge, the steeper the slope the more likely a head-cut will erode. It is this relationship between longitudinal slope and discharge of a wetland that is used here to assess vulnerability to erosion. For the purposes of this assessment wetland area is used as a proxy for discharge. Therefore, for a given discharge, which is approximated in Fig. A5.1 by wetland size, an estimate of wetland vulnerability is obtained, based on longitudinal slope.

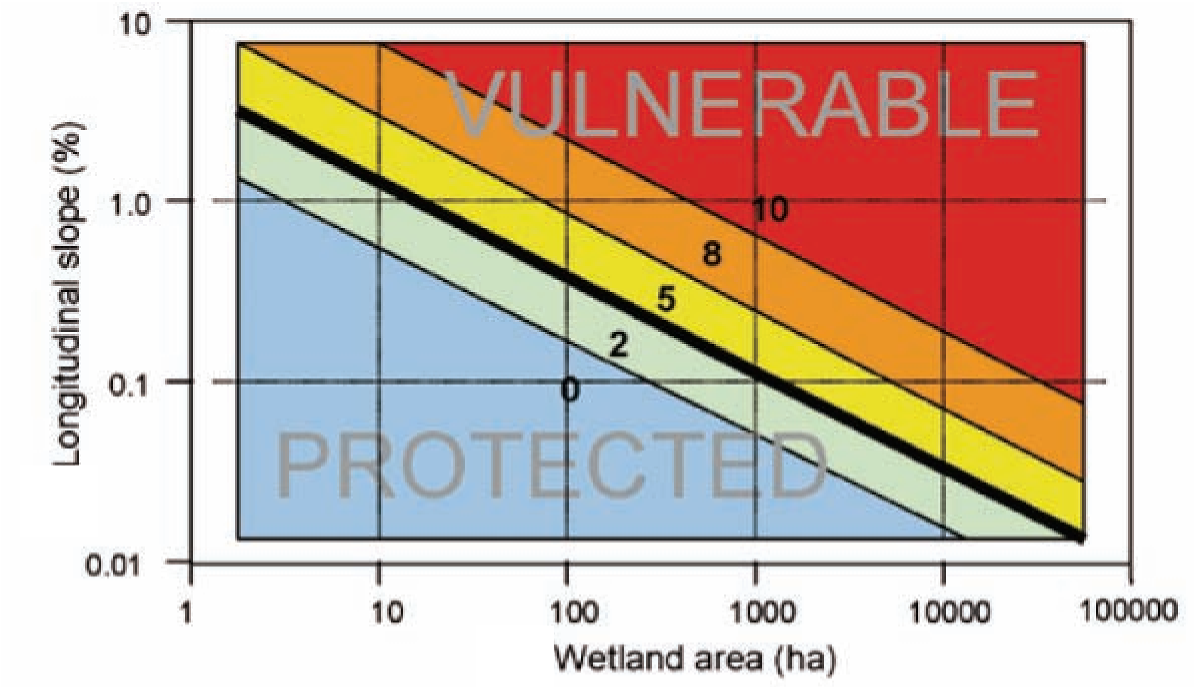


Figure A5.1: Vulnerability of HGM units to erosion based on wetland size (a simple surrogate for mean annual runoff) and wetland longitudinal slope. Note the logarithmic scale of the axes.

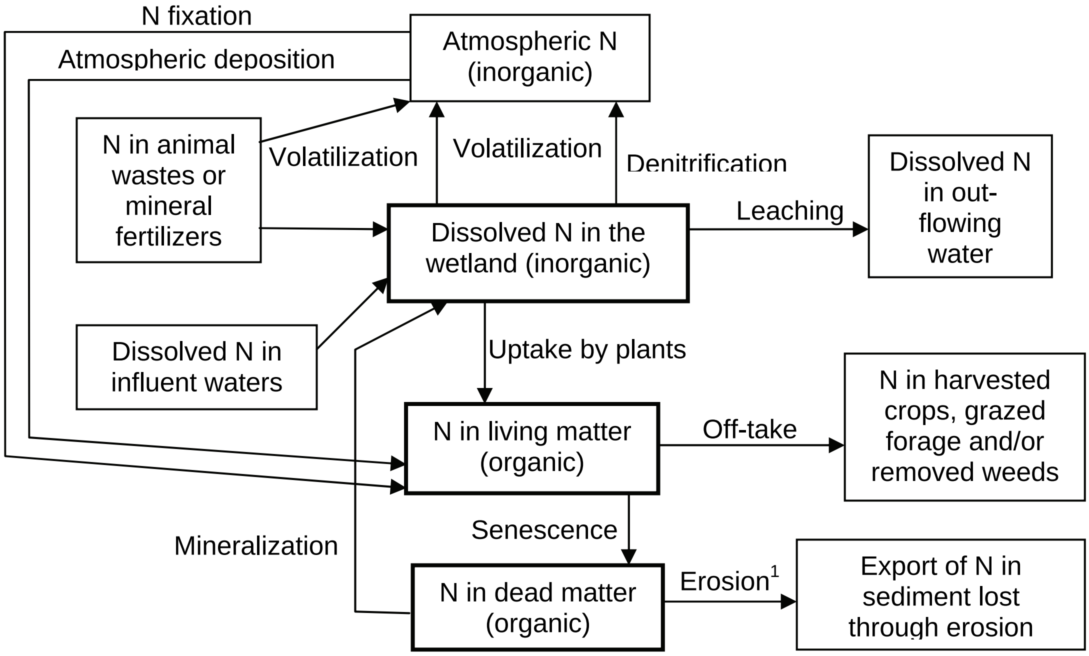
In interpreting the figure one should be aware that both area and slope are plotted logarithmically. In other words, for each interval on the x- and y-axes the values increase by a factor of 10. Therefore, points between the plotted intervals need to be plotted on the same scale. Thus, if the area is 20 ha and slope is 0.5%, the location of the area measurement is roughly midway between the 10 ha and 100 ha marks on the x-axis, and the slope measurement is about ¾ of the way between the 0.1% and 1% marks on the y axis. Users also need to be aware that the relationship plotted in Fig. A5.1 is based on ongoing research into the relationship between discharge (area) and slope in various HGM types. A score of zero suggests that no change is likely, a score of two or five indicates that change may proceed slowly and dissipate a relatively short distance upstream, while a score of eight or ten suggests that head-cut advance will be rapid and lead to substantial deterioration.

APPENDIX 6: AN OVERVIEW OF THE RETENTION OF NITROGEN AND PHOSPHORUS IN CULTIVATED WETLANDS

The retention and internal cycling of N and P in a cultivated wetland, and the manner in which these two elements enter and are lost from a wetland, shows some important contrasts (Figures A6.1 and A6.2). In the case of P, loss and gain of this element is closely linked to erosion/deposition of mineral particles, to which P tends to be adsorbed, and atmospheric inputs and losses are very limited. Phosphorous is not biologically fixed from the air, and the main sources of P inputs are organic material, either recycled within the field or collected from a larger area (e.g. the upstream catchment), and commercial mineral fertilizers. Soil P is made available to plants through the weathering of soil minerals, but this is generally a very slow process (Buresh and Giller, 1998).

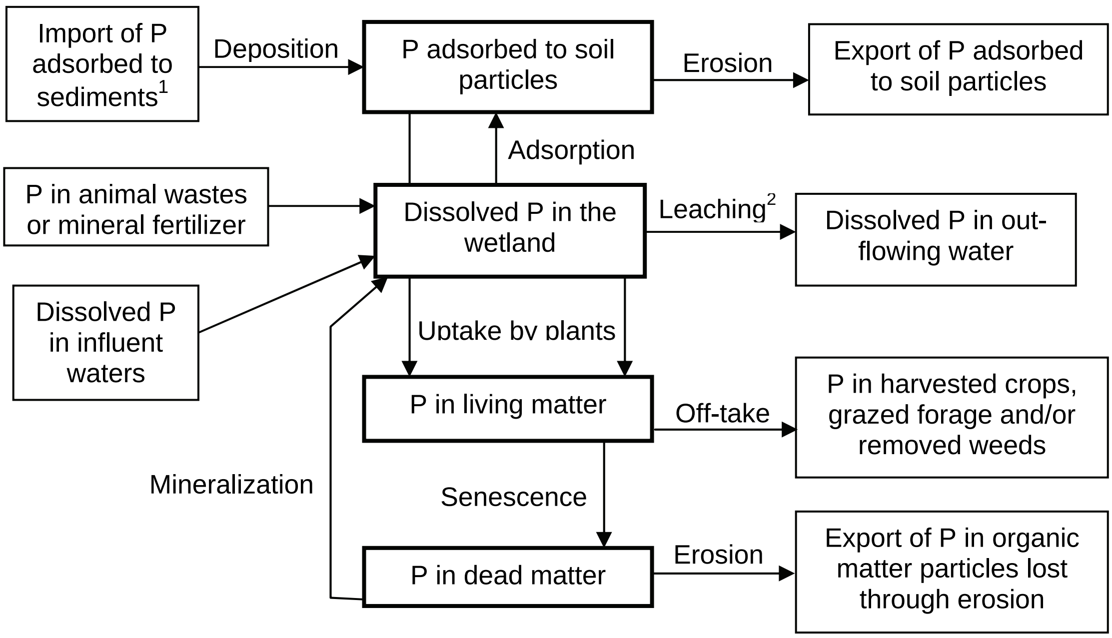
In croplands generally, the main sources of N inputs are biological N_2 fixation, organic material either recycled within the field or concentrated from a larger area (e.g. by applying manure from animals that have grazed over a larger area), and commercial mineral fertilizers. Inorganic N is much more mobile than inorganic P, and unless it is taken up by plants it is easily leached from the system or lost to the atmosphere through ammonia volatilization and denitrification, as explained later in this appendix.

The manner in which stocks of these two elements in the soil can be replenished following depletion differs for N and P. Soil P stocks can be built up rapidly with a large, one-time application of P fertilizer, but N stocks can be replenished only gradually through increases in SOM (Buresh and Giller, 1998). Thus, the key to building up soil N stocks is increasing the SOM content. As highlighted in Section 8.5, this depends on several interacting factors. The P content of plant residues and manures is normally insufficient to meet the requirements for sustained crop production. These organic resources tend to be better sources of other nutrients such as N, potassium (K), sulphur (S) and calcium (Ca; Buresh and Giller, 1998).



[1] Relative to leaching, this loss is generally low, unless erosion is severe.

Figure A6.1: Factors affecting the retention of N in a cultivated wetland (boxes with bold outline represent stocks within the wetland itself).



[1] This is predominantly through transport by water, but also includes dust transported in the atmosphere (Jacobs *et al.,* 2007).
[2] This is generally minimal, unless P levels in the influent waters are very high.

Figure A6.2: Factors affecting the retention of P in a cultivated wetland

A wealth of literature exists concerning nutrient cycling in wetland-based rice growing systems, which account for 50% of global rice supplies (e.g. Mengel *et al.,* 1986; Kirk *et al.,* 1998; Shibu *et al.,* 2006). This literature provides useful insights regarding nutrient cycling in cultivated wetlands. In wetland rice systems, under flooded conditions, the majority of N is in the form of ammonium (NH_4^+) because of the anaerobic conditions in the soil (Mengel *et al.,* 1986; Shibu *et al.,* 2006). The major mode of N loss in flooded rice soils is through volatilization of ammonia (Shibu *et al.,* 2006). Substantial N losses can also occur when nitrate accumulated during the fallow, dry period is lost through denitrification or leaching upon re-flooding of the field for the next rice crop (George *et al.,* 1993; Witt *et al.,* 1998; Shibu *et al.,* 2006). Grant (1994) reports N losses of up to 75% in Zimbabwe wetlands, due to denitrification, when soil fertilized with ammonium nitrate is saturated immediately after fertilization. However, the application of the nitrification inhibitor methyl fluoride (at a concentration of 1%) caused the N_2 emission to decrease by nearly 80%, indicating that nitrification of urea-N to nitrate or nitrite was necessary for denitrification. Aerenchymous rice plants are important for the transport of gaseous oxygen and nitrogen into and out of the rhizosphere. The rhizosphere is the major site of coupled nitrification-denitrification in planted rice (Shibu *et al.,* 2006).

Research into improving N management of irrigated rice has received considerable investment, because yield levels presently achieved by Asian farmers depend on large inputs of N fertilizer. Most work has focused on placement, form, and timing of applied N to reduce losses from volatilization and denitrification (Cassman *et al.,* 1998). However, Cassman *et al.* (1998) highlight that more attention should be given to development of methods to adjust N application rates in relation to the amount of N supplied by indigenous soil resources. Sahrawat (2004), for example, highlights the fact that even in fertilized rice paddies, 50-75% of the N in the rice crop is derived from mineralized organic matter in the soil. As a result of ignoring these sources of N, fertilizer recommendations are typically made with the implicit assumption that soil N supply is relatively uniform. Recent studies, however, document tremendous variation in soil N supply among lowland rice fields with similar soil types or in the same field over time. Despite these differences, rice farmers do not adjust applied N rates to account for the wide range in soil N supply, and the resulting imbalance contributes to low N use efficiency. Cassman *et al.* (1998) argue that increased N use efficiency would depend on field-specific N management tactics that are responsive to soil N supply and plant N status. Nitrogen fertilizer losses are thus considered a symptom of incongruence between N supply and crop demand.

As already mentioned, P is much less mobile than N in both the aerobic and anaerobic states, and therefore much less vulnerable to leaching. However, in alternating dry, aerobic and wet, anaerobic conditions, there is a narrow transitional period where P is more mobilized (because of a reduction of Fe (III) compounds) that liberate sorbed and co-precipitated P to increase the P concentration in soil solution (Dobermann *et al.,* 1998; Kirk *et al.,* 1998). Thus, although soils differ greatly, there is a generally a flush of mobilized (easily extractable) soil P in the first few days following the development of anaerobic conditions. This P is potentially vulnerable to loss via leaching. However, much of this easily extractable P soon becomes immobilized again as it is sorbed on solid phases (e.g. Fe (II) hydroxides), which are mostly amorphous, with high surface areas and high P-sorption capacities (Kirk *et al.,* 1998). Overall, anaerobic soils generally sorb phosphate more strongly than comparable aerobic soils (Turner, 2006; Patrick and Khalid, 1974).

It is interesting to note that rice and other wetland plants adapted to prolonged anaerobic conditions are able to access this immobile P through rhizosphere acidification, which results in solubilization of P in the rhizosphere, allowing uptake by plants. Kirk *et al.* (1998) show that in most soils the concentration of P freely available to plants is negligible, and rice plants seem to depend on root-induced solubilization for the bulk of their P. Rhizosphere acidification occurs through several processes, including the oxidation of ferrous iron by O_2 (“leaked”) from the roots and the release of hydrogen (H^+) ions in order to balance the cation-anion intake, with N being taken up chiefly as NH_4^+. These processes result in the pH within a few millimetres of the roots being 0.5 to 2 units lower than in the bulk of the soil (Kirk *et al.,* 1998).

Nitrate losses to surface water from drained and cultivated wetlands are very strongly related to the cropping system (Randall and Goss, 2001). Row crops (e.g. maize, potatoes or soybean) yield much greater nitrate concentrations in the drainage water than do perennial crops (e.g. alfalfa or tall fescue) or unfertilized grass leys (Catt *et al.,* 1998). This is especially true for spring planted annuals which lack any catch crop (e.g. winter rye planted as a catch crop for maize). In some cases, nitrate losses can be 30 to 50 times higher from row crops than perennial crops, which exhibit an extended period of root activity during which nutrients are taken up (Catt *et al.,* 1998).

In annual crops there is a period when very little uptake of nutrients takes place, between the time when one crop is harvested or senesces and when the next crop is fully developed and taking up N. During this period, leaching of nitrates from residual fertilizer, and mineralization of organic matter (e.g. from crop residues and weeds), may be extensive. The period during which N uptake is interrupted can be reduced by planting a cover crop to alternate with the main crop, e.g., winter rye alternating with maize.

Nonetheless, there are still periods between the sequential crops when uptake of nutrients is interrupted.

In fields subject to alternating wet and dry periods, depending on the particular cropping management practices, the potential for N losses to denitrification are great. During the dry season, mineralization of crop residues results in the production of ammonia-N, which under aerobic conditions is converted to nitrate-N. If the dry season is characterized by a bare fallow then much of the nitrate will accumulate in the soil. On flooding of the field at the onset of the wet season, the potential for rapid denitrification of the accumulated nitrate-N is likely to be high, as is the potential for leaching of N at this time. From an N use efficiency perspective it would thus be better if the dry season was characterized by a weedy fallow or catch-crop fallow, which would take up most of the nitrate-N produced during the fallow period. Then, during the wet season growing period, as residues from the fallow crop / weeds decompose, N is made available to the wet season crop(s). Buresh *et al.* (1993) demonstrated the potential for reduction in nitrate-N loss if flooded rice was preceded by either a weedy fallow or *Sesbania rostrata* rather than a bare fallow. Wade *et al.* (1998) show that a weedy fallow is extremely N-conserving, as soil nitrate-N accumulation is minimal. If rain-fed lowland soils were properly managed, they could conserve up to 130 kg N/ha for plant uptake (Wade *et al.,* 1998).

The potential contribution to N_2 fixation by grain legumes is well recognized, but has also too frequently been uncritically overestimated (Giller *et al.,* 1998). Under favourable conditions, tropical grain legumes may fix large quantities of N. However, the amount/proportion of N that returns to the cropping system as a result of biological N_2 fixation varies greatly amongst different nitrogen fixing crops (Box A6.1). Livestock manure is an integral component of soil fertility management in many regions of sub-Saharan Africa (Giller *et al.,* 1998). The contribution of manure to soil fertility depends on the amount applied (and it may be in short supply for many farmers), and the nutrient content of the manure, which is affected by the quality of the animals' diet and the manner in which the manure is stored (Box A6.2).

A net loss of nutrient stocks (i.e. losses exceed inputs) will often not be immediately reflected in reduced levels of crop yield / plant growth, particularly in the case of less mobile nutrients such as P, which may have large stocks. The time required for this depletion to reach a threshold level and result in a pronounced yield reduction will depend on the size of the stock. If this stock is very large then the net loss could occur over many years, whereas if the stock is small, the threshold would be reached very soon (Buresh and Giller, 1998).

Box A6.1 N_2 fixing crops as a means of increasing N inputs

The higher the biomass yield and the lower the N harvest index (i.e. the proportion of nutrients that are removed with the crop), the higher will be the N returns to the overall cropping system (Mapfumo *et al.,* 1998). Pigeonpea has both a high biomass yield and a very low N harvest index. Fallen leaves have been reported to contribute 40 kg N/ha to the system (Whiteman *et al.,* 1985, cited by Mapfumo *et al.,* 1998). In contrast, intensively bred crops, such as soybeans, have a high N harvest index – they are very efficient in translocating most of the N to the grain, which, when removed, leaves little N for the field, even if all residues are retained (Giller *et al.,* 1998).

Nitrogen harvest indices (%) for some commonly cultivated grain legumes:

Cowpea	61%
Soyabean	75%
Groundnut	80%
Chickpea	73%
Pigeonpea (short duration of the growing period)	52%
Pigeonpea (long duration of the growing period)	21%

In addition to the legume crop type, growing conditions may also have a substantial effect on N fixation, and therefore the potential to contribute N to the field. A P deficiency, for example, may substantially restrict the N_2 fixing capacity of these plants. Legumes are generally responsive to P as they have a less dense root system than cereals and grasses (Giller and Cadisch, 1995). Because yields of grain legumes under smallholder conditions in Africa are often very low, the amounts of fixed N contributed to the field are also low (Giller *et al.,* 1998).

A further factor to remember is that the N contributed to the field by an N_2 fixing crop is made available primarily through the senescence of roots, N fixing nodules and leaves, which is a gradual process (i.e. the benefits are delayed). Thus, a companion crop growing with an N_2 fixing crop will receive little of the fixed N, but other crops planted in the subsequent season would benefit (Giller *et al.,* 1998).

Box A6.2 The nutrient content of manure

The nutrient content of manure differs according to the quality of the animals' diet and the manner in which the manure is stored. Phosphorus is most affected by the quality of the animals' diet, N is less affected, and K is the least affected by diet quality. In Zimbabwe, manure from communal farming areas was found to be a poor source of P compared with that from a feedlot (Nzuma *et al.,* 1998), as shown in the table below. For a given area, the nutrient content of the diet will also vary according to the season, which influences the quality of the manure (Giller *et al.,* 1998). Powell (1986, as cited by Giller *et al.,* 1998) found that dry season manure had an N content of 6g/kg dry matter compared with 19g/kg during the early rainy season, when the quality of the diet was higher.

Average nutrient contents (g/kg) on a dry matter basis of manures collected in Zimbabwe compared with selected plant materials (adapted from Palm *et al.,* 1998)

	N	P	K
High quality manure	23	11	6
Low quality manure	7	1	8
Maize stover	6	<1	7
Banana leaves	19	2	22
Sesbania sesban[1]	34	1.5	11

[1] A leguminous tree used to improve soil quality

Storage and handling practices of the manure has a significant effect on N losses, in particular. Exposure of the manure to the sun and wind greatly accelerates the rate of ammonia volatilization by raising the temperature of the manure and rendering it less anaerobic. Losses through leaching following rainfall may also be high (Giller *et al.,* 1998; Nzuma *et al.,* 1998; Murwira and Nzuma, 1999; Van Straaten, 1999).

Finally, it is important to remember that human disturbances associated with the cultivation are not the only the only disturbances affecting the cycling of nutrients in a wetland. Particularly in the case of semi-arid ecosystems, other disturbances such as herbivory, floods and droughts (which are natural but can obviously be affected by human activities) may have important influences. Much of the review by Jacobs *et al.* (2007) of nutrient vectors and riparian processing in semi-arid savanna ecosystems is relevant to wetlands in semi-arid savannas, given that the majority of wetlands are located within riparian areas.

APPENDIX 7: OBSERVATIONS FROM WETLAND SITES IN A GRAZING EXPERIMENT IN THE KRUGER NATIONAL PARK

A research programme termed *The Savanna Convergence Experiment* aims to determine if the effects of grazing and fire on aboveground net primary production and diversity converge or diverge across continents (Southern Africa and North America). The programme is being undertaken by Colorado State University, Yale University, Kansas State University, the University of New Mexico and the University of KwaZulu-Natal. On 9 April 2008 a long term grazing trial in the Kruger National Park which forms part of *The Savanna Convergence Experiment* was visited. The trial consists of a series of exclosure plots, and at the time of the visit, the trial had been running for two years. Four sites were examined which had areas of wetland within the site, identified by R. Fynn at the University of KwaZulu-Natal, who has been responsible for setting up and maintaining the trial.

For each of these four sites, the level of wetness of the wetland areas was described. As long term hydrological data were lacking for all of the sites, the degree of soil wetness was described by using the best surrogate measure possible, namely soil morphology. The key soil morphological features examined were chroma of the soil matrix, and intensity and depth of soil mottling described for a core sampled to a depth of 1.2 m using a Dutch screw auger. Once the soil morphology of a profile had been described, it was assigned to a wetness class based on comparison with the scheme given in Kotze *et al.* (1996).

A fairly narrow range of wetness was represented by the wetland areas at the four sites examined (Table A7.1). Nonetheless, within the represented range, different levels of wetness could be identified.

Table A7.1: Level of wetness of the four sites examined

Increasing level of wetness	**Sites**	
Dryland/temporary wetland transition	Mananga	
Temporary wetland	Shibotwana	
Temporary/seasonal transition	Setara North	Tambling flats

Using a rapid visual estimate of the aerial cover and the percentage of bare soil, the situation in exclosure cages was compared with the adjacent area that was open to grazing. Percentage bare ground is inversely related to both % aerial cover and % litter cover, but it is not simply 100% – % aerial cover. Where litter cover is very high, the percentage bare ground may be low despite a low aerial cover.

Table A7.2: Percentage aerial cover and percentage bare soil visually estimated for each paired grazing exclosure and adjacent grazed area

Sites (& exclosures)	**Percentage aerial cover**			**Percentage bare ground**		
	Exclosure	**Outside**	**Difference**	**Exclosure**	**Outside**	**Difference**
Mananga (A)	70%	60%	10%	10%	20%	10%
Mananga (C)	75%	60%	15%	10%	25%	15%
Mananga (E)	70%	50%	20%	15%	35%	20%
Shibotwana (A)	80%	65%	15%	5%	30%	25%
Shibotwana (B)	80%	68%	12%	10%	25%	15%
Setara North	65%	30%	35%	20%	50%	30%
Setara North	60%*	45%	15%	10%	35%	25%
Tambling flats	60%	50%	10%	25%	40%	15%
Mean	70%	53%	17%	14%	34%	21%

* The aerial cover was diminished somewhat by extensive lodging of the vegetation

From Table A7.2 it can be seen that aerial cover was consistently lower and percentage bare ground consistently higher in the grazed portion compared with the un-grazed portion of each paired exclosure and adjacent grazed area comparison. It is important to add that these measurements were taken at the beginning of the dry season. At the end of the dry season the differences are likely to be even more dramatic given the fact that further grazing is likely to occur with little further vegetation growth. This highlights the tremendous effect that grazing by indigenous herbivores has on vegetation cover.

APPENDIX 8: IMPACTS OF HUMAN USE ON WETLAND DEPENDENT BIRDS

by PB Taylor

1. INTRODUCTION

The habitats of wetland birds are subject to considerable disturbance and modification as a result of human actions, but little is known about the effects of these practices on bird species diversity and populations. Wetland resources are widely exploited via management practices such as the harvesting, burning and grazing of wetland vegetation, while wetland plant communities are also affected by nutrient inflow and soil disturbance as a result of agricultural practices. Disturbance is an important component of many wetland ecosystems, and can affect ecosystem and community structure and functioning. The “intermediate disturbance hypothesis” (Connell, 1978), and accumulated empirical evidence, suggest that plant and animal species diversity should be highest at moderate levels of disturbance (Hobbs and Huenneke, 1992), and it is reasonable to suppose that this should also apply to wetland bird communities. However, very few relevant studies have been carried out on wetland birds, with most work being carried out in Europe and very little in Africa. No investigations have been conducted on the extent to which the results of studies in Europe can be applied to wetlands birds in Africa, but it is probable that the findings of many such studies may be considered relevant to African wetlands, as many wetland bird species inhabit both regions, and the habitat requirements of wetland dependent birds are known to be similar in temperate and tropical regions.

2. THE EFFECT OF DISTURBANCE AND MANAGEMENT ON WETLAND PLANT COMMUNITIES

Plant species diversity is known to be affected by factors such as fire, grazing, soil disturbance and nutrient addition, while disturbance can also increase the possibility of natural communities becoming invaded by non-native plant species, which can cause serious problems by reducing or displacing native plants and animals, and even altering ecosystem function (Hobbs and Huenneke, 1992). In terms of plant communities, it is recommended that preserves should be large enough to allow the natural disturbance regime to operate and to support a mosaic of patches in different stages of disturbance, successional recovery and community maturation (Hobbs and Huenneke, 1992).

3. THE EFFECT OF DISTURBANCE AND MANAGEMENT ON WETLAND BIRD COMMUNITIES

The effects of habitat fragmentation

Habitat fragmentation is one of the most significant results of human activities in reedbeds and other emergent vegetation, and is likely to considerably affect the suitability of such wetland habitats for birds. It can be brought about in many ways, including cultivation (probably the most important), infrastructural development, over-harvesting, burning, heavy grazing, changes in water level and the creation or enlargement of open water areas for recreational purposes. The reed genus *Phragmites,* is a major component of wetland vegetation in Europe and Africa, and in many wetlands it is the dominant vegetation, occurring in extensive monospecific stands. In Germany, fragmentation of *Phragmites* habitats has been shown to affect the populations of insects, causing local extinctions that could affect the food supply of insectivorous reedbed bird species (Tscharntke, 1992). The same study also showed that fragmentation also affects the physical characteristics of the vegetation, in that small *Phragmites* stands had thinner shoots with more leaves than did large stands. In Africa, such habitat fragmentation, if accompanied by similar effects on insect populations, would certainly affect the suitability of the vegetation as foraging habitat for insectivorous reed-frequenting birds such as *Acrocephalus, Bradypterus* and *Cisticola* warblers, and might also affect the suitability of such habitats for breeding. The preferred breeding habitats of such birds are known to differ in terms of vegetation structure and plant species composition in that, for example, the Lesser Swamp Warbler *Acrocephalus gracilirostris* nests in more robust vegetation with larger stems, and is the only species normally found in tall, robust stands of pure *Phragmites*, while species like the African Reed Warbler *Acrocephalus baeticatus*, the Little Rush Warbler *Bradypterus baboecala* and Levaillant's Cisticola *Cisticola tinniens* nest in shorter vegetation that has thinner stems, including sedges, grasses and forbs that may grow within fragmented or otherwise disturbed areas of *Phragmites* (pers. obs.).

Another European study (Schiess, 1989) showed that fragmentation of *Phragmites* reedbeds also had a direct effect on breeding birds, including *Acrocephalus* and other warblers, rails (family Rallidae), the Grey Heron *Ardea cinerea* and the Little Bittern *Ixobrychus minutus*. The study concluded that the conservation of almost all species in the reedbed bird community requires reed stands of at least 2 ha, showing that small European *Acrocephalus* warblers, when breeding, need habitat stands of 1600 m^2 to 9000 m^2, while the larger Great Reed Warbler *A. arundinaceus* inhabits the edges of reedbeds larger than 2.1 ha.

Little is known about the minimum habitat areas required for nesting wetland birds in Africa, and consulting the most recent and comprehensive publications on African birds, such as Hockey *et al.* (2005), only serves to emphasise our lack of knowledge. However, unpublished observations by PB Taylor do give some indication of the patch sizes required by palustrine wetland birds in Southern and Central Africa. Among warblers, the Little Rush Warbler, which inhabits sedges, rushes and reeds and is a loosely colonial nester, can live and breed in reedbed patches of <500 m^2 in extent, as can Levaillant's Cisticola, which inhabits reedbeds and adjacent moist grass. The African Reed Warbler, which occurs in all reedbeds and adjacent forbs, has smaller breeding territories (335 ± 36 m^2), while the larger Lesser Swamp Warbler, which lives mainly in *Phragmites* and *Typha* beds in standing water, probably needs reedbeds larger than 500 m^2 in extent for permanent residence.

Among nonpasserine birds, the Purple Heron *Ardea purpurea* inhabits reedbeds, mainly of *Phragmites* and *Typha*, in which it is a solitary or loosely colonial breeder. In Africa, it usually requires extensive reedbeds, probably in excess of 5000 m^2, for permanent residence (pers. obs.). The Little Bittern occurs in similar habitats, and in southern Africa is found in reedbeds of <1000 m^2 (pers. obs.). The Eurasian Bittern *Botaurus stellaris*, which may be a monogamous or polygynous breeder, needs extensive reedbeds in large wetlands, in Europe occurring at a density of one breeding male per 2-50 ha, while the endangered African race may occur in wetlands of 5-20 ha (Taylor, 2000). In Italy, Puglisi *et al.* (2005) showed that the Eurasian Bittern is affected by marsh utilization, particularly burning and the enlargement of pools for hunting, and that Bitterns preferred unfragmented vegetation 1-3yrs old. Although no similar information is available for Eurasian Bitterns in Africa, observations indicate that this species is intolerant of disturbance and is often found in extensive continuous reedbeds that are free of large quantities of dead vegetation by being partly burned every few years (pers. obs.).

Cranes also require large wetlands: in Southern Africa, a pair of Wattled Cranes *Bugeranus carunculatus* (a species very sensitive to disturbance) needs a wetland of 18-40 ha for breeding and foraging, while the Grey Crowned Crane *Balearica regulorum* nests at a density of up to 13 pairs in marshes >100 ha, with nests 20-50 m apart (Hockey *et al.,* 2005).

The requirements of rails that inhabit palustrine wetlands in Africa are more precisely known. Of the species whose habitat preferences include reedbeds and also seasonally flooded marsh vegetation (sedges, grasses, forbs etc), the Red-chested Flufftail

Sarothrura rufa nests at a density of 2-6 pairs/ha in extensive habitat and may occupy habitat patches of <0.5 ha, holding permanent territories of 1200-4500 m^2 (Taylor, 1994), while the African Rail *Rallus caerulescens* has territories 1.25-3.5 ha in extent (Taylor and Van Perlo, 1998). The territories of Black Crakes *Amaurornis flavirostris* have been measured at 0.18-0.31 ha in KwaZulu-Natal, South Africa (Taylor and Van Perlo, 1998), while densities of one pair/2.2-7.5 ha are recorded elsewhere in South Africa (Hockey *et al.,* 2005). Baillon's Crake *Porzana pusilla* probably occupies breeding territories of <0.2 ha in KwaZulu-Natal (pers. obs.). The African Purple Swamphen *Porphyrio madagascariensis* normally occurs in tall reedbeds of *Typha, Phragmites* and *Cyperus*, sometimes at densities as low as one pair/2.5 ha (Taylor, 1997a), but occupied habitat patches may also be smaller than one hectare (pers. obs.).

Fragmentation also increases the proportion of reedbed edge relative to overall reedbed area, and can affect the birds using reedbed habitats. In Europe, Báldi (2005) found that short term temporal changes in the "edge effect" in Hungarian *Phragmites* reedbeds, brought about by water level changes, significantly affected the distribution and abundance of three warbler and one bunting species, some declining and others increasing with changes in the homogeneity of the reedbed.

The effects of grazing

Grazing by domestic stock can affect the biomass of wetland vegetation, the structure and composition of the plant community, and the nature of the substrate. In Europe, wetlands are relatively unstable and fragile, being influenced by cutting and grazing, and management is needed to prevent succession to drier habitats or homogeneous reedbeds (Gordon *et al.,* 1990). Grazing by domestic livestock is a useful tool for maintaining early plant successional stages, while biological richness is increased by the coexistence of a range of successional stages, and carefully managed grazing has beneficial effects (Gordon *et al.,* 1990).

In Europe, grazing marshes are important habitats for ground-nesting marsh birds such as waders and waterfowl, and studies in England indicate that the suitability of such marshes for breeding waders increased concomitantly with the complexity of the grass sward and surface topography (Milsom *et al.,* 2000), which are positively affected by limited grazing and trampling. This situation has a parallel in African wetlands, where the African Snipe *Gallinago nigripennis* lives and breeds in short wet vegetation and muddy areas. This species finds increased muddy foraging habitat in areas moderately grazed and trampled by domestic stock, and may nest at densities of over 2 pairs/ha in such areas (pers. obs.).

Ausden *et al.* (2005) investigated the effects of cattle grazing on tall-herb fen vegetation in England and found that grazing reduced the biomass of *Phragmites australis* and increased stem densities of the grass *Glyceria maxima*, resulting in a shift of dominance from *Phragmites* to *Glyceria*, while plant species richness was also significantly higher in areas open to grazing. Such effects can have an influence on bird populations, communities and species diversity by making the wetland less suitable for reed-dwelling species and more attractive to grass-frequenting species. An increase in plant species diversity could improve the diversity of plant and insect food for birds, and might make available more foraging niches for such species.

The effects of harvesting and burning

Harvesting of reedbed vegetation is a common practice in Europe and Africa, and reedbeds and marsh vegetation are also often burnt, principally to encourage new growth for grazing or harvesting. Management of reedbeds is often effected by selective burning or cutting, and a study in England (Cowie *et al.,* 1992) determined the effects of managing *Phragmites* reedbeds in this way. It found that most plant species were more abundant in managed reedbeds than in unmanaged ones, while several were more common in burnt than cut plots. Managed reeds were shorter and denser, with burnt plots having the highest proportion of flowering stems. An investigation of the rate of decomposition of reed leaf litter showed no difference in weight loss or associated soil invertebrates between cutting and burning treatments. Thus, managed cutting and burning positively affected floristic diversity, and this could also have a positive effect on the diversity of bird species occupying managed reedbeds, as a result of more foraging and breeding niches becoming available to the birds, although the study did not address this issue.

In France, harvesting of *Phragmites* reedbeds has been shown to significantly affect breeding colony location and size in the Purple Heron, European breeding populations of which winter primarily in the Sahel region. Barbraud *et al.* (2002) found that most harvesting takes place in winter, and that the herons did not return to completely harvested reedbeds the next spring, occupying only areas that were unharvested or partially harvested. They also found that occupied reedbeds had higher water levels than unoccupied reedbeds, and that water level was the most important variable for the selection of breeding sites on the birds' arrival in spring, apparently because of the increased risk of nest predation in less deeply flooded reedbeds (water level did not affect the choice of reedbeds to be harvested in winter). Their modelling indicated significant effects of harvesting intensity and reedbed surface area on colony size: there was a strong tendency for colony size to increase with increasing reedbed surface area, and the authors concluded that Purple Heron conservation is likely to be favoured by maintaining the largest possible uncut reedbeds.

In another French study of *Phragmites* reedbeds, the effects of harvesting and associated water level management and salinity on passerine bird communities were investigated by Poulin *et al.* (2002). It was found that water level management affected the availability of arthropod food, which was higher in wetter areas, and also affected vegetation parameters such as reed diameter, the density of dry reeds, growing reed height, etc. The largest warbler species, the Great Reed Warbler (which is a nonbreeding visitor / seasonal migrant to southern Africa) preferred reeds with thick stems, while the smaller Eurasian Reed Warbler *A. scirpaceus* (also a migrant to central and southern Africa) preferred monospecific reedbeds with tall growth – which were usually those that had been cut in the winter – and the Moustached Warbler *A. melanopogon* preferred reedbeds with a high diversity of emergent plants. Another passerine, the Bearded Tit *Panurus biarmicus*, needed dense cover of thin, dry reed stems. Thus, management would affect different bird species in different ways. Water management for reed cutting negatively affected emergent plant species and produced monospecific stands of taller, thicker reeds, while cutting negatively affects dry stem density by replacing areas of dry stems with a high density of new, growing stems. Poulin and Lefebvre (2002) further found that cut *Phragmites* reedbeds had a higher spring water level and less dry ground (apparently because of preferential flooding to encourage reed growth) and higher reed biomass than uncut beds, while arthropod food for passerine birds was highest at cut sites. Cut and uncut reedbeds had a similar bird species richness, but cut reeds had a lower bird abundance due to significant decreases in Bearded Tits, which need dry reeds, and Moustached Warblers, which need early growth and emergent cover. The authors concluded that an optimal mosaic of cut and uncut reeds can provide as high a conservation value as unmanaged reedbeds.

As mentioned above (Section 3.1, habitat fragmentation), resident African warbler species also show differences in their preference for vegetation structure and plant species composition, so that the effects of harvesting and burning noted by Poulin *et al.*

(2002) in Europe could well be reproduced in the African reedbed habitats occupied by resident African species.

The scale of harvesting can have profound effects. Large scale mechanically completely harvested *Phragmites* beds in France were found to host altered arthropod communities, lacking major food components used by vulnerable passerine birds, but small scale reed cutting may increase habitat heterogeneity and species richness at a landscape level (Schmidt *et al.,* 2005). Uncut reed patches should always be left adjacent to cut areas, to permit recolonization by arthropods (Schmidt *et al.,* 2005).

In a review of the impact of *Phragmites* reedbed management on wildlife in Europe, Valkama *et al.* (2008) emphasised that reedbed management by harvesting, burning, mowing and grazing modifies the structure of regrowing reeds, promoting shorter, denser stems. Harvesting has no impact on above-ground biomass, but plant species richness increases in managed stands. Long term management negatively affects the reedbed invertebrate community, but short term (1-2yrs) management has no effect. The authors' meta-analysis found that reed harvesting and burning can reduce the abundance of passerine birds by about 60%, probably because of food limitation (reduced numbers of butterflies, spiders and beetles). The optimal reedbed management regime to preserve the numbers of birds and invertebrates could be a rotation of short term management.

4. STUDIES IN AFRICA

Turning to the African continent, in Uganda Maclean *et al.* (2006) studied the effects of disturbance by harvesting, burning and habitat fragmentation on six passerine bird species associated with papyrus *Cyperus papyrus* swamps. The occurrence of all six species was positively affected by increased swamp size and was also affected by disturbance and habitat fragmentation. Only two species, the Papyrus Yellow Warbler *Chloropeta gracilirostris* and the White-winged Warbler *Bradypterus carpalis* (which are insectivorous), were positively affected by disturbance. The Papyrus Canary *Serinus koliensis* (a seedeater) and two other warbler species, the Greater Swamp Warbler *Acrocephalus rufescens* and Carruthers's Cisticola *Cisticola carruthersi,* tolerated low levels of disturbance, while the swamp-dwelling Papyrus Gonolek *Laniarius mufumbiri* (a shrike which eats large insects and small vertebrates) did not tolerate disturbance. The results suggested that many papyrus-dwelling passerines can tolerate low intensities of disturbance, and therefore controlled harvesting was recommended as having a positive effect on the goodwill of rural communities without having a seriously detrimental effect on bird communities.

No studies have been done on the effects on wetland birds of harvesting *Phragmites* in African wetlands, but the harvesting of *Phragmites* reedbeds by local communities in the Muzi Swamp, South Africa, has been thought to be excessive and unsustainable, with heavily utilized areas being more degraded than less harvested ones. A study by Tarr *et al.* (2004) found that current levels of harvesting have caused no distinct degradation gradient, although the condition of the reeds in the harvested areas is poorer than in unharvested areas. They concluded that expansion of the harvested area, coupled with adaptive harvesting systems and yearly monitoring, would improve the quality of the reeds within the harvesting area without affecting harvesting quotas, but they did not speculate on the possible effects of such action on the reedbed fauna, including birds.

The Red-chested Flufftail, a small, sedentary wetland rail, inhabits permanent and seasonal marshes and reedbeds over much of sub-Saharan Africa (Taylor and Van Perlo, 1998). Studies of this species in South Africa (Taylor, 1994) have shown that this species can tolerate non-breeding season reductions in territory size (principally as a result of burning, cattle trampling and desiccation) of 20-53% for up to 4 months, and up to 70% for 1-2 months, and that residents thus displaced inhabit marginally suitable habitat close to the affected territories, moving back as soon as sufficient habitat regeneration occurs. Cutting and burning experiments in inhabited *Cyperus* dominated reedbed habitats showed that dry season burning of reedbed and sedgebed vegetation increased habitat suitability after spring regrowth, through the removal of dead vegetation and litter, which increased the extent of the substrate available for foraging and promoted new growth of vegetation and a concomitant increase in invertebrate food abundance (Taylor, 1994). It was concluded that the best management strategy for wetlands occupied by this and other rail species with similar habitat requirements is one that incorporates patch burning to remove dead vegetation, variations in burn timing to provide different stages of regeneration in different patches, years without burns to reduce the frequency of emigration and to allow early nesting, and some annual burning to improve overall productivity of the vegetation (Taylor, 1994).

Studies of the globally endangered White-winged Flufftail *Sarothrura ayresi* in the highland marshes of Ethiopia have shown that the only known breeding population of this species has been severely negatively affected by the over-harvesting of marsh vegetation (principally *Eleocharis* sedges) and the disturbance and destruction of extensive areas of breeding habitat by overgrazing (Taylor, 1996; 1997b; 1998; Taylor and Kotze, 1999).

APPENDIX 9: THE SUSTAINABILITY OF HARVESTING OF WETLAND RESTIOS

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1. INTRODUCTION

The prototype of WET-SustainableUse (Kotze, 2007) provided guidelines for the harvesting of wetland plants. These guidelines were considered to be relevant to grasses (Graminae), sedges (Cyperaceae), rushes (Juncaceae) and bulrushes (Typhaceae). However, they were not developed with any consideration of the particular features and responses of restios (Restionaceae) to harvesting. Thus, a review was undertaken of the specific effect of harvesting on restios, in particular those that occur in wetlands.

The effect of harvesting on restios was assessed based on the following:

- a review of the literature, given in Section 2 of this appendix;
- observations of a wetland site where harvesting of restios takes place, and an interview with the land-owner regarding the specific harvesting practices applied and his personal observations, given in Section 3 of this appendix.

It was beyond the scope of this study to conduct long term investigations of the effects of harvesting on wetland restios. A long term investigation of the sustainability of harvesting of the restio *Condropetalum tectorum* (pannetjies riet) has, in fact, recently been initiated in association with Flower Valley, involving different cutting treatments applied to individual plants (S Privett, 2007, pers. comm., Flower valley, Stanford), but it is still too early to draw conclusions from this study.

2. A REVIEW OF THE LITERATURE

Almost all of the literature relating to the harvesting of restios deals with non-wetland restio species. However, to the extent that these non-wetland species share some key functional features with the harvested wetland species, the findings of this research have some relevance here.

Some key features of restios that are relevant to their harvesting

The Restionaceae comprise an unusual family of grass-like plants occurring in the southern hemisphere. Restionaceae have a peculiar culm anatomy characterized by a sclerenchymatous ring in the centre of the culm. This is interpreted as a response to xeric conditions, and provides high mechanical strength for the slender culm, which is sometimes up to 3 m tall. This feature also makes the culms potentially suitable as thatching material. Furthermore, the finely sculptured quality and the contrasting rich green and brown colours of many of the Restionaceae species makes them attractive plants for the cut flower industry.

Almost all of the habitats in which Restionaceae occur are subject to fire (natural or human-induced) and it is likely that fire has played a major role in shaping the evolutionary history of the group (Pate *et al.,* 1999). As is the case with other plant taxa, Restionaceae species can be classified as either 'seeders', in which the plant is generally killed by fire and recruitment occurs from seed, or 'resprouters', in which the pereniating buds of a plant generally survive fire, and regeneration takes place by sprouting of new shoots from trunks, rhizomes or rootstocks. Pate *et al.* (1999) found seeder and resprouter species to be approximately equally distributed between wetland and dryland habitats.

The categories "seeder" and "resprouter" are given in relation to burning. In the South African Restionaceae, resprouting is the most dominant regeneration mechanism, although some species (e.g. *Chondropeatalum mucronatum*) are seeders. As shown by Ball (1995) a seeder, *Thamnochortus insignis*, still resprouts following harvesting by cutting. Furthermore, Van Wulgen and Kruger (1981, as cited by Linder, 1991) report all Restionaceae (both resprouters and seeders) as surviving a fire near Paarl, and resprouting. However, Le Maitre (1986) showed that fire survival of seeders depends on the burning season. If the fire occurs after the new cohort of culms has been initiated, the plants are killed, while fire which occurs shortly before culm initiation is less lethal.

There are two features that make the individual plants of resprouters potentially better adapted to defoliation (whether from fire, grazing or cutting) than seeders. Firstly, the pereniating buds are lower relative to the soil surface, making them more protected, especially from fire. Secondly, starch and sugar reserves are larger, potentially allowing adult plants to recover more rapidly from defoliation. Although the average culm length of seeders is similar to resprouters, seeders have pereniating buds positioned on average 2 cm higher in the soil than resprouters (which makes the plants more vulnerable to fire and to very low cutting), and the mean rhizome diameter of seeders is less than resprouters (2.9 mm compared with 3.8 mm). In reseeders, rhizomes tend to grow in an ascending fashion, and may extend well above the soil surface with the result that the plant develops a tufted or even stilt-like habit. In addition, expressed in terms of percentages of dry matter of rhizomes, the resprouters as a group show significantly higher mean levels of starch (6.4%) and sugars (3.5%) than do seeders (0.06 and 1.4% respectively; Pate *et al.,* 1999).

Thus, it is suggested that seeders may be more vulnerable to the negative effects of harvesting than obligate resprouters. Nevertheless, it is interesting to note that two of the most widely harvested restios, *Thamnochortus insignis* and *Chondropeatalumn tectorum* are, in fact, seeders. It would appear that the vulnerable features highlighted above can be accounted for in the harvesting regime by not cutting too low and allowing the individual plants several years to regrow and accumulate reserves.

At a community level, Restionaceae vary in their successional response to disturbance, depending on the particular local situation. Where climate and edaphic conditions potentially support a low to moderate cover of woody shrubs, Restionaceae generally increase progressively in abundance for several years following a disturbance event. This situation would appear to apply to the study site of Ball (1995) which is described as Dry Restioid Fynbos, which has a sparse shrub stratum (< 30%) and a high (>60%) restioid cover. This situation also applies to the example of Hoffman *et al.* (1987) where in a lowland fynbos area the cover of Restionaceae increased progressively over a 20 year period following a burn. This suggests that in these situations Restionaceae play an important role in community structure and composition in old vegetation. However, where climate and edaphic conditions potentially support a high cover of woody shrubs, restios initially increase in abundance (becoming most dominant in earlier post-fire vegetation) and then later decrease in favour of taller woody shrubs (Linder, 1991).

The harvesting of wetland restios

Currently, *Chondropetalum tectorum* is the only wetland restio in South Africa that is harvested in any abundance. Harvested *C. tectorum* material is used mainly in the cut flower industry. *Chondropetalum tectorum* is the most commonly occurring species of its genus, and is found from Clanwilliam to Grahamstown, growing in damp/marshy localities in the coastal forelands (Linder, 1991; Hoaksma and Linder, 2000). According to Caddick and Linder (2002) *C. tectorum* is a seeder. Of the 13 different restio species examined in diaspore experiments, *C. tectorum* had by far the smallest seed, with a mean seed mass more than 1000-fold smaller than the species with the largest seed (Caddick and Linder, 2002). In addition, *C. tectorum* had the smallest seedling, with a mass more than 30-fold smaller than the species with the largest seedling. Caddick and Linder (2002) suggest that there is a trade-off between producing small dispersal units that do not form very robust seedlings, but can be produced in very large numbers, thereby enhancing chances that some will germinate in favourable habitats, and producing large dispersal units that cannot be produced in large quantities, but which produce larger seedlings better able to survive environmental hazards, particularly drought. The seed size of *C. tectorum* may also possibly be related, in part, to its wetland habitat. In wetland habitats, droughts, while by no means absent, would be less severe than in adjacent non-wetland areas.

> *In the past, several species were regionally important in the thatching trade. Rourke (1974) suggests that* C. tectorum *was used in the western Cape (Tulbagh, Swartland and west coast) and* Thamnochortus insignis *in the southern Cape from Caledon to Mossel Bay. In the Elim district,* Willdenowia argentea *[*Ceratocaryum argenteum*] was occasionally used, while* Cannomois virgata *is used for shepherd huts in the mountains, and* Hypodiscus aristatus *is occasionally used in the Langeberg. The only significant modern thatching industry is based on* Thamnochortus insignis*. It appears as if* T. insignis *only came into popular use after the First World War, as Marloth (1915) does not mention it being used for thatching"* (Linder, 1991).

Thamnochortus erectus is sometimes used for thatch, but is of inferior quality to *T. insignis* as a result of the shorter culms and higher percentage of dead culms in the tussock, and is only harvested when there is an unusually high demand (Ball, 1995).

Rourke (1974) records that in 1652, just six weeks after his arrival in the Cape, Van Riebeeck made the following entry in his diary:

> *Have been busy today cutting rushes or reeds (which we found in abundance in the down behind the rump of the Lion Mountain) for thatch dwellings.*

A few days later he records further:

> *Had another person start thatching today in a different manner using the reeds already cut. These are so fine and suitable for roof that it would be a pity if no one could be found among the men with a knowledge of thatching.*

While it is not certain which plant species Van Riebeeck was referring to, Rourke (1974) suggests that it was either *C. tectorum* or *Thamnochortus spicigerus*, which are likely to have been abundant on the Cape flats at the time, and are still present in a few places among the dunes along the False Bay coast. Furthermore, *C. tectorum* was in such common use as thatch when the Swedish botanist CP Thunberg arrived in Cape Town in 1772 that he assigned it the specific name *tectorum*, which in Latin means “of the roofs” (Rourke, 1974).

Research on the harvesting of non-wetland restios

Research has been undertaken on the effect of harvesting on *Thamnochortus insignis*, which is a seeder like *C. tectorum*, and *T. erectus*, which is a resprouter (Ball, 1995). Ball (1995) found the seed bank densities of both species to be high, with that of *T. insignis* approximately twice that of *T. erectus.* This was attributed to differences in the volume of seed production between the two species. *Thamnochortus insignis* can therefore be seen as a pioneer species, and *T. erectus* as a persistent species (Ball, 1995). It is estimated that the lifespan of *T. insignis* is about 20 years, while of *T. erectus* it is about 80-100 years (Ball, 1995).

Populations of *T. insignis* are usually harvested seven to ten years after fire, and approximately every five years subsequently (in many cases more frequently; Ball, 1995). Harvesting occurs mainly from late autumn to mid-winter (May to August) after the seed has set, but some harvesting takes place outside of this season. Harvesting is non-selective, and all of the culms are removed from the tussock at a height of 50-70 mm by a mechanized brush-cutter. Plants that escape harvesting are either small or inaccessible (Ball, 1995).

Thamnochortus insignis and *T. erectus* seedling death as a result of harvesting (i.e. trampling by harvesters and smothering by harvested thatch) was not quantified, although Ball (1995) suspected it to be low. A few adult *T. insignis* plants were killed by harvesting (mean for 1993 and 1994 = 8.6% of harvested plants). Although this is higher than *T. erectus* (0.6% of harvested plants killed) it is nonetheless a small proportion and is unlikely to threaten the persistence of the population, given that harvesting stimulates the recruitment of many new *T. insignis* seedlings.

Following harvesting, the next cohort of culms begins to grow in winter (June to July) and emerges above the cropped stubble in early spring (August to September). By early summer (October) inflorescences develop and wind-borne dispersal of mature seed occurs from the end of autumn (mid-April) to mid-winter (July). The first seedlings germinate in late winter (Ball, 1995).

"Harvesting does not result in drastic changes in the population structure of both study species, except for a reduction in average plant height and an increase in the percentage of non-reproductive individuals, both of which return to pre-harvest levels within 1-3 years following harvesting" (Ball, 1995). In the short term, harvesting damages the harvested plant, and harvesting strategies should take plant recovery into account, especially for the seeder *T. insignis*, which showed higher numbers of dead plants following harvesting than the sprouter *T. erectus.* In addition, total seed production is severely reduced in the year following harvesting in both species, and therefore repeated annual harvesting would deplete the seed bank. However, Ball (1995) also found that harvesting results in higher levels of *T. insignis* seedling recruitment, due possibly to the creation of “open” spaces for seedlings, and the dispersive action of harvesting.

Ball (1995) recommends that harvesting should take place shortly after seeds are ready for dispersal and before the new culms reach the critical height, because removal of growing culms increases the likelihood of death of the adult plant. Ball (1995) recommends further that mature populations of both species could be harvested approximately every five years to ensure sustainable utilization of the resource. If a burn occurs then this needs to be taken into account, because in *T. insignis*, in particular, there is significant mortality of adults, but often a massive recruitment of seedlings which need to be given a few years to mature and to replenish the soil-seed store. Even if the stand had been given several years' rest (e.g. four years) prior to the burn, several years would be required for the stand to recover fully from the burn before it could be harvested again. Ball (1995) recommends waiting seven years following a burn before harvesting *T. insignis*. *Thamnochortus erectus* would generally require less time for recovery following a burn, as a result of the lower fire mortality of adults. Ball (1995) also recommends that for *T. insignis* prescribed burns could occur immediately after harvesting, provided that sufficient time had been allowed for seed bank accumulation.

Linder (1990) reports that the harvesting of *T. insignis* is generally in synchrony with the biological rhythm of the plant. Harvesting does not interfere with seed production because it takes place once the culms have completed flowering, which corresponds with when the hardening of the nodes is complete (which, according to locals, is after the first cold snap of winter). If harvesting takes place before hardening then the culms break at the nodes and fragments fall out of the roof (Linder, 1990). Harvesting takes place very soon after flowering is complete because if it is delayed then it will damage the new cohort of culms (i.e. harvesting takes place during a narrow time period of about a month which is the most appropriate time in the growth cycle of the plant).

The findings and recommendations given for *T. insignis* are likely to be relevant to *C. tectorum* given the fact that both are seeders and have a similar growth form, although *C. tectorum* is somewhat shorter.

Besides assessing the effect of harvesting on the sustained yield of the utilized species, the effect of harvesting on the overall community needs to be assessed as well. The main tools used by vegetation harvesters are:

- brush-cutting of (a) the restios and (b) woody shrubs and other species growing with the restios; and
- burning.

Brush-cutting has become a major disturbance factor in restioid fynbos types of the Cape lowlands (Ball, 1995). Brush-cutting entire stands selectively suppresses the growth of co-occurring over-storey taxa (e.g. *Leucadendron* and *Proteaceae* species) and under-storey taxa (e.g. *Erica*, *Passerina* and *Metalasia* species). Frequent brush-cutting of woody plants potentially results in the stand becoming increasingly poor in terms of native plant species, especially woody species, with a concomitant heavy impact on biodiversity if this occurs on a large scale. Where the objective is to conserve biodiversity and maintain a sustained supply of thatch, Ball (1995) recommends that disturbance (burning or brush-cutting) should take place after reproductive maturity (>10 years) and before senescence of the *T. insignis* plants (<20 years) and before the shrubs reach a size where they suppress the *T. insignis* population.

A late summer to autumn burn would ensure maximum regeneration of fynbos species, including *T. insignis* (Bond *et al.,* 1984), and ensure conservation of species diversity. Burning outside of the late summer to autumn period would result in the local extinction of many fynbos species (Bond *et al.,* 1984), although *T. insignis* with its persistent seed bank would show good regeneration, provided that sufficient time had been allowed for seed to accumulate in the soil seed bank. Thus, if biodiversity conservation is one of the objectives, then burning should take place within the late summer to autumn period.

On the basis of the findings of his study and observations of current management practices, Ball (1995) provides the following recommendations for the sustainable utilization of the two species:

1. only mature populations which have accumulated seed in their seed banks for several years (i.e. approximately seven to ten years after a fire) should be harvested or burnt*;
2. the harvesting frequency should be approximately every five years, and never less than three years*; Anon (2004) recommends a three year harvesting frequency;
3. a minimum fire frequency interval of seven years is suggested*;
4. the practice of harvesting populations at the time of seed dispersal or immediately afterwards, and before the season of new culm growth, is recommended;
5. harvested thatch should be removed timeously to ensure maximum seedling recruitment;
6. burning after seed dispersal, but before the season of new culm growth, is recommended;
7. the practice of not harvesting very small or inaccessible adult plants and occasionally leaving a few unharvested culms is recommended (in order that there will be some seed production in the year following harvesting)**;
8. the practice of harvesting thatch with a mechanized brush-cutter that aids in the dispersal of seeds is recommended;
9. care must be taken to prevent the trampling of seedlings by harvesters;
10. harvesting methods should take plant recovery, especially for the non-sprouter *T. insignis*, into account and plants should not be harvested below the new culm growing tips; and
11. high intensity fires which result in poor regeneration should be avoided.

* The time periods mentioned in 1, 2 and 3 above would potentially allow for seed bank accumulation and population replacement after disturbance.

** Rotational harvesting could also achieve this, provided that the harvested blocks were in close proximity.

3. FIELD OBSERVATIONS OF A HARVESTED STAND OF *CONDROPETALUM TECTORUM*

Practices associated with harvesting of *Condropetalum tectorum* in the stand

A stand of approximately 30 ha of seasonally flooded *C. tectorum* (34°39′ 33″S, 19 °48′ 33″E) on the farm Moddervlei of Dirk Human is harvested for the cut flower industry. The market requires that the *C. tectorum* be at least 800 mm high to be acceptable. Last year (2007) the *C. tectorum* material harvested was sold for R3 per kg, resulting in a net profit of R200 000 from the *C. tectorum* harvest (D Human, 2008, pers. comm.).

The *C. tectorum* site is located very close to the *T. insignis* site of Ball (1995) and is likely to have very similar local climatic conditions. The *C. tectorum* stand is harvested from January to May, and areas are cut on an approximately three to four year cycle, but it is not cut in a formal rotational system (e.g. with four blocks that are rotationally cut). The contractors tend to go to the best areas, and in so doing they will avoid the recently cut areas where re-growth is still too young (D Human, 2008, pers. comm.). In 2008 the *C. tectorum* stand was not harvested because the land-owner did not receive any orders.

Growth of *C. tectorum* varies naturally from year to year, and is reduced in a dry year compared to a wet year. According to the land-owner, the *C. tectorum* stand has been harvested for over ten years, and is looking better and more vigorous now than before, when it was not cut.

The stand is very seldom burnt, and only occasionally as a result of runaway fires. A portion of the stand burnt in 1980, and then the stand was not burnt again until around 2002/2003 when another portion of the stand was burnt as a “back-burn” to control a major runaway fire driven by a strong north-westerly wind (D Human, 2008, pers. comm.). None of the area has burnt since then. The land-owner observed that the area that was burnt five or six years ago took a lot longer to regrow than the portion of the stand that was not burnt.

In "the old days" (a few decades ago) the stand used to be burnt much more frequently, along with wetland areas generally. Annually they used to ride through the wetland areas, setting alight to the vegetation at multiple ignition points (presumably because the wetland does not burn easily). *Condropetalum tectorum* is eaten to some extent by the cattle. About 150 head of cattle are grazed in the camp (which includes the *C. tectorum* stand) for five months in the summer (D Human, 2008, pers. comm.).

Nearby to the site, in the Elim area, *C. tectorum* has been harvested for well over 150 years for use as thatch. Although *T. insignus* is by far the most widely used restio for thatching, *C. tectorum* is also used for this purpose. It is much finer, resulting in a heavier thatch, which is more expensive than *T. insignis* and is also longer lasting (D Human, 2008, pers. comm.).

Observations made of the *Condropetalum tectorum* stand

The *C. tectorum* stand was visited on 6 February 2008 and sixteen 2 m by 2 m quadrats were located within the harvested stand (Plates A9.1, A9.2 and A9.3). Unfortunately there were no known uncut areas against which to compare the cut areas as a control. Within each of the 16 quadrats the diameter of each *C. tectorum* tussock present was measured at ground level. This included tussocks that consisted entirely of live material, those that were entirely dead and those that were mixed. For the mixed tussocks, the proportional basal area of dead to live material was estimated visually. From these the total basal area (partitioned between dead and alive) was determined for each 2 m by 2 m quadrat.

From Table A9.1 it can be seen that overall, the live basal cover is only slightly higher than the dead basal cover. This is probably not surprising for a species that is a seeder, and is therefore likely to be short-lived. If another seeder, *T insignis*, is to be used as an indicator, the plants are likely to live for a few decades.

Table A9.1: Mean cover values for *Condropetalum tectorum* measured in sixteen 2 m by 2 m quadrats (mean ± SD)

Aerial cover (%)	Basal cover, overall (%)	Basal cover, live (%)	Basal cover, dead (%)
20 ± 10.8	1.1 ± 0.60	0.6 ± 0.36	0.5 ± 0.35

Cover of *C. tectorum* is naturally heterogeneous, and aerial cover measured in the sixteen 2 m by 2 m quadrats ranged from 0% to 35%.

The results suggest that although cutting has caused the mortality of some tussocks, cut tussocks do, in fact, usually resprout. It is likely that cutting also strongly stimulates seedling recruitment, as is the case with *T. insignis*, although it was not possible to confirm this in this pilot investigation. From Table A9.2 it can be seen that there is no major difference between the mean tussock size of dead, live and mixed tussocks.

However, the distribution across tussock diameter classes varies for the three tussock types (Table A9.3). Live tussocks show a higher relative frequency in the smallest diameter classes in particular, compared with mixed and dead tussocks. In addition, all tussocks larger than 30 cm in diameter are mixed.

Long term harvesting trials will be needed before sound conclusions can be drawn. However, based on the literature review and preliminary field observations reported in this appendix, the harvesting being undertaken at Moddervlei appears to be sustainable. It is recommended that in order to sustain this resource, the recommendations given in Section 2.3 of this appendix should be followed. In addition, it is recommended that in order for the recommendations to be implemented, the harvested area at Moddervlei should be divided into blocks that are harvested on a rotational basis.

Table A9.2: Mean tussock diameter for *Condropetalum tectorum* in 16 pooled 2 m by 2 m quadrats, for three tussock types.

Live tussocks (cm)	Mixed tussocks (cm)	Dead tussocks (cm)
10.0 ± 5.12	13.3 ± 3.24	13.6 ± 4.29

Table A9.3: Distribution across *Condropetalum tectorum* tussock diameter (cm) classes for three tussock types in 16 pooled 2 m by 2 m quadrats

Tussock type	Tussock size classes (cm)									Total
	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	
Live	7	21	7	7	1	1	0	0	0	**44**
Mixed	1	16	23	13	14	5	4	2	1	**79**
Dead	2	3	13	8	0	1	0	0	0	**27**
Total	**10**	**40**	**43**	**28**	**15**	**7**	**4**	**2**	**1**	**150**

Plate A9.1: A stand of *Condropetalum tectorum*, showing the striking dark green and brown of the *C. tectorum* plants growing amongst shorter grass dominated vegetation

Plate A9.2: Two contrasting *Condropetalum tectorum* tussocks; the first, in the left corner of the picture, is comprised almost entirely of dead basal cover, while the second, in the centre of the picture, consists of a portion of dead basal cover but also a large actively growing portion

Plate A9.3: *Condropetalum tectorum* tussocks cut a few years previously, with discarded culms visible between the tussocks