Titles in the Wetland Management Series

WET-RoadMap: A Guide to the Wetland Management Series – TT 321/07

WET-Origins: Controls on the distribution and dynamics of wetlands in South Africa – TT 334/09

WET-ManagementReview: The impact of natural resource management programmes on wetlands in South Africa – TT 335/09

WET-RehabPlan: Guidelines for planning wetland rehabilitation in South Africa – TT 336/09

WET-Prioritise: Guidelines for prioritising wetlands at national, regional and local scales – TT 337/09

WET-Legal: Wetland rehabilitation and the law in South Africa – TT 338/09

WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands – TT 339/09

WET-Health: A technique for rapidly assessing wetland health – TT 340/09

WET-RehabMethods: National guidelines and methods for wetland rehabilitation – TT 341/09

WET-RehabEvaluate: Guidelines for monitoring and evaluating wetland rehabilitation projects – TT 342/09

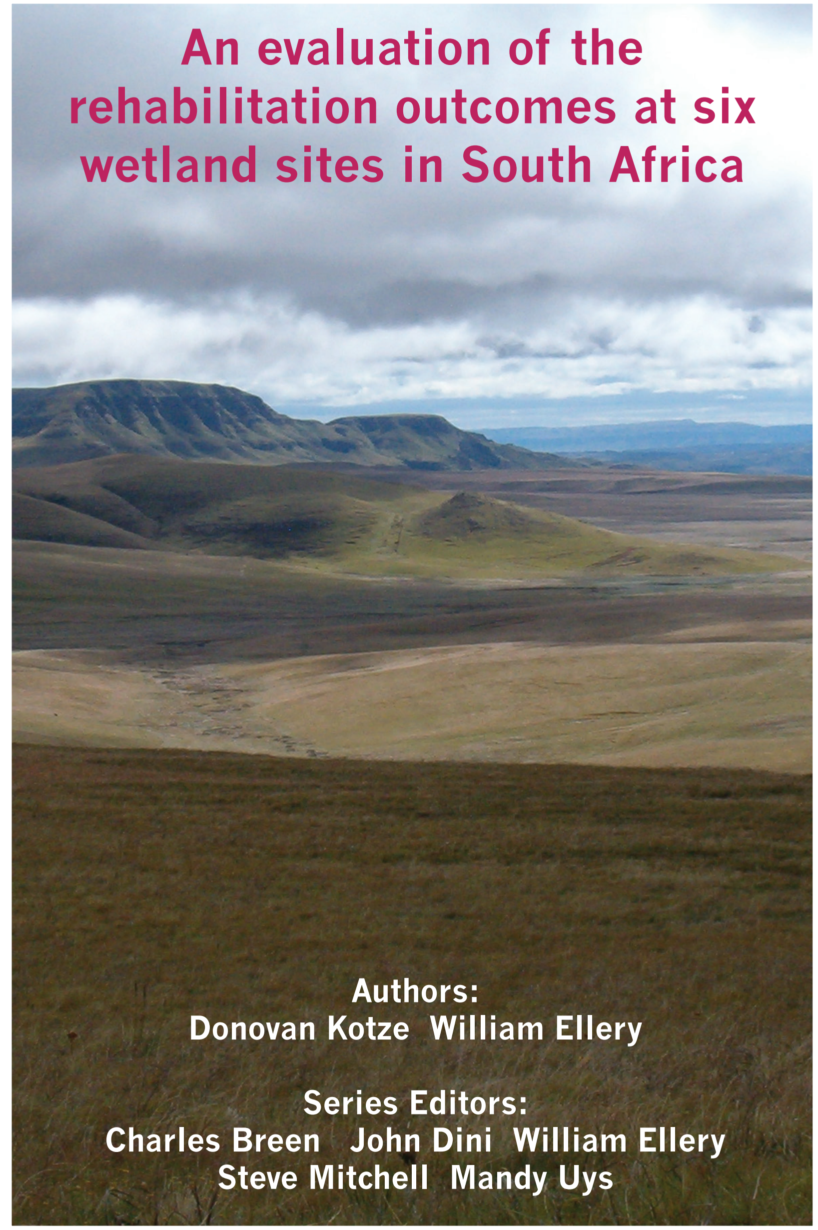
WET-OutcomeEvaluate: An evaluation of the rehabilitation outcomes at six wetland sites in South Africa – TT 343/09

9781770056428

TT 343/09 WET-OutcomeEvaluate

Wetland Management Series

WET-OutcomeEvaluate



An evaluation of the rehabilitation outcomes at six wetland sites in South Africa

Authors:
Donovan Kotze William Ellery

Series Editors:
Charles Breen John Dini William Ellery
Steve Mitchell Mandy Uys

Environmental Affairs and Tourism
Water Affairs and Forestry
Agriculture

TT 343/09

Water Research Commission

Working for Wetlands

Working for Wetlands
South African National Biodiversity Institute
Private Bag X101
Pretoria, 0001
Tel: 012 843 5191
Fax: 012 843 5250
wetlands@sanbi.org
http://wetlands.sanbi.org

Working for Wetlands (WfWetlands) uses wetland rehabilitation as a vehicle for both poverty alleviation and the wise use of wetlands, following an approach that centres on cooperative governance and partnerships. The Programme is managed by the South African National Biodiversity Institute (SANBI) on behalf of the departments of Environmental Affairs and Tourism (DEAT), Agriculture (DoA), and Water Affairs and Forestry (DWAF). With funding provided by DEAT and DWAF, WfWetlands forms part of the Expanded Public Works Programme (EPWP), which seeks to draw unemployed people into the productive sector of South Africa's economy, gaining skills while they work and increase their capacity to earn income. Rehabilitation projects maximise employment creation, create and support small businesses, and transfer relevant and marketable skills to workers.

The Water Research Commission

Water Research Commission
Private Bag X03
Gezina, 0031
Tel: 012 330 0340
Fax: 012 331 2565
info@wrc.org.za
www.wrc.org.za

The Water Research Commission (WRC) aims to develop and support a representative and sustainable water-related knowledge base in South Africa, with the necessary competencies and capacity vested in the corps of experts and practitioners within academia, science councils, other research organisations and government organisations (central, provincial and local) that serve the water sector. The WRC provides applied knowledge and water-related innovations by translating needs into research ideas and, in turn, transferring research results and disseminating knowledge and new technology-based products and processes to end-users. By supporting water-related innovation and its commercialisation where applicable, the WRC seeks to provide further benefit for the country.

University of KwaZulu-Natal

School of Environmental Sciences
University of KwaZulu-Natal
Durban, 4041
Tel: 031 260 1278
Fax: 031 260 1391
www.ukzn.ac.za

William (Fred) Ellery and Donovan Kotze of the University of KwaZulu-Natal (UKZN) managed the programme that supports the production of this component of the *WET-Management* Series. They can be contacted at:
f.ellery@ru.ac.za
kotzed@ukzn.ac.za

The institutions whose logos appear on this page have made a substantial contribution to the production of this document.

Wetland Management Series

WET-OutcomeEvaluate

An evaluation of the rehabilitation outcomes at six wetland sites in South Africa

WRC Report TT 343/09
March 2009

Authors:
Donovan Kotze
William Ellery

Series Editors:
Charles Breen
John Dini
William Ellery
Steve Mitchell
Mandy Uys

Environmental Affairs & Tourism
Water Affairs & Forestry
Agriculture
South African national biodiversity institute SANBI
Working for Wetlands
University of KwaZulu-Natal

Obtainable from:

Water Research Commission
Private Bag X03
Gezina
0031

The publication of this report emanates from a project entitled: *Wetlands Research Programme: Wetland Rehabilitation* (WRC Project No. K5/1408)

WRC Report TT 343/09

ISBN 978-1-77005-642-8

Set No 978-1-77005-631-2

Printed in the Republic of South Africa

Authors:

William Ellery

Donovan Kotze

Series Editors:

Charles Breen

John Dini

William Ellery

Steve Mitchell

Mandy Uys

Front cover: Ntsikeni Vlei in the foothills of the southern Drakensberg of KwaZulu-Natal/ Eastern Cape. The Killarney Wetland rehabilitation site is located within the valley at the centre of the photograph, with the main body of Ntsikeni Vlei evident in the distance beyond and to the right of the Killarney site. The photograph was taken in March 2007.
Photograph: Michael Grenfell

Inside front cover: Boneberg's frog (*Natalobatrachus bonebergi*), commonly known as Ngoye frog, is a threatened endemic species along the coastal region of KZN.
Photograph: Errol Douwes

Preface: Background to the *WET-Management* Series

The need for wetland rehabilitation in South Africa is compelling: loss and degradation of wetlands have been great and national policy and legislation provide clear direction and support for rehabilitation. However, rehabilitating wetlands is often complex because wetlands and their links with people are complex (e.g. through the ways that people use wetlands and the different benefits that people receive from the ecosystem services that wetlands supply). Thus a series of tools has been developed to assist those wishing to undertake wetland rehabilitation in a well-informed and effective way (Box 1P).

These tools were developed as part of a comprehensive nine-year research programme on wetland management which was initiated in 2003 by the Water Research Commission (WRC) and a range of partners that examines wetland rehabilitation, wetland health and integrity and the sustainable use of wetlands. The rehabilitation component, which was co-funded by the WRC and the Department of Environmental Affairs and Tourism, through the Working for Wetlands (WfWetlands) programme, was prioritised to take place first because of the need to provide a firm, scientific and technical foundation for the extensive rehabilitation work already under way.

The Working for Wetlands programme is a national initiative that seeks to promote the protection, rehabilitation and wise use of wetlands in South Africa. As part of this initiative, WfWetlands has a national programme for the rehabilitation of wetlands, including a structured process of prioritising rehabilitation sites and supporting their rehabilitation. At the same time, however, it is acknowledged that sustainable use of wetlands in the long term can be achieved only through the dedicated participation of civil society, whose wetland interests may have a strong local focus. Thus the tools have been developed in such a way that they can be applied outside of the Working for Wetlands programme, and without having to engage the process of national or provincial prioritisation should the user not desire to do so. Even so, the tools encourage local wetland rehabilitation efforts to strengthen links with the national initiative and the opportunity these provide for fruitful partnerships.

The series consists of a roadmap, two background documents, eight tools and an evaluation of the success of six individual projects (Box 1P). From Table 1P it can be seen that some of the tools (e.g. *WET-RehabMethods*) are designed to be used by those dealing specifically with wetland rehabilitation and its technical requirements. Other tools (e.g. *WET-Health*) have much wider application such as assessing impacts associated with current and future human activities in Environmental Impact Assessments (EIAs) or assessing the Present Ecological State (PES) of a wetland in an Ecological Reserve Determination (ERD).

One can locate the tools in terms of some basic 'who', 'what', 'where' and 'how' questions that any team undertaking wetland rehabilitation should be asking (Table 2P). Furthermore, each of the tools can be used individually, but there are close links between them (Figure 1P).

Box 1P: Overview of the *WET-Management* Series

The series includes documents that provide background information about wetlands and natural resource management, tools that can be used to guide decisions around wetland management, and an evaluation of rehabilitation outcomes in a number of case studies.

WET-Roadmap

WET-Roadmap provides an introduction to the *WET-Management* tools and includes:

- a brief outline of the documents and tools in the *WET-Management* series and how they inter-relate
- an index of wetland rehabilitation related terms
- reference to specific sections in the relevant tools.

WET-Origins

WET-Origins describes the remarkable geological and geomorphological processes that give rise to wetlands in South Africa, and provides a background description of:

- the geology, geomorphology, climate and drainage of southern Africa
- an introduction to wetland hydrology and hydraulics
- geomorphic controls on different wetland types
- wetland dynamics due to sedimentation and erosion.

It incorporates this understanding into a methodology that can be used to help develop insight into the hydrological and geomorphological factors that govern why a wetland occurs where it does, which is useful when planning rehabilitation.

WET-ManagementReview

WET-ManagementReview has four parts:

1. An assessment of effectiveness at programme level, including:
   - a national overview of land-uses affecting the status of wetlands and the institutional environment that affects wetlands.
   - an overview of five natural resource management programmes affecting wetlands and their impact in different land-use sectors; Working for Wetlands, Working for Water, LandCare, the Crane Conservation Programme of the Endangered Wildlife Trust, and the Mondi Wetlands Programme.
2. An assessment, using the *WET-EffectiveManage* tool, of the management effectiveness of 21 wetland sites in a variety of different land-use and land-tenure contexts.
3. An assessment of stakeholder participation in wetland rehabilitation at six wetland sites.
4. A framework for assessing the effectiveness of collaboration between partners, described and applied to a site where a rehabilitation project has been under way for several years.

WET-OutcomeEvaluate

WET-OutcomeEvaluate is an evaluation of the rehabilitation outcomes at six wetland sites in South Africa, including an evaluation of the economic value of rehabilitation. The six sites are:

1. Killarney Wetland
2. Manalana Wetland
3. Kromme River Wetland
4. Dartmoor Vlei
5. Kruisfontein Wetland
6. Wakkerstroom Vlei.

WET-RehabPlan

WET-RehabPlan offers a process that can be followed to develop comprehensive wetland rehabilitation plans. It has three main elements:

- Introduction to rehabilitation, planning and stakeholder involvement.
- General principles to follow in planning wetland rehabilitation.
- Step-by-step guidelines for undertaking the planning and implementation of wetland rehabilitation at a range of scales from national/provincial to catchment to local. It directs the user to the right tools and sections at appropriate points in the rehabilitation process.

Good planning ensures a rational and structured approach towards rehabilitation as well as a clear understanding of the reasons for rehabilitation, the actions and interventions required, and the benefits and beneficiaries.

WET-Prioritise

WET-Prioritise helps to identify where rehabilitation should take place once the objectives of rehabilitation are identified. It works at three spatial levels. At national and provincial level an interactive GIS modelling tool assists in identifying priority catchments by evaluating a range of scenarios, based on different combinations of 13 socio-economic and bio-physical criteria (e.g. Biodiversity Priority Areas, High Poverty Areas). Once a catchment is selected, the tool helps to identify areas for rehabilitation within that catchment. Finally, individual wetlands are selected based on the predicted cost-effectiveness and sustainability of rehabilitation.

WET-Prioritise provides step-by-step guidelines applicable at all three spatial scales, including:

- identifying objectives and an appropriate scale.
- developing prioritisation criteria.
- applying the criteria, usually in a two step process of rapidly screening all candidate sites to arrive at a preliminary set of sites, from which individual priority sites are selected.

Three case examples of prioritisation are described.

WET-Legal

WET-Legal presents South African legislation that is relevant to wetland rehabilitation, including the Conservation of Agricultural Resources Act (CARA), National Environmental Management Act (NEMA), and National Water Act (NWA), as well as relevant international agreements such as the Ramsar Convention on Wetlands. *WET-Legal* lists the environmental impacts potentially associated with typical wetland interventions and the legislative provisions that apply to each of these impacts. It also covers laws compelling rehabilitation and the legal responsibilities of different parties involved in rehabilitation.

TOOLS

TOOLS

WET-EcoServices

WET-EcoServices is used to assess the goods and services that individual wetlands provide, thereby aiding informed planning and decision-making. It is designed for a class of wetlands known as palustrine wetlands (i.e. marshes, floodplains, vleis or seeps). The tool provides guidelines for scoring the importance of a wetland in delivering each of 15 different ecosystem services (including flood attenuation, sediment trapping and provision of livestock grazing). The first step is to characterise 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).

WET-Health

WET-Health assists in assessing the health of wetlands using indicators based on geomorphology, hydrology and vegetation. For the purposes of rehabilitation planning and assessment, *WET-Health* helps users understand the condition of the wetland in order to determine whether it is beyond repair, whether it requires rehabilitation intervention, or whether, despite damage, it is perhaps healthy enough not to require intervention. It also helps diagnose the cause of wetland degradation so that rehabilitation workers can design appropriate interventions that treat both the symptoms and causes of degradation. *WET-Health* is tailored specifically for South African conditions and has wide application, including assessing the Present Ecological State of a wetland for purposes of Ecological Reserve Determination in terms of the National Water Act, and for environmental impact assessments. There are two levels of complexity: Level 1 is used for assessment at a broad catchment level and Level 2 provides detail and confidence for individual wetlands based on field assessment of indicators of degradation (e.g. presence of alien plants). A basic tertiary education in agriculture and/or environmental sciences is required to use it effectively.

WET-EffectiveManage

WET-EffectiveManage provides a framework that can be used to assess management effectiveness at individual wetlands based on 15 key criteria (e.g. the extent to which a regularly reviewed management plan is in place for the wetland). A scoring system is provided for rapidly assessing the criteria. This tool is Chapter 2 in the *WET-ManagementReview* manual.

WET-RehabMethods

WET-RehabMethods is used to guide the selection and implementation of rehabilitation methods that are appropriate for the particular problem being addressed and for the wetland and its catchment context. It provides detailed practical rehabilitation guidelines for inland palustrine wetlands and their catchments, and focuses particularly on wetlands associated with natural drainage networks. It can be adapted to meet specific needs. Some aspects of the tool require high levels of civil engineering expertise, but it is designed primarily for rehabilitation workers who have completed training in soil conservation, life sciences or engineering at a diploma level or higher, and who have practical field experience.

WET-RehabMethods includes the following:

- Key concepts relating to wetland degradation, particularly those resulting from erosion.

- Guidelines for the selection of an appropriate type of rehabilitation intervention (including both ‘soft’ and ‘hard’ engineering options).
- Detailed guidance, provided for designing a wide variety of intervention types (e.g. determining an adequate spillway to account for runoff intensity).
- Detailed guidance provided for the implementation of the different intervention types.

WET-RehabEvaluate

WET-RehabEvaluate is used to evaluate the success of rehabilitation projects, and is designed with the understanding that monitoring and evaluation are closely tied to planning, which, in turn, should accommodate monitoring and evaluation elements. *WET-RehabEvaluate* provides the following :

- Background to the importance of evaluation of wetland rehabilitation projects.
- Step-by-step guidelines for monitoring and evaluation of rehabilitation projects, both in terms of project outputs and outcomes. The outcomes are based on system integrity and the delivery of ecosystem services, and results from *WET-Health* and *WET-EcoServices* are therefore included. The guidelines include review project objectives, identify performance indicators and standards, develop and implement a monitoring and evaluation plan, and evaluate and report on performance.

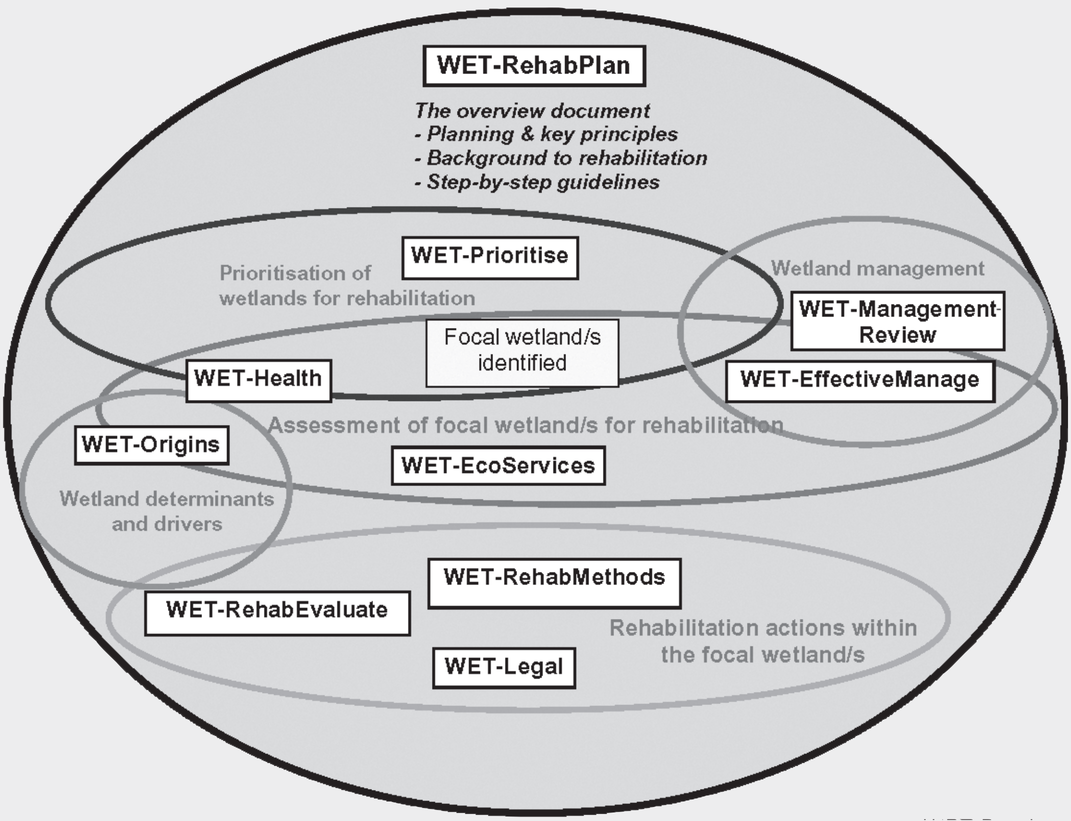


Figure 1P: How do the *WET-Management* tools relate to each other in a rehabilitation context?

Table 1P: Likely relevance of the background reading and tools in the *WET-Management* series to a variety of different potential uses

Potential users	*WET-Origins*	*WET-Management - Review*	*WET-RehabPlan*	*WET-Prioritise*	*WET-Effective-Manage*	*WET-Legal*	*WET-Rehab-Methods*	*WET-Eco-Services*[1]	*WET-Health*[2]	*WET-Rehab-Evaluate*
Rehabilitation planning - wetland specialist	Very high	Some	Some	Some	Some	Some	Some	Very high	Very high	Very high
Rehabilitation planning - engineer	Some	Some (Part 1)	Some (Step 5)			Some	Very high			
Rehabilitation programme coordination - *national*	Some	Very high	Very high	Very high	Some	Very high	Some	Some	Some	Some
Rehabilitation programme coordination - *provincial*	Some	Very high	Very high	Some	Very high	Very high	Some	Some	Some	Some
Rehabilitation implementation			Some (Step 5)		Some	Some	Very high			Very high
Impact assessment	Some	Some (Part 1)				Some		Very high (Level 1)	Very high (Level 2)	
Wetland management	Some	Some	Some		Very high	Some				
Ecological Reserve Determination - DWAF officials & consultants	Very high	Some (Part 1)		Some		Some		Very high (Level 1)	Very high (Level 2)	
Catchment planners - CMAs and others	Some	Some (Part 1)		Very high		Some		Some	Some	
Broad-scale biodiversity conservation planning	Some	Some (Part 1)		Very high		Some		Some	Some	

Some (light grey): The tool is likely to have some relevance

Very high (dark grey): The tool is likely to have a very high level of relevance

[1] *WET-EcoServices* is of particular relevance in determining the Ecological Importance and Sensitivity (EIS) of a wetland.

[2] *WET-Health* is of particular relevance ino determining the Present Ecological State (PES) of a wetland.

CMA = Catchment Management Agency
DWAF= Department of Water Affairs and Forestry

Table 2P: Rehabilitation-related questions typically posed at different spatial levels, and the tools most relevant to assisting the user in answering each question

Common questions	Tool/s likely to be relevant in addressing the question
Questions that might typically be asked at the national or regional level	
What is causing the degradation of wetlands?	*WET-Health* (Level 1) & *WET-ManagementReview*
Which are the most important wetlands?	*WET-Prioritise* & *WET-EcoServices* (Level 1)
Which wetlands should we rehabilitate?	*WET-Prioritise*
How should wetland rehabilitation be integrated within broad-scale catchment management?	*WET-Prioritise* & Dickens *et al*. (2003)
Questions that might typically be asked at the local level	
How effectively is the wetland being managed?	*WET-EffectiveManage*
What is causing the degradation of the wetland?	*WET-Health* (Level 2)
Is the wetland in need of rehabilitation?	*WET-Health* (Level 2) & *WET-Origins*
How do I decide what rehabilitation interventions will be appropriate for meeting my rehabilitation objectives?	*WET-RehabPlan* (Step 5F) & *WET-RehabMethods*
What are specific technical considerations I must make when designing a rehabilitation intervention?	*WET-RehabMethods*
Will the planned project be legally compliant?	*WET-Legal*
How do I evaluate my rehabilitation project?	*WET-RehabEvaluate*
Who should be involved in the rehabilitation project?	*WET-RehabPlan*
How do I align my rehabilitation project with catchment-, regional- or national-level programme/s?	*WET-RehabPlan* & WfWetlands Strategy (Working for Wetlands, 2005)

The National Water Act defines wetlands as:

'....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.'

This is the definition used by the *WET-Management* Series.

Acknowledgements

The Water Research Commission (WRC), South African National Biodiversity Instutute (SANBI) and Working for Wetlands (WfWetlands) are gratefully acknowledged for funding the development of this tool. The entire WfWetlands team has taken an active interest and participated in the development of this tool. The WRC has been very supportive in offering strategic and administrative assistance. The research programme was managed by Fred Ellery of the University of KwaZulu-Natal (UKZN), who was ably assisted by Kerry Philp. Karen Ellery provided substantial editorial input during the production of this document.

Citation

The correct citation for this document is: Kotze DC and Ellery WN, 2009. *WET-OutcomeEvaluate: An evaluation of the rehabilitation outcomes at six wetland sites in South Africa*. WRC Report No. TT 343/09. Water Research Commission, Pretoria.

Feedback

In South Africa the rehabilitation of wetland ecosystems is still in its infancy. In order to promote the growth of this activity, this manual needs to be revised by including the experiences of those individuals involved in wetland rehabilitation within South Africa. Any comments or advice can be sent to:

Donovan Kotze
University of KwaZulu-Natal
e-mail: kotzed@ukzn.ac.za

OR

Fred Ellery
Rhodes University
e-mail: f.ellery@ru.ac.za

TABLE OF CONTENTS

Part 1:

A comparative evaluation of the rehabilitation outcomes of six case study wetlands in South Africa

DC Kotze and WN Ellery

1 Introduction and purpose

Despite the abundant ecosystem services that wetlands provide, many wetlands in South Africa have been degraded and even lost altogether. Consequently there is a great need for wetland rehabilitation (Kotze *et al*., 2009a). In response to this need a national programme was established, called Working for Wetlands (WfWetlands), which has wetland rehabilitation as one of its key focal activities. However, the process of rehabilitation is often very costly, and thus attention needs to be given to examining the returns on investment for these projects, particularly if they are being supported with public funds. Regular audits (both internal and external) of the outputs (i.e. the physical rehabilitation structures) of WfWetlands are conducted. However, there has been very limited evaluation of the outcomes of these rehabilitation projects in terms of ecosystem health and the provision of ecosystem services. The importance of this research is highlighted by the fact that if a funding agent does not have information about the outcomes of projects it has funded, it becomes increasingly difficult to maintain support for such projects (Rutherfurd *et al*., 2000; Woodhill and Robins, 1998). Furthermore, engaging with the outcomes of rehabilitation projects (what rehabilitation has achieved) is important in that practitioners and scientists alike learn a great deal about the ecosystems concerned and how to better rehabilitate them (Jordan *et al*., 1987).

The purpose of this document is to evaluate the rehabilitation outcomes of six different wetland sites, all of which are sites where WfWetlands has undertaken rehabilitation interventions. Part 1 of the document provides a comparative evaluation of all of the six sites (i.e. an overview), while the details of the evaluations undertaken for the individual wetlands are given in Parts 2 to 7 of the report.

Two main general types of rehabilitation are undertaken by WfWetlands. The first type involves the construction within artificial drainage channels of 'plugs' to assist in the recovery of the health of drained wetland areas. The second type involves the construction of erosion control structures which assist in halting the advance through a wetland of erosion headcuts, thereby arresting the wetland's declining health. The sites were chosen to represent both of these types: Killarney Wetland, Dartmoor Vlei and Kruisfontein Wetland, of the former type and Manalana Wetland, Kromme River Basin 1 Wetland (henceforth referred to as the Kromme) and Wakkerstroom Vlei of the latter type. The sites also represent a range of different land tenure types and land-uses (Table 1).

2 Methods

The rehabilitation outcomes were evaluated in terms of their effect either on the health of the rehabilitated wetland area or on its delivery of ecosystem services. Some were evaluated for both health and ecosystem services delivery.

Table 1: Sites examined in this assessment

Site name	Location	Land tenure and use
Killarney (only a portion of the entire wetland)	Formerly the Eastern Cape, now KwaZulu-Natal	Government owned land; formally protected nature reserve for nature conservation
Manalana	Mpumalanga Province	Communal land; cultivation and livestock grazing
Kromme	Eastern Cape	Private; limited livestock grazing
Dartmoor	KwaZulu-Natal	Private; limited livestock grazing
Kruisfontein	KwaZulu-Natal	Private; limited livestock grazing
Wakkerstroom	Mpumalanga	Municipal land; livestock grazing

The case studies were compared using the same approach, which is given in detail in *WET-RehabPlan* (Kotze *et al*., 2009a) section 3.9 and *WET-RehabEvaluate* (Cowden & Kotze, 2009) sections 11.2.1 & 12.8.2. For both health and ecosystem services, two scenarios are compared, the situation 'without rehabilitation' (i.e. no intervention) and the situation 'with rehabilitation'.

For both situations, the health of the wetland is scored on a scale of 0 (pristine) to 10 (critically altered/ degraded), and this is undertaken for the hydrology, geomorphology and vegetation components of health, using *WET-Health* (Macfarlane *et al*., 2009). The scores for these three respective components are integrated based on a weighted average ratio of 3: 2: 2, given that hydrology is considered to have the greatest contribution to health. For example, if hydrology, geomorphology and vegetation scored 4/10, 8/10 and 3/10, respectively then the integrated score would be ((4 x 3) + (8 x 2) + (3 x 2))/7 = 4.9. As indicated in *WET-Health*, these ratios may be modified with justification.

The benefit achieved in terms of health were determined by comparing the integrated score for the 'with rehabilitation' and the 'without rehabilitation' scenarios. Take, for example, a wetland of 60 hectares. Imagine that the health score without rehabilitation is 7 (seriously impacted) owing to the desiccating effect of a network of artificial drains. This translates to a hectare equivalent score of (10-7)/10 x 60 ha = 18 hectare equivalents of healthy wetland. Through the construction of rehabilitation plugs in the artificial drains, the health score may be predicted to be 2 (moderate impact). This translates to a hectare equivalent score of (10-2)/10 x 60 ha = 48 hectare equivalents of healthy wetland. Therefore the rehabilitation will effectively re-instate 48 – 18 = 30 hectare equivalents of healthy wetland.

The evaluation of the effect of rehabilitation interventions on the delivery of ecosystem services is based on assessing the extent to which rehabilitation will affect key characteristics, determining the delivery of services, as given in *WET-EcoServices* (Kotze *et al*., 2009b). For example, the pattern of low flows in a wetland has an important effect on the wetland's effectiveness in assimilating pollutants (the more diffuse the flow, the better). If by plugging drains, for example, the flow patterns in a wetland can be converted from very concentrated to very diffuse, then the effectiveness of the wetland in assimilating pollutants is likely to be markedly enhanced. Each of 15 ecosystem services listed in *WET-Ecoservices* is scored for the area affected by rehabilitation by comparing the same area 'with' and 'without' rehabilitation and scoring the difference in level of ecosystem delivery between the rehabilitated situation and the un-rehabilitated situation

(0=none/ negligible; 1=moderately low; 2=intermediate; 3=moderately high; 4= high and a '+' indicating an improvement and a '-' indicating a deterioration).

The rehabilitation at all of the six projects was undertaken by WfWetlands, and if costs of rehabilitation were calculated the following were included:

- Planning,
- Implementation (including management, labour, transport and material costs),
- Operating costs of WfWetlands related to the interventions (for monitoring of implementation and for maintaining financial controls),
- Projected maintenance costs for a 50 year period (determined by considering type of intervention [e.g. gabions generally have a higher maintenance requirement than concrete] and the erosion hazards of the site).

Application of the approaches described above for evaluating rehabilitation outcomes at the six individual case studies is reported in detail in Parts 2-7. Three of the case studies provide a more detailed description of further specific aspects of the project.

- The Killarney Wetland report provides a comprehensive description of the application of *WET-RehabEvaluate* (Cowden and Kotze, 2009) to a wetland rehabilitation project, including an evaluation of both the outputs and outcomes of rehabilitation. The wetland was chosen because it had been monitored in terms of hydrology and vegetation, including both a pre- and post-rehabilitation period.
- The Manalana Wetland report focuses specifically on an economic evaluation of the effect of the rehabilitation on the provisioning services supplied by the wetland to the livelihoods of local households (Part 3B). The wetland was chosen because it had already been the subject of a livelihoods study prior to rehabilitation, and data were therefore available relating to livelihoods.
- The Kromme River Wetland report focuses specifically on an evaluation of the structural integrity of the rehabilitation interventions. It is one of the longest running wetland rehabilitation projects in South Africa, and the circumstances under which the project is attempting to halt advancing erosion are very challenging, as there are large and rapidly advancing gullies in a system subject to high peak-discharges. Therefore the potential to draw out lessons from this case study was considered to be high.

3 The effect of rehabilitation on wetland health

The effect of rehabilitation on the overall health score of the wetland varies for the six different wetlands considered in this document (Table 2). Of the four presented in detail here, the greatest improvement in health was recorded for Wakkerstroom (difference = 3.7) and least in Dartmoor (difference = 1.3) and Killarney (difference = 1.4). The contribution in terms of hectare equivalents of health maintained or reinstated by rehabilitation is greatest in the Kromme, owing to the high contribution to the overall health score (see Table 12, Section 4) and to the large size of the area in which the health is positively affected (Table 2). Due to its small size, the lowest hectare equivalents of health maintained occurred in the Manalana Wetland.

Kotze *et al.* (2009a) refer to rehabilitation as a process, which can be expressed, in its simplest terms, by defining the starting point and the endpoint.[1] What is the wetland's health at the time of starting the rehabilitation intervention?

[1] At the same time it is accepted that wetlands are dynamic and evolve, and therefore wetlands in themselves do not have 'endpoints' in the true sense.

Table 2: A summary of the effect of rehabilitation on the health of the six wetlands

The situation without rehabilitation:	**Killarney**	**Manalana**[1]	**Kromme**[2]	**Dartmoor**	**Kruis-fontein**	**Wakker-stroom**
Hydrology	3.0			2.9	8.2	6.0[3]
Geomorphology	1.7			2.3	2.5	2.5[3]
Vegetation	3.2			2.0	9.0	5.0[3]
Overall health score	**2.7**			**2.5**	**6.8**	**4.7**
Hectare equivalents without rehabilitation[4]	**42.0**			**52.5**	**5.8**	**37.6**
The situation with rehabilitation:						
Hydrology	1.0			1.5	4.9	1.0
Geomorphology	1.0			0.7	2.0	0.5
Vegetation	2.2			1.3	4.5	1.5
Overall health score	**1.3**			**1.2**	**4.0**	**1.0**
Difference in health score due to rehabilitation	**1.4**			**1.3**	**2.8**	**3.7**
Hectare equivalents with rehabilitation[4]	**50.0**			**61.6**	**10.8**	**63.9**
Size of the area in which rehabilitation occurs (ha)	57.5 ha	3.4ha	147 ha	70 ha	18 ha	71 ha
Hectare equivalents of intact wetland re-instated/ maintained	**8 ha**	**1.0 ha**	**70.1 ha**	**9.1 ha**	**5.0 ha**	**26.3 ha**

Note:

- Health is scored on a scale of 0 (pristine) to 10 (totally degraded)
- The scores for these three respective components (Hydrology, Geomorphology and Vegetation) are integrated based on a weighted average ratio of 3: 2: 2, given that hydrology is the most defining driving force in a wetland and considered to have the greatest contribution to health.

[1] The scores for this wetland are available in Section 3A, Table 2. They are not presented here as there are two different portions to the wetland, but the overall secured hectare equivalent has been presented here for comparative purposes.

[2] The scores for this wetland are available in Section 4, Table 12. They are not presented here as there are three different Basins that were considered, but the overall secured hectare equivalent has been presented here for comparative purposes.

[3] The 'without rehabilitation situation' assumes that there will be extensive erosion, but the likelihood of this occurring is not high, as explained in the accompanying text.

[4] Hectare equivalents = (10 – health score)/10 x area of rehabilitation in hectares. For example, the hectare equivalents for the overall situation without rehabilitation for Killarney = (10 – 2.7)/10 x 57.5 = 42 hectare equivalents.

Is it close to pristine, totally degraded, or somewhere between these two ends of the continuum? Also, is the health stable, slowly declining, rapidly declining or, in some cases, improving (e.g. through the colonization by indigenous plants)? 'Stable' refers specifically to health and does not mean that ecologically the wetland is kept constant (e.g. a wetland with a stable health or integrity will still respond dynamically to changes in wetness between seasons and between wetter and drier years). The next question addressed is how have the rehabilitation interventions affected this state of health and its future change? (e.g. has the decline in wetland health been arrested?). The rehabilitation journeys of the six wetlands are summarised in Figure 1.

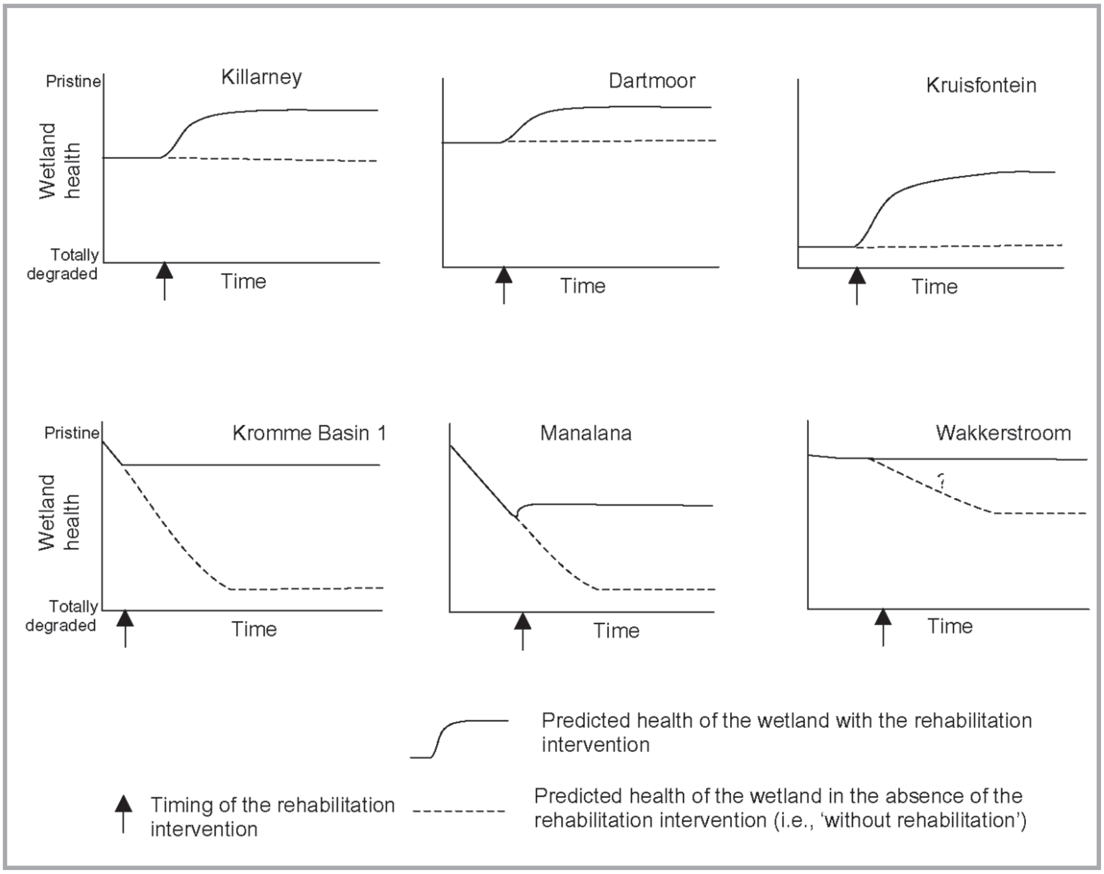


Figure 1: Schematic summary of the effect of rehabilitation interventions on the health trajectory of six selected wetlands

Of the three examples where health has been re-instated, Kruisfontein represents the greatest improvement in health. Kruisfontein Wetland, which had been very effectively and fully drained through cut-off drains and ridge and furrows across the wetland surface, was rehabilitated by plugging the cut-off drains and some of the ridge and furrowed areas. However, some of the influence of the drains and ridges and furrows still remain. Thus, it still falls well below a pristine state. Of the rehabilitation projects reviewed, it is noteworthy that none were found to move a system from being close to degraded to being close to pristine. This is probably owing to the difficultly, resources and time that are typically required to 'move' the health of a system such a great 'distance'.

Killarney and Dartmoor are similar in that both start in a much less degraded state than Kruisfontein and finish in a close to pristine state, although the Killarney system moves slightly further than Dartmoor. This has resulted from the fact that at Killarney the rehabilitation involved a greater density of plugs in the channels that were causing the desiccation of the system.

Of the three sites where health is being maintained by construction of erosion control structures, Kromme and Manalana are similar in that prior to rehabilitation the health of both of these wetlands was declining rapidly as a result of rapidly advancing headcut erosion. The main difference between the two sites is that the Kromme wetland was 'caught earlier' in its decline. Wakkerstroom differs markedly from the Kromme and Manalana sites in that prior to the rehabilitation interventions, no rapid decline in health was evident. The area of Wakkerstroom wetland under threat from erosion is an un-channelled valley bottom, with several channel arms extending into the downstream end of this area. In an airphoto-series analysis starting in 1937, it can be seen that these arms are dynamic, both extending (through erosion) and shortening. However, over the 70 year period in which it was examined, there has been only a very slight increase in the net collective length of these arms, and the threat of one or more of these arms advancing through the 71 ha area is considered low, given the very gentle slope of the wetland and other factors regarding the origin of the wetland discussed in Part 7.

4 The effect of rehabilitation on ecosystem service delivery

The effect of the rehabilitation on the delivery of ecosystem services varies greatly across the different sites (Table 3). The contribution towards regulatory and supporting services (e.g. flood attenuation, nitrate assimilation and erosion control) is greatest in the Manalana, Kromme and Kruisfontein sites, while the contribution to biodiversity is greatest in the Kromme, Dartmoor and Wakkerstroom sites. The contribution of the rehabilitation towards the provisioning services is generally low, except for the Manalana wetland, where it is very high, particularly in terms of maintaining suitable sites for cultivating foods.

Table 3: Anticipated difference in the delivery of ecosystem services by the six case study wetlands under a rehabilitated situation compared with an un-rehabilitated situation

Ecosystem service	**Wetland site**					
	Killarney	**Manalana**	**Kromme**	**Dartmoor**	**Kruisfontein**	**Wakkerstroom**
Flood attenuation	0	+2	+3	+1	+2	+1
Streamflow regulation	+1	+3	+3	+1	+2?	+2?
Sediment trapping	+1	+3	+3	+1	+2	+2
Phosphate assimilation	+1	+1	+1	+1	+2	+1
Nitrate assimilation	+1	+1	+1	+1	+3	+1
Toxicant assimilation	+1	0	+1	+1	+1	+1
Erosion control	+1	+3	+4	+1	0	+3
Carbon storage	+2	+2	+4	+1	+1	+3
Biodiversity maintenance	+1	+1	+4	+4*	+2	+4
Water supply for human use	+2	+2	+1	+1	+1	0
Natural resources	0	+2	0	0	+2	-1
Cultivated foods	0	+4	0	0	0	0
Cultural significance	0	+1	0	0	0	0
Tourism and recreation	+1	0	0	+1	+2	+2
Education and research	+2	+2	0	+2	0	+1
*Ranked contribution to general ecosystem delivery***	6	2	1	5	3	4

Difference in level of ecosystem delivery between the rehabilitated situation and the un-rehabilitated situation:

0=none/ negligible; 1=moderately low; 2=intermediate; 3=moderately high; 4= high; + =improvement, - =decline.

The values derived here are based on the absolute scores in the analysis of ecosystem services in each study, rather than on relative scores (e.g. if the with rehabilitation score was 0.6 and the without score 0.3, then this is considered a slight increase with a score of +1, even though it represents a 100% increase)

* Although the rehabilitation did not result in a substantial improvement in the biodiversity maintenance value as assessed with *WET-Ecoservices*, it was assigned a high score because it resulted in the Wattled Crane, a critically endangered species, breeding at the site

** 1= highest rank and 6= the lowest rank. Justifications for the scores assigned in above table are given in individual reports for the six respective rehabilitation sites

Dartmoor and Killarney are similar in that both have catchments consisting of almost entirely natural vegetation, with very low levels of human activity. The presence of mayflies and Elmidae beetles in influent waters at the Killarney site further suggest good quality water (Mangold and Moor, 1996). Thus, there is unlikely to be increased levels of nutrients or toxicants that could potentially be assimilated by the wetland (i.e. the opportunity to provide regulatory services are low). Furthermore, some of the features of the un-rehabilitated wetland are not a great distance below their optimal level (particularly in the case of Dartmoor), and thus the extent to which the effectiveness of the wetland in performing these services can be enhanced through rehabilitation is somewhat limited. This contrasts most strongly with Kruisfontein, which has a portion of its catchment used for fertilized pastures and dairy production, thereby providing opportunity for nutrient assimilation. Furthermore, several features (e.g. the pattern of flow and hydrological zonation) are at their lowest level in terms of the effectiveness of the wetland in supplying regulatory services. Thus, there is much that can be done to improve the effectiveness of the wetland. And, in fact, this is achieved in Kruisfontein by restoring a much more diffuse pattern of low flows and a much higher level of wetness.

As explained in Section 3 above, in the un-rehabilitated situation, both the Kromme and Manalana sites will be subject to severe gully erosion, and therefore the service that the wetland provides in controlling erosion would be severely compromised. In the rehabilitated situation, the Kromme site remains intact and well vegetated, and has a high effectiveness for controlling erosion, while the Manalana site is less effective because, although gully erosion is arrested, there is likely to be some sheet erosion from the cultivated portions of the site.

The primary reason for the high contribution of rehabilitation to biodiversity maintenance at Dartmoor is through re-instating the site's suitability as a breeding site for the critically endangered Wattled Crane. Although the hydrological health of the wetland had not been greatly diminished prior to rehabilitation, it was below the threshold level of wetness required by breeding Wattled Crane, given that Wattle Crane require permanently flooded conditions during the driest time of the year. The cranes had not been recorded breeding in the site for at least 15 years prior to rehabilitation, and in the year following the completion of the rehabilitation plugs, a pair of Wattled Crane bred in the wetland. Wattled Cranes also breed in Killarney wetland, but the natural slope of the portion being rehabilitated is insufficiently gentle to allow the level of ponding of water required by nesting Wattled Cranes. The biodiversity contribution at Wakkerstroom is also related to a critically endangered species, the White winged flufftail, for which the rehabilitated area provides suitable habitat, while in the Kromme it relates to the fact that the Kromme is one of only a few remaining large, intact palmiet wetlands, which is a wetland type that has been subject to very high cumulative impacts.

The contribution of rehabilitation to carbon storage is considerably higher at the Kromme site than at any of the others sites. In the rehabilitated situation, the Kromme site comprises an intact peat basin, with an average depth of 2 m (and maximum recorded depth of 4.75 m, Haigh *et al.*, 2002) and a total estimated volume of 1 760 000 m^3 of peat. It is conservatively estimated that without rehabilitation at least 704 000 m^3 of peat will be physically lost to erosion, given the dimensions of the advancing headcut, and over the next 50 years a further 53 000 m^3 will be lost to oxidation, owing to the much drier conditions of the eroded wetland. Thus, it is conservatively estimated that the rehabilitation has 'saved' 1 003 000 m^3 of peat. Following the Kromme, the next highest contribution of rehabilitation to carbon storage is at the Dartmoor site. Here the peat is an average depth of 0.8m (R Edwards, 2007; *pers. comm*.) giving a total volume of 560 000 m^3. However, the contribution of rehabilitation to maintaining the peat is less than in the Kromme site, given the fact that even under the situation of no rehabilitation, extensive areas of the wetland have a close to natural hydrology and no visible erosion. The contribution of rehabilitation to preventing the erosion of peat affects an estimated 1% of the wetland, and therefore 5 600 m^3 of peat. It is also estimated that over a 50 year period the oxidation of a further 21 840 m^3 of peat will be prevented as a result of re-instating close to natural hydrological conditions in 39% of the wetland that was partially drained. Thus, it is estimated that the rehabilitation will 'save' 27 440 m^3 of peat, more than 36 times less than the contribution at the Kromme site. In the other sites, peat is either absent (Kruisfontein) or weakly developed and shallow (Killarney and Wakkerstroom).

The Manalana site stands out very prominently above all of the other sites in terms of the contribution to provisioning services, despite the fact that the area of wetland affected positively by the rehabilitation is considerably smaller than was the case in all of the other sites. The most important contribution of rehabilitation at the Manalana site is through the food cultivated in the wetland, with 34 households, mainly poor, dependent on this source of food. The wetland also provides grazing for livestock (which is particularly valuable in late winter and early spring when forage is scarce elsewhere), water for livestock and human use, and reeds for producing crafts. Part 3 quantifies this contribution in detail.

5 Cost effectiveness of the rehabilitation interventions

As explained in Section 3 above, at the Wakkerstroom site the likelihood of extensive headcut erosion taking place is not high, although it is acknowledged that there is a possibility that it could occur. Thus, the rehabilitation interventions can be seen as 'an insurance measure' against possible future erosion. Even so, it would not be fair to compare the cost-effectiveness of this site to that of the others where the certainty is much higher. Thus, Wakkerstroom was omitted from the cost-effectiveness comparison given in Table 4.

Table 4: A comparison across five sites of the cost effectiveness of wetland rehabilitation in terms of health re-instated or maintained

	Killarney	Manalana	Kromme	Dartmoor	Kruisfontein
Cost of the rehabilitation interventions (R)	R1 623 000	R 861 256	R6 432 983	R541 430	R390 193
Projected costs of maintenance over a 50 year period (R)	R162 300	R 86 125	R643 298	R54 143	R39 019
Total costs of rehabilitation (R)	R1 785 300	R 947 382	R7 076 281	R595 573	R429 212
Hectare equivalents of intact wetland re-instated/maintained (R)	8 ha	1.0 ha	70 .1ha	9.1 ha	5 ha
Cost effectiveness (R ha-1)	**223 163**	**947 382**	**100 946**	**65 448**	**85 842**

Dartmoor and Kruisfontein are reasonably similar in terms of the cost effectiveness with which wetland health has been secured or re-instated (Table 4), and they fall into the category of intermediate to high cost effectiveness (Table 5). So too does the Kromme Wetland at approximately R100 000 per hectare equivalent of intact wetland. However, it should be noted that the figure presented here for the Kromme does not represent the full costs of rehabilitation (costs for years 2005 and 2006 are not available, Table 19 Section 4), and the final cost effectiveness figure may be considerably higher. In terms of secured health, the Manalana Wetland rehabilitation intervention was the least cost effective, costing nearly R1 million ha^{-1}, which is an order of magnitude less cost effective than the other three sites. Killarney was considered moderately cost effective for health.

Table 5: Cost-effectiveness of rehabilitation interventions

Cost of rehabilitation interventions per hectare of re-instated/ secured intact wetland	Likely cost-effectiveness
< R50 000 per ha	The cost-effectiveness of the project is likely to be high.
R50 000-R150 000 per ha	The cost-effectiveness of the project is likely to be intermediate to high.
R150 001-R300 000 per ha	The cost-effectiveness of the project is likely to be moderate but can be justified if returns in terms of ecosystem system delivery are moderate to high.
R300 001-R500 000 per ha	The cost-effectiveness of the project is likely to be low to intermediate, but can be justified if benefits are high. Therefore, benefits would need to be well justified.
>R500 000 per ha	Cost-effectiveness of the project is likely to be low. Such a project would need to be extremely well motivated such that it could only be justified if benefits are exceptionally high.

Except in the case of the Manalana Wetland where the provisioning services were quantified, the delivery of ecosystem services was not quantified, although it was scored. It is therefore not possible to quantitatively compare the cost-effectiveness of the rehabilitation at the different sites in terms of ecosystem service delivery. Nevertheless, based on the scores and the discussion reported in Section 4 above, the sites were subjectively ranked in terms of their cost-effectiveness from the perspective of ecosystem service delivery (Table 6).

Table 6: Cost-effectiveness of the rehabilitation in terms of broad ecosystem services delivery

Cost-effectiveness of the rehabilitation	Sites	Notes
High	Kromme	The contribution of rehabilitation to the delivery of most supporting and regulatory services (e.g. carbon storage and flood attenuation) is high.
Moderately high	Kruisfontein	The opportunity for the wetland to perform water quality-related functions is high given the location of the wetland downstream of a dairy and fertilized pastures.
Intermediate	Dartmoor, Manalana	The opportunity for Dartmoor wetland to perform water quality-related functions is low given the wetland's pristine catchment; the rehabilitation contributes significantly to enhancing the breeding habitat for the critically endangered Wattled Crane.The contribution of rehabilitation in the Manalana wetland to the delivery of provisioning (notably, cultivated foods) is high.
Moderately low	Killarney	The opportunity for Dartmoor wetland to perform water quality-related functions is low given the wetland's pristine catchment.
Low	None	-

The cost effectiveness assessment was based on the ecosystem assessment given in Table 3 considered in relation to the total cost of the rehabilitation given in Table 4.

Although the Killarney site scored as the least cost-effective of the four sites examined, from Part 2 it can be seen that there does not appear to have been a much more efficient way of achieving the objective of obtaining a health state as close as possible to pristine (i.e. for the particular circumstances and objectives, the project can be considered to have been cost effective). This highlights the fact that sites will vary in terms of the ease with which health can be re-instated or maintained. Killarney must be seen in the context that it is in a formally protected area where the priority was to attain a state of health for the wetland that was as close to pristine as possible. In this context it was considered to have been a cost effective project, and Part 2 highlights further that it was well implemented in relation to the objectives and rehabilitation plan and was evaluated as a successful project.

The results from the different study sites highlight that the relationship between wetland health and ecosystem service delivery may vary considerably from one site to the next depending on the particular characteristics and context of the wetland. The Manalana site highlights the importance of considering cost effectiveness not only in terms of health but also in terms of ecosystem service delivery. Despite the fact that the Manalana Wetland is considerably less cost effective than all of the other sites from the perspective of maintaining or re-instating wetland health, the detailed benefit-cost analysis undertaken in Part 3B, clearly demonstrates that the benefits of the rehabilitations well exceed the costs. Considering provisioning benefits alone over a 50 year period, the benefits were found to exceed two million rand, and were therefore approximately twice as much as the costs. If the regulatory and supporting services were added in the calculation, the benefit-cost ratio would be even more favourable.

6 Recommendations for further research and evaluation

The approach for evaluating the cost-effectiveness of projects applied in this study appears to have broad application across a wide variety of contexts. It is recommended that the approach should be applied to several more sites, which could be selected using stratified random sampling to provide an overview of the contribution of the WfWetlands programme to the health and ecosystem service delivery of South Africa's wetlands (i.e. the outcomes of the WfWetlands Programme). This evaluation of sites would also assist in developing norms and standards for future evaluations of wetland rehabilitation projects and for providing an improved basis for planning.

It is recommended further that detailed studies of reference wetlands be undertaken (such as that at the Manalana Wetland) from which ecosystem services delivery can be quantified, and against which more rapid evaluations can be validated. In these reference site studies it would be useful to quantify benefits derived from alternative uses of the wetlands (agriculture, development etc.) and compare these benefits with the costs and returns associated with rehabilitation. The Millennium Ecosystem Evaluation suggests that wetlands are often more valuable in their natural state than in a converted state, and these reference site assessments would test the extent to which this suggestion is supported.

7 References

Cowden C and Kotze DC, 2009. *WET-RehabEvaluate: Guidelines for the monitoring and evaluation of wetland rehabilitation projects.* WRC Report No. TT 342/09. Water Research Commission, Pretoria.

Edwards R, 2007. Scivest, PO Box 1899, Umhlanga Rocks, 4320; *pers. comm.*

Haigh EH, Grundling P-L, and Illgner PM, 2002. *Kromme River Peatland Complex. Report on the scoping study on the status of the Kromme River peatland complex and recommended mitigatory measures.* Unpublished report submitted to Department of Water Affairs and Forestry, Cradock.

Jordan WR (III), Gilpin ME and Aber JD, 1987. Restoration Ecology: ecological restoration as a technique for basic research. In: Jordan WR (III), Gilpin ME and Aber JD (eds.), *Restoration Ecology: A synthetic approach to ecological research*, Cambridge University Press, Cambridge, 3-21.

Kotze DC, Ellery WN, Rountree M, Grenfell MC, Marneweck G, Nxele IZ, Breen DC, Dini J and Batchelor AL and Sieben, E 2009a. *WET-RehabPlan: Guidelines for planning wetland rehabilitation in South Africa.* WRC Report No. TT 336/09. Water Research Commission, Pretoria.

Kotze DC, Marneweck GC, Batchelor AL, Lindley DS and Collins NB, 2009b. *WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands.* WRC Report No. TT 339/09. Water Research Commission, Pretoria.

Macfarlane DM, Kotze DC, Ellery WN, Walters D, Koopman V, Goodman P and Goge M. 2009. *WET-Health: A technique for rapidly assessing wetland health.* WRC Report No. TT 340/09. Water Research Commission, Pretoria.

Mangold ST and de Moor FC, 1996. A preliminary survey of the macroinvertebrate fauna of the rivers of the former Transkei region with notes on freshwater snails (Mollusca), freshwater prawns (Decapoda), Mayflies (Ephemeroptera), Caddisflies (Trichoptera) and Blackflies (Diptera: Simulidae). In: Bok A (ed.), *Survey of freshwater biota, amphibians and reptiles of selected areas in ex-Transkei.* Department of Economic Affairs, Environment and Tourism. Province of the Eastern Cape.

Rutherfurd IK, Jerie K and Marsh N, 2000. *A rehabilitation manual for Australian streams.* CRC for Catchment Hydrology and Land and Water Resources R&D Corporation, Canberra. Available from www.rivers.gov.au.

Woodhill J and Robins L, 1998. *Participatory Evaluation for Landcare and Catchment Groups: A Guide for Facilitators.* Greening Australia Yarralumla.

Part 2:
Performance evaluation of the wetland rehabilitation undertaken at Killarney Wetland in Ntsikeni Nature Reserve, KwaZulu-Natal Province

C Cowden, W Ellery, D Kotze, M Grenfell, D McCulloch, D Woods, S Grenfell and O Bambus

1 Introduction

The Ntsikeni Vlei, situated within the Ntsikeni Nature Reserve (NNR) in the upper reaches of the Gungununu River catchment near Franklin in KwaZulu-Natal, was identified in 2002 as a project area by the Working for Wetlands Programme (WfWetlands). The rehabilitation intervention within the upper Killarney Wetland, which forms part of the upper portion of the Ntsikeni Vlei, was identified as an appropriate case study to test the performance-evaluation technique outlined in *WET-RehabEvaluate* (Cowden and Kotze, 2009), since monitoring could be initiated prior to rehabilitation and continue after the rehabilitation was complete.

The aim of the study was to evaluate, using the *WET-RehabEvaluate* framework, the success of the rehabilitation in the Killarney Wetland in terms of both project outputs and outcomes, and based on monitoring before and after the installation of rehabilitation structures. Outputs are the interventions that are implemented (e.g. a concrete weir) to achieve the rehabilitation objectives, while outcomes are the effects of those interventions on the state of the wetland system (e.g. to re-instate a more diffuse water flow pattern in a given wetland area).

2 Background information

2.1 General description of Killarney Wetland

The Killarney Wetland is a channelled valley-bottom wetland that is one of the tributaries draining into the main Ntsikeni Vlei. It receives flow from the western part of the NNR and drains into the main body of the Ntsikeni Vlei east of the study area (Figure 1). In the vicinity of the study area, the wetland is characterised by the presence of two large gullies and two smaller gullies (Figure 2):

- a major gully occurs on the northern side of the wetland and crosses the wetland, from where it is confined to the southern side of the wetland. This gully extends upstream of the present study area and is labelled 'Main gully' in Figure 2
- a large gully is located on the northern side of the wetland, that also crosses the wetland, but which arises within the study area
- two small gullies occur on the southern side of the wetland, one of which arises within the study area while the other enters the wetland via a tributary from the south.

It is likely that the combination of increased runoff from poorly-managed grassland areas (overgrazing and frequent burning) and a poorly-planned road crossing, have served to increase and concentrate flow within the wetland, resulting in the formation of the identified gullies.

Wetland rehabilitation was historically undertaken in the smaller tributaries that drain into the Killarney Wetland, but a more recent rehabilitation plan identified the Killarney Wetland as a priority within the NNR. The focus of the wetland rehabilitation activities was to stabilise the largest gully and thereby minimise the impact of drainage on the Killarney Wetland. Therefore the intention was to promote increased flooding of the wetland in order to promote the establishment of hydric species more typical of seasonally and/or semi-permanently flooded soils.

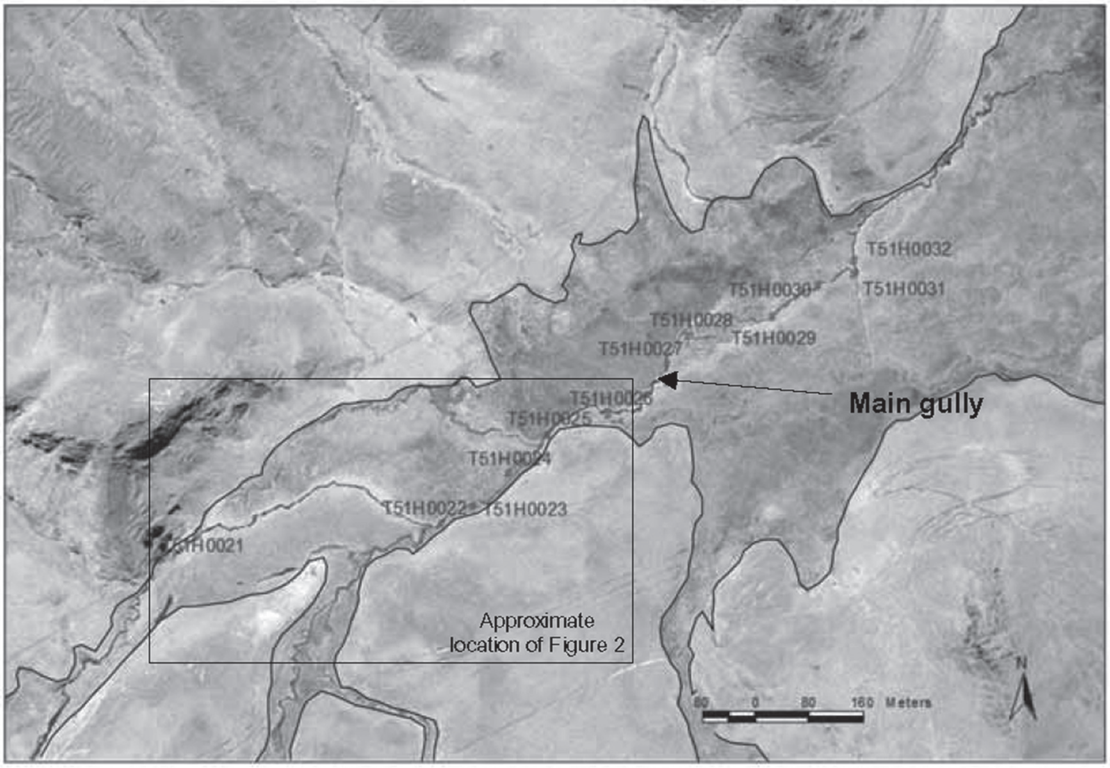


Figure 1: Location of the planned interventions within the Killarney Wetland system. The location of rehabilitation structures is shown according to intervention number (T51H0021 to T51H0032). The boundary of the wetland is shown

2.2 Detailed description of biophysical characteristics of the site

In accordance with *WET-RehabEvaluate*, transects were set up across the wetland (Figure 2) and the starting points and end points of the transects were recorded with a Global Positioning System (GPS) accurate to 1 m. The starting points and end points were permanently identified by planting iron fencing standards firmly in the ground. Sampling was based on the recording of information along each transect.

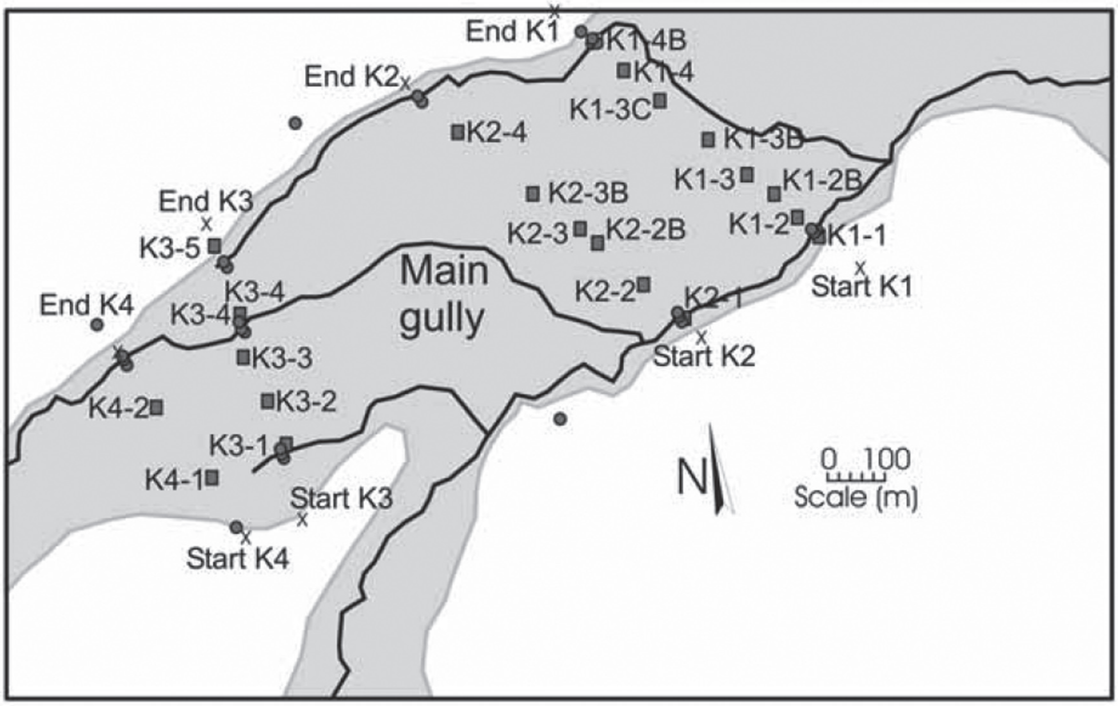


Figure 2: Location of transects and peizometers in relation to gullies on the site

The series of cross-sections (K1, K2, K3 and K4) illustrated in Figure 3 depicts the relative elevation of the land surface, groundwater and bedrock across the valley floor, as determined using a dumpy-level survey and coring/auguring in April 2005. The profiles are presented in order from the top of the page to the bottom of the page from the most upstream site going downstream. It is clear from the cross-sections in that the relative elevation of the valley floor decreases fairly systematically from K4 through to K1.

In general the cross-sections also reveal that there is a slope across the valley from north to south, with the northern side of the valley being at a slightly higher elevation than the southern side.

In all cross-sections, there is a major gully present that drains the main catchment area of the wetland to its west. In the upper two cross-sections, this gully is on the northern side of the valley. Between transects K3 and K2, the main gully crosses the valley so that in the lower two cross-sections it occurs on the southern side of the valley (see Figure 2). It is surprising that the gully should occur on the more elevated northern side of the valley in the two upper sites.

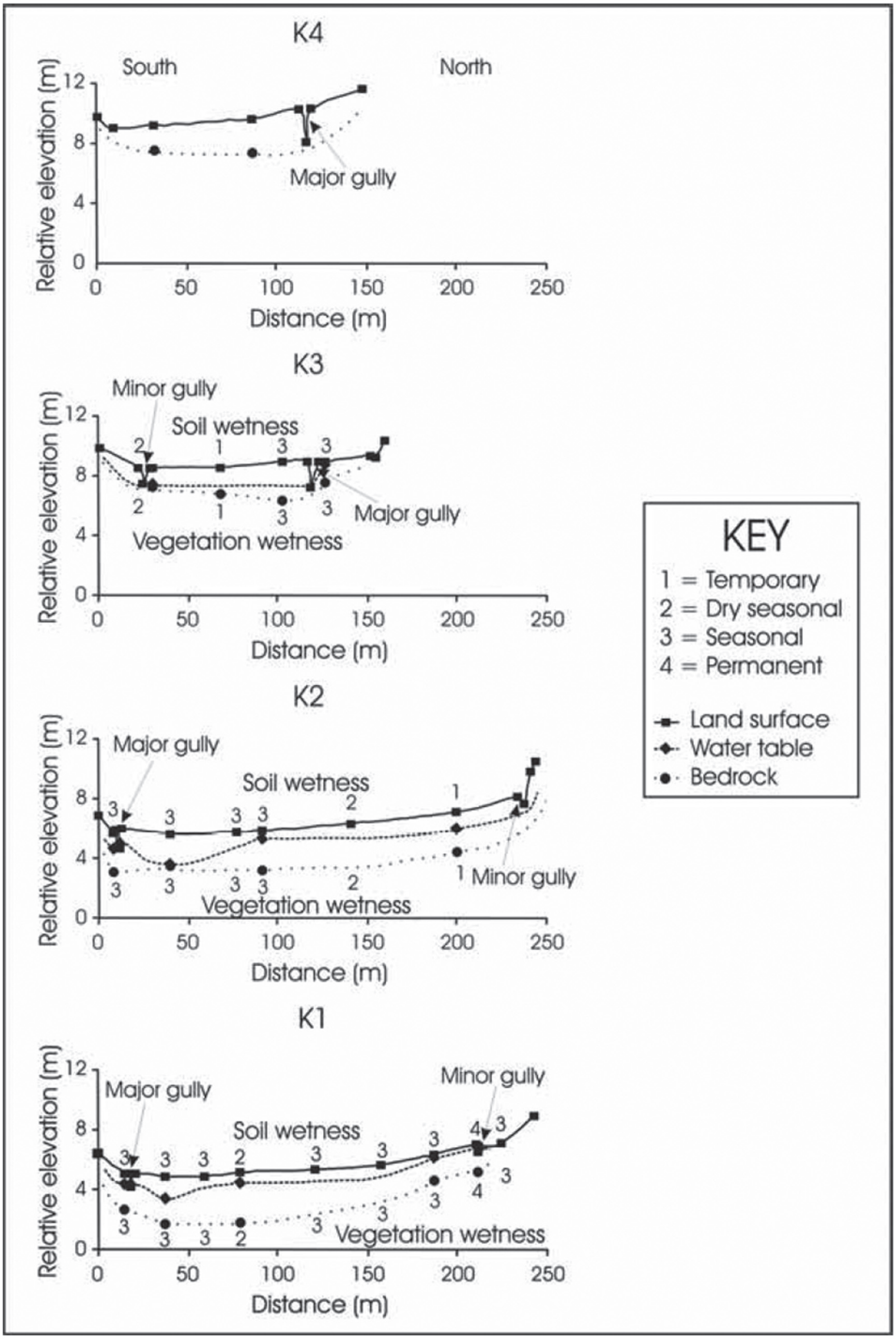


Figure 3: Cross-sections of Killarney Wetland displaying topography, soil and vegetation wetness, and depth to water table and bedrock

In the lower three cross-sections there is also a minor gully present on the northern edge of the wetland. In the case of site K3 there is also a minor gully present on the southern side of the wetland. The minor gullies arise within the valley itself, being a product of erosion that arises as a consequence of runoff entering the valley from the adjacent hillslopes.

The depth to bedrock is typically 2-3 m below surface, and the bedrock floor is typically fairly flat, in most cases flatter than the land surface. Based upon field descriptions, the fill material comprises a mixture of fine sand, silt and clay, suggesting that the energy of flow within the valley is variable.

The elevation of the water table is generally greater than 0.5 m below surface, which at the end of the wet season is somewhat surprising. It may be accounted for by a dry summer season, or alternatively by lowering of the water table due to gullying. Unfortunately, it was not possible within the available time to measure the depth to the water table at the uppermost transect. Nevertheless, a general feature of the data was a general increase in water table depth upstream in the study site. Furthermore, a surprising feature of the water table is its occurrence at a particularly low elevation on the southern side of the valley at sites K2 and K1, which probably is an effect of the gully. Rehabilitation would be expected to lift the water table in this region in particular.

Table 1: Soil wetness zones (after Kotze *et al.,* 1994)

	Soil wetness zones			
SOIL DEPTH	**Non-wetland**	**Temporary**	**Seasonal**	**Permanent / Semi-permanent**
0-10 cm	Matrix usually brown/red (chroma >1)[1] No/very few mottles Low OM[2] Nonsulphidic[3]	Matrix brown to greyish brown (chroma 0-3, usually 1 or 2)[1] Few/no mottles Low / Intermediate OM[2] Nonsulphidic[3]	Matrix brownish grey to grey (chroma 0-2)[1] Many mottles Intermediate OM[2] Sometimes sulphidic[3]	Matrix grey (chroma 0-1)[1] Few/no mottles High OM[2] Often sulphidic[3]
30-40 cm	Matrix usually brown (chroma >2) No/few mottles	Matrix greyish brown (chroma 0-2, usually 1) Few/many mottles	Matrix brownish grey to grey (chroma 0-1) Many mottles	Matrix grey (chroma 0-1) No/few mottles
VEGETATION	Dominated by plant species which occur extensively in non-wetland areas; hydrophytic species may be present in very low abundance	Predominantly grass species; mixture of species which occur extensively in non-wetland areas, and hydrophytic plant species which are restricted largely to wetland areas	Hydrophytic sedge and grass species which are restricted to wetland areas, usually <1 m tall.	Dominated by: (1) emergent plants, including reeds (*Phragmites australis*), sedges and bulrushes (*Typha capensis)*, usually >1 m tall (marsh); or (2) floating or submerged aquatic plants.

[1] Chroma refers to the relative purity of the spectral colour, which decreases with increasing greyness. To determine chroma, a Munsell colour chart is required. If this is not available then in order to characterise the colour of the soil matrix, use the following colour descriptions, given in order of increasing greyness: Brown/Red, Greyish brown, Brownish grey, Grey.

[2] High OM: soil organic carbon is greater than 5% and often exceeds 10%.

Low OM: soil organic carbon is less than 2%

Intermediate OM: soil organic carbon is between 2% and 5%

[3] Sulphidic soil material has sulphides present which give it a characteristic 'rotten egg' smell, and nonsulphidic material lacks sulphides.

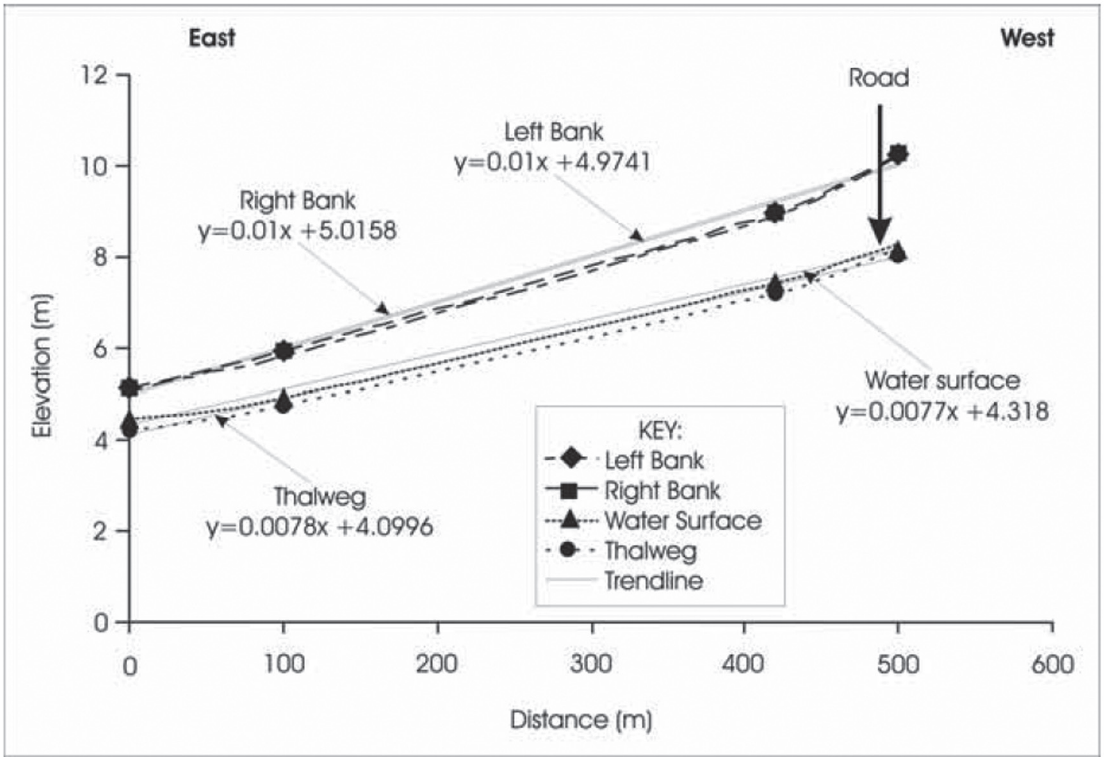


Figure 4: Longitudinal profile of the gully bed (thalweg), water surface and both banks of the Killarney Wetland

Based upon soil characteristics it is possible to determine the degree of wetness of the site (Table 1; modified after Kotze *et al*., 1994), the results of which are summarised in Figure 3. There was surprising co-incidence of the indications of wetness based upon vegetation and soils, suggesting that the present site conditions have been present for years to decades.

The slope on the valley was shallow at approximately 1%, while the slope on the bed of the gully (thalweg: the lowest point on the floor of a stream or gully at any location along its length) was lower at approximately 0.8% (Figure 4).

3 Rehabilitation performance evaluation

WET-RehabEvaluate (Cowden and Kotze, 2009) recommends that the project objectives are revisited prior to the implementation of the evaluation of a wetland rehabilitation project, to ensure that the objectives clearly outline the project goals and are useful in the performance evaluation process. The project objectives are described as needing to be SMART:

- Specific
- Measurable
- Achievable
- Relevant,and
- Time-framed.

The primary objective of the rehabilitation within the Killarney Wetland was to restore more permanent flooding of the wetland between the two gullies that cross the wetland downstream of the road crossing such that species characteristic of seasonally to permanently flooded conditions reestablish at the site. The objective is considered to meet a number of the abovementioned criteria, except that it lacks specific timeframes, but this is inferred as being the amount of time required for vegetation to respond to improved hydrological health (two to five years).

4 Methodology

4.1 Levels of monitoring

The performance evaluation of wetland rehabilitation activities relies on the collection of data to assess the changes in the wetland's features and characteristics associated with the rehabilitation. The monitoring and evaluation of the Killarney Wetland rehabilitation project was based on the principles outlined in *WET-RehabEvaluate* (Cowden and Kotze, 2009). To account for the limitations associated with the time and costs of monitoring and performance evaluation, *WET-RehabEvaluate* distinguishes between different levels of monitoring to assess the performance of wetland rehabilitation activities:

- Level 1: assessment of execution and social outputs;
- Level 2: rapid assessment of rehabilitation outcomes; and
- Level 3: comprehensive assessment of rehabilitation outcomes, generally linked to specific indicators.

Generally, wetland rehabilitation within the WfWetlands programme would be assessed based on the results of Level 1 and 2 assessments due to the large number of projects and their distribution throughout the country. The selection of the Killarney Wetland rehabilitation as a case study for the WRC Research project, meant that it was possible to conduct all three levels of assessment in order to evaluate project success.

4.2 Level 1 monitoring

The collection of information required for the majority of the Level 1 monitoring was undertaken as part of the management and implementation of the Killarney Wetland rehabilitation by Highland Wetland Rehabilitation (HWR) and WfWetlands. The required information was supplied by the respective parties for incorporation into this report. The supplied information included details on the following aspects of the project:

- costs
- compliance with BMPs
- employment, target groups and remuneration, and
- training.

In addition to the supplied information, a site visit was undertaken following the completion of the interventions to determine if the interventions were constructed in accordance with the designs and to assess the structural integrity of the interventions. As per *WET-RehabEvaluate*, the monitoring of structural stability and integrity focussed on the presence of the following forms of structural vulnerability:

- undermining
- sliding, tilting or overturning
- side bank collapse
- scouring/erosion downstream
- scouring/erosion upstream
- side cutting around structure
- exposed soil, and
- premature decay of the structural material (e.g. gabion wire, earthwork settlement).

The productivity and efficiency of the rehabilitation was not assessed for the Killarney Wetland rehabilitation project as it was considered unlikely to generate realistic figures due to the unique nature of the site in terms of its remote location and limited accessibility. It is important to note that the Killarney Wetland rehabilitation project formed part of a cluster of projects, and as such the supplied data was considered to be somewhat vague, and was in some instances based on estimates rather than on accurate data.

4.3 Level 2 monitoring

The Level 2 monitoring required the collection of baseline information and a site visit was undertaken prior to the initiation of wetland rehabilitation activities in 2004. Most of the rehabilitation structures were completed in 2005/2006. A subsequent site visit was carried out in 2007 following the completion all of the rehabilitation interventions and the information was then compared to assess the changes in the wetland. As outlined in *WET-RehabEvaluate*, outcomes of the wetland rehabilitation were assessed in terms of the effects on:

- ecosystem health; and
- the delivery of ecosystem services.

The health of the wetland system was described using *WET-Health* (Macfarlane *et al.*, 2009) and the delivery of ecosystem services was described using *WET-EcoServices* (Kotze *et al.*, 2009a). Ecosystem health is taken to be synonymous with ecosystem integrity. Using *WET-Health* it was possible to derive hectare equivalents to compare the health of the wetland before and after rehabilitation, as described in *WET-RehabEvaluate*.

4.4 Level 3 monitoring

Generally, Level 3 monitoring activities comprise finer scale and more intensive monitoring of the characteristics of the wetland. It is recommended that baseline monitoring of both the rehabilitation site and a reference site be undertaken to provide comparative data following wetland rehabilitation (Cowden and Kotze, 2009). In this instance the implementation of the Level 3 monitoring was limited to monitoring specific indicators, as the project had relevance to key research questions, as well as being accessible to research bodies and personnel.

The objectives of the rehabilitation were to stabilise the gully, raise the water table and promote diffuse flow, in order to encourage growth of vegetation typical of a seasonally or permanently flooded wetland. The Level 3 monitoring thus required detailed studies of ground water elevation, vegetation species composition and morphological change of the gullies.

4.4.1 Groundwater elevation

The elevation of the land surface, depth to bedrock, extent of valley fill, indications of soil wetness and groundwater elevation within the Killarney Wetland were measured based on auger holes and permanent peizometers at different locations along each transect. The location of these sample points was initially surveyed with a dumpy level and then recorded using a GPS accurate to 1m. Rather than the biannual sampling recommended in *WET-RehabEvaluate,* the sampling frequency was increased to monthly monitoring, undertaken by Highland Wetland Rehabilitation (HWR).

4.4.2 Vegetation species composition

The *WET-RehabEvaluate* technique of monitoring vegetation was used to determine the vegetation communities that occur in the Killarney Wetland system. This included:

- broad-scale classification of the vegetation types (sedge meadow, wet grassland) within the wetland;
- field assessments of each vegetation type detailing the composition and relative contribution of the species present to the communities; and

- description of the hydric status of dominant species.

A series of 5 m x 5 m quadrats were sampled at intervals along three transects across the wetland (Figure 2). The position of the quadrats coincided with discernable changes in vegetation type.

4.4.3 Gully cross sections

Gully cross-sections were surveyed with a dumpy level along the transect lines, and post-rehabilitation data was compared with cross-sections surveyed during the initial site visit, to determine whether there had been any infilling or alteration of gully morphology since the completion of the rehabilitation. This would provide some indication of the impacts of the rehabilitation on the system's geomorphology.

5 Results

Generally, the information collected for the Level 1 monitoring was compared to the anticipated or projected values from the rehabilitation-planning process or the expectations of the WfWetlands programme. The Level 2 and 3 monitoring comprised a comparison of pre- and post-rehabilitation information to assess the change in the Killarney Wetland system potentially caused by the rehabilitation intervention.

5.1. Level 1 monitoring

WET-RehabEvaluate outlines that the monitoring required for this level relies on the existence of an information management system to record the information relating to the planning, design, and implementation of the wetland rehabilitation operations. The information relating to the implementation and management of the wetland rehabilitation is currently recorded on WfWetland's In-Form system and WET-PIS (WfWetland's Planning Information System).

However, discussions and correspondence with HWR highlighted that the recording of information for implementation is generally not assigned to specific wetlands. In this instance the Killarney Wetland rehabilitation project forms part of a cluster of projects, and the costs and materials associated with all the projects within the cluster were taken from information from other projects, such as Penny Park. Where possible, HWR supplied information relating to the implementation of the rehabilitation activities, but did caution that these values were estimates derived from the information recorded for the cluster.

5.1.1. Costs and materials

Without the site visits being conducted on a daily basis to record the inputs into each intervention as stores records, it is not possible to determine the quantities of materials used for the construction of the structures within the wetland. It was therefore assumed that if the interventions were constructed in accordance with the design specifications, it is likely that the required materials specified in the rehabilitation plan's Bill of Quantities (Table 2) were used for construction. The interventions within the Killarney Wetland were thus assessed in terms of the extent to which they complied with the technical designs in the rehabilitation plan, including spillway width, key wall-length, and shoulder wall-length. The general compliance of the interventions with the designs is also reported in the WfWetlands Project Inspection Report.

Table 2: Bill of Quantities for the interventions in Killarney Wetland

	Pockets of Cement	Sand (m^3)	Stone (m^3)	Rock (m^3)	Earth work (m^3)	Concrete work (m^3)	High tensile steel mesh reinforcing Ref. no. 517 (Apron)	High tensile steel mesh reinforcing Ref no. 888 (Heel)
Estimated Quantities: Planning	731	78.6	80.9	38	1050	152.3	20	5

The 2006 rehabilitation plan included the interventions within the Killarney Wetland system shown in Table 3, together with the estimated costs in the rehabilitation plan as well as the implementation plan.

Table 3: List of interventions and the planned and estimated costs

Intervention no.	Design Type	Estimated Costs: Planning	Estimated Costs: Project Implementation Plan
T51H0021	Concrete weir	R115 639.00	R107 475.41
T51H0022	Concrete weir	R94 966.00	R102 055.29
T51H0023	Concrete weir	R79 461.00	R89 744.29
T51H0024	Concrete weir	R81 400.00	R89 840.29
T51H0025	Concrete weir	R89 152.00	R88 480.29
T51H0026	Concrete weir	R108 533.00	R96 674.29
T51H0027	Concrete weir	R100 780.00	R89 853.29
T51H0028	Concrete weir	R70 417.00	R82 197.83
T51H0029	Concrete weir	R70 417.00	R80 849.29
T51H0030	Concrete weir	R83 984.00	R83 229.28
T51H0031	Earthen berms	R133 204.00	R114 109.00
T51H0032	Concrete weir	R89 152.00	R99 192.28
TOTAL		R1 117 105.00	R1 123 700.83

The individual costs of a further six structures, T51HA to T51HF were not available, but collectively they were determined to be R499 300 in the project implementation plan, giving an overall implementation cost of R1 623 000 for the Killarney Wetland.

The difference in Table 3 between R1 117 105 and R1 123 700 in the cost of the interventions were considered to be associated with a number of issues:

- The remote location resulted in increased costs linked to transport, camping and camping allowances,
- The recording of data for the Killarney Wetland rehabilitation project together with several other rehabilitation projects in an overall cluster resulted in difficulty in allocating costs to specific individual projects.

5.1.2 Structural integrity of interventions and dimensions of interventions

The interventions within the Killarney Wetland were assessed in terms of their structural integrity. Generally, the interventions were considered to be structurally sound (Table 4), but in some instances it appears that the concrete on the spillway was subjected to corrosion associated with perennial flow. The structural interventions within the Killarney Wetland were also assessed in terms of their compliance with the designs specified within the rehabilitation plans compiled for the wetland system. The majority of the interventions were recorded as having been constructed in accordance with the designs specified in the rehabilitation plans for the Killarney Wetland (Table 4).

In some instances there was some variation from the designs (Table 4), but these were noted as posing a low risk to the structural interventions' integrity and can probably be attributed to inexperienced contractors and use of unskilled labour.

Table 4: List of interventions, recorded comments on structural integrity and suggestions for corrective action

Intervention no.	Comments on Structural Integrity	Recommended Corrective Action
T51HA	No evidence of risk to the concrete weir's structural integrity was recorded. However, the spreader canal was identified as redirecting base flow across the wetland into an existing channel, which appears to have resulted in the formation of a small-scale multiple-step headcut at the outflow of the spreader canal.	Realign the spreader canal to a lower slope and excavate outlets at intervals on the downstream side of the spreader canal in order to increase the area across which flow is spread. This will reduce the potential for erosion.
T51HB	No evidence of risk to the concrete weir's structural integrity was recorded, except for what appeared to be slight corrosion of the spillway associated with perennial flow.	Monitor the corrosion/wear of the spillway to ensure that the level of the spillway still achieves the specified objectives.
T51HC	No evidence of risk to the concrete weir's structural integrity was recorded.	N/A
T51HD	No evidence of risk to the concrete weir's structural integrity was recorded.	N/A
T51HE	No evidence of risk to the concrete weir's structural integrity was recorded, except for what appeared to be slight corrosion of the spillway associated with perennial flow.	Monitor the corrosion/wear of the spillway to ensure that the level of the spillway still achieves the specified objectives.
T51HF	No evidence of risk to the concrete weir's structural integrity was recorded, except for what appeared to be slight corrosion of the spillway associated with perennial flow.	Monitor the corrosion/wear of the spillway to ensure that the level of the spillway still achieves the specified objectives.
T51H0021	No evidence of risk to the concrete weir's structural integrity was recorded and the outflow of the pipe appears to be stable with no evidence of scour. A slight variation on design was necessary to accommodate the site characteristics, with sheet rock along the left hand side of the channel preventing compliance with the design, which was modified by reducing the spillway width and altering the shoulder wall design to follow the rock outcrop.	N/A
T51H0022	No evidence of risk to the concrete weir's structural integrity was recorded and the intervention appeared to be constructed in accordance with the design.	N/A
T51H0023	No evidence of risk to the concrete weir's structural integrity was recorded, except for what appeared to be slight corrosion of the step below the spillway associated with perennial flow. A slight variation in the design was recorded with key walls extending further than the design specifications.	Monitor the corrosion/wear of the step to ensure that the structure remains stable.
T51H0024	No evidence of risk to the concrete weir's structural integrity was recorded, but the spillway width was identified as being slightly wider than the design specifications.	N/A

T51H0025	No evidence of risk to the concrete weir's structural integrity was recorded, except for what appeared to be slight corrosion at the base of the key walls and shoulder wall where perennial flow concentrates slightly. A slight variation in the design was recorded with key walls extending further than the design specifications.	Monitor the corrosion/wear to ensure that the structure remains stable.
T51H0026	No evidence of risk to the concrete weir's structural integrity was recorded. However the pipe at the base of the spillway wall has not been blocked to force water to flow over the spillway. A slight variation in the design was recorded with key walls extending further than the design specifications.	Block the pipe to raise the water level within the channel upstream of the intervention to the height of the spillway.
T51H0027	No evidence of risk to the concrete weir's structural integrity was recorded, but the flood levels do not appear to flood back to the upstream intervention (T51H0026) and the flow is relatively high in velocity. This potentially could result in scouring of the channel downstream of the intervention further upstream.	The possibility of raising the spillway to flood back to the toe of intervention T51H0026 should be investigated to attempt to slow water flow within the channel, reducing the risk of scour downstream.
T51H0028	No evidence of risk to the concrete weir's structural integrity was recorded, except for what appeared to be slight corrosion at the base of the shoulder walls and the step below the spillway where perennial flow occurs.	Monitor the corrosion/wear to ensure that the structure remains stable.
T51H0029	No evidence of risk to the concrete weir's structural integrity was recorded.	N/A
T51H0030	No evidence of risk to the concrete weir's structural integrity was recorded.	N/A
T51H0031	No evidence of risk to the concrete weir's structural integrity was recorded. A slight variation in the design was recorded, with spillway width being wider than the design specifications.	N/A
T51H0032	No evidence of risk to the earthen berm's structural integrity was recorded.	N/A

5.1.3 Employment and target groups and remuneration

The information relating to the personnel involved in the rehabilitation of the Killarney Wetland (Table 5) was obtained from HWR.

It should be noted that the information obtained from HWR for the Ntsikeni project is not considered to be representative of the region's performance in terms of compliance with WfWetlands' targets due to the limitations associated with the remote location of the site and difficult working environment.

Table 5: Composition of the teams employed to rehabilitate the Killarney Wetland

	Actual Employment		WfWetlands targets
	Numbers	Percentage	
Men	42	64%	-
Disabled	0	0%	2%
Women	24	36%	60%
Youth	9	14%	20%
Remuneration (daily)	R46.00		

5.1.4 Training

The information relating to the training received by personnel involved in the rehabilitation of the Killarney Wetland (Table 6) was obtained from HWR. Given the training-days reported, the project has met the Working for Wetlands' target number of training days. Training is included to improve the quality of work on the project and to improve the likelihood of participants obtaining further work when they are finished working on the project. Assessing such long-term socio-economic impacts was beyond the scope of this assessment but is addressed in an assessment by Nkoko and Macun (2005).

Table 6: The number of training days for project staff employed to rehabilitate the Killarney Wetland

	Actual Training Days	WfWetlands' Required Training Days[1]
Training Days	765	764

[1] It should be noted that WfWetland requires that for every 20 days worked on a project, 2 days be allocated for personnel training. HWR recorded 7644 days of work for the project, which equates to 764.4 training days.

5.1.5 Project inspection report and audits

Level 1 monitoring was also carried out by the WfWetlands Regional Co-ordinator, which is reported in the form of a Project Inspection Report (PIR), and an external audit was undertaken by Price Waterhouse Cooper in 2006, of the WfWetlands projects.

The PIR compiled by the WfWetlands Regional Co-ordinator reported the following:

- All interventions were considered to be complete and in compliance with the rehabilitation plans.
- The quality of work was considered to be of a good standard.

The wetland rehabilitation activities undertaken were considered to be in accordance with the WfWetlands' best management practices, including compliance with WfWetlands' requirements in terms of Employment and Target Groups, Remuneration and Training.

The summary report compiled by Price Waterhouse Cooper (2006) stated the following:

- The interventions were found to have contributed to improving the overall ecological health by preventing erosion, increasing sedimentation, and rewetting the wetland systems.

- The concrete structural interventions were considered to have generally complied with the specifications and have reduced maintenance costs, enabled rewetted areas to be maximized and in some instances, were more cost effective than other interventions.
- The management, control and reporting for the project as a whole was adequate. However approved technical drawing and amendments should all be available in the rehabilitation plan.

5.2 Level 2 monitoring

WET-RehabEvaluate recommends that the monitoring required for this level relies on the collection of information for the pre- and post-rehabilitation scenarios within the identified wetland system. Ideally this information should be stored on an information management system in order to allow various researchers to access available information relating to a wetland and to carry out subsequent monitoring in a manner that is consistent with the initial monitoring. For the Killarney Wetland, the pre- and post-rehabilitation assessments were implemented by the same individuals, minimising the risk of loss of data or inconsistencies in its collection.

5.2.1 Assessment of wetland ecosystem service delivery

The assessment of the ecosystem service delivery highlighted the importance of the system in terms of maintaining biodiversity and stream flow regulation, with the wetland also providing benefits and services associated with sediment trapping, erosion control and phosphate assimilation (Table 7). The assessment of the level of service delivery after rehabilitation identified a number of positive impacts on the ecosystem services supplied by the Killarney Wetland rehabilitation project. It is important to note that some of the increases in ecosystem service delivery are associated with changes in the management of the nature reserve rather than being directly linked to the wetland rehabilitation activities, but the extent to which rehabilitation or reserve management have contributed to altered ecosystem service delivery is recorded in Table 7. According to the assessment the greatest contributions of the rehabilitation project are carbon storage (resulting from the increased level of wetness) and education and research. Although the effectiveness of the wetland in assimilating nutrients and toxicants has been enhanced by the rehabilitation project, the wetland is afforded little opportunity for performing these services due to the wetland's pristine catchment.

Table 7: Ecosystem service delivery by Killarney Wetland before and after rehabilitation

Ecosystem Services	Pre-Rehabilitation	Post-Rehabilitation	Notes
Flood attenuation	1.71	1.69	Slight loss in function linked to reduced runoff from improved grassland areas in the catchment and increased wetness within the wetland
Stream flow regulation	2.67	3.00	Increased functioning associated with the increase in wetness zones and promotion of diffuse flow across the wetland due to rehabilitation
Sediment trapping	2.27	2.39	Slight increase in function linked to the interventions serving to trap sediment within the channel. The benefits would be greater but have been diluted by the reduced sediment load associated with the improvement in the grassland areas linked to the newly adopted mosaic burning-regime
Phosphate trapping	2.03	2.24	Increased functioning associated with the increase in wetness zones and promotion of diffuse flow across the wetland due to rehabilitation
Nitrate removal	1.80	2.30	Increased functioning associated with the increase in wetness zones and promotion of diffuse flow across the wetland due to rehabilitation
Toxicant removal	1.92	2.26	Increased functioning associated with the increase in wetness zones and promotion of diffuse flow across the wetland due to rehabilitation
Erosion control	2.46	2.67	Increased functioning associated with stabilisation of incising channel and increased vegetative cover due to rehabilitation
Carbon storage	1.67	2.33	Increased functioning associated with the increase in wetness zones and promotion of diffuse flow across the wetland due to rehabilitation
Maintenance of biodiversity	3.25	3.56	Increased functioning associated with the increase in wetness zones and consequent change in species composition due to rehabilitation
Water supply for human use	0.61	1.00	Increased functioning due to opportunity due to increased water availability linked to rehabilitation
Natural resources	1.80	1.80	Functioning linked to opportunity as the nature reserve does not permit access to community members for harvesting of natural resources
Cultivated foods	1.60	1.60	Functioning linked to opportunity as the nature reserve does not permit access to community members for cultivation of foods in the wetland
Cultural significance	1.00	1.00	No known cultural significance
Tourism and recreation	1.86	2.71	Increased importance due to improved aesthetics (more dense vegetation), but mostly linked to increase in tourism facilities (not linked to rehabilitation)
Education and research	1.50	2.50	Increased importance due to the WRC research carried out on the site and generally pristine nature of the site

Note: the scores for delivery of service range from 0 (minimum) to 4 (maximum), and were derived through the application of *WET-EcoServices* (Kotze *et al*., 2009a).

Table 8: Hydrological, geomorphological and vegetation impact on health scores for Killarney Wetland before and after rehabilitation (terms and scores are explained in the text)

Scenarios	Health		
	Hydrology	Geomorphology	Vegetation
Pre-Rehabilitation	3.0 (moderate)	1.7 (small)	3.2 (moderate)
Post-Rehabilitation	1.0 (small)	1.0 (small)	2.2 (moderate)

5.2.2 Assessment of wetland health

The assessment of the health of the wetland system showed that rehabilitation improved the hydrological, geomorphological and vegetation health as shown in Table 8 above. Health is related to impacts such that a low score (close to 0) indicates little or no impact and therefore good health, while a high score (close to 10) reflects critical impacts and poor health.

Prior to rehabilitation the hydrological and vegetation health were moderately impacted such that health is described as moderately modified. In contrast the geomorphic health could be described as largely natural. Following rehabilitation both the hydrological and geomorphologic health can be described as largely natural but the vegetation health remained moderately modified. It is likely that the vegetation health will improve by a health category and possibly by two categories given sufficient time, although this will depend on the extent to which the native vegetation is able to compete against the invasive alien grass, *Phalaris arundinacea* (see Section 5.3.2).

5.3 Level 3 monitoring

5.3.1 Water level monitoring

Fourteen peizometers were installed on 14 April 2005 and intensive monitoring of water table elevation was conducted over a period 9 August to 17 October 2005, which was prior to the construction of the rehabilitation structures. The rainfall that fell during this period was also measured and has been recorded in Figure 5. Rain fell intermittently during this period, with three rainfall events of 10 mm or more.

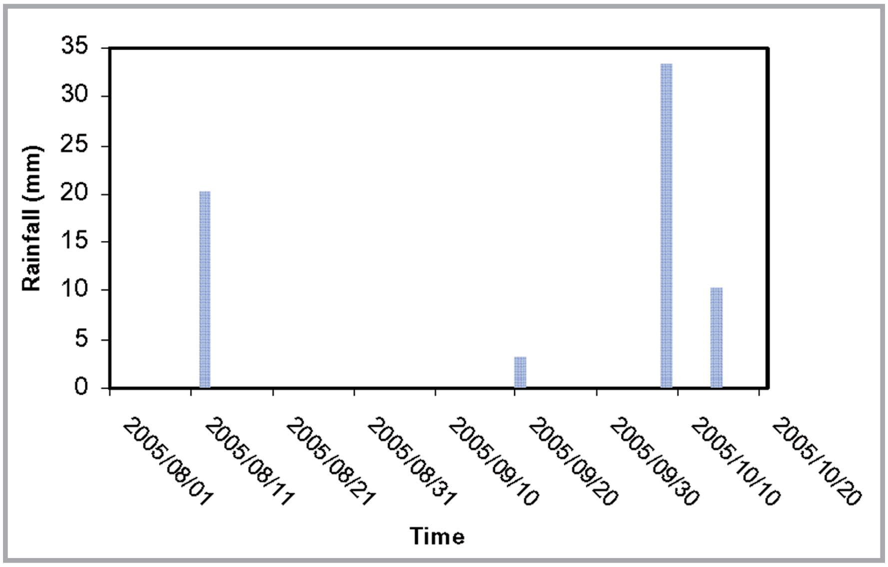


Figure 5: Rainfall records from August 2005 to October 2005, for the water-table monitoring site

The peizometer measurements indicate that the elevation of the water table remained remarkably constant at site K4 over the period of monitoring (Figure 6, K4). In contrast, the water level measured to the north of the gully at site K3 declined over the period of monitoring. The water level in the central portion of the wetland varied considerably (>1 m), and remained relatively constant at the edges of the wetland on the south of the gully (Figure 6, K3). The water level at the centre of the wetland rose following the rainfall events prior to 11 October 2005 and gradually fell again thereafter. These data suggest that the gullies were having a substantial effect on maintaining low water-levels at the edges of the main wetland, due to their hydraulic efficiency. However, sites that were some distance from the gullies responded predictably to water inputs and deficits.

Following the preliminary investigation in April 2005, the elevation of the water table east of the gully at site K2 declined dramatically, reflecting the dry winter season, to reach a constant elevation throughout the remainder of the monitoring period (Figure 6, K2) despite some rainfall. However, the elevation of the water table west of the gully rose somewhat, to reach a relatively constant elevation during the same period, reflecting water inputs by rainfall as well as water deficits. This pattern of events reflects the significant role of the main gully crossing the wetland between K3 and K2 (Figure 2), as the gully intercepts surface-flow of water on the valley floor from its west. Therefore, east of the gully the wetland is not receiving water from upstream and recharge of groundwater is non-existent despite significant rainfall. The minor gully on the northern edge of the wetland (Figure 2) seems to play a similar role.

The lowermost site shows a relatively constant water-level throughout the study period (Figure 6, K1), with the exception of the start of the study and following the large rainfall event prior to 11 October 2005. The data suggest that in areas far-removed from gullies, the water table elevation responds to variation in water inputs as rainfall and water deficits, whereas in areas close to gullies the elevation of the water table varies in an unpredictable way. This is presumably due to the lag between rainfall and flow of water in the gully, as the main catchment area for the gully is a considerable distance away (several km). Wetlands in the catchment will also delay the delivery of water into the gully.

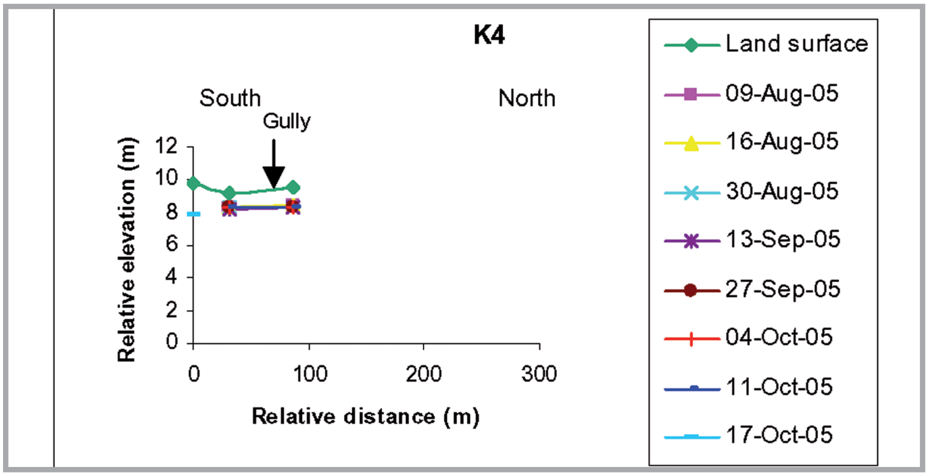


Figure 6: Continued overleaf

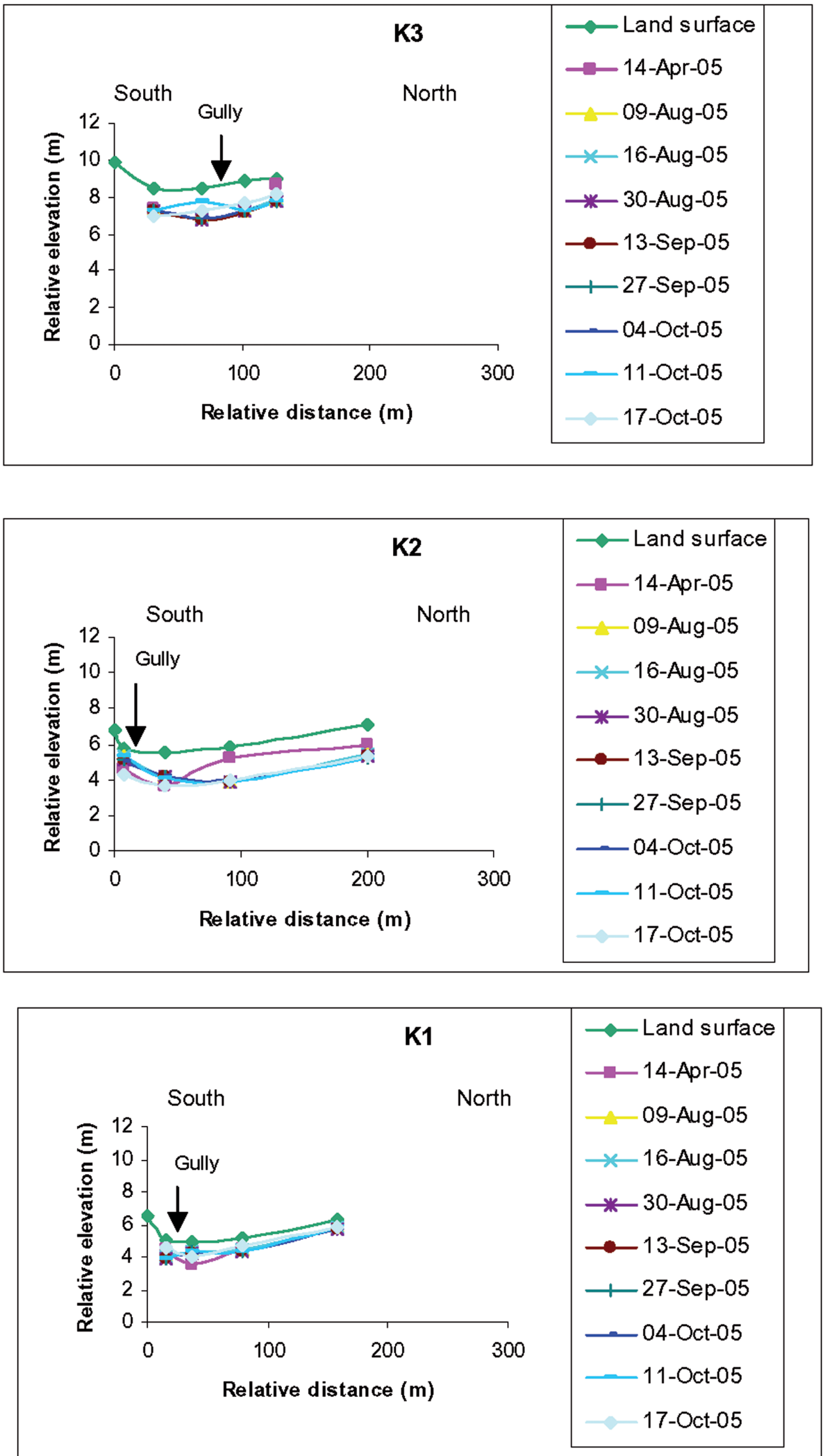


Figure 6: Changes in elevation of the water table over the period April to October 2005 for transects from the upper (K4) to the lower (K1) section of the valley

Visits during the summer of 2005 and 2006, after rehabilitation, showed that the water level measured by all the peizometers was at, or above, the land surface such that the base of the aerially-exposed portions of the peizometers was flooded. This indicates that the objective of increasing water elevation in the wetland had been achieved.

5.3.2 Vegetation monitoring

Vegetation communities in wetlands tended to follow a gradient in response to varying degrees of wetness, resulting in zones of particular vegetation types within the wetland. At Killarney, the wetland margins tend to be dominated by terrestrial species such as *Themeda triandra, Tristachya leucothrix* and *Aristida junciformis.* The next zone of wetness, the temporary to seasonal zone, is dominated by facultative wetland grass-species such as *Eragrostis planiculmis, Arundanella nepalensis,* and *Andropogon appendiculatus.* The wetter seasonal-to-permanent zone is dominated by wetland species such as *Carex acutiformis, Eleocharis dregeana, Fuirena* sp and *Cyperus* spp.

The percentage cover of each plant species within each of the quadrats was recorded in 2007 and plotted against the quadrat-records for 2004. The wetland was considered to be wetter in 2007 than in 2004 and this is reflected in the response by the vegetation within the rehabilitated portion of the wetland to the wetter conditions.

The general trend across Transect K1 was for obligate wetland species such as *Carex acutiformis, Phalaris arundinaceae, Pennisetum thunbergii* and *Eliocharis dregeana* to increase markedly in abundance from 2004 to 2007 (Figure 7), and for more terrestrial species such as *Themeda triandra, Tristachya leucothrix* and *Aristida junciformis* to decrease in abundance. *Eragrostis planiculmis*, a wetland facultative grass species representative of the seasonal to temporary wetland interface also tended to decrease in abundance, in favour of the more hydrophytic species.

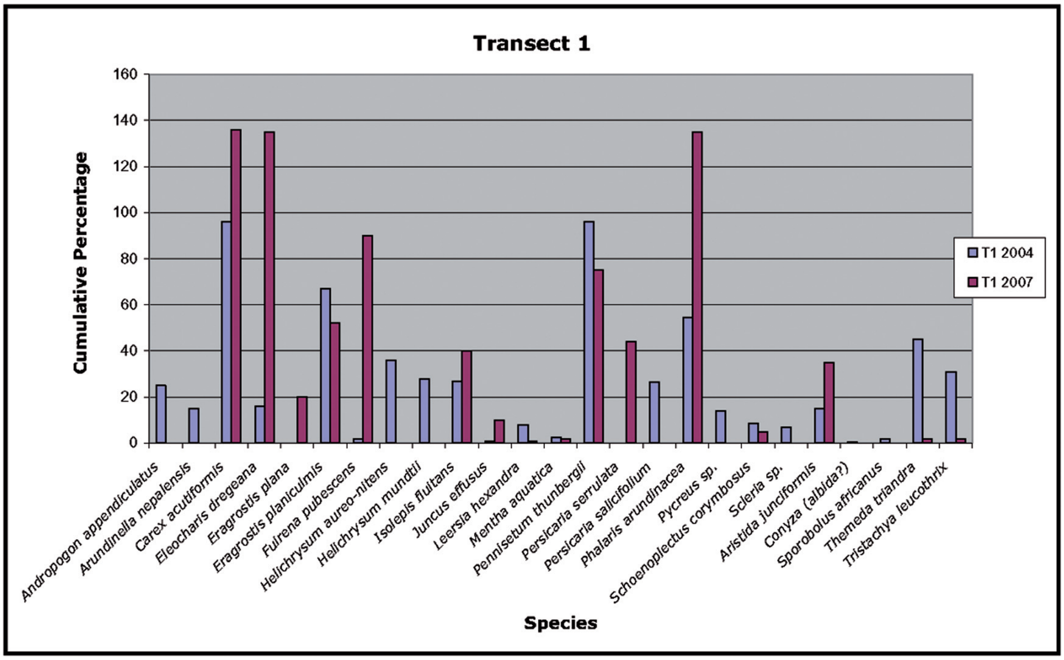


Figure 7: Change in species composition in transect K1 from 2004 to 2007

Transect K2 showed similar trends (Figure 8). Wetland species such as *Andropogon appendiculatus* and *Cyperus denudatus* increased significantly while *E. planiculmis* and *P. thunbergii* decreased, indicating that conditions have become slightly wetter, favouring the former species.

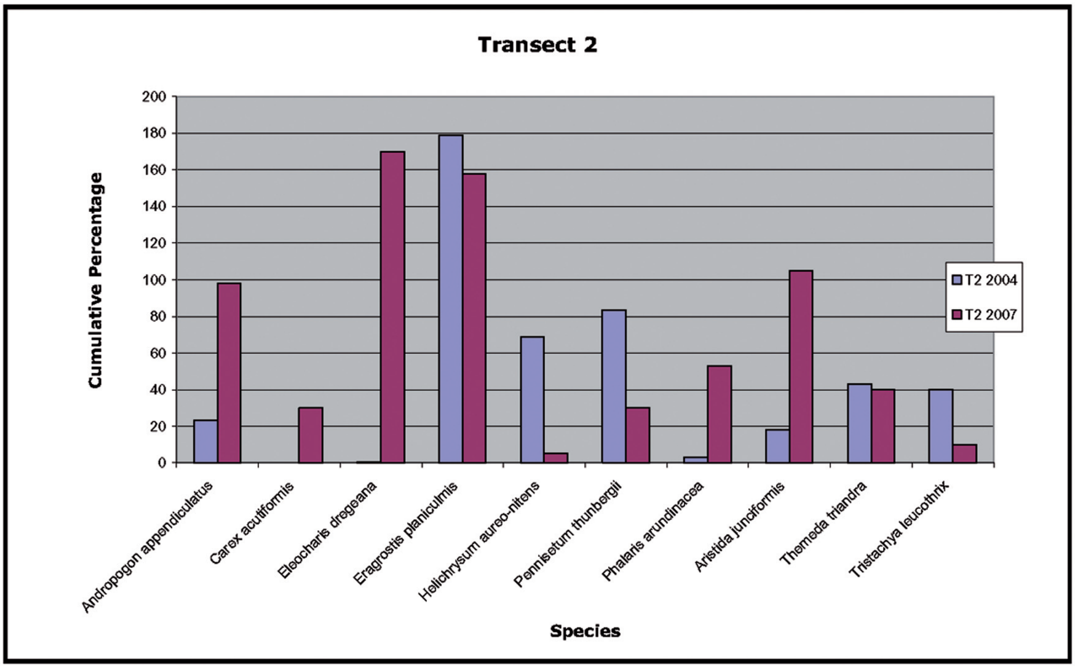


Figure 8: Change in species composition in transect K2 from 2004 to 2007

Themeda triandra and *Tristachya leucothrix* decreased in abundance with *Aristida junciformis* replacing them (Figure 8). However, for these species that occur in temporarily flooded (drier) sites, this is likely to be related more to management in the form of reduced grazing-pressure or reduced burning-frequency, rather than wetter conditions that result from wetland rehabilitation. *Eragrostis planiculmis, Pennisetum thunbergii* and *Helichrysum mundii* are species that thrive under moderately wet conditions but their relative abundances have decreased in favour of *Phalaris urundinaceae* and *Carex cognata*, species that prefer wetter conditions. Thus, wetter sites appear to have become wetter due to rehabilitation.

The trends evident in transects K1 and K2 were not as pronounced in transect K3 (Figure 9). Generally the same dominant species were recorded in 2004 and 2007, but their abundances varied slightly. *Eragrostis planiculmis* and *Aristida junciformis* did show an increase in abundance in 2007, in the case of the former probably due to increasing wetness while the latter may have been due to management. *Themeda triandra* showed a slight decrease from 2004.

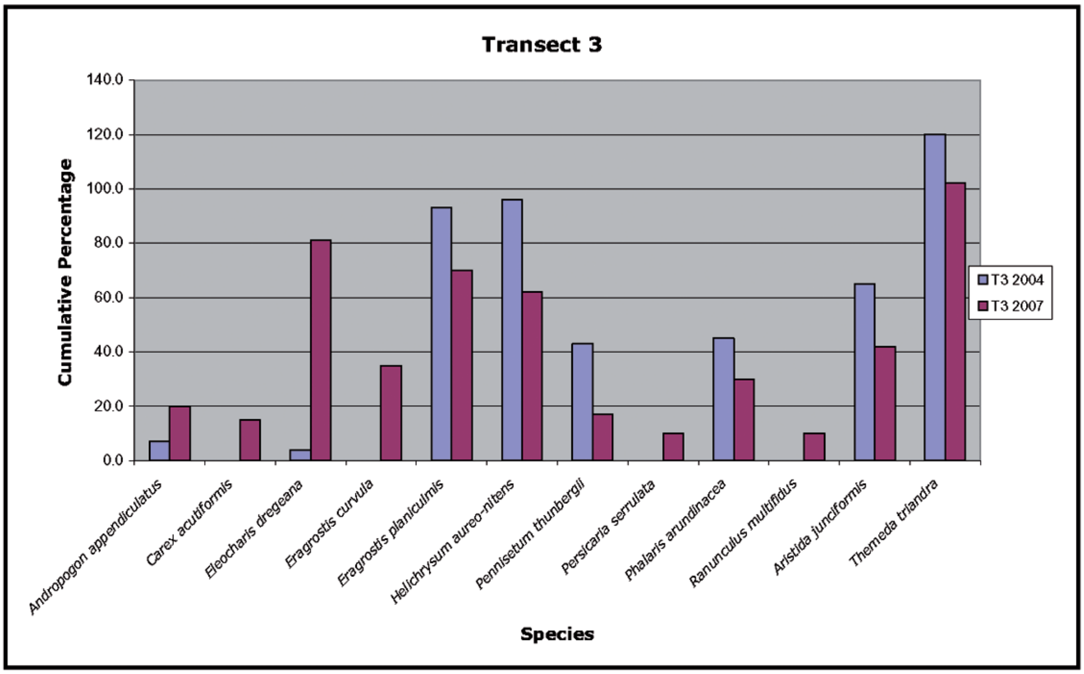


Figure 9: Change in species composition in transect K3 from 2004 to 2007

Transect K3 is situated upstream of the other two transects, and generally the hydrology of the system has not been re-instated to near natural conditions due to the limitations of flooding the road-crossing upstream. For the vegetation to respond in a similar way as in the other transects, it would be necessary to place an additional structure between T51H0021 and T51H0022 to restore hydrological conditions to near-natural conditions. However, this would drown the road which crosses the wetland just downstream of structure T51H0021.

All of the species mentioned above are indigenous except for *Phalaris arundinacea*, which is an invasive alien. It is interesting to note that this species increased dramatically in abundance in the two transects that were strongly re-wetted, but it decreased slightly in abundance in the third transect were wetness had not been re-instated.

5.3.3 Gully cross sections

The cross-sectional profiles of the channels within the Killarney Wetland system along each transects are shown in Figure 10. These illustrate that the depth of the gullies following the implementation of the rehabilitation interventions has typically decreased as a result of the trapping of sediment generated from the collapse of the gully walls between the structures. The structures are therefore effectively trapping sediment.

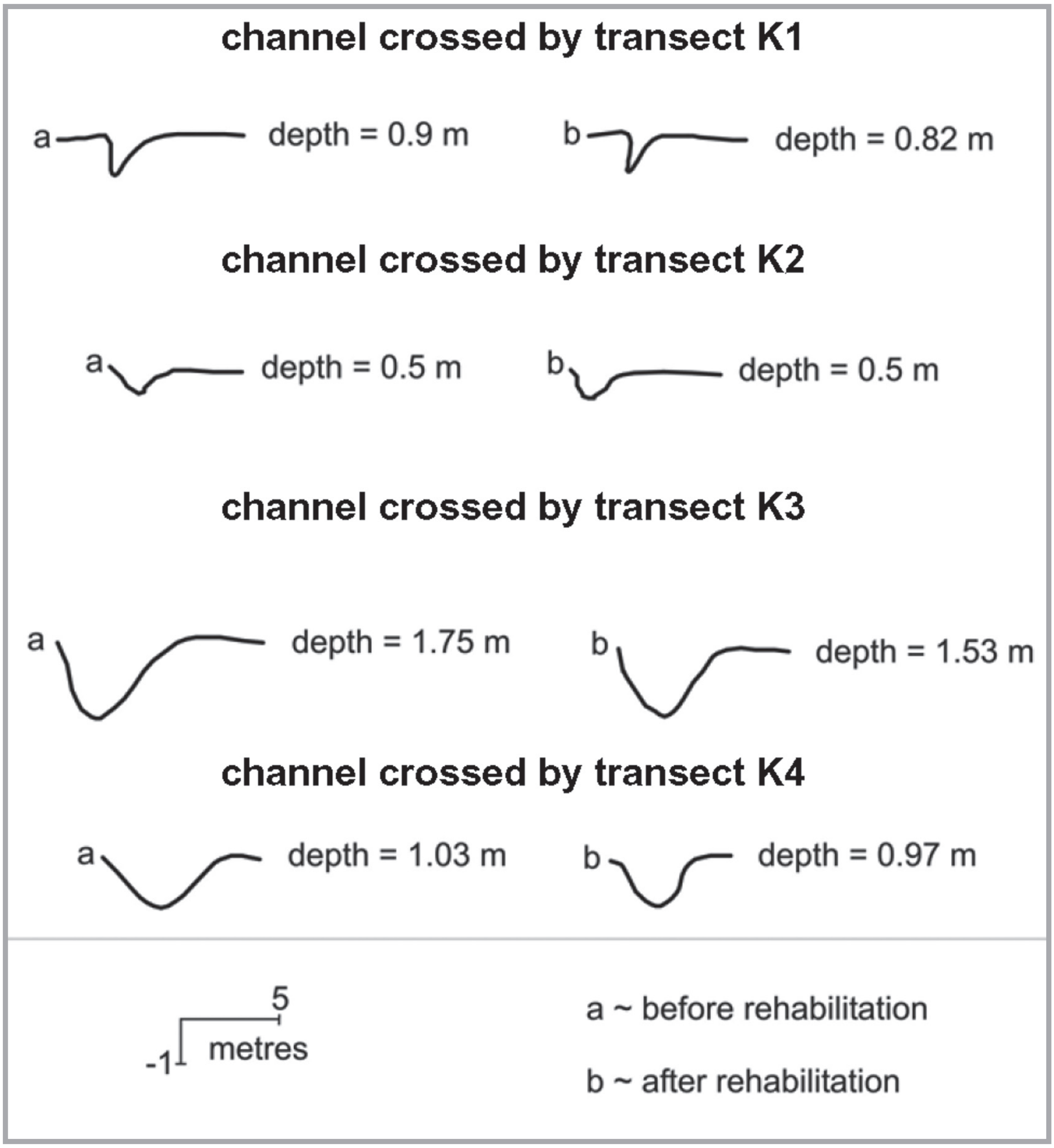


Figure 10: Cross sections of gullies before (a) and after (b) rehabilitation

6 Discussion

The information collected relating to the Level 1 monitoring illustrated that the implementation of wetland rehabilitation activities by Highland Wetland Rehabilitation was generally in accordance with WfWetlands' policies and standards. This is also supported by the inspection reports carried out by the WfWetlands regional co-ordinator and the external auditor. The implementation of the rehabilitation activities in this instance is therefore considered to be successful. The results of the assessment of the structural integrity of the interventions in the Killarney Wetland highlight that the interventions are generally in good condition, other than where there appears to be slight wear of the spillway by the continuous flow of water. It is recommended that these interventions be monitored to ensure corrective action is implemented prior to excessive wear of a number of spillways, lowering the level of water upstream of the intervention, as this would reduce the intervention's ability to achieve the specified objectives.

The monitoring of the groundwater level and the vegetative composition highlights that the rehabilitation of the Killarney Wetland has improved conditions such that they are similar to the historical condition, with seasonally to permanently wet areas dominated by mixed sedge meadow. The monitoring of elevation of water level in the soil on the post-rehabilitation field trip indicates that wetland hydrology has been reinstated, as groundwater is being retained in the critical 0-50 cm zone. Although this represents just a snapshot in time, there is evidence of a trend. The vegetation has responded to the wetter conditions brought about by the introduction of the interventions to the system. There appears to have been a shift in species dominance towards those that thrive under seasonally to permanently wet conditions.

It is evident that the rehabilitation has resulted in the improved health of all three of the ecological processes within the wetland. This is considered significant given that Killarney Wetland is in a formally protected area and the priority was to attain a state of health for the wetland that is as close to pristine as possible. It should be noted that the hydrological and vegetation health of the system are likely to improve further with the vegetation composition continuing to revert to natural, provided that the native species such as *Carex acutiformis* and *C. cognata* are able to out-compete the invasive *P. arundinaceae*. This would result in a vegetation composition similar to the historical vegetation. It is evident from the assessment of the wetland's functioning and health that the rehabilitation of the system has resulted in an improvement in ecosystem service delivery as well.

Using the health scores determined in the assessment of Killarney Wetland's ecological health for pre- and post-rehabilitation, it is possible to determine the gain in hectare equivalents of health associated with the implementation of the WfWetlands rehabilitation activities (Table 9).

Table 9: Gain in hectare equivalents due to rehabilitation interventions at Killarney Wetland. Note, the total hectares affected by rehabilitation is 57.50 hectares

Derivation of Hectare Equivalents		Hydrological health	Geomorphological health	Vegetation health	Overall scores
Pre-rehabilitation	Health Score[1]	3.0	1.7	3.2	2.7[3]
	Hectare Equivalents[2]	**40.25**	**47.73**	**39.10**	**42**[4]
Post-Rehabilitation	Health Score	1.0	1.0	2.2	1.3[3]
	Hectare Equivalents	**51.75**	**51.75**	**44.85**	**50**[4]
	Gained Hectares	**11.50**	**4.02**	**5.75**	**8**[5]

[1] 0 = pristine, 10 = completely destroyed

[2] Hectare equivalents = (10 – health score)/10 x area of rehabilitation in hectares.

[3] The scores for these three respective components are integrated based on a weighted average ratio of 3: 2: 2, given that hydrology is considered to have the greatest contribution to health. For example, if hydrology, geomorphology and vegetation scored 4/10, 8/10 and 3/10, respectively then the integrated score would be ((4 x 3) + (8 x 2) + (3 x 2))/7 = 4.9.

[4] Based on overall health score

[5] Based on overall hectare equivalents scores

It is apparent that the rehabilitation of the system has resulted in an increase in the area of healthy wetland for all three components of health. It is important to note that generally the deterioration of the system's hydrology was considered to be the driving factor behind the deterioration of the wetland's functioning and health. Vegetation health could also be used to assess the rehabilitation of the system, but in this instance it was considered that not enough time had lapsed to illustrate the anticipated response in vegetative condition. The increase in hydrological health is therefore the ecological process that was utilised to assess the success of the rehabilitation.

In order to assess the entire rehabilitation process the information has been recorded taking into consideration improvements in wetland ecosystem service delivery and health and the cost of the interventions implemented to achieve the gain in functioning wetland area (Table 10).

Table 10: Cost effectiveness of rehabilitation interventions at Killarney Wetland

Cost of Interventions	Affected Area (ha)	Hectare Equivalents Gained	Cost Effectiveness(R/ha)
R1 623 000 + R162 300 (10% for maintenance)	57.5	8	R223 163

The cost-effectiveness of the project could be considered moderate based on the figures provided in *WET-RehabPlan* (Kotze *et al*., 2009b), and presented in Table 11.

Table 11: A preliminary, general standard for assessing the cost-effectiveness of a rehabilitation project in terms of cost per hectare equivalent of maintained/re-instated intact wetland (from Kotze *et al.*, 2009b)

Cost per hectare of re-instated/ maintained intact wetland	Likely cost-effectiveness
< R50 000 per ha	The cost effectiveness of the project is likely to be high.
R50 000-R150 000 per ha	The cost effectiveness of the project is likely to be intermediate to high.
R150 001-R 300 000 per ha	The cost effectiveness of the project is likely to be moderate but can be justified if returns in terms of ecosystem system delivery are moderate to high.
R300 001-R500 000 per ha	The cost effectiveness of the project is likely to be low to intermediate, but can be justified if benefits are high. Therefore, benefits would need to be well justified.
>R500 000 per ha	The cost effectiveness of the project is likely to be low. Such a project would need to be extremely well motivated such that it could only be justified if benefits are exceptionally high.

Note: costs are based on 2007 prices, and do not include the costs of social engagement and monitoring and evaluation

As indicated, the focus of this evaluation is on the contribution of the project to the health of the wetland and its delivery of ecosystem services. However, it is important to add that the wetland rehabilitation project had additional benefits. It contributed to alleviating poverty in the communities neighbouring the Ntsikeni Nature Reserve (Nkoko and Macun, 2005), as well as to improving the effectiveness with which the wetland is managed (see Kotze *et al.*, 2009c). Furthermore, Kotze *et al*. (2009c) showed that wetland rehabilitation undertaken in Ntsikeni Nature Reserve (including that of the Killarney Wetland) was characterised by good stakeholder participation, including that of management and neighbouring communities. This is a positive feature in terms of the long-term maintenance of the rehabilitation outcomes described in this report.

7 References

Cowden C and Kotze DC, 2009. *WET-RehabEvaluate: Guidelines for the monitoring and evaluation of wetland rehabilitation projects*. WRC Report No. TT 342/09. Water Research Commission, Pretoria.

Kotze DC, Hughs JC, Breen CM and Klug JR, 1994. *The development of a wetlands soil classification system for KwaZulu-Natal.* WRC Report No. 501/4/94, Water Research Commission, Pretoria.

Kotze DC, Marneweck GC, Batchelor AL, Lindley DS and Collins NB, 2009a. *WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands*. WRC Report No. TT 339/09. Water Research Commission, Pretoria.

Kotze DC, Ellery WN, Rountree M, Grenfell MC, Marneweck G, Nxele IZ, Breen DC, Dini J, Batchelor AL and Sieben E, 2009b. *WET-RehabPlan: Guidelines for planning wetland rehabilitation in South Africa*. WRC Report No. TT 336/09. Water Research Commission, Pretoria.

Kotze DC, Breen CM, Nxele IZ and Kareko J, 2009c. *WET-ManagementReview: The impact of natural resource management programmes on wetlands in South Africa.* WRC Report No. TT 335/09. Water Research Commission, Pretoria.

Macfarlane DM, Kotze DC, Ellery WN, Walters D, Koopman V, Goodman P and Goge M. 2009. *WET-Health: A technique for rapidly assessing wetland health.* WRC Report No. TT 340/09. Water Research Commission, Pretoria.

Nkoko M and Macun I, 2005. *Rapid evaluation of the socioeconomic impact of Working for Wetlands.* The Community Agency for Social Enquirey (CASE), Braamfontein.

Price Waterhouse Cooper, 2006. *South African National Biodiversity Institute: Working for Wetlands - Performance Audit Summary Report.* Unpublished Report.

Part 3A

Evaluation of the effect of rehabilitation interventions on the health and ecosystem service delivery of the Manalana Wetland, Craigieburn Village, Mpumalanga Province

DC Kotze, MR Nkosi, E Riddell, SR Pollard,
N Ngetar and WN Ellery

1 Introduction and objectives

The Manalana Wetland of Craigieburn village is situated in the upper Sand River Catchment in the north-eastern region of South Africa. It is commonly referred to as the Craigieburn Wetland because of its location in the village of Craigieburn, but for the purposes of this report we will refer to it as the Manalana Wetland. In a survey of the Manalana Wetland it was revealed that intact portions of the wetland were under considerable threat from headcut erosion (Pollard *et al.*, 2005). Based on the past rate of advancement and the current severity and level of activity of two erosional headcuts, and the lack of any upstream controls, it was predicted that the headcuts were likely to soon advance through all of the remaining intact areas unless there was some form of rehabilitation intervention. The overall impact of this erosion would be felt directly by those people whose livelihoods are dependent on the wetland (Pollard *et al.*, 2005). In response, a rehabilitation project, initiated in 2006 and completed in early 2007, was undertaken by Working for Wetlands. The rehabilitation project appears to have been successful in halting the advancement of the two headcuts.

The purpose of this investigation is to report specifically on the contribution of the rehabilitation interventions to the health of the wetland and its delivery of ecosystem services ('health' is taken as synonymous with 'integrity', as elaborated by Macfarlane *et al.*, 2009). The provisioning services (e.g. water and areas for cultivating food) likely to result from the rehabilitation interventions are assessed in detail in Part 3B of this document.

It is important to emphasize that the rehabilitation interventions that form the focus of this report took place within the context of a much broader and longer-term initiative that began in 2003, and which is still ongoing. The longer-term initiative, facilitated by the Association for Water and Rural Development (AWARD), aims to achieve the following:

- Strengthen the governance and management system for the wetland, while recognizing that controls over land-use are necessary if the long-term outcomes of the Working for Wetlands rehabilitation project are to be sustained; and
- Work closely with individual wetland and catchment users at a plot-level to increase the sustainability of land-use practices.

2 Methods

The approach used in this evaluation is outlined in *WET-RehabEvaluate* (Cowden and Kotze, 2009). The 'current health' of the wetland (which represents the situation 'with rehabilitation') was assessed and compared to the projected health of the wetland given the full advance of the headcuts (i.e. the situation 'without rehabilitation'). For both situations health was scored on a scale of 0 (pristine) to 10 (critically altered). This was conducted for the hydrology, geomorphology and vegetation components of health using *WET-Health* (Macfarlane *et al*., 2009).

The benefits of the rehabilitation intervention in terms of the delivery of ecosystem services were determined based on the framework given in *WET-EcoServices* (Kotze *et al*., 2009) and with reference to the assessment of how the rehabilitation was likely to have affected health. For example, if a wetland's health was diminished as a result of the reduction of the natural level of wetness of a wetland, then this would impact upon services such as nitrogen assimilation, which are favoured by a high level of wetness.

3 A brief description of the Manalana Wetland and rehabilitation interventions

The wetland examined in the study consists of Portion 1, which forms the wetland's head, and Portion 2 that extends down the valley (Figure 1). The wetland also extends further downstream beyond the toe of Portion 2, but this was not part of the rehabilitation project. The hydro-geomorphic type of Portion 1 is an un-channelled valley bottom while Portion 2 is a channelled valley bottom, although the channel is not strongly defined unless incised by gully erosion. The two portions were assessed as separate units because of their different hydro-geomorphic settings.

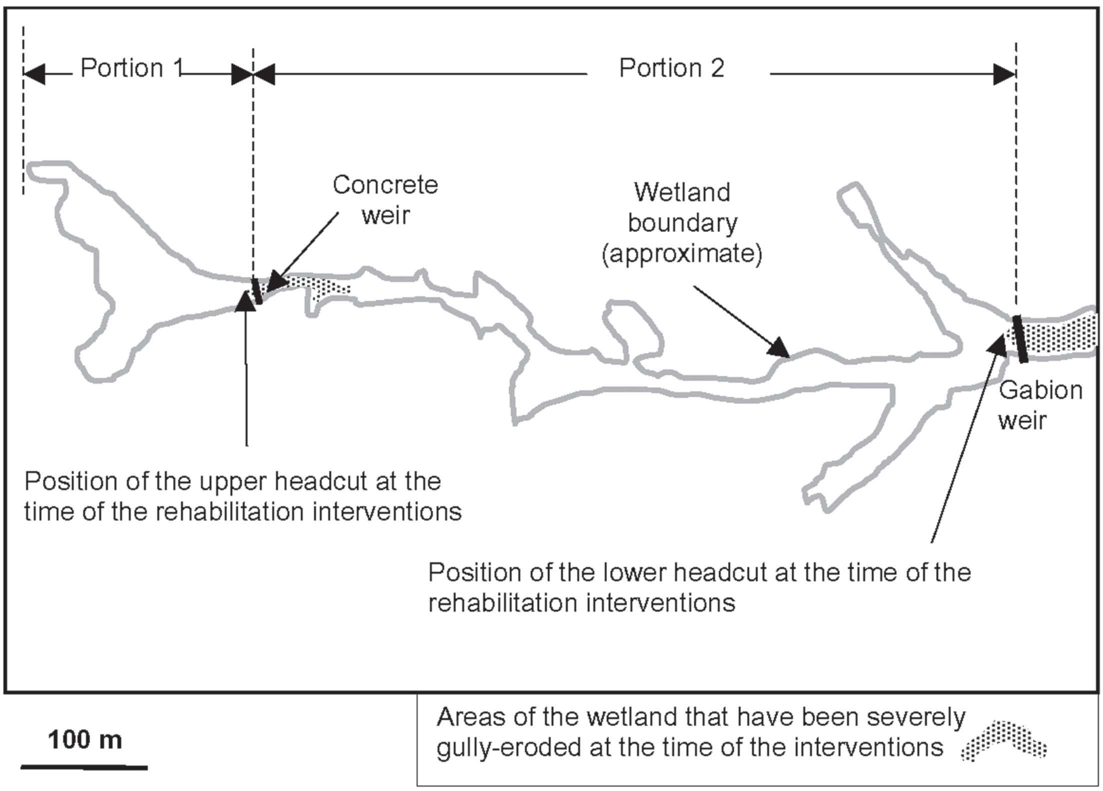


Figure 1: Map of the Manalana Wetland and the location of the two portions of the wetland and the two rehabilitation interventions

The two portions were both affected by gully erosion at their downstream ends. Prior to the rehabilitation interventions, the head-cuts of the two gullies had been very actively eroding and continued to propagate upstream into the respective portions (Figure 2). The rehabilitation project consisted of two erosion control structures, a smaller concrete weir to deal with a lesser headcut threatening Portion 1 and a larger gabion weir to deal with a greater headcut threatening Portion 2.

Figure 2: The two main erosion heacuts threatening the Manalana Wetland (a) Portion 1, and (b) Portion 2. The photographs were taken in 2004 prior to the rehabilitation interventions.

The concrete weir was also designed to raise the water table in Portion 1, based on the observation that prior to rehabilitation the water table became markedly lower towards the head-cut (Riddell, 2007). It appears to have resulted from the loss to erosion, of a 'plug' of fine sediment at the toe-end of Portion 1 that served to retard the lateral movement of water through this part of the wetland. This contrasted with Portion 2, where only a slight lowering of the water table was observed towards the headcut at its toe.

Based on pre- and post-intervention hydrological modelling, Riddell (2007) documented in detail how the concrete weir has, very successfully, raised the water table, particularly in the toe of Portion 1. This is despite the post-intervention period (2007) being a drier year than the pre-intervention period (2006).

Close examination of the Manalana Wetland showed that the longitudinal gradient of the wetland is steepest upstream of the headcuts and shallowest below them (Figure 3). Above the upper headcut (Portion 1) the longitudinal slope is 2.5% and below it the slope is 1.3%. The slope is steeper upstream of headcut 2 towards the toe of Portion 2 at 2.3%, while downstream of the headcut the slope is 1.1%.

The question as to why the Manalana Wetland had eroded was an obvious issue to be clarified before deciding on the appropriate rehabilitation interventions. The popular interpretation is that the erosion occurred as a result of changes in catchment land-use where the rural catchment became peri-urban due to the settlement of large numbers of people. While there is no question that the change in land-use from rural to peri-urban could lead to erosion of valley-bottom wetlands, it was not clear that this was the cause of the erosion. In order to resolve this issue land cover was mapped in the Manalana Wetland's catchment from aerial photographs taken over the period 1954 to 1997. This was based on the assumption that if urbanisation was the cause of degradation there would be a direct relationship between the development of infrastructure in the catchment and gully erosion. Gullies were present in the catchment and the wetland in the 1954 photographs, and there was little change despite the dramatic increase in the number of homesteads and infrastructure in the catchment from 1954 to 1997 (Figure 4).

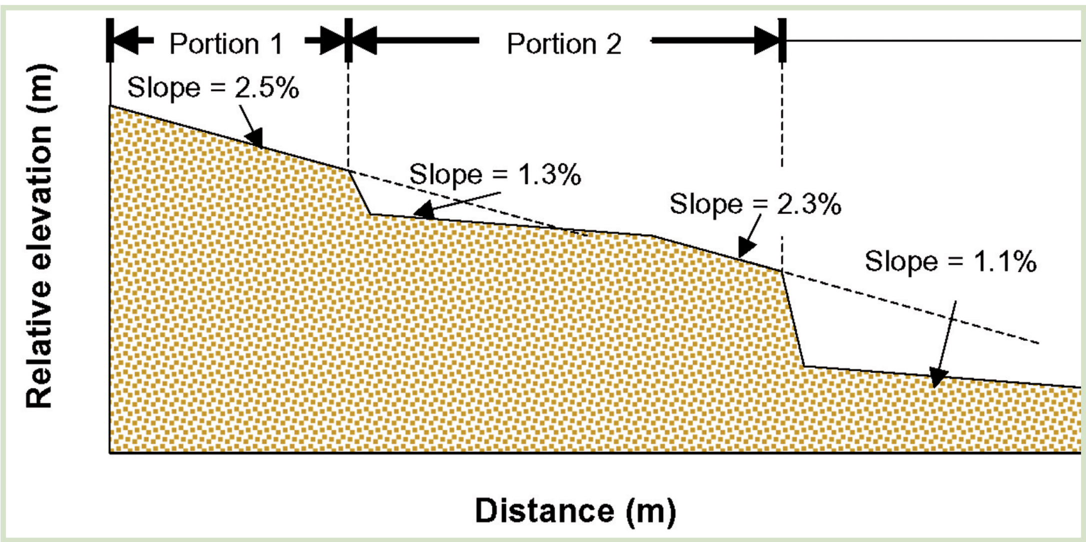


Figure 3: The longitudinal slope of the Manalana Wetland as measured down the axis of the valley and its gullies. The gradient of the valley adjacent to the gullies is presented as a dashed line.

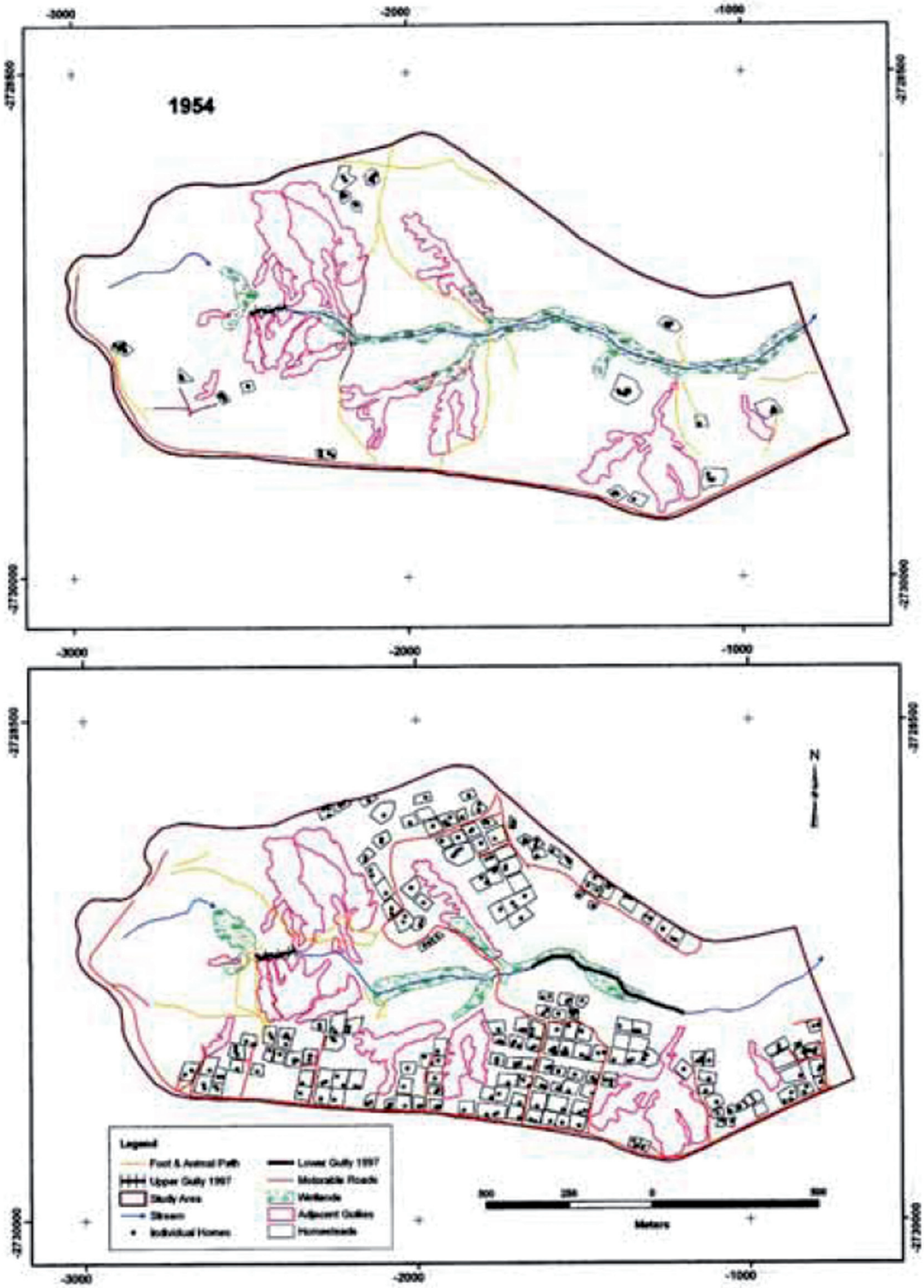


Figure 4: Landscape evolution and land-use change in the Manalana catchment from 1954 to 1997

Based on field surveys, it is clear that the Manalana valley has a long history of erosion by incision and infilling by deposition such that two depositional surfaces and three erosional surfaces are present and clearly visible (Figure 5). The valley was carved initially to bedrock (E1), subsequent to which there was infilling of the valley due to excessive sediment production in the catchment that could not be removed (D1). Subsequent erosion then carved out a portion of the sedimentary fill in the valley (E2), which was followed by a second cycle of deposition that partially filled the eroded sedimentary-fill from the previous cycle of erosion (D2). The current cycle of erosion has removed a portion of this sedimentary fill (E3).

The geomorphological evolution of the Manalana Wetland is illustrated in greater detail in Figure 6, where individual erosion and deposition cycles are illustrated. The erosional cycles are thought to occur during warm, wet interglacial phases of the Earth's climatic history, while the depositional cycles are thought to occur during dry, cool phases that are characteristic of the southern African climate during glacial periods (see *WET-Origins*; Ellery *et al.*, 2009).

From the perspective of rehabilitation, this study illustrates that it is not recent events in the wetland's catchment that has been the primary determinant of the present cycle of erosion, but rather it is a consequence of external factors. Given this, the most appropriate feature on which to focus is the erosion gullies.

The intervention structures that were placed in the gullies in the Manalana Wetland are illustrated in Figure 7: a concrete structure at the headcut below Portion 1 of the wetland and a large gabion structure at the headcut below Portion 2.

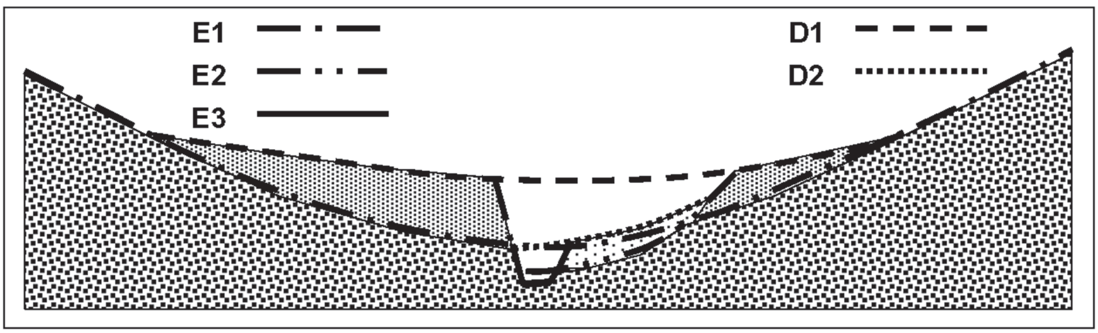


Figure 5: Valley cross-section of the Manalana Wetland illustrating erosional surfaces and depositional features described in this study

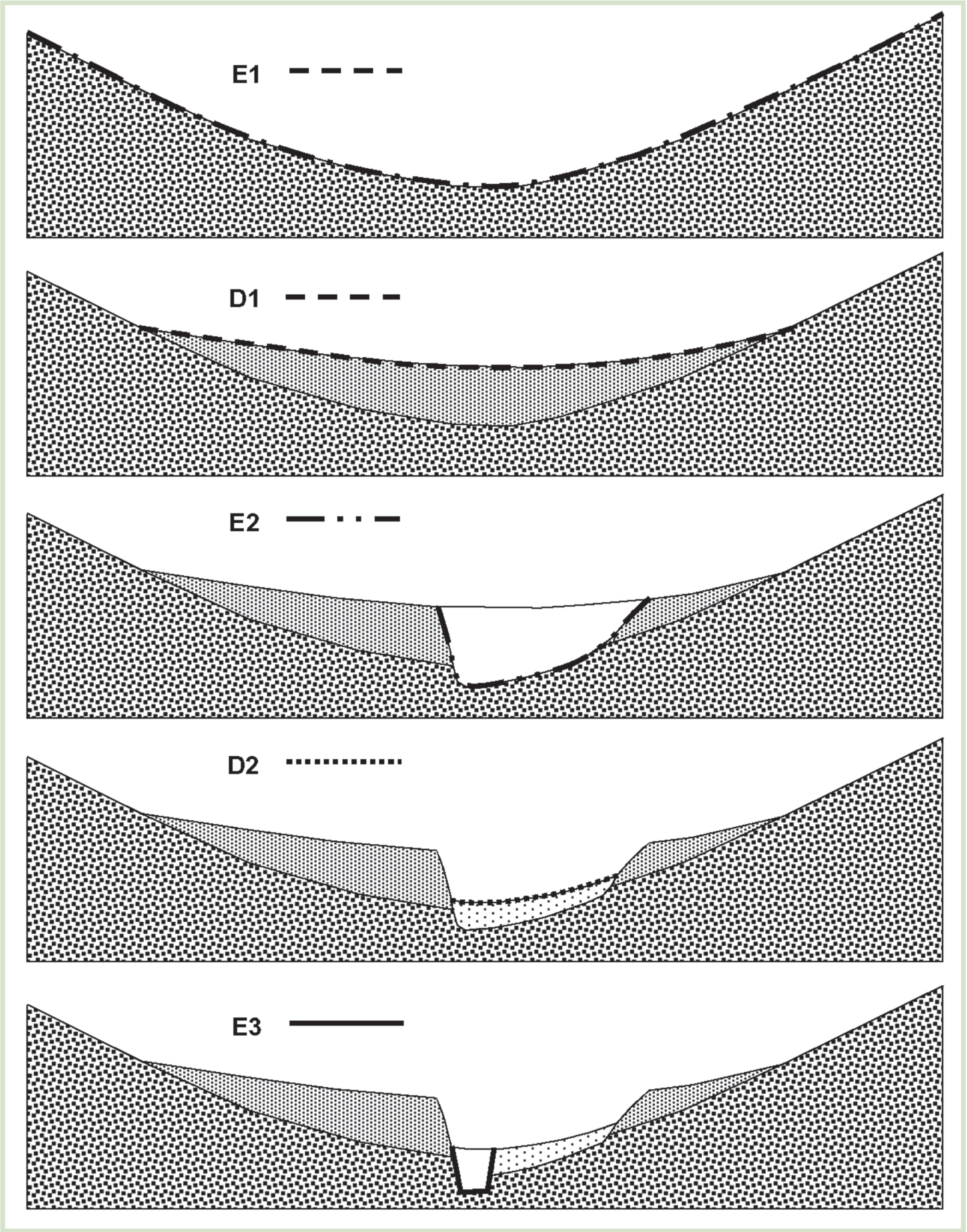


Figure 6: Interpretation of the evolution of the Manalana Wetland through periods of erosion and deposition

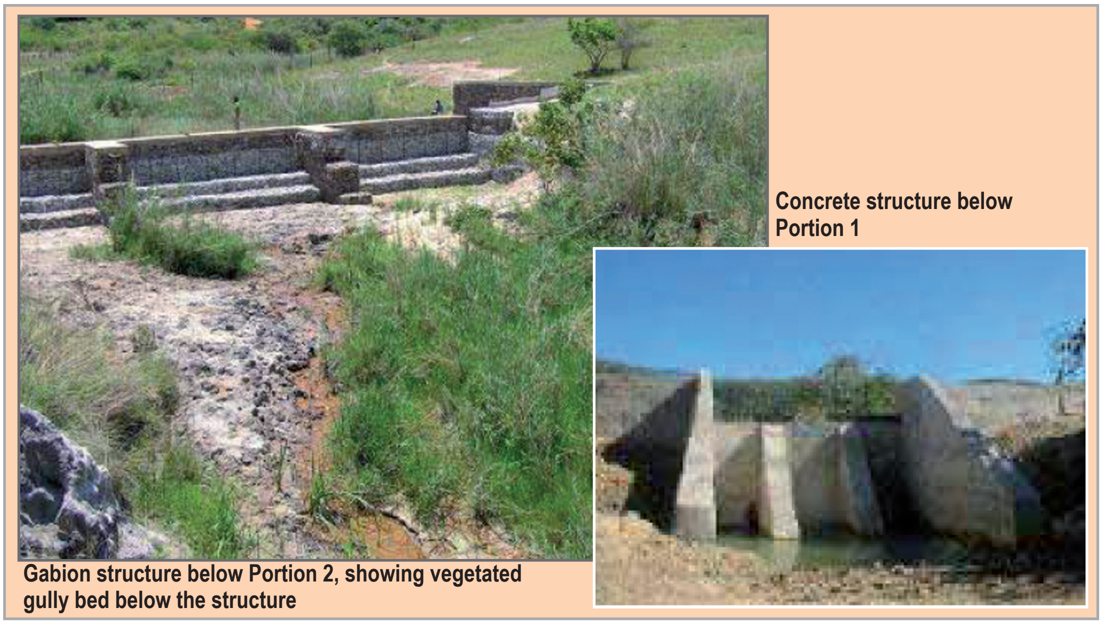


Figure 7: The two principal rehabilitation structures in the Manalana wetland

4 An assessment of the effect of the rehabilitation interventions on wetland health

The results of applying the *WET-Health* (Macfarlane *et al*., 2009) framework to the wetland are presented in Table 1, which provides the rationale for the scores applied. A summary is given in Table 2.

Figure 8 illustrates the evolution of a wetland prior to and after gulley formation. Erosion of a deep narrow gully is followed by gulley widening and progressive infilling as material generated by headwall erosion and sidewall collapse is gradually deposited on the gulley floor. Figure 9 shows the re-colonisation of the head of a deep, narrow gully below Portion 2.

Table 1: Predicted health scores of the Manalana Wetland, Portion 1 and Portion 2, under a rehabilitated state (i.e. headcut advance halted through erosion control weirs, and the water table raised in Portion 1) compared with an un-rehabilitated state (i.e. where the headcuts would advance through both portions of the wetland)

Health component	Portion		Rationale
	1	2	
Hydrological health with rehabilitation	5.5/10	5.5/10	In both portions, the hydrological health has been impacted by: (1) disturbances in the upstream catchment that resulted in a moderate increase in bare soil and hardened surfaces in the catchment, which have reduced infiltration in the catchment, thereby moderately increasing stormflows and moderately reducing sustained inputs of subsurface water to the wetland; (2) disturbances in the wetland, mainly from extensive raised beds associated with active and fallow cultivation, which have reduced onsite water-retention. Reduced surface roughness, associated with the replacement of native vegetation with less-robust crops, also contributes slightly to the reduced hydrological health.
Hydrological health without rehabilitation	8.5/10	8/10	Impacts from the upstream catchment remain as above. The impacts of disturbances in the wetland are primarily from the draining effect of the erosion gully in the wetland. This affects the gully sides and adjacent valley bed. The bed of the gully is, however, subject to sustained wetness and the re-establishment of hydric species, and is therefore not drained. Given the fact that the width of the gully bed relative to the width of the wetland is predicted to be greater in Portion 2 than Portion 1, the extent of the drained area will therefore be somewhat less in Portion 2 than Portion 1 (Figure 8).
Geomorphic health with rehabilitation	2.8/10	2/10	Impacts on the geomorphic health of the wetland are low. Localized erosion is present in Portion 1, and in Portion 2 there is localized recent sedimentary deposition.
Geomorphic health without rehabilitation	5.9/10	7.2/10	The projected headcut erosion will result in considerable impact on geomorphic health, particularly in Portion 2, where the headcut is >50% of the width of the wetland and it is > 2 m deep. Some deposition of eroded sediment in the bed of the gully is predicted, particularly in Portion 1, which has the lowest slope and is also likely to collect some sediment eroded from Portion 1. Sediment deposition will also be encouraged through the establishment of vegetation in the gully. Nonetheless, there is likely to be considerable export of sediment before the gully has stabilized.
Vegetation health with rehabilitation	4.5/10	6.5/10	By far the most important factor diminishing the vegetation health is cultivation in the wetland, with active and fallow lands covering ~60% of the wetland. Actively cultivated land, where almost no native vegetation remains, is concentrated particularly in Portion 2. The native vegetation has established to varying degrees on fallow land, which is concentrated particularly in Portion 1. Uncultivated areas are dominated by indigenous hydric species, e.g. *Phragmites mauritianus, Schoenoplectus brachycerus, Pycreus mundii* and *Imperata cylindirca*. Desiccation appears to be diminishing vegetation health to some extent.
Vegetation health without rehabilitation	7.1/10	6.8/10	Under eroded conditions: (1) it is assumed that indigenous hydric species will become established on the bed of the lower part of the gully, as has occurred below the lower headcut (Figure 9), but that the vegetation in the remaining areas will be severely affected by desiccation; and (2) cultivation will largely be absent.

Score: 0=completely natural (pristine), 10=completely degraded. See Macfarlane *et al*. (2009) for the underlying rationale of the scoring system.

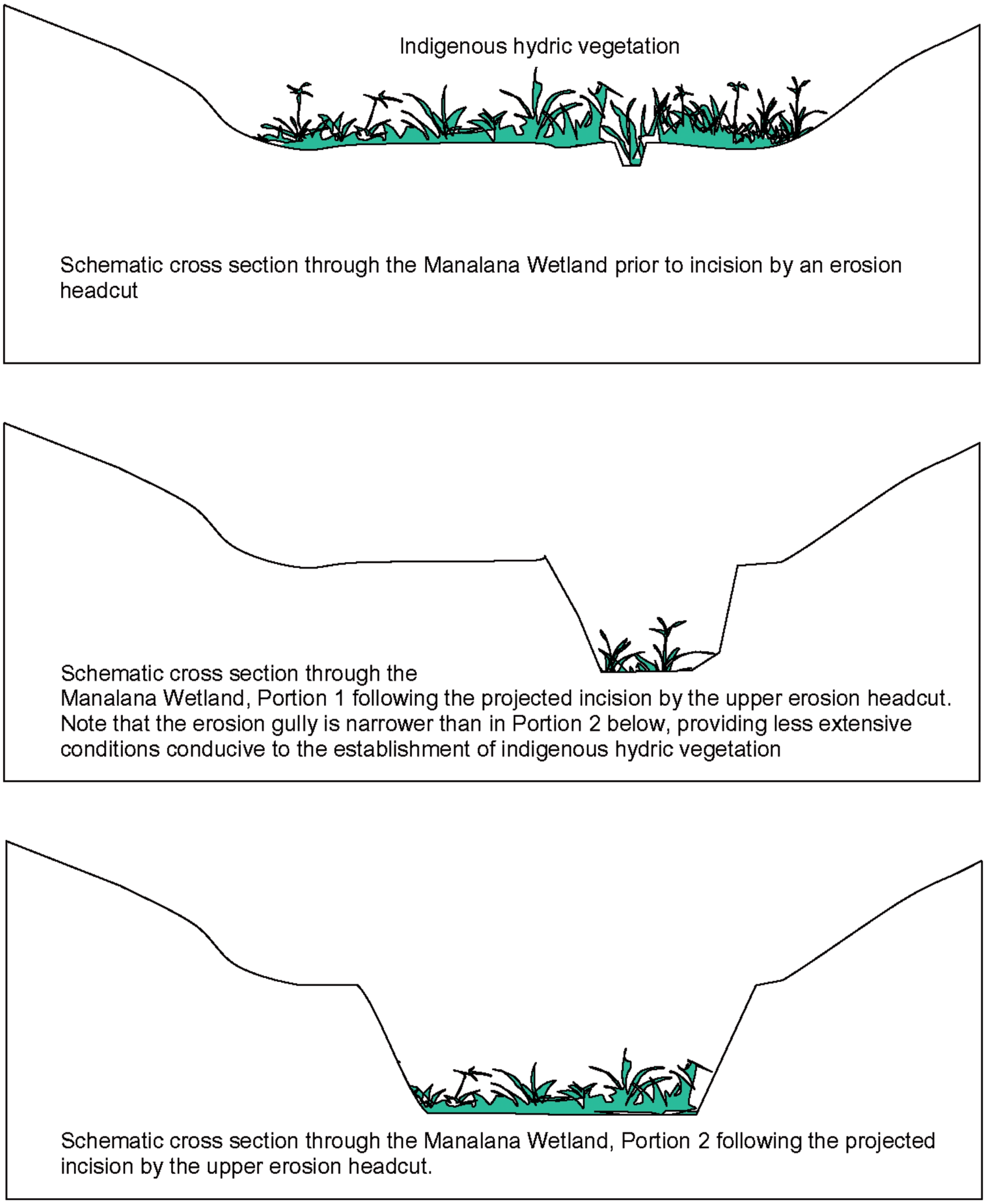


Figure 8: Schematic cross sections through the Manalana Wetland under different scenarios of headcut erosion

While it may have been tempting to conclude that a major gully eroding through the wetland would result in the entire health of the system being lost, the results of application of the *WET-Health* framework (Table 2) indicate that this conclusion is not entirely valid. From Table 2 it can be seen that wetland rehabilitation interventions have contributed greatly to the geomorphic health, somewhat less to the hydrological health, and modestly to the vegetation health. This assessment does, however, need to be seen in the context that even in its rehabilitated state the wetland will continue to be actively cultivated. While cultivation can be practiced in a manner which minimizes any impacts on the hydrological and geomorphic health of a wetland, the impacts of cultivation on the natural vegetation composition are inevitable.

Figure 9: View shortly downstream of the second headcut, showing the bed of the gully which is well-vegetated with hydric species, notably *Phragmites mauritianus*

Table 2: Summary of the contribution of the rehabilitation interventions to wetland health. The areas of Portions 1 and 2 are 1.1 ha and 2.3 ha respectively

		Portion 1	Portion 2	Total
With rehabilitation	Integrated health score[1]	4.5	4.8	
	Hectare equivalents[2]	0.6	1.2	
Without rehabilitation	Integrated health score	7.8	7.4	
	Hectare equivalents	0.2	0.6	
	Secured hectare equivalents	0.4	0.6	1.0

[1] 3 : 2 : 2 ratio, given that hydrology is considered to have the greatest contribution to health. For example with health scores for hydrology, geomorphology and vegetation being 6, 4 and 3 respectively, the integrated score would be ((6x3) + (4x2) + (3x2))/7 = 4.6.

[2] Hectare equivalents = (10 – health score)/10 x area of rehabilitation in hectares. For example, the hectare equivalents for the integrated health score of 4.6 = (10 – 4.6)/10 x 3.5 = 1.9 hectare equivalents.

5 An assessment of the effect of the rehabilitation interventions on the provision of ecosystem services

Having demonstrated the contribution of the rehabilitation structures to the health of the Manalana Wetland, the next question to ask was: what are the implications of the maintained health in terms of altered delivery of ecosystem services? This question was addressed based on an assessment of the extent to which the rehabilitation will affect key characteristics determining the delivery of services, as elaborated upon in *WET-EcoServices* (Kotze *et al*., 2009). For example, the pattern of low flows in a wetland has an important effect on the wetland's effectiveness in assimilating pollutants (the more diffuse the flow, the better). Therefore if a rehabilitation structure contributes to the maintenance of diffuse flows then it is also likely to contribute to the effectiveness of the wetland in assimilating pollutants. Table 3 shows that the greatest contribution made by the rehabilitation intervention was to the provision of cultivated crops (Figure 10). The rehabilitation also made a moderately high contribution to streamflow regulation, sediment trapping and erosion control and an intermediate contribution to several ecosystem services, including flood attenuation, carbon storage, water supply for human use, natural resources (grazing and sedges), and education and research. Overall, therefore, the rehabilitation structures have made a significant contribution to a broad range of ecosystem services, particularly to provisioning services, with this contribution being quantified in Part 3B.

Table 3: Anticipated difference in the delivery of ecosystem services by Manalana Wetland under an eroded situation compared with a rehabilitated situation

Ecosystem service	Difference between the un-rehabilitated (eroded) situation and rehabilitated situation[1]	
	Score	**Rationale for the score**
Flood attenuation	+2	In the eroded situation, because of the considerable size of the anticipated gully, flood flows will be largely confined within the gully, particularly in Portion 2. Thus, extent of the area over which flood-flows can spread will be greater for the rehabilitated situation than for the eroded situation. The surface roughness will be similar in both, given that cultivation practices will reduce surface roughness in the rehabilitated situation. The higher level of wetness in the rehabilitated situation, by reducing the volume of floodwaters that can be stored in the wetland's soils, will counteract to some extent its potentially greater positive contribution to flood attenuation.
Streamflow regulation	+3	The preliminary results of Riddell (2007) strongly suggest that the intact wetland regulates the movement of water from the hillslope, but in an eroded state it would be much less effective (Box 1). The potential contribution is, however, somewhat diminished by the greater abundance of actively-transpiring vegetation in the rehabilitated situation, which does not die back strongly during the winter season.
Sediment trapping	+3	The opportunity for the wetland to trap sediment is high given that erosion is prevalent in the wetland's upstream catchment, leading to an abundant supply of sediment to the wetland. As highlighted in 'flood attenuation' the area over which flood flows (which are likely to carry much of the sediment delivered to the wetland) is more limited in the eroded situation. Therefore the rehabilitated situation is likely to be more effective in trapping sediment. However, it is not scored +4 because the clearing of permanent natural vegetation for annual cultivation would diminish the capacity for sediment trapping in the rehabilitated situation (Figure 10).
Phosphate assimilation	+1	The effectiveness of a wetland in assimilating phosphates is generally closely associated with its effectiveness in trapping sediment (Hemond and Benoit, 1988). Therefore, the rehabilitated situation will be more effective in assimilating phosphates than the eroded situation. However, the potential sources of phosphates in the wetland's catchment are limited and thus the wetland is not afforded a high opportunity to assimilate phosphates. Furthermore, the disturbances associated with cultivation would reduce the phosphate assimilative capacity of the rehabilitated situation.
Nitrate assimilation	+1	The rehabilitated situation will be more effective in assimilating nitrates than the eroded situation owing to: (1) its higher level of wetness, which enhances denitrification; (2) more favourable flow patterns, which provide for greater contact between water and sediment; and (3) greater accumulation of soil organic matter (Hammer, 1992; Reddy and Patrick, 1984). However, the opportunity for the wetland to assimilate nitrates will remain relatively low as there are limited sources of nitrates in the catchment. Furthermore, the disturbances associated with cultivation, particularly those leading to the interruption of plant growth, would reduce the nitrate assimilative capacity of the rehabilitated situation.
Toxicant assimilation	0	The opportunity afforded to the wetland for the assimilation of toxicants is very limited as there are no known sources of toxicants in the catchment.
Erosion control	+3	The eroded situation, by its very nature, would contribute very little to erosion control. In contrast, the rehabilitation structures have been designed specifically to control erosion. However, it is not scored +4 because although the major gully erosion is assumed to have been halted, there would still be small-scale erosion at plot-level resulting from the disturbance associated with cultivation. Box 2 provides an estimate of the volume of sediment likely to be generated in the eroded situation.
Carbon storage	+2	The higher level of wetness in the rehabilitated situation compared with the eroded situation favours a greater accumulation of soil organic carbon (Tiner & Veneman, 1988). Again, this would be lessened to some extent by cultivation.

Biodiversity maintenance	+1	Hydrology is the most important determinant that affects the biota in a wetland (Mitsch and Gosselink, 1986). Therefore, the rehabilitated situation, where the hydrology is more intact, than the eroded situation, will provide a greater contribution to biodiversity maintenance. This however, is diminished significantly by cultivation reducing the extent of natural vegetation.
Water supply for human use	+2	By significantly increasing the retention of water, the rehabilitated situation results in water being much more readily available for domestic use. Local people are, however, only dependent on this supply when their piped water scheme fails.
Natural resources	+2	The two primary natural-resources used from the wetland are livestock grazing and harvesting of the sedge, Schoenoplectus brachyceras for crafts. The more favourable moisture conditions in the rehabilitated situation result in both of these resources being provided in greater abundance than in the eroded situation.
Cultivated foods	+4	The rehabilitated situation provides very favourable conditions for crop production. In contrast, the eroded situation provides very poor conditions owing to the drying out of the wetland and the erosion-gully bed, which is subject to intense flood flows, and the steep banks of the gully being totally unsuitable for cultivation.
Cultural significance	+1	Local people reported that the wetland has little cultural significance, although some cultural value is associated with the utilization of Schoenoplectus brachyceras for weaving traditional sleeping mats.
Tourism and recreation	0	There is no tourism in the area, although in the future this could become a potential benefit.
Education and research	+2	Currently the wetland is being extensively researched. Although the rehabilitated situation provides particularly valuable lessons, the eroded situation would also be of value from a research perspective.

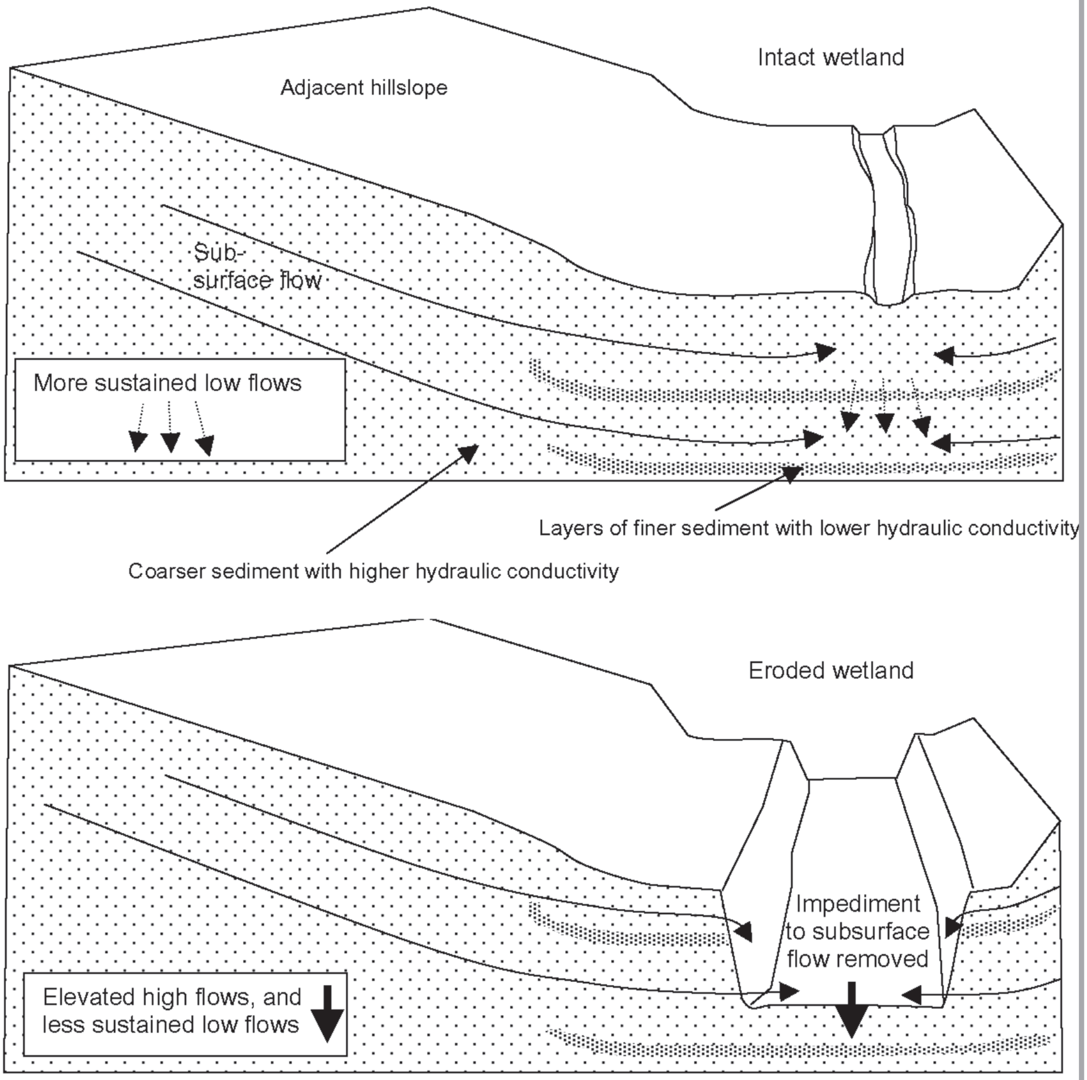
1 Difference in level of ecosystem delivery between the rehabilitated situation and the un-rehabilitated situation (0=none/ negligible; 1=moderately low; 2=intermediate; 3=moderately high; 4= high, where + =improvement and - =decline)

Box 1: A conceptual model of the regulating effect that the Manalana Wetland has on hillslope hydrological processes, and how this regulatory effect is diminished under eroded conditions.

The hillslopes surrounding the Manalana Wetland are predominantly sandy, with a relatively high hydraulic conductivity. Thus, the sub-surface movement of water down the slope to ultimately generate streamflow is potentially rapid, unless there are impediments to this lateral flow. The wetland sediments, which include layers of finer particles with lower hydraulic conductivities, provide such an impediment at the base of the hillslope and in the floor of the valley. The effects of the wetland sediments in affecting water movement is demonstrated by the findings of Riddell (2007), which show the existence of a differential water table system within the Manalana Wetland, in which exists a deep, permanent water-table and a seasonal, perched water-table. This perched water-table is, in fact, further differentiated into subtle water-tables that exist on low-permeability horizons in the wetland substrate, which are only apparent when the system is unsaturated.

The impeding effect of wetlands on the movement of water through the hillslope is, of course, dependent on the wetland sediments remaining in place. If the sediments were severely eroded by the propagation of headcut erosion, as would occur in the absence of the rehabilitation interventions, this impediment and its regulatory effect would be lost. This, in turn, would lead to less-sustained low-flows in the stream. It is recognized that in detaining water in the local catchment, the water will be more available for loss through evapotranspiration, thereby reducing the total water yield from the catchment. Even so, it is predicted that low flows would be reduced under the eroded situation

Box 1: continued



Cross section through the Manalana wetland under an intact and eroded situation

Figure 10: Actively-cultivated raised beds in Portion 2 of the wetland, photographed shortly before the planting season

Box 2: Predicted loss of sediment from the wetland likely to result from the advance of erosion headcuts through Portion 1 and 2 of Manalana Wetland. Based on the dimensions of the existing headcuts and the distance that they are projected to advance, an estimate of the total volume of the sediment likely to erode is made as follows:

'Reach'	Length (m)	Width (m)	Depth (m)	Volume (m^3)
Portion 1, main	220	10	1.4	3080
Portion 1, left arm	50	5	1.0	250
Portion 2, main, upper	190	15	2.2	6270
Portion 2, main, mid	200	20	2.2	8800
Portion 2, main, lower	180	25	2.2	9900
Portion 2, right arm	130	5	1.5	975
Portion 2, left arm	160	5	1.5	1200
Total Volume:				30475

It is important to emphasize, however, that some of the 30475 m^3 will be deposited within Portion 1 and 2 and will therefore not be exported immediately from the wetland.

6 Conclusion

The interventions that were assessed in this study have been shown to have contributed significantly to wetland health and, in particular, to the delivery of ecosystem services by the Manalana Wetland. As elaborated upon in Part 3B, the contribution to provisioning services by the interventions has been considerable. Nonetheless, it is important to emphasize that these structural interventions are part of a much broader and longer-term initiative that involves other components. These components address the governance of natural resources at Craigieburn and the cultivation practices of individual farmers at 'plot level' and in the catchment surrounding the wetland. Pollard *et al*. (2005) highlighted important deficiencies in the governance of natural resources in Craigieburn, together with a need for improving the sustainability of cultivation practices. It is recognized, therefore, that failure to address these important issues will threaten the long-term sustainability of the outcomes of the structural interventions assessed in this document.

Parts 3A and 3B of this report represent an integrated approach to assessing the outcomes of a wetland rehabilitation project. This integrated approach addressed several aspects, and included a socio-economic assessment, together with an assessment of hydrology, geomorphology and vegetation. It is recognized that rehabilitation is a long term process rather than a once-off event, and that rehabilitation takes place in dynamic ecosystems, and is also subject to dynamic human use patterns. Thus, research on several of the aspects mentioned above is ongoing, and is likely to yield further insights into wetland rehabilitation within the context of a dynamic social-ecological system.

7 References

Cowden C and Kotze DC, 2009. *WET-RehabEvaluate: Guidelines for the monitoring and evaluation of wetland rehabilitation projects*. WRC Report No. TT 342/09. Water Research Commission, Pretoria.

Ellery WN, Grenfell M, Grenfell S, Kotze DC, McCarthy TS, Tooth S, Grundling P-L, Beckedahl H, le Maitre D and Ramsay L, 2009. *WET-Origins: Controls on the distribution and dynamics of wetlands in South Africa.* WRC Report No TT 334/09, Water Research Commission, Pretoria.

Hammer DA, 1992. *Creating freshwater wetlands*. Lewis Publishers, Baco Raton.

Hemond HF and Benoit J, 1988. Cumulative impacts on water quality functions of wetlands. *Environmental Management*, 12: 639-653.

Kotze DC, Marneweck GC, Batchelor AL, Lindley DS and Collins NB, 2009. *WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands*. WRC Report No. TT 339/09. Water Research Commission, Pretoria.

Macfarlane DM, Kotze DC, Ellery WN, Walters D, Koopman V, Goodman P and Goge M. 2009. *WET-Health: A technique for rapidly assessing wetland health*. WRC Report No. TT 340/09. Water Research Commission, Pretoria.

Mitsch WJ and Gosselink JG, 1986. *Wetlands*. Van Nostrand Reinhold, New York.

Pollard S, Kotze D, Ellery W, Cousins T, Monareng J, King K and Jewitt G, 2005. *Linking water and livelihoods: the development of an integrated wetland rehabilitation plan in the communal areas of the Sand River catchment as a test case*. Unpublished report submitted to Water Research Fund for Southern Africa, Harare, Zimbabwe

Reddy KR and Patrick WH, 1984. Nitrogen transformations and loss in flooded soils and sediments. *CRC Critical Reviews in Environmental Control*, 13: 273-309.

Riddell ES, 2007. *The Craigieburn-Manalana Hydrological Processes Research Catchment, Sand River. Year 1-2 Interim Summary (August 2005 – June 2007)*. Unpublished report. School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, Pietermaritzburg.

Tiner RW, and Veneman PLM, 1988. *Hydric soils of New England*. University of Massachusetts Cooperative Extension, Massachusetts.

Part 3B:

Valuation of the livelihood benefits of structural rehabilitation interventions in the Manalana Wetland

SR Pollard, DC Kotze and G Ferrari

1 Introduction

Considerable literature exists concerning the effect of rehabilitation on the regulating services of wetlands such as water purification (e.g. D' Angelo *et al*., 2005; Hogan *et al*., 2004; Rheinhardt *et al*., 1997; Smith *et al*., 1995), and many of these studies would be globally relevant. There has, however, been much less research undertaken on the effect of rehabilitation on the provisioning services of wetlands. This has particular relevance to wetlands located in poor communities given the fact that poor people generally have limited access to technological solutions and are often directly and strongly dependent on natural ecosystems, including wetlands, to provide resources for meeting their basic needs. For example, Dovie *et al*. (2006) estimated that in one village in Bushbuckridge (the area into which the study site falls), the relative contribution of land-based livelihoods was 57.5%, compared to 42.5% from cash income streams.

One such wetland is the Manalana Wetland of Craigieburn village, which is situated in the upper Sand River Catchment in the north-eastern region of South Africa (although commonly referred to as the Craigieburn Wetland because of its location in the village of Craigieburn, for the purposes of this report we will refer to it as the Manalana Wetland). This catchment falls into the Bushbuckridge local municipality which is significant in terms of being the study area of numerous research initiatives over the past decade, many focusing on natural resources and their use to support peoples livelihoods (e.g. High and Shackleton, 2000; Pollard *et al*., 2003; Shackleton *et al*., 2005; Shackleton and Shackleton, 2005).

In a survey of the Manalana Wetland by Pollard *et al*. (2005) it was revealed that although some portions of the wetland had already been subject to severe gully erosion, other portions still remained intact. These intact areas were used by local residents for a variety of activities including cultivation, livestock grazing and reed harvesting. However, the wetland was under considerable threat from headcut, gully erosion. This was exacerbated by the steep longitudinal slope of the wetland and the sandy character of the soil in the wetland. Based on the past rate of advancement, it was predicted that the headcuts were likely to soon advance through all of the remaining intact areas unless there was some form of intervention. Based on previous research results, which showed an intimate link between erosion, desiccation and fertility, it was further predicted that the wetland erosion gullies would leave the landscape in a highly desiccated state, thereby reducing fertility and production. The overall impact would be felt directly by people whose livelihoods are dependent on the wetlands (Pollard *et al*., 2005). In response, two physical rehabilitation interventions, completed in early 2007, were undertaken by Working for Wetlands to halt the headward advance of two erosional headcuts into two portions of the Manalana Wetland. The structures, and their location in the wetland, are described in Part 3A, section 3.

2 Objective of the study

The objective of the study was to provide an assessment of the livelihood benefits likely to accrue from structural rehabilitation[1] that halts headward erosion of an erosional nick point through the Manalana Wetland. This was done by quantifying the current contribution of the intact portions of the Manalana Wetland to the livelihoods of local households. The assumption is that if rehabilitation is successful then it will prevent the loss of the livelihood contribution of the wetland. On the other hand, with no stabilization intervention, the livelihood benefits will be largely lost with the advancement of the headcuts. Although it was not the intention of the rehabilitation project to re-instate integrity to the degraded portions, but rather to secure the integrity of the remaining intact portions, the benefits of rehabilitation to soil water and to water security more generally, were recognised. Given this the current research project was not faced with the difficulty of waiting for the rehabilitation outcomes to be achieved before the assessment could be undertaken.

An assessment of the costs of the rehabilitation was undertaken as part of this study, allowing an assessment of the returns on investment. Moreover, to limit the pressure placed on communities by being subjected to further field research, the approach was to use already existing data bases.

3 Key concepts and background information

A number of key concepts are important to elaborate for this work. These include those of ecosystems goods and services and their valuation, as well as links between goods and services and livelihoods.

Ecosystem goods and services and societal well-being

Humanity has long been dependent on the earth's natural resources and, despite the apparent safeguard of technological advances, society is still fully dependent on ecosystems. Ecosystems are the productive engines of the planet that provide us with soils, nutrients, water, food, genetic resources, timber, and non-timber products. They also provide a range of ecosystem services such as water supply and flood control, which are a product of natural ecosystem processes and cycles. Compromising these goods and services and processes compromises life itself. A central tenet of the approach is that healthy societies are more likely to be associated with healthy ecosystems. Society's productive base is composed of natural, human, social and manufactured capital (Millennium Ecosystem Assessment, 2003). A society's 'natural capital' – its living and non-living resources - is therefore a key determinant of its well-being. Ecosystems are thus an important component of societal well-being through the provision of a wide range of 'goods and services'.

Nowhere are these links starker than for the rural areas of developing countries where an estimated 80% of the people rely directly on ecosystems for their livelihoods (Jazairy *et al*., 1992). For poor rural communities there are few substitutes (Millennium Ecosystem Assessment, 2003). This does not imply that the wealthy are independent of ecosystems but that they are less directly reliant on goods and services provided by ecosystems. In fact, their demand for these far exceeds that of the poor (e.g. Wackernagel and Rees, 1995). In a society focused on technological advances, these services have been, until recently, largely undervalued or ignored, particularly since they are not traded in

[1] This refers to the physical control of a headcut or erosional nick point to halt headward erosion and gully formation, and not to a wider rehabilitation initiative that focuses on broader catchment scale management.

the conventional economy (Carpenter and Gunderson, 2002). However, a publication by Costanza and his colleagues (Costanza *et al.*, 1997), which valued the world's natural resources and associated services at three times as much annually as all human created economic activities[2] provided some perspective on the market value of ecosystem services globally. Rivers, wetlands and lakes proved to be the most valuable systems by area (US $8 500-15 000 per hectare versus US $1 000 for land-based systems). Since these publications the valuation of ecosystem services has been refined through local-level studies. More formally, ecosystem goods and services are composed of the underlying supporting services, and the attendant provisioning, regulating and cultural services. These all contribute in different ways to human well-being (Figure 1). A number of different terms are applied to ecosystem goods and services mainly reflecting the discipline within which they are used. Resource valuation studies refer to direct (consumptive) and indirect (non-consumptive) use values and use a total economic value framework of environmental resources. Various valuation tools exist from market-value approaches, to surrogate and simulated market approaches (de Groot *et al.*, 2006). Direct-use values have been determined using any one of these (de Groot *et al.*, 2006; Emerton and Bos, 2004).

2 The 1996 value of $ 33 trillion is (i) conservative, and (ii) at a 3 % inflation would be equivalent of $45.6 trillion today

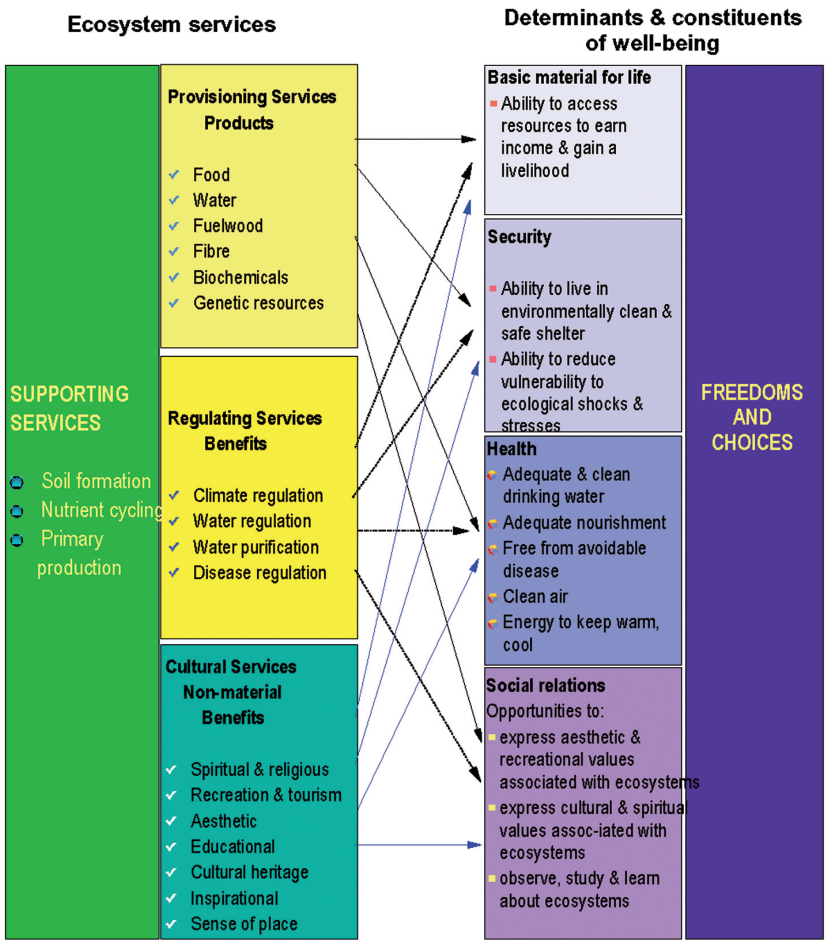


Figure 1: The links between ecosystems goods and services and human well-being (Millennium Ecosystem Assessment, 2003)

In South Africa, work on quantifying these goods and services for wetlands (Table 1) has also categorized these as either indirect or direct benefits (Kotze *et al*., 2009). Indirect benefits would broadly correspond to supporting and regulating services whilst direct benefits would incorporate provisioning and cultural services and the associated products used by people.

Livelihoods

The emergence of livelihoods approaches has led to new understandings for the poverty discourse, and the ability to move out of poverty. It recognises that peoples' ability to survive is not simply reliant on financial resources, but is predicated on a range of assets. This has fundamentally reshaped development interventions. Much of the thinking emerged from Chambers and Conway (1992) who defined livelihood as:

Table 1: Summary of ecosystem services provided by wetlands (from *WET-EcoServices*; Kotze *et al*., 2009)

Ecosystem services supplied by wetlands	Regulating & supporting benefits[1]		Flood attenuation	The spreading out and slowing down of floodwaters in the wetland, thereby reducing the severity of floods downstream
Ecosystem services supplied by wetlands	Regulating & supporting benefits[1]		Streamflow regulation	Sustaining streamflow during low flow periods
Ecosystem services supplied by wetlands	Regulating & supporting benefits[1]	Water quality enhancement benefits	Sediment trapping	The trapping and retention in the wetland of sediment carried by runoff waters
Ecosystem services supplied by wetlands	Regulating & supporting benefits[1]	Water quality enhancement benefits	Phosphate assimilation	Removal by the wetland of phosphates carried by runoff waters, thereby enhancing water quality
Ecosystem services supplied by wetlands	Regulating & supporting benefits[1]	Water quality enhancement benefits	Nitrate assimilation	Removal by the wetland of nitrates carried by runoff waters, thereby enhancing water quality
Ecosystem services supplied by wetlands	Regulating & supporting benefits[1]	Water quality enhancement benefits	Toxicant assimilation	Removal by the wetland of toxicants (e.g. metals, biocides and salts) carried by runoff waters, thereby enhancing water quality
Ecosystem services supplied by wetlands	Regulating & supporting benefits[1]	Water quality enhancement benefits	Erosion control	Controlling of erosion at the wetland site, principally through the protection provided by vegetation
Ecosystem services supplied by wetlands	Regulating & supporting benefits[1]		Carbon storage	The trapping of carbon by the wetland, principally as soil organic matter
Ecosystem services supplied by wetlands	Biodiversity maintenance[2]			Through the provision of habitat and maintenance of natural process by the wetland, a contribution is made to maintaining biodiversity
Ecosystem services supplied by wetlands	Provisioning benefits[1]		*Provision of water for human use*	*The provision of water extracted directly from the wetland for domestic, agriculture or other purposes*
Ecosystem services supplied by wetlands	Provisioning benefits[1]		*Provision of harvestable resources*	*The provision of natural resources from the wetland, including livestock grazing, craft plants, fish etc.*
Ecosystem services supplied by wetlands	Provisioning benefits[1]		*Provision of cultivated foods*	*The provision of areas in the wetland favourable for the cultivation of foods*
Ecosystem services supplied by wetlands	Cultural benefits[1]		*Cultural heritage*	*Places of special cultural significance in the wetland, e.g. for baptisms or gathering of culturally significant plants*
Ecosystem services supplied by wetlands	Cultural benefits[1]		*Tourism and recreation*	*Sites of value for tourism and recreation in the wetland, often associated with scenic beauty and abundant birdlife*
Ecosystem services supplied by wetlands	Cultural benefits[1]		*Education and research*	*Sites of value in the wetland for education or research*

[1] The wetland benefits included in *WET-EcoServices* are those considered most important for South African wetlands, and which can be readily and rapidly described. This is by no means exhaustive. Other benefits include **groundwater** recharge and discharge and biomass export, which may all be important but are difficult to characterize at a rapid assessment level.

[2] Biodiversity maintenance is not an ecosystem service as such, but encompasses attributes widely acknowledged as having potentially high value to society.

11 WET - OutcomesEvaluate Part 174 74 21/07/2009 12:17:11 PM

A livelihood comprises the capabilities, assets (stores, resources, claims and access) and activities required for a means of living: a livelihood is sustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation: and which contributes net benefits to other livelihoods at the local and global levels in the long and short term.

Central to the livelihoods approach is to understand the capabilities and assets (or lack thereof) that are available to people particularly the poor. This includes:

1. Human capabilities (such as education, skills, health, psychological orientation);
2. Assets - access to tangible and intangible assets (this includes human, material[3], social, natural and economic capital);
3. Activities - these capabilities and assets define the sorts of activities that make up the livelihoods of the poor and, through strengthening them, form the basis for many actions to reduce poverty.

The interaction between these attributes defines what livelihood strategy a household may pursue. Based on work by Chambers and Conway (1992), a number of fairly similar livelihoods models exist, the primary of these being those of DFID and CARE (see Carney *et al*., 1999 for a comparison of these models). The model used in this report (Figure 2), is adapted from these aforementioned models. Natural resources are one of the five capitals upon which people rely directly and hence are viewed as contributing to peoples' livelihoods. The tenet of this study is that the rehabilitation of wetlands (the natural capital) will lead to improved financial and social security.

[3] Access to land, other natural resources, financial capital and credit, tools and inputs into productive activities and others.

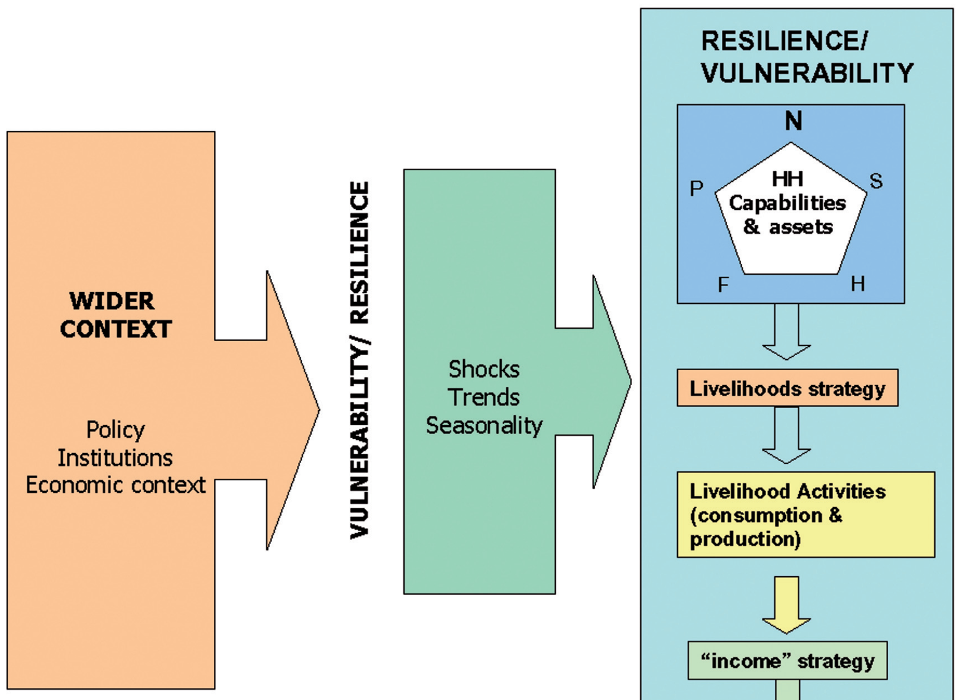


Figure 2: The livelihoods model that frames work reported in this study (Pollard and Perret, 2007 - adapted from DFID; Drinkwater and Rusinow, 1999). The five capitals used by households (HH) include natural (N); social (S); human (H); financial (F) and physical (P).

4 Summary of research in the Manalana Wetland

General approach to studies

As stated, the overall approach was to base the economic assessment on existing information where possible. In order to orientate the reader, this section provides a synopsis of work that is relevant to this research. Much of the baseline work was conducted between 2003 and 2004 and involved both biophysical and socio-economic research (see Pollard *et al*., 2005). Since then further work is being undertaken on the rehabilitation of the wetlands and their catchment. This includes a farmer support programme, including an assessment of land-use practices and cropping systems, as well as rehabilitation of the uplands, an assessment of wetland condition and support for governance.

In summary, in 2004 information was collected regarding wetland use, users and wetland health, with some 80 wetland users (mainly farmers) through semi-structured household interviews and group Participatory Rural Appraisal (PRA) exercises (abbreviated as the '2004 database'). The information included the following: (a) household characteristics of wetland users; (b) use of the wetland; (c) length of time in use; (d) field and plot information; (e) well-being status of users; (f) means of access; (g) livelihood contributions and (h) questions relating to perceived wetland health. The second dataset represents an assessment of farmer practices and included a description of the characteristics of their fields. This assessment was undertaken in May 2005 (AWARD, internal report) and is referred to as the '2005 database'. It was designed largely to describe soil and water conservation practices undertaken by farmers, as well as to determine the crops and crops status in different zones of the wetlands.

Livelihoods and well-being categories

Some 70% of Craigieburn residents use wetlands to meet their livelihood needs. The overriding profile of wetland users is that of women between 35 and 70 years of age - mainly from single-headed households. In general, livelihoods are very vulnerable to shocks and stresses such as drought. Any such event, including the loss of a family member or a drought, can cause a household from one well-being category to a lower one.

According to participatory wealth-ranking, wetland users categorised themselves into four well-being categories (Table 2). They also listed characteristics of each category. Accordingly, some 63% of households were ranked as very poor. Included in this category were a quarter of all households that had no regular income and secured food through what they grew. Indeed, only 15% of users were regarded as 'well-off'. Equally striking is that 63% have accessed their fields in the last ten years, citing hunger as the key driver.

Thus it was concluded that the Manalana

Table 2: Well-being/wealth categories that wetland-users used to describe themselves

Codes	Categories	% of users upstream of the rehabilitation structures
1	Poorest, no paid work or cash income	33
2	Occasional paid work, some with pensions/grants but many dependents	30
3	Pensions and grants	22
4	Someone has a full time job	15

Wetland offers an important safety-net, particularly for the poor, and is estimated to contribute 40% of the food grown locally. However, within-wetland practices, the demise of governance and varying levels of awareness regarding the fragility of these wetland systems, results in landuse practices by some users that compromises the integrity of wetlands and hence livelihoods and catchment water security (Pollard *et al*., 2005).

A key aspect of this work that forms a basis for understanding the value of the Working for Wetlands rehabilitation intervention, is the understanding of linkages. In these studies farmers raised three key problems: erosion, desiccation of the land and reduced fertility. The research indicated that within the wetlands, a number of landuse practices exacerbate erosion and hence desiccation, either directly by reducing soil structure and cover or by increasing water velocity (Figure 3). As a consequence of the associated reduction in fertility, and compounded by practices that directly reduce soil organic matter, agricultural production declines. These factors and interactions impact negatively on peoples' livelihoods.

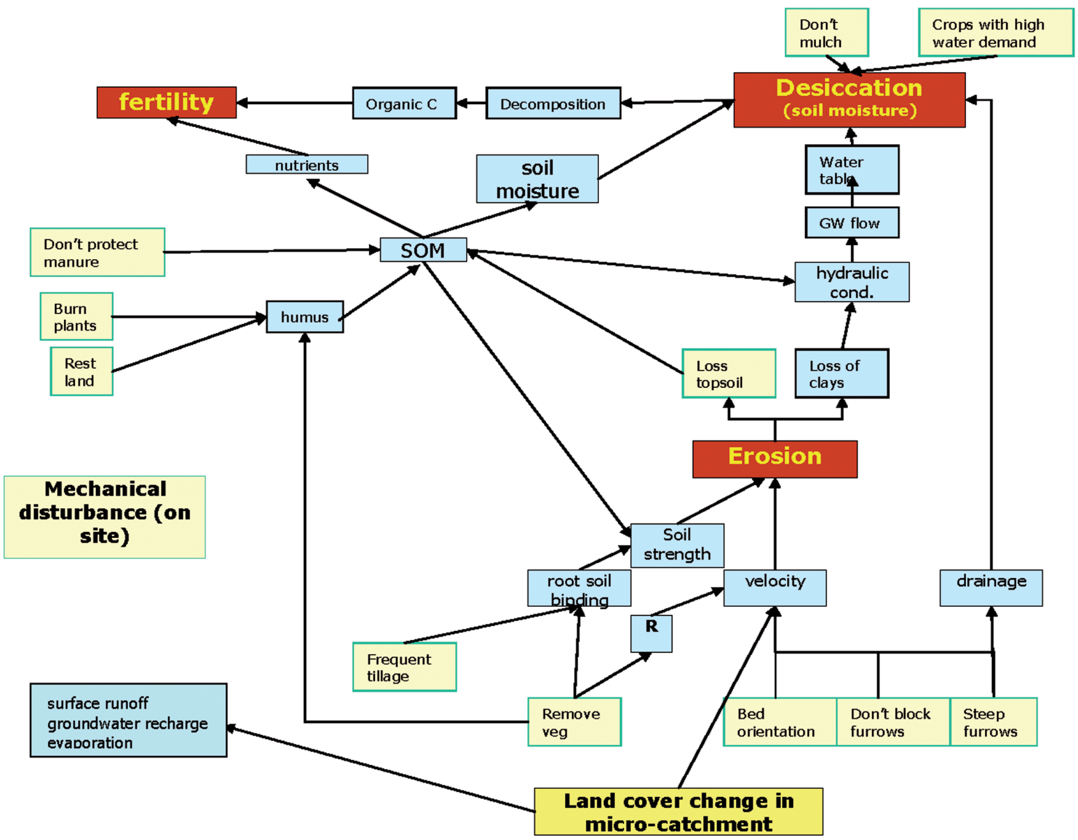


Figure 3: An overview of the linkages between on-site land use practices and wetland degradation, expressed through three key biophysical attributes that the wetland users raised (red boxes). Land-use practices are shown in green boxes (from Pollard *et al.*, 2005). Headcut rehabilitation acts to control erosion and thus improve soil moisture and fertility. R = surface roughness; SOM= Soil Organic Matter.

Cropping and the role of wetlands

Residents noted that wetlands allowed them to plant crops for a longer period than in rainfed fields, and moreover, they were able to plant a greater variety of crops. They explained that in the wet season they could rely on the wetlands for food more heavily than in the dry season (i.e. these wetlands are insufficiently wet to support extensive dry season cropping). In the wet season, 76% of respondents indicated that they grow 'some' or 'a lot' of their food in the wetlands. However, in the dry season about the same proportion secured only a little to some food from the wetlands.

Ecozones and crop types

Three ecozones were defined in the wetlands based on the duration of inundation (Figure 4) and were used for discussions and interactions with farmers as part of the farmer support programme. Different crops are grown in each zone (see Table 3).

An assessment of data collected in 2005 revealed that many fields (38%) had all three zones. Just under a quarter (21%) had only zones B and C. Some fields have only zone C.

The variety of crops that is grown in wetlands is higher than that in drylands. This differentiation is also seen between zones in the wetlands. From observed crop types on each of the farmers' fields, some 14, 9 ad 5 crop types occurred in zones A, B, and C respectively (Table 3).

- Madumbes (*Colocasia esculenta*), maize and pumpkins are the most ubiquitous crops, with madumbes being more common in the wetter zones and maize in the drier zones. Madumbes have particular nutritional attributes that make them a valuable crop.
- The variety of crops, and in particular the diversity of vegetables, offer important sources of nutrition over longer periods of the year than would be available from dryland plots.

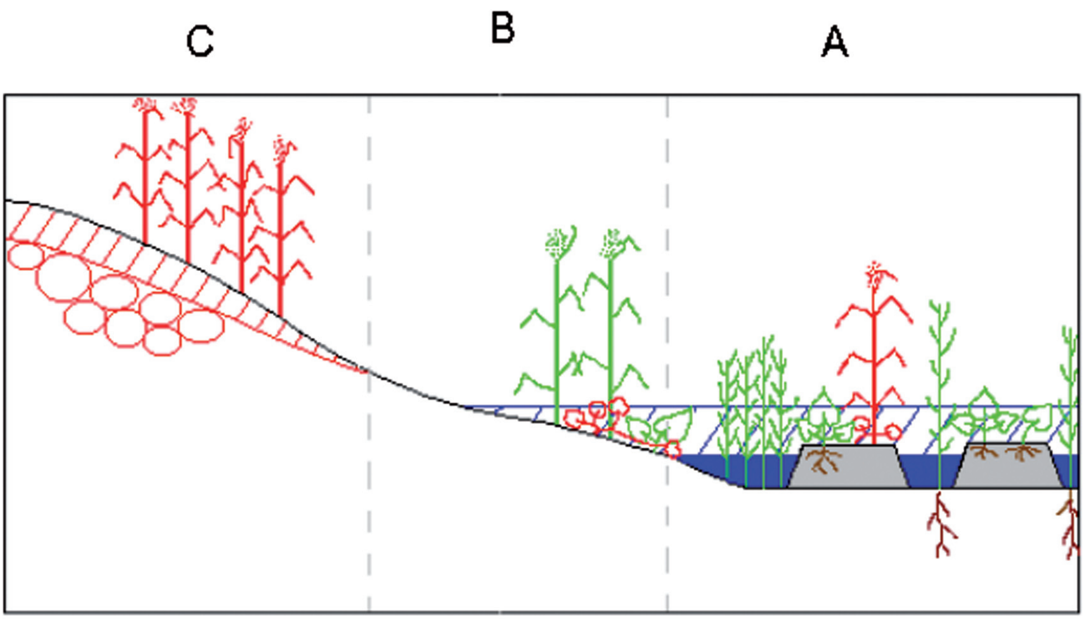


Figure 4: Ecozones that have been defined in the wetlands and that are used for interaction with farmers as part of the farmer support programme. Zone A is permanently wet, Zone B is seasonally wet and Zone C is temporally wet.

Table 3: Occurrence of crop varieties in plots of different wetland zones (information comes from an assessment at end of wet season and so may under-represent the full crop variety; Pollard & du Toit, internal report)

CROP TYPE	Zone A n=27	Zone B n=18	Zone C n=13
Sugarcane	7		
Maize	6	10	10
Root crop			
Madumbe	19	12	3
Sweet potatoes		1	
Masetla		1	3
Vegetables			
Spinach	2		
Pumpkins	5	5	2
Tomatoes	1	3	
Cabbage	1	1	
Beans		2	1
Onions	2		
Nkaka	1		
Nuts	1		
Groundnuts	1		
Bambarra nuts/ beans	2	1	
Fruit			
Bananas	2		
Watermelon	1		

5 Overall approach and methodology

Three key questions guided the assessment of the likely benefits of rehabilitation designed to halt the advance of headcut erosion threatening the wetland:

1. Which suite of goods and services are likely to be maintained or improved by the rehabilitation of the wetland?
2. Which of these goods and services are directly linked to people's livelihoods and thus likely to contribute to livelihood resilience?
3. What are the estimated financial benefits associated with these improvements?

To answer these questions a number of steps were undertaken which involved (a) establishing the links between rehabilitation and the environmental goods and services that will be secured (i.e. the benefits), (b) establishing the links between these benefits and peoples livelihoods, and then (c) valuing these benefits. These steps are detailed below.

5.1 Establish links between rehabilitation and environmental goods and services (benefits)

In order to assess the goods and services that were likely to improve (or at least, to stabilise), the systems diagram developed as part of Phase I (see Figure 3) was examined. This provided the foundation for understanding how rehabilitation is expected to impact on wetland functioning. Thereafter the benefits were conceptualised as both upstream and downstream benefits and detailed accordingly.

In order to estimate the value of rehabilitation, the area of the catchment and the wetland itself was estimated from a GIS map of the area. This was later cross-checked from field mapping.

5.2 Establish links between environmental goods and services and livelihoods

Two main databases (2004 and 2005) were used to establish the relative contribution of wetland goods to people's livelihoods (described in Section 4). A subset of the 2004 database was extracted to represent those users that have fields in the wetland and/or that use the wetlands for reed harvesting. This data was used to ascertain (a) the demographic profile of the wetland users and, (b) wetland uses. In terms of user demographics, the following attributes were examined:

- Total number of users (number of households);
- Number of people per household and therefore the total number of people relying on the wetland;
- The wealth category of the users (see Table 2), which gives an indication of the vulnerability of the households.
- The number of single-headed households since these (often headed by women) are more vulnerable.
- Dependency ratio, since examining the adult-to-child ratio provides an indication of their vulnerability.

The same database was also examined to establish the various uses of the wetland. A preliminary exploration of the data confirmed that the Manalana Wetland is used primarily for cropping purposes, although reeds are harvested by some users. Also, cattle grazing takes place during the dry season and water is collected especially during times of poor water supply. Both of these give an indication of the safety-net value of the wetland - an important issue that is given attention in Sections 6 and 7.

In terms of crops grown in the wetland, a number of attributes were examined. These data were extracted from the 2005 database. The attributes examined were:

- crop types
- crop varieties and the occurrence of crops in each zone. This was done (a) to establish the three most commonly grown crops (madumbes, maize and pumpkins) for further analysis and (b) to examine the relative importance of wetness in terms of crop types and variety.

As part of the work reported here, some additional field work was undertaken between April and May 2007, including estimates of cropped area, yield and sale price per crop. The area under crops upstream of the rehabilitation structures was measured in the field. Yields for each of the three crops were estimated in two ways: (a) five farmers were visited as harvesting was underway and the crop per plot of known area was weighed; (b) a group of seven farmers were interviewed using participatory tools regarding yields, cash price, storage and use of the three crops. An activity calendar was also drawn up to estimate when crops are harvested and used, in order to establish the timing of benefits to the household of cultivation in the wetland.

5.3 Valuation of benefits

This study focused principally on the provisioning services and products that accrue as a result of improved regulating services (see Figure 1) associated with the two rehabilitation structures. This is because, with the exception of water regulation and sediment trapping, insufficient data existed to meaningfully address other regulating services, or the supporting or cultural services.

Most of the analysis focused on the upstream benefits although some attempt was made to capture the downstream benefits associated with rehabilitation (Figure 5). The provisioning services (i.e. benefits) that were examined upstream of the structures included: crop production, reeds for harvesting, grazing for cattle, water for livestock and water for domestic purposes. It was assumed that rehabilitation would halt the headcut and secure the wetland upstream, thereby safeguarding these services. In the case of downstream benefits only water for domestic and livestock purposes were examined. We assumed that the rehabilitation structures would improve dry season base flows as indicated by Pollard *et al.* (2005). However, all other services – crops, grazing and reeds – are associated with an intact wetland and insufficient information was available regarding these services downstream.

For our purposes, a Cost-Benefit Analysis (CBA) was undertaken which, as pointed out by Emerton and Bos (2004), is the most commonly used decision-making tool for appraising and evaluating programmes. The CBA entailed the following steps:

- A valuation of the provisioning services for which information was available or to which meaningful inputs could be ascribed from the literature.
- Thereafter the total use value was calculated.
- Finally, relevant indicators were calculated: Net Present Value (NPV), Benefit Cost Ratio (BCR), Internal Rate of Return (IRR).

The CBA was complemented by a qualitative analysis of the contribution of the wetland to livelihoods.

For the purposes of the valuation, conservative estimates were made (i.e. the lowest yields, lowest prices). Where appropriate, a sensitivity analysis was undertaken to estimate the best case scenario where, for example, higher yields, or better prices could be anticipated.

The importance of wetland products as a contribution to livelihoods has been discussed. An important component of people's livelihoods is how vulnerable (insecure) or resilient they are. To get a better understanding of the 'buffering against livelihood insecurity' that the wetland provides, a number of issues such as poverty levels and nutritional contributions of food from wetlands, were also considered.

All values are expressed in ZAR 2007.

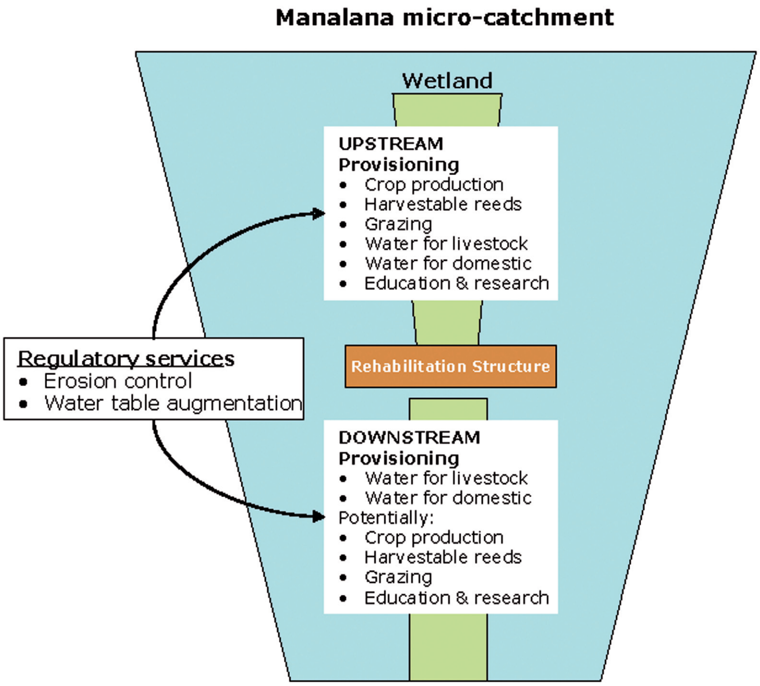


Figure 5: Schematic representation of the livelihood benefits of physical rehabilitation of the Manalana Wetland. The rehabilitation improves two key regulatory ecosystem services which in turn improve a number of provisioning services both upstream and downstream. In the case of downstream benefits only the first two (water for livestock and domestic use) were estimated.

5.3.1 Upstream: Estimate of total direct value of the rehabilitation intervention

The total net direct value (TNDV) per year was calculated as the aggregate value of individual resources as follows:

TNDV = Cr + Rd + GSNV + Wl + Wd

Where:

- Cr is the net value of crops
- Rd is the net value of reeds
- GSNV is the livelihood value of the total number of cattle sustained by wetland grazing
- Wl is water for livestock
- Wd is water for domestic purposes

The net added value attributed to the rehabilitation structures was then estimated by subtracting the value added attached to the wetland in a degraded condition (i.e without rehabilitation structures) from that of the rehabilitated wetland. The following sections elaborate these concepts.

i) Crops for household consumption

Wetland crops contribute most significantly to food for household consumption and also - to a lesser degree - to the sale of crops. As stated, only the three most commonly grown crops were valued: madumbes, pumpkins and maize. From interviews with farmers at harvest time (May 2007), estimates were made of the yields per crop per unit area, and the price of purchasing these crops locally was established. Then knowing the average bed size per field and the average number of beds used for each of the three crops, the average yield per year per farmer (or household), was calculated. Pumpkins are grown together with madumbes and so the same bed area was used for these two crops. Crop yields were reduced by 20% to account for retention for planting and some wastage. Crops for sale were not treated separately to those for household consumption. This is because the same valuation method was employed irrespective of whether or not the crop was used for household consumption or sold. If farmers do not have access to madumbes, they have to purchase them and, as madumbes are a preferred food, will go out of their way to do so. Thus any crop grown represents a saving. Only when a household has 'excess' is the crop sold. This is also true for pumpkins. In the case of maize, almost no farmers reported selling.

These results were then extrapolated to estimate the yields for all households that utilise the Manalana Wetland above the rehabilitation structures. Figures were adjusted to account for the fact that not all households grow pumpkins or maize in their wetland fields.

The annual gross value of each crop / resource to the household was calculated as follows

Annual use value = $p_i \times q_i$ [1]

Where:

- p_i = the unit price of the i-th resource;
- q_i = quantity of the i-th resource produced in one year.

Finally, a sensitivity analysis was undertaken to estimate the best case scenario. Here a scenario where higher prices for madumbes, maize and pumpkin were fetched was used for the calculations.

Under degraded conditions (i.e. no rehabilitation intervention), it was assumed that both the extent and yield of the wetland would decline by 50%. Yields decline because of the impacts of erosion on soil moisture content and fertility (Pollard *et al.*, 2005).

The net added value of the rehabilitation structures was estimated by subtracting the value under degraded conditions from that under rehabilitation.

ii) Harvesting of reeds

The wetland is used for the harvesting of reeds (*Schoenoplectus corymbosus*) for mats, some of which are sold. In order to value the protection of reeds for household use by the rehabilitation structures, replacement costs of reeds were used. The average area of reeds per field was calculated from the measurements of ten fields. Knowing that not all of the area would be harvested each year, it was assumed from discussions with farmers that 70% of the reeds would be harvested. Further, examination of the 2004 database showed that not all farmers harvest reeds; about 70% of farmers harvest reeds, which translates to 24 farmers above the rehabilitation structures. Thus the total area of reeds harvested was estimated by multiplying the average area of reeds harvested per farmer by the number of farmers that harvest reeds. Farmers reported that on average, a 1 m^2 area produces one bundle of reeds. Each bundle sells for R10. This value was used as the unit price. A conservative estimate of three bundles per mat was used (including wastage).

Based on these figures, the total number of mats made was then calculated. It was then assumed that 50% (12) households only make mats for their own use. The other 12 households retain 50% of their mats for household use and sell 50% of their mats. Mats sell for between R40 – R70. The conservative figure was used for the valuation and the upper value for the sensitivity analysis (i.e. best case scenario).

The net profit of mats that were sold was estimated by subtracting the production cost of mats from the gross market value. The value of the mats that were retained for household was calculated in the same way, based on the difference between the production cost and the gross market value.

Under degraded conditions (i.e. no rehabilitation intervention), it was assumed that the extent of the wetland would decline by 50%. The yields would also decline slightly because of the impacts of erosion on soil moisture content and fertility (Pollard *et al*., 2005), thus increasing the inputs to a single mat from 3 bundles to 3.2 bundles due to a reduction in the quality of the reed and hence increased wastage.

The net added value of the rehabilitation structures was then estimated by subtracting the value under degraded conditions from that under rehabilitation.

iii) Livestock grazing

The value of wetlands as forage has been widely recognized. In order to determine the value of the Manalana Wetland for grazing a five step model was used. Importantly, the rationale for this was based on determining the **safety-net value** of this ecosystem service which, we argue, represents a more realistic and appropriate value of this resource than a replacement cost approach.

- The numbers of cattle in the area above the rehabilitation structures were estimated.
- The grazing area under both intact and eroded scenarios was estimated.
- Based on a review of the literature, a qualitative estimate was made of the forage quality in order to estimate the numbers of cattle that could be supported by the wetland fodder.
- The numbers of cattle that could be supported by the wetland fodder through a number of 'bottle-neck' scenarios was estimated (it is recognised that in reality most cattle that graze in the area will survive the dry season but in poorer condition, an issue discussed below).
- Using the numbers of cattle surviving the bottle-neck, the total household value was determined based on estimates of the direct-use value of a cow to both cattle-owning and non-owning households in Bushbuckridge.

Cattle numbers

As explained, not all households in Craigieburn have cattle. This has implications for (a) estimating the numbers of cattle and (b) estimating the distribution of benefits (see later discussion on 'safety-net' value).

In keeping with patterns from semi-arid areas, cattle numbers vary cyclically in Bushbuckridge, mainly as a function of rainfall (Pollard *et al*., 1998; Shackleton *et al*., 1999). A study in 1998 estimated that, on average, 34% of all households have an average of 10.5 cattle in Bushbuckridge (Pollard *et al*., 1998). Shackleton *et al*. (1999) reported a value of 25% and a mean of 3.3 cattle per household. Another study from one village in the east of the Sand River Catchment reported that 60% of households own livestock, 34% of which own cattle (Dovie *et al*., 2006). The authors pointed out that there had been an increase in cattle numbers since 1994 following a major drought in 1992. This increase meant a much higher average (19.8) number of cattle per household.

In Craigieburn, the (a) numbers of cattle and (b) households with cattle were calculated from field data from 2004 (Pollard *et al*., 2005). These data indicated that 33% of households own an average of 4.9 cattle. Thus, of the 46 households in the catchment area above the rehabilitation structures, we estimated that 19 households own 91 LSU (Large Stock Units). This was cross-checked with calculating the total number of cattle for all of Craigieburn (240 LSU). If the area above the structure represents 45% of the total area of Craigieburn, then the corresponding estimate of cattle is 108 LSU. We used an average of these two estimates as 100 LSU.

Forage area and quality

The grazing area for cattle, and the associated fodder production, was estimated for both the intact and degraded scenarios in the catchment above the rehabilitation structures. It was assumed that the estimated 3.5 ha of intact wetland, would reduce in both extent (by 60%) to 1.4 ha, and in quantity of forage produced per unit area. The basis for these values is discussed below.

A key aspect of the grazing valuation was to examine what we have called the **safety-net value** of wetlands, as explained below. The rationale is to understand the value of wetlands in terms of fodder production and the numbers of cattle sustained during critical periods of stress or bottle-necks.

The value of wetlands for livestock grazing has been widely demonstrated (e.g. Cooper *et al.*, 1957; Findlayson and Moser, 1991; Morris *et al.*, 1989; Oellerman *et al*., 1994.; Richardson and Arndt, 1989). Owing to the favourable moisture conditions in wetlands, and probably also the higher soil fertility (Scotney and Wilby, 1983), the amount of forage produced in a wetland is typically much greater than that produced in the adjacent non-wetland areas. (Morris *et al*., 1989) note that wetlands in the Sani Pass area of the Drakensberg have the potential to produce, on average, twice as much forage as the surrounding grassland. The quality of this forage varies according to the particular wetland. In many wetlands the quality of the forage is greater than in the adjacent non-wetlands. Morris *et al*. (1989) found the quality in the wetland to be 100% better than that in the non-wetland (crude protein: 14.0 % compared with 6.7 %). In an interview-based survey of 8 different farmers in KwaZulu-Natal and the Free State, all farmers considered the quality of forage within the wetland to be either better or no worse than that of the adjacent non-wetland areas (Oellerman *et al.*, 1994). Estimates by the Department of Agriculture over 4 years in Middelberg indicated that seepage wetlands were twice as productive as natural veld (6 tons versus 3 tons of grass per ha; cited by Turpie and van Zyl in Palmer *et al.*, 2002). Using this figure they valued the replacement costs (gross, for fodder purchase) at R1800 per ha.

In some situations, however, the forage quality may be lower in the wetland compared with adjacent areas. One of the factors contributing to this is the high proportion of poorly-digested structural material typically found in tall, robust wetland plants such as *Typha* spp. and *Phragmites* spp. For example, the cell wall component of *Typha domingensis*, which is poorly digested, may comprise over 70% of the dry weight of the plant (Howard-Williams and Thomson, 1985). While this applies to the mature growth of these species, the quality of the young growth is generally much higher. For example, the young growth of *Phragmites australis* provides good forage for domestic stock, and has a high crude protein:fibre ratio (23% for mature growth and 31% for young growth), and no secondary compounds (Duncan and D' Herbes, 1982). The excess water and very soft soil of some wetland areas renders them inaccessible for livestock, and therefore of little grazing value.

The Manalana Wetland is characterized by the following features:

- The level of wetness of the wetland is intermediate, almost entirely temporarily and seasonally wet, and the entire wetland is easily accessible to livestock.
- There is a moderate abundance of relatively palatable species (e.g. *Paspalum dilitatum* and *Leersia hexandra*) and the tall, robust *Phragmites mauritianus* which is only palatable when immature.
- The non-wetland areas are in poor condition, with a low cover of herbaceous vegetation.

Thus, compared with wetlands generally in South Africa, the forage value of the Manalana Wetland is probably below average, but when compared to the adjacent non-wetland areas, it is relatively high. Given the above features, the Manalana Wetland is assumed to provide, on a unit area basis, a conservative estimate of 75% more forage than the non-wetland areas. Thus, the production of forage was adjusted in wetland areas to 75% higher per unit area than the production in non-wetland areas.

Estimating the safety-net value: Grazing

Certain characteristics of wetlands such as the fact that they typically have moisture for longer into the dry season, mean they become a key resource in times of stress. At the end of winter both fodder production and water availability (both for domestic and livestock purposes) are important resources.

In the case of pasture for livestock grazing in the Craigieburn, the wetland offers just such a safety-net suggesting that its value is much higher than simply the financial values given above. Although it may appear that the wetland offers grazing to a relatively small percentage of the cattle relative to other grazing lands, it is the **timing and duration** of the fodder that is critical. Given that during the bottleneck period of winter and early spring – anywhere between 4 to 10 weeks – when the livestock rely particularly heavily on the wetland, any loss due to degradation would be all the more acutely felt. We argue that the wetland represents a key resource in that it supports higher stocking rates and reduced mortality in times of stress – thereby reducing the impact of the bottleneck period. Thus, its value is not just in the amount of fodder it produces, but the fact it is produced at a time when other fodder is minimal (thus increasing stress on the animals, causing body mass loss, and possible mortality). The safety-net value in this case is the value to peoples' livelihoods of the cattle that are sustained over the period of stress.

In reality wetland grazing supports many cattle, though in poor condition, through the bottleneck period in an average year. However, in view of the lack of data reflecting this change in cattle condition (and hence value), it was decided that for the purpose of this model, this change be formalised in terms of a change in the total number of (healthy) cattle that the wetland would support. The underlying assumption is that the number of cattle not maintained in a healthy condition by the wetland over the bottleneck period would either not survive or be so weakened that their associated goods and services – and hence benefits to peoples' livelihoods – would be been minimal.

We calculated the total fodder produced by the wetland and then, assuming a consumption of 10 kg dry matter LSU^{-1} d^{-1}, we calculated how many cattle could be maintained under different 'stress periods'. Assuming a 'bottleneck' period of 4 weeks for the purposes of our model, the numbers of cattle that could be sustained by the wetland over that period was determined (based on a production of 1254 tons ha^{-1} yr^{-1}; see below). This was calculated for two scenarios: the rehabilitated wetland and the degraded wetland.

Given the fact that Manalana Wetland is in mixed veld (i.e. between sweet and sour veld) a conservative estimate of production of 1 800 kg ha^{-1} yr^{1} of dry matter was made for non-wetland areas. Assuming that the wetland produces 75% more than this, production from the wetland can be estimated at 3 150 kg ha^{-1} yr^{1}. However, in order to account for the fact that the wetland vegetation is not in good condition, production is reduced by 20% to give 2520 kg ha^{-1}. Account is also taken of the fact that not all of this is going to be available during the 'bottleneck period'. Some fields are opened up well before the bottleneck. An estimate of 30% of the fields being eaten before the bottleneck, leaves 1764 kg available in the bottleneck period. Finally, account needs to be taken of the fact that not all of the 1764 kg is grazed. Some material is left (e.g. because it is trampled to the ground, or is stalky material not considered acceptable to livestock). Thus, the 1764 kg is reduced by a further 30%, leaving 1254 kg utilised by the livestock for the rehabilitated wetland available during the bottleneck period.

For the degraded scenario, we assumed a 40% reduction in extent (owing to the inaccessibility of the steep gully sides to cattle) and a reduction in fodder production in the remaining wetland to 617 kg ha^{-1} yr^{-1} due to the effects of desiccation and reduced fertility associated with erosion (Pollard *et al.*, 2005).

The numbers of cattle sustained over the 4-week period was then calculated as follows:

$$CSn = \frac{Pf}{Tbn*Cc}$$

Where:

- CSn = number of cattle sustained
- Pf = fodder production (kg per unit area of wetland * total wetland area)
- Tbn = length of time of bottleneck period (days)
- Cc = consumption per cow per day (kg)

Then in order to give value to these cattle in terms of the safety-net value to peoples' livelihoods, the value of cattle to households was used to calculate savings. Shackleton *et al*. (1999) estimated that total annual direct-use value of the goods and services provided by a cow to cattle-owning households for the Bushbuckridge area as the net direct use value per cow, including savings, was R497.21 LSU^{-1} yr^{1}. This figure was adjusted at 3% inflation over 7 years to R630 LSU^{-1} yr^{1}. In view of the assumptions above, this value of a LSU was multiplied by the number of cattle sustained to give an overall value, termed the 'grazing safety-net value'

(GSNV).

GSNV = CSn x Vc

Where:

- CSn = number of cattle sustained
- Vc = value of a LSU

This value was calculated for all cattle-owning households. A similar process was adopted to calculate the value of cattle to non-owning households, such as the use of dung for soil improvement. A value of R163 LSU^{-1} yr^{1} was adjusted over 7 years to R206.48 LSU^{-1} yr^{1}. The total of these values represented the total safety-net value.

In order to explore the differences in valuation using a conventional approach versus a safety-net valuation, the replacement cost of fodder was also calculated. The value was calculated using the market price for fodder in September 2007.

Finally, the net added value of the rehabilitation structures was estimated by subtracting the value added of the wetland in degraded conditions from that under rehabilitation.

iv) Water for livestock

The purpose of this section is to calculate the added value of the rehabilitation structures in relation to the water required for livestock rearing that they guarantee. The shadow price of this service was calculated based on the costs saved from not having to resort to boreholes and pumps to provide livestock with water. In Craigieburn, livestock are totally dependent on wetlands for their drinking water. If the resource was not available livestock owners would have to find alternative sources of water. This replacement value was calculated as follows:

- The likely alternative to the surface water provided by wetlands is groundwater from boreholes pumped into tanks and distributed into drinking troughs. To calculate the number of boreholes and tanks required to meet demand, the total demand by livestock was estimated – in this case cattle and goats belonging to households above the rehabilitation structures. The total number of cattle and goats was estimated as 100 and 170 respectively. Water demand by cattle in particular can vary hugely depending on the type of cattle, their production purpose (milking cows typically consume more) and ambient temperature. For example, at temperatures of 10°C, the estimated demand is between 22 and 32 l $animal^{-1}d^{-1}$ whereas at a temperature of 35°C the demand escalates to 109 l $animal^{-1}d^{-1}$ (Gerrish & Davis, 1999 cited by Griffith http:// www. noble.org/ag/ Livestock / WaterConcerns/index.html). Other sources cite the demand for milking cows as 160 l $animal^{-1}d^{-1}$ (see http://pubs.cas.psu.edu/FreePubs/ watersystems planning- estimating water needs). The water demand by goats is estimated at between 20-30 l per day (WHO 2005). For cattle, an average value of 80 l d^{-1} was used, and for goats, 25 l d^{-1}.

Knowing the total daily demand, and assuming tanks would be filled twice a week, the tank sizes required were estimated.

To calculate establishment costs we assumed that, given the distances, two boreholes would be required. Each borehole would pump into plastic tanks (referred to locally as 'Jojo' tanks) and then into troughs (the numbers of which are a function of the demand calculated above). Each borehole would be fitted with a diesel pump encased in a pump cage for security purposes. The annuitised capital costs were then calculated based on a life-expectancy of ten years, a discount factor of 3%, and an annuitisation factor of 8.53, based on the assumption that costs would be paid at the beginning of the period of relevance.

Then the annual running costs were estimated. These included a monthly cost of diesel of R150 for each pump and an estimated R1500 maintenance costs for each borehole and pump.

The total annual costs were calculated as the sum of the annuitised capital costs and the annual running costs.

Under degraded conditions (i.e. no rehabilitation intervention), it was assumed that the wetland would meet a negligible amount of the water demand by livestock. This is based on our knowledge of the impacts of erosion on soil moisture in the Manalana Wetland (Pollard *et al*., 2005). Moreover, a spring that was historically used for domestic and livestock purposes had completely dried up with progressive headcut erosion near the top structure. Thus it was assumed that under a no-intervention scenario, conditions would be so dry that cattle owners would be forced to follow the alternative scenario described above. For the purposes of the assessment it was assumed that the degraded wetland would supply water for only the wettest months of the year (taken as 25% of the year).

v) Water for domestic purposes

Craigieburn is part of a bulk distribution system for domestic water supply. However, this system is regarded as unreliable and when the system fails, people use the wetlands as a source of water to meet their basic water consumption needs. This includes water for drinking, personal hygiene (washing) and cleaning, as well as for cleaning clothes.

In order to give a value to this water, which acts as a safety-net in times of failure (stress), the replacement cost of buying water from water vendors was estimated. Residents report that the water supply system fails, on average, three times a week (43% of the time). We used a conservation estimate of 2 days a week or 29% of the time - amounting to 106 days per year. To calculate the demand for the 248 residents living above the structure, we used estimates of the basic domestic consumption from a detailed economic survey conducted in the Bushbuckridge area (Perez de Mendiguren and Mabelane, 2001). This study estimated that in worst-case villages (those with limited water availability) an average of 22 l $c^{-1}d^{-1}$ was used for basic water consumption needs (see above). This value, which is less than the Reconstruction and Development Programme (RDP) minimum of 25 l $c^{-1}d^{-1}$, was used as a conservative estimate. The purchase price of water in Craigieburn is R0.5 for 25 litres (or 2c per litre, which concurs with other figures for the area which range between 6c and R1.75 for 25 litres (Perez de Mendiguren and Mabelane, 2001).

No sensitivity analysis was carried out in this case because, although other productive uses of water would be prejudiced (loss of opportunity costs) with the failure of bulk supply, it is unlikely that these would be met through water from the wetlands. For example, a small-scale productive activity such as brick-making is more likely to cease during times of supply failure.

For the same reason discussed in the previous sections (water for livestock), it was assumed that the wetland would meet a negligible amount of the domestic water demand under degraded conditions (i.e. no rehabilitation intervention). For the purposes of the assessment it was assumed that the degraded wetland would supply water for only the wettest months of the year (25% of the year). The value added of the rehabilitation structures in relation to water provision for domestic purposes was found to be equal to costs saved from not having to purchase the water needed on the market during the remaining 75% of the year.

5.3.2 Downstream benefits: Estimate of total direct value of the rehabilitation intervention

As stated, only a small component of the total downstream benefits was valued. This included water for domestic and livestock purposes. Calculations were based on the assumption that benefits of continued water in the channel associated with the rehabilitation structures would be felt up to 1 km downstream. This included some 60 households, or 438 people, 132 cattle and 222 goats dependent on this water supply. The same methods described above for the upstream benefits were used. The net values were then summed.

5.3.3 Summary indicators: Balancing costs and benefits

Emerton and Bos (2004) point out that CBA presents three basic measures of worth:

- Net Present Value (NPV) is the sum of discounted net benefits (i.e. benefits minus costs), and shows whether a project generates more benefits than it incurs costs.
- Benefit Cost Ratio (BCR) is the ratio between discounted total benefits and costs, and shows the extent to which project benefits exceed costs.
- Internal Rate of Return (IRR) is the discount rate at which a project's NPV becomes zero.

They assert that a project can be considered to be worthwhile if its NPV is positive, the BCR is greater than one, and if its IRR exceeds the discount rate. A positive NPV and a BCR greater than one means the project generates benefits that are greater than its costs. An IRR above the discount rate means that the project generates returns in excess of those which could be expected from alternative investments. Although the use of the IRR as a measure of investment profitability has been questioned in the literature (Layard and Glaister, 2003), we report it here, since the conditions under which IRR results may be questionable do not apply here.

The total cost of the upper and lower rehabilitation structures was R183 543 and R496 990 respectively totaling R680 533.

5.3.4 Contribution of the wetland to the reduction of livelihood vulnerability

In terms of the relationship between wetlands and livelihoods, an important component to consider – albeit qualitatively – is the impact on the reduction in the livelihood vulnerability of local people. To get a better understanding of the 'buffering against insecurity' that the wetland provides, a number of issues were considered:

- The wealth categories of the users were examined (see Table 2).
- These data were compared to the census data from 2001 for concordance (Craigieburn falls within Ward 4). This comparison was done to explore if the wetland users' perceptions of their own vulnerability agreed with that of the census data.
- The average net value from the wetland to households per annum was calculated per well-being category by multiplying the average value by the proportion of households in each category.

The nutritional benefits of the crops were also described based on a literature review.

6 Results

The following results indicate the area of the catchment and wetland above the rehabilitation structures, where a large number of provisioning ecosystem goods and services are likely to be secured through rehabilitation. These results provide the foundation for the valuation exercise.

6.1 Links between rehabilitation and environmental goods and services

The total catchment above the rehabilitation structures is estimated as 70 ha. A GIS mapping study conducted in 2004 (to estimate the proportional extent of wetlands per micro-catchments), estimated that Catchment 55 into which Manalana falls, comprised 3.4 ha of wetland, or 5% of the catchment area.

By halting the advance of the two severe erosion headcuts, a couple of benefits were immediately apparent. Firstly, upstream of the structures, the wetland and the fields will not be lost. This might seem obvious and somewhat of an extreme statement, but in 2006 a number of farmers lost their fields further downstream of the wetland due to headcut erosion into another similar wetland area. Poor landuse practices by one farmer, together with a number of contiguous storm events in 2005-2006 resulted in the movement upstream of a headcut by nearly 1000 m. The banks of the wetland also collapsed and this was followed by erosion of the fields into the donga.

Secondly, by reinstating the water table through the construction of a simulated clay lens, the desiccation of the landscape will also be averted. It is hypothesised that the impacts of this drawdown of the water table are felt in the slopes of the catchment and not just in the wetland. Together with the retention of topsoil and the improved soil moisture, soil fertility and crop yield are improved.

The systems diagram (Figure 6) illustrates how rehabilitation of the wetland will impact on both provisioning and regulatory services. The former is principally in the form of food as well as reeds, water and grazing for cattle. Cattle are normally excluded from wetland fields by fences until towards the end of the dry season (around September), when farmers open their fields for cattle. The regulating services most likely to be positively impacted relate to streamflow regulation, water table augmentation and sediment trapping and erosion control (Table 4; see Pollard *et al.*, 2005).

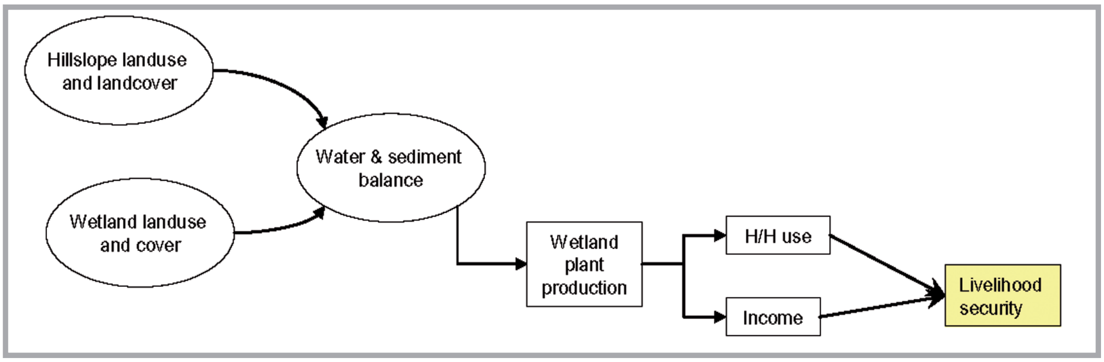


Figure 6: The links between catchment health, wetland yields and livelihood security (from DFID; Pollard and Perret, 2007). Crops and plants from the wetlands are used for household (H/H) consumption or for sale.

Table 4: Regulating and provisioning services associated with the Manalana Wetland

Ecosystem goods and services	From 2005 assessment
Regulating services	**Essentially the regulating services sustain the wetland. Thus, securing these services allows for the existence of provisioning services.**
Water table augmentation	The accumulation of clays at the toe of the wetland acts as a barrier to reduce water movement and augments the water table of the wetland and surrounding landscape
Streamflow regulation	Augmentation of baseflow, especially important during the dry season
Sediment trapping and erosion control	Wetlands act to trap and stablise the movement of sediment downstream. This has an important consequence in Manalana Wetland since headcut erosion starts with the increased slope associated with deposition of sediments in the channel.
Provisioning services	**These occur upstream and downstream of the rehabilitation structures**
Food	• Some 16 crop types grown in Zones A-C; 88% of these occur in Zone A. • Madumbes, maize and pumpkins most common crops
Zone A	• Highest diversity • 14 crop types • Madumbes and sugarcane most common, then maize and pumpkin
Zone B	• 9 types • Madumbes and maize most common
Zone C	• 5 types • Maize most common
Water	• Domestic supply in times of bulk supply failure. Also used daily for clothes washing • The only source of water for livestock
Fibre (reeds)	• For mats for household consumption and for local sale
Grazing for cattle	• Important resource for cattle towards the end of the dry-season

6.2 Links between environmental goods and services and livelihoods

Of the 46 households that derive benefit from the wetland above the rehabilitation structures, 27 farmers were reported to be using the Manalana Wetland area in 2004. This amounted to a total of 198 people (in households of farmers). Some 60% of these are children, 34% of which are five years or younger. Since 2004, seven additional farmers have started cultivation and, at an average of 7.3 people per household, this amounts to a total of 248 people that are dependent on the wetland for some of their food requirements. Over half of these are children. Some 50% of the farmers were born in the area, 15% did not know when they arrived and the remainder arrived between the 1960's and 80's. Only 33% of the farmers have cattle. Wetland-dependent households constitute some 73% of the total population living above the structure, estimated at 336 people.

In terms of the vulnerability of wetland users, some 63% of farmers fall into the lowest wealth categories (1 and 2). These categories comprise the poorest-of-the-poor (33%) or very poor (30%) that may receive occasional income but that have many dependents.

6.3 Valuation of benefits

The total value of the benefits was estimated both upstream and downstream of the structures. The benefits upstream of the structures were substantial while the benefits downstream were smaller by comparison. These are elaborated upon in the next section.

6.3.1 Upstream: Estimate of total direct value of the rehabilitation intervention

i) Crops for household consumption.

The total bed area above the rehabilitation structures that is used for vegetable production was estimated as 6 188 m^2 for madumbes (grown by all 34 households), 2 184 m^2 for pumpkins (12 households) and 2 028 m^2 for maize (26 households).

The reported yield for madumbes of 25 tons ha^{-1} was used (or 2.5 kg m^{-2}, Table 5). This compares with yields of 25 to 35 t ha^{-1} reported for small scale madumbe production from Mbongolwane, KwaZulu-Natal (Kotze, *et al*., 2002). As indicated in Table 5, an estimated 15 470 kg of madumbes are harvested. Madumbes are sold for R70 per 20 kg crate (R3.5 per kg) if they are sold in bulk. Higher prices are fetched if they are divided into 2 kg bags which are sold for R10 (R5 kg^{-1}). For the purposes of this study the conservative price of R3.5 kg^{-1} was used. This amounted to an average net use value of R1 274 $household^{-1}$ yr^{-1} and R43 316 for all households above the rehabilitation structures. In the best case scenario, the total value would be R74 256.00.

The annual estimated yield for pumpkins is

Table 5: A summary of the estimated net annual direct use values for three wetland crops harvested from the Manalana Wetland above the rehabilitation structures with the rehabilitation intervention in place (h/h = household)

Item	Madumbes (kg m^{-2})	Pumpkin (fruit m^{-2})	Maize cobs (cobs m^{-2})	Total
Household scale				
Yield (kg m^{-2}/ fruit m^{-2})	2.5	1.2	3	
Average bed size per h/h	26	26	26	
Average no beds per h/h	7	7	3	
Total bed area per h/h (m^2)	182	182	78	
Yield per h/h (kg/ cobs/fruit)	455	218.4	234	
Yield after retention for planting /losses (kg/ cobs/fruit)	364	174.7	187.2	
Price	**R 3.50/ kg**	**R 5.00/ fruit**	**R 1.50/ cob**	
Net direct value per h/h (Rands)	**1 274.00**	**873.60**	**280.80**	**2 428.40**
Net direct value per h/h: Best case scenario	**2 184.00**	**1 048.32**	**374.40**	**3 606.72**
Catchment scale				
No of h/h that grow/ consume	34	12	26	
Total bed area above rehabilitation structures (m^2)	6 188	2 184	2 028	
Total yield (kg/ cobs/fruit)	15 470	2 621	6 084	
Yield after retention for planting/ losses (kg/ cobs/fruit)	12 376	2 097	4 867	
Total net value (Rands)	**43 316.00**	**10 483.20**	**7 300.80**	**61 100.00**
Total net value (Rands): Best case scenario	**74 256.00**	**12 579.84**	**9 734.40**	**96 570.24**
Net added value of rehabilitation (Rands)				**45 825.00**
Net added value of rehabilitation: Best case scenario				**81 294.52**

1.2 pumpkin fruit m^{-2}. Given that the average bed area for pumpkin production is 182 m^2 per household, the yield per household is estimated as 218.4 kg, and allowing for losses, 174.7 kg (Table 5). Based on a sale price of R5 per fruit (which are about the size of a football), the net direct value per producing household is R873.60, and the total value is R10 483.20, given that 12 households produce pumpkins. In the best case scenario, the total value would be R12 579.84.

Maize is not sold but farmers interviewed said that on the odd occasion that they do sell. They would charge between R1.50 and R2.00 per cob. The use value was estimated based on a yield of 3 cobs m^{-2}. If each household has an average area of 78 m^2 for maize, then they would produce 187 cobs (after 20% retention for planting) amounting to a replacement value of R280.80 yr^{-1}. Not all farmers produce maize in the wetland – the 26 farmers that reported doing so could then produce 4 867 cobs which amounts to a use value of R7300.80 yr^{-1}. In the best case scenario, the total annual value would be R9 734.40.

Under degraded conditions with no rehabilitation structures, there would be an estimated 75% reduction in revenue due to decreased yield associated with the reduction in wetland area and productivity (Table 6). The annual value would decline from a conservative estimate of R61 000 to R15 275. Thus the added value of rehabilitation is R45 825 although this could be as high as R81 294.00.

Table 6: A summary of the estimated net annual direct use values for three wetland crops harvested from the Manalana Wetland with no rehabilitation intervention (h/h = household)

Item	Madumbes (kg m^{-2})	Pumpkin (fruit m^{-2})	Maize cobs (cobs m^{-2})	Total
Household				
Yield (kg m^{-2}/ fruit m^{-2})	1.25	0.6	1.5	
Average bed size per h/h	13	13	13	
Average no beds per h/h	7	7	3	
Total bed area per h/h (m^2)	91	91	39	
Yield per h/h (kg/ cobs/fruit)	**113.75**	**54.6**	**58.5**	
Yield after retention for planting /losses (kg/ cobs/fruit)	**91**	**43.68**	**46.8**	
Price	3.5	5	1.5	
Net direct value per h/h (Rands)	318.50	218.40	70.20	607.10
Catchment scale				
No of h/h that grow/ consume	34	12	26	
Total bed area above rehabilitation structures (m^2)	3 094	1 092	1 014	
Total yield (kg/ cobs/fruit)	3 868	655	1 521	
Yield after retention for planting/ losses (kg/ cobs/fruit)	**3 094**	**524**	**1 217**	
Total value (Rands)	**10 829.00**	**2 620.80**	**1 825.20**	**15 275.00**

ii) Harvesting of reeds

With rehabilitation in place, the average wetland area under reeds per household is 40 m^2. Assuming that 70% of the area is harvested annually, each household would use approximately 28 m^2. For the 24 households that reported harvesting of reeds, a total of 224 mats are produced annually with an estimated net value of R2 240 per year. If mats all are sold at the highest price of R70 per mat, the total net value would be R8 960 (Table 7).

Under degraded conditions the total net value declines by over 60% to R840 per year. Thus the total added value of the rehabilitation structures is R1 400 per year although this could be as high as R8 120 (Table 7).

Table 7: A summary of the estimated net annual direct use values for reeds/mats harvested from the Manalana Wetland with and without the rehabilitation intervention (h/h = household)

Item	Wetland with rehabilitation intervention	Wetland without rehabilitation intervention	Sensitivity analysis (best case scenario)
Bundles per mat	3	3.2	3
Price of mat	40	40	70
No of HH that harvest (70%)	24	24	24
Average area under reeds/ field (m^2)	40	20	40
Average area harvested per h/h (m^2 yr^{-1})	28	14	28
Average no of mats produced per h/h yr^{-1}	9.3	4.4	9.3
Total no of mats produced	224	105	224
Mats sold			
Average no of mats sold/yr	56	26	56
Gross value of mats (Rands yr^{-1})	2 240.00	1 050.00	2 240.00
Cost of production (Rands yr^{-1})	1 680.00	840.00	1 680.00
Net Profit from mats sold	560.00	210.25	2 240.00
Mats for h/h use			
No of mats produced for h/h use/yr	168	79	168
Market value of mats for h/h use (Rands yr^{-1})	6 720.00	3 150.00	1 760.00
Cost of production (Rands yr^{-1})	5 040.00	2 520.00	5 040.00
Net Savings from h/h Mats Production (Rands yr^{-1})	1 680.00	630.75	6 720.00
Total net value of reeds/mats (Rands yr^{-1})	2 240.00	840.00	8 960.00
Total net value of reeds per h/h ((Rands yr^{-1})	93.33	35.00	373.33
Net Added Value of Structure (Rands yr^{-1})	1 400.00		8 120.00

iii) Livestock grazing:

Estimating the safety-net value: Grazing

Assuming a bottle-neck period of 4 weeks, an estimated 14 LSU would be sustained on the fodder produced within non-degraded wetland (i.e. under rehabilitated conditions). The replacement value of this fodder is R4 322 yr^{-1}. However, if the safety-net value of the grazing provided for the same cattle is considered, then the total net value is estimated at R9 073 yr^{-1} (Table 8). Additional benefits accrue to non-cattle owning households amounting to R2 974 yr^{-1}. The total safety-net vale is estimated as R12 049.

Under a scenario where no rehabilitation intervention has taken place, only 4 LSU would be sustained on the wetland, representing a 71% reduction in the safety-net value to R2 722 yr^{-1} for cattle-owning households and to R892 yr^{-1} for non cattle-owning households. The total safety-net vale is estimated as R3 614 yr^{-1}.

Overall then, the added value of the rehabilitation structure on the provision of fodder to cattle, given as a safety-net value to peoples' livelihoods, is estimated to be R8 435 yr^{-1}. It is important to note that these benefits are spread across wealth categories since it is not just the wealthier households that benefit from cattle.

Table 8: Estimated grazing value of Manalana Wetland in good condition (i.e. with rehabilitation structures) and under degraded conditions (i.e. no rehabilitation). For comparative purposes, the value is given both as fodder replacement cost and the livelihoods safety-net value. The safety-net value was calculated for a bottle-neck period of 30 days (see text for details).

ITEM	Wetland in good condition	Degraded wetland
Wetland area (ha)	3.5	2.1
Fodder production (kg ha^{-1})	1235	617
Total production (kg)	4322	1297
LSU consumption (kg $^{-1}$)	10	10
No. cattle sustained	14	4
Replacement costs of fodder	R4 322	R1 297
Net direct use value to cattle owning h/h	R9 073	R2 722
Net direct use value to non cattle-owning h/h	R2 974	R892
Total direct-use value: Safety-net to livelihoods	R12 049	R3 614
Added value of rehabilitation structures	R8 435	

iv) Water for livestock

The daily water demand for cattle and goats was estimated at 12 854 litres (or 90 000 litres per week). Assuming tanks would be filled twice a week, storage capacity would be needed for some 45 000 litres, requiring 5 tanks of 10 000 litre capacity. The establishment costs amounted to R89 500 in total. This included the costs for two boreholes, two diesel pumps, five storage tanks and five troughs.

The annual running costs amounted to R8 100 (Table 9). At a ten-year life expectancy on infrastructure, the running costs plus the annuitised capital costs amounted to a total annual cost of R18 592. This equaled the total net value that the wetland in good condition provides in water for livestock (cattle and goats). In contrast to the wetland in good condition that supplies water throughout the year, the degraded wetland supplies water only during the wettest months of the year, and is taken as 25% of the net value of the wetland in good condition (i.e. R4 648).

Table 9: Estimated annual costs of replacing the water for livestock provided by the intact Manalana Wetland with an alternative water supply. For comparative purposes, the value is given for an infrastructural life-expectancy of ten and five years. The former value was used for the total valuation.

Item	Total
Total Capital Costs (Rand)	89 500
Annual running costs (Rands yr^{-1})	8 100
Ten year life expectancy	
Annuitised Capital Costs (Rands yr^{-1})	10 492
Total Annual Cost (Rands yr^{-1})	18 592
Five year life expectancy	
Annuitised Capital Costs (Rands yr^{-1})	19 578
Total Annual Cost (Rands yr^{-1})	27 678

v) Water for domestic purposes

If the water supply of Craigieburn fails for 29% of the time (twice a week), the demand is estimated at 781 978 litres (at 22 l $c^{-1}d^{-1}$). The replacement cost of buying this water from water vendors is estimated at R15 639 per year or R340 per household (Table 10). This value was used as the total net value that the wetland provides when the bulk supply fails. In this case the wetland offers an important safety-net for people in terms of domestic water supply. As in the case of water for livestock, the degraded wetland supplies water only during the wettest months of the year, and is taken as 25% of the net value of the wetland in good condition (i.e. R3 910).

Table 10: Estimated replacement cost of water for domestic purposes when the bulk supply system fails two months out of seven. This value represents a 'safety-net' value in times of stress.

No of days of water supply failure	106
Demand during failure (litres)	781 978
Price per litre (Rands)	0.02
Total replacement cost	**R15 639.55**

6.3.2 Downstream benefits: Estimate of total direct value of the rehabilitation interventions

Recall, only the provisioning services of water for domestic use and livestock were considered downstream of the rehabilitation structures.

The daily water demand for cattle and goats was estimated at 16 066 litres (or 112 462 litres per week). Assuming tanks would be filled twice a week, storage capacity would be needed for some 60 000 litres, requiring 6 tanks of 10 000 l capacity. The establishment costs amounted to R95 000 in total (Table 11). This included the costs for two boreholes, two diesel pumps, five storage tanks and five troughs.

The annual running costs amounted to R8 100 (Table 11). At a ten-year life expectancy on infrastructure, the running costs plus the annuitised capital costs amounted to a total annual cost of R19 237. This equaled the total net value that the wetland provides in water for livestock (cattle and goats).

Table 11: Estimated annual costs of replacing the water for livestock downstream of the rehabilitation structures with an alternative water supply. For comparative purposes, the value is given for an infrastructural life-expectancy of ten and five years. The former value was used for the total valuation.

Item	Total
Total Capital Costs (Rand)	95 000
Annual running costs (Rands yr^{-1})	8 100
Ten year life expectancy	
Annuitised Capital Costs (Rands yr^{-1})	11 137
Total Annual Cost (Rands yr^{-1})	19 237
Five year life expectancy	
Annuitised Capital Costs (Rands yr^{-1})	20 782
Total Annual Cost (Rands yr^{-1})	28 882

If the water supply of Craigieburn fails for 29% of the time (twice a week), the demand is estimated at 1 101 970 litres (at 22 l $c^{-1}d^{-1}$). The replacement cost of buying this water from water vendors is estimated at R20 340 per year or R340 per household (Table 12). This value was used as the total net value that the wetland provides when the bulk supply fails. In this case the wetland offers an important safety-net for people in terms of domestic water supply.

The total value of these services of water to downstream users is R39 636 per year. As in the case of upstream water supply, the degraded wetland supplies water only during the wettest months of the year, and is taken as 25% of the net value of the wetland in good condition, which is equal to R9 909.

Table 12: Estimated replacement cost of water for domestic purposes downstream of the rehabilitation structures when the bulk supply system fails twice a week. This value represents a "safety-net" value in times of stress.

No of days of water supply failure	106
Demand during failure (litres)	1 109 970
Price per litre (Rands)	0.02
Total replacement cost	**R20 399.41**

6.3.3 Total direct value upstream of the rehabilitation intervention

The total net direct value with and without the rehabilitation structures is given in Table 13. The livelihood benefits derived under a degraded scenario are a mere 34% of what could be achieved with an investment in rehabilitation.

Table 13: Estimated total net direct benefits (in Rands) derived from the Manalana Wetland in good condition (i.e. with rehabilitation structures) and under degraded conditions (i.e. no rehabilitation)

Item	Wetland in good condition	Degraded wetland	Sensitivity Best Case Scenario
Crops (3 types)	61 100	15 275	96 570
Reeds	2 240	840	17 248
Grazing for cattle	12 048	3 614	12 049
Water for livestock	18 592	4 648	18 592
Water for domestic purposes	15 640	3 910	15 640
Total value upstream	109 619	28 287	151 810
Value added of the Structure upstream	81 332		123 523
Total value downstream	39 636	9 909	
Value added downstream	29 727		29 727
Total Value added	111 059	38 196	

6.3.4 Summary indicators: Balancing costs and benefits

The total costs of the rehabilitation interventions was calculated as R947 328, which includes the costs of planning, materials, implementation, and monitoring and financial controls, and maintenance over a 50 year period. A synthetic representation of the results above indicates the profitability of the investment, even at the current conservative estimates. Considered over a 50 year period, a positive NPV, equal to R1 995 885, indicates a worthwhile investment, as it generates benefits greater than the costs it commands. Specifically, the benefits are more than twice as large as the costs of the rehabilitation interventions (Table 14). Finally, the IRR is equal to 12%, which is well above the 3% discount rate considered for the purpose of this study, further confirming the project profitability – even when measured against alternative investments.

Table 14: Summary Cost-Benefit Analysis Indicators

NPV (Net Present Value)	R1 995 885
BCR (Benefit Cost Ratio)	R 2.11
IRR (Internal Rate of Return)	12%

6.3.5 Contribution of the wetland to the reduction of livelihood vulnerability

The results from research data on well-being categories (Pollard *et al.*, 2005) and that of financial categories from the 2001 census data (which covers more villages than Craigieburn) agree fairly well. However, the census data ranked a higher percentage of households as poor. These data indicate that between 33% and 40% of people in the area have virtually no income whatsoever. The census data suggests that about 10% of households survive on R4 800 p.a. or less. This group, together with the 20% that rely on R9 600 p.a. or less probably corresponds to what farmers consider to be category 2 (see Table 2). Thus, between 60% and 70% of the farmers can be considered to be amongst the poorest of the area. The census data indicates that 75% of households income is R10 000 or less p.a.

The average net contribution of the wetland to each household using the wetland is R3 466 per year. The total estimated net contribution to each household category is shown in Figure 7. Notably, the livelihood contribution to Category 1 households (33%) is substantial given that they have no regular financial income and are entirely dependent on what they grow for food security. Even in the 'wealthier' categories the wetland contribution is significant. In category 3 households, for example, assuming they correspond roughly to the census income bracket of between R5 731-R11 940 (adjusted 2001 values), the wetland offers the equivalent of between 30%-60% additional 'income'.

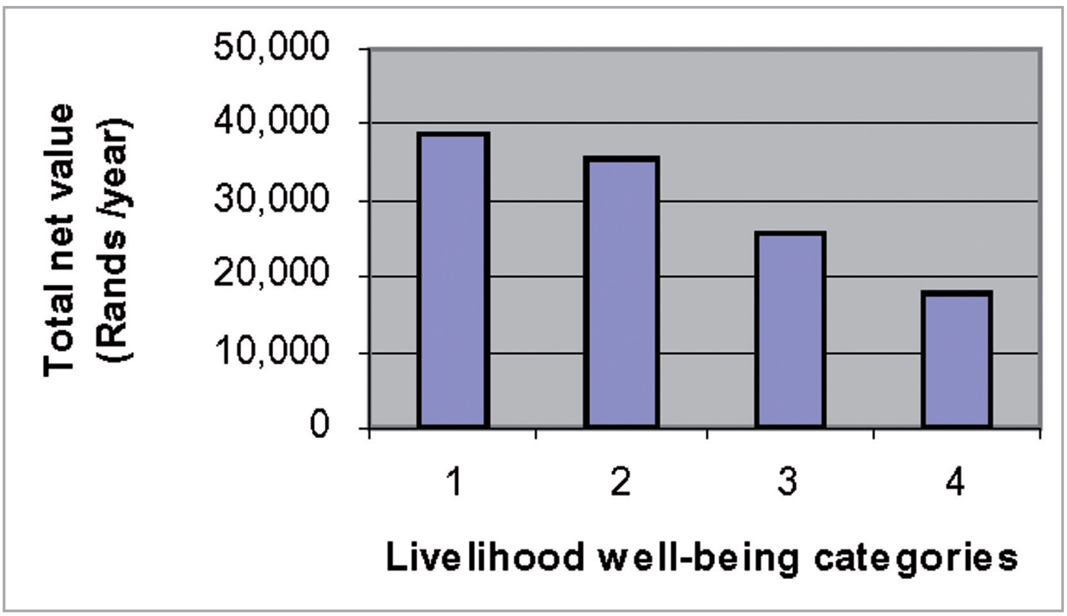


Figure 7: Estimates of total net value of the wetland to the four well-being categories (see Table 2) of the residents living upstream of the rehabilitation structures

A review of the literature indicates the nutritional importance of the crops grown in the wetland (Table 15). It can be seen that in comparison to the staple of maize meal, the main contribution of madumbes is to dietary fibres, Ca, Mg, and K, while the main contribution of pumpkin is fibre, K and Vitamin A. A further nutritional contribution of madumbes is the moderately low glycemic index (GI) (54 compared with 75 in brown bread) (http://www.glycemicindex.com), which suggests that it may be useful in the dietary management of diabetes. In addition, the corms of madumbe contain the anthocyanins, cyanidin 3-glucoside, pelargonidin 3-glucoside and cyanidin 3-rhamnoside, reported to have antioxidant and anti-inflammatory properties, providing some measure of protection against non-infectious diseases (Cambie & Ferguson, 2003).

Table 15: Food composition and nutritive value (%) of edible parts of madumbes and other common starch sources (data from Huang et al., 2000; Langenhoven et al., 1991).

Item	Madumbe	Maize meal-cooked*	Maize on the cob	Pumpkin	Sweetpotato	Potato
Water (%)	72.5	87.8	69.6	89.0	72.8	79.8
Fat (%)	0.2	0.3	1.3	0.6	0.3	0.1
Carbohydrate (%)	24.2	9.4	21.4	6.0	21.3	17.1
Fibre (%)	3.7	0.3	3.7	2.8	3.0	0.5
Protein (%)	1.9	1.8	3.3	0.9	1.7	2.1
Kcal 100 g^{-1}	104	45	108	39	105	76
kJ 100 g^{-1}	435	188	454	162	439	318
Ca (mg 100 g^{-1})	40	2	2	14	21	8
Fe (mg 100 g^{-1})	1.7	0.6	0.6	0.3	0.6	0.3
Mg (mg 100 g^{-1})	55	4	32	8	10	20
P (mg 100 g^{-1})	140	20	103	20	27	49
K (mg 100 g^{-1})	550	35	249	437	184	328
Vit A (µg RE 100 g^{-1})	4	11	22	356	1705**	0
Vit B1 (mg 100 g^{-1})	0.09	0.06	0.22	0.09	0.05	0.1
Vit B2 (mg 100 g^{-1})	0.03	0.02	0.07	0.02	0.14	0.02
Vit B3 (mg 100 g^{-1})	0.4	0.6	1.6	0.7	0.6	1.3
C (mg 100 g^{-1})	13	34	46	28	11	10

* The values given are for SUPER maize meal, which has been refined and also fortified in accordance with the statutory requirements for maize meal

**The Vitamin A in sweet potato may vary considerably depending on the particular variety of sweet potato

7 Discussion

This study evaluated the provisioning services provided by the Manalana Wetland under two scenarios: with and without a rehabilitation intervention. The provisioning services (including crop and reed production, water for domestic purposes and livestock, and grazing) were secured by safeguarding two key regulatory services: water regulation and erosion control. Without rehabilitation the overall net benefit of the wetland to peoples' livelihoods declined by approximately 75%.

It is important to appreciate a number of factors with respect to the derived valuation estimates. Firstly, these represent a snapshot of the potential value at a particular time. Values are dynamic over space and time, being influenced by climatic conditions, socio-economic factors, demand and individual management decisions. Secondly, they are conservative estimates of the full potential value. The total value could potentially be significantly higher for one or a combination of the following reasons:

- The most obvious reason is that this study did not consider the full range of benefits and thus does not represent a total economic valuation. Additionally, the valuation of benefits downstream of the structure was constrained by lack of data and would be higher than that suggested by this study.
- Moreover, conservative estimates were used throughout the analysis. For example, the costs of purchasing domestic water were based on a demand of 22 $l\ c^{-1}d^{-1}$, which is less than the RDP minimum of 25 $l\ c^{-1}d^{-1}$. The additional impacts on the small-scale economic activities which require an average of between 23 and 40 l extra per day (Perez de Mendiguren and Mabelane, 2001) were not considered.
- Specific values may be higher than those used as indicated by the sensitivity analysis. Indeed, at the highest possible values (mainly achieved through higher yields and prices), the net added value was 70% higher than the conservative estimate.
- The resources that were valued comprised only a limited range of resources that are used. An additional 13 crop types are grown by some farmers in the wetland but could not be valued due to lack of data. Other studies have also demonstrated the value of additional resources including medicinal plants and wild herbs such as *Amaranthus* sp. (see for example Dovie *et al.*, 2003; Shackleton *et al.*, 1995). Generally in Bushbuckridge, Shackleton and Shackleton (2000) estimated that 92% of households use edible herbs (so-called annual 'weeds') which are collected mainly from disturbed sites such as arable plots. This equates to 42.39 kg per ha and had the highest value of all secondary resources that they valued. This warrants further attention as it is likely that wild herbs are collected from the wetland and that their contribution to the total value is considerable. In Bushbuckridge, the values of secondary resources, such as wild herbs and fruits, compare favourably to returns from other land uses (Pollard *et al*. 1998; Shackleton and Shackleton, 2000).
- The link between erosion and desiccation of the micro-catchment landscape (i.e. a larger area than just that of the wetland) suggests that the negative impacts of headcut erosion would be much more widely felt than just in the wetland. The drawdown of the water table would result in drying out of the hillslopes upstream of the wetland and a loss of dryland productivity (including crops and grazing), leading to further land degradation. This study does not include such drying out of hillslopes upstream of the wetland that has been prevented by the rehabilitation.

The highest value of all the resources was attributed to crops (madumbes, pumpkin and maize collectively) and cattle. This is commensurate with the findings of other studies in the area. The implications of the loss of wetland and hence these resources are discussed below in terms of their contribution to the livelihood safety-net. However, it is also worth noting that in terms of crops, the degradation of the Manalana Wetland would likely result in a diet more dominated by maize meal, which is the current staple. Besides the health impacts associated with the loss of wetland crops, the more monotonous diet associated with a reduced availability of madumbes and pumpkin (as well as other crops not valued here), would also reduce the enjoyment associated with a greater variety in peoples' diet. This would ultimately affect the overall welfare of these people. Again, it would be the poorest households most severely affected because their capacity to purchase diverse foods would be most limited. In the household interviews, several respondents spoke about how household members eagerly await the madumbes each year, which are highly appreciated. Madumbe, internationally referred to as taro, is, in fact, grown throughout the humid tropics and subtropics, and is a major food crop in the Pacific Islands (Cambie and Furguson, 2003). The nutritional value of this crop is widely recognised and indeed, taro is one of the key crops that has been researched in Hawaii for over two decades (e.g. Miyasaka *et al*., 2001; Navarro and Misa, 1985); see Traditional Pacific Island Crops AgNIC Web Site).

The value of the wetland: The safety-net factor

As pointed out above, monetary valuation exercises tend to be conservative estimates by their nature because they often do not capture the full range of benefits. However another reason that they tend to under-estimate values is because of what we have called the 'safety-net factor'. We suggest that this has not received adequate attention in valuation studies. Natural resources have been recognised for offering a 'safety-net' in times of shock or stress and we have attempted to make this value more explicit. Indeed we argue that in the case of the Manalana Wetland this is not a 'nice to have' value, but is central to understanding the real value of these ecosystems. This is because the safety-net value can buffer a household from slipping further into poverty. In Craigieburn, people spoke of how easily they could flip from one well-being category to another (see Table 2) with a change in one livelihood input (e.g. people reported that the loss of a wetland field meant that a household became poorer and more vulnerable). The fact that the wetland typically has moisture for longer – thereby supporting fodder production and furnishing water supplies for people and livestock - means they become a key resource in times of stress. It is argued that the presence of the Manalana Wetland reduces the lean time, or bottleneck time, allowing some animals to survive – just – until the rains arrive. The implication is that values are higher than the actual quantity of resource used or consumed and valued by conventional direct value approaches.

A number of the resources that have been valued as part of this study offer such a safety-net, including water for domestic purposes, an extension of the cropping season (into April), an increase in the variety and hence nutritional value of the diet, better crop yields, and water and grazing for livestock (Figure 8). These benefits extend both upstream of the rehabilitation intervention and downstream, although the latter have been less well-defined.

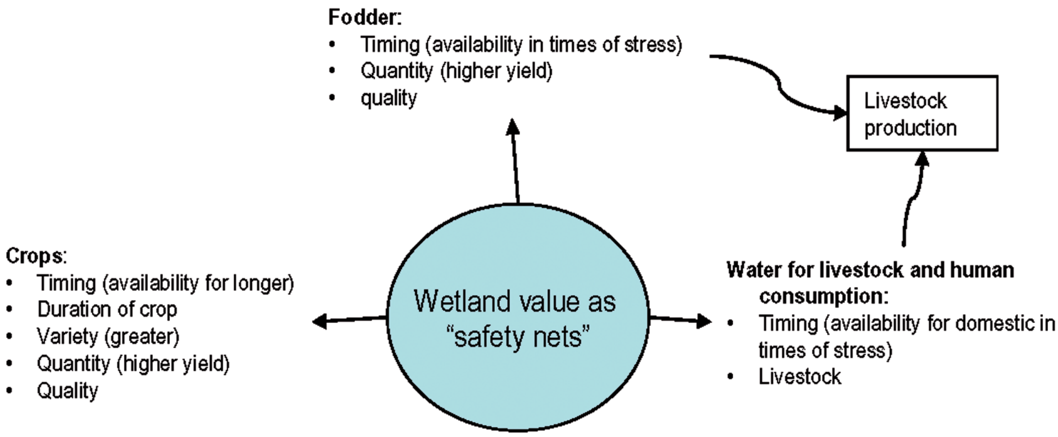


Figure 8: Overview of the contribution of Manalana Wetland as a safety-net in peoples' livelihoods. The characteristics that are listed lend the resource to functioning as a safety-net in times of stress.

By way of example we examine just one of these aspects in more detail. In terms of livelihoods, this safety-net value of the wetland for water and for grazing by livestock is significant. Both of these essentially offer a free resource to livestock owners that would otherwise have to be bought. The grazing value of the wetland reduces the lean time at the end of the dry season, allowing some animals to make it through to the next season. The value attached to the reduction in cattle mortality is evident through numerous goods and services that the owner receives[1] from animals in the next year that would have otherwise died or been severely weakened. In an attempt to highlight this safety-net value, we estimated values of cattle to a household under scenarios of the wetland in good and degraded states. We estimated that with the wetland in good condition, the value to cattle-owning households - based on information collected in the area -represented a R43 907 to all households (cattle-owning and non-owning households). This is significantly higher than that rendered through conventional valuation methods such as, for example, the replacement cost of fodder (estimated at R15 750 per year). Fortunately for our work, Shackleton *et al.* (2005) and Shackleton *et al*. (1999) had undertaken a detailed study designed specifically to look at the livelihood benefits associated with cattle. They showed that multiple benefits accrue from cattle, and not only to cattle-owning households, but also to non-owning households who receive benefits in kind (see also Dovie *et al*., 2006).

It is important to note the distribution of benefits. These benefits are spread across all wealth categories because livestock ownership is widely distributed across different household wealth categories, including the poorest. Moreover, non-owning cattle households also benefit from goods and services associated with cattle (e.g. manure for cultivation).

In poor rural areas, these safety-net values can offer the difference between a reasonable livelihood and abject poverty. The savings accrued to each household are significant particularly for the very poor (see for example, Dovie,*et al*., 2005; Shackleton and Shackleton, 2006; Twine *et al*., 2003). In one village in Bushbuckridge some 40 km from Craigieburn, the proportional contribution of natural

[1] Ranked in terms of their importance, goods and services from cattle include cash sales, savings, ploughing, ritual slaughter, meat, milk, manure, celebrations, lobolo, dung for floors, hides, dung for fuel, transport, loans and inheritance value to children.

resources to a household's livelihood was higher (57%) than cash streams from formal (27%) and informal (15%) sources (Dovie *et al*., 2003). The census data indicate that 50% of households in the Craigieburn area survive on an income of less than R5 700 per year and a further 20% on less than R12 000 per year. Thus, although not received as cash income, the savings represented by wetland resources are notable. If the Manalana Wetland contributes provisioning services, estimated conservatively at an additional R3 466 to some 70% of the village households, then the investment in rehabilitation cannot be sufficiently emphasised. This conclusion is supported by the results of the cost-benefit analysis.

Costs versus benefits: The final say

The conservative estimates used in this study indicate in fact that the investment is worthwhile from all perspectives. Even at the most conservative estimates, NPV is equal to R1 995 885, with benefits more than twice the costs. The investment is profitable even when compared to other potential alternatives, as indicated by an IRR equal to 12%, which is considerably higher than the 3% discount rate used for the purposes of this investigation.

Finally, it should be borne in mind that not all dimensions of benefits were included in this evaluation exercise. Further research in this direction may help refine current conclusions and shed further light into the valuation of the wetland in the Craigieburn area as complex resources with a key role in ensuring the sustainability of the inhabitants' livelihoods.

8 Acknowledgements

This project was funded by the Water Research Commission and Working for Wetlands through a project on the rehabilitation of wetlands. The authors also wish to thank Kirthee Pillay of the Department of Dietetics and Community Resources, University of KwaZulu-Natal for advice regarding the nutritional value of crops and Craig Morris of the Department of Grassland Science, University of KwaZulu-Natal, for information and advice regarding estimating the forage production potential of the wetland.

9 References

Cambie RC and Ferguson LR, 2003. Potential functional foods in the traditional Maori diet. *Mutation Research*, 523: 109-117.

Carney D, Drinkwater M, Rusinow T, Neefjes K, Wanmali S and Singh N, 1999. *Livelihoods approaches compared a brief comparison of the livelihoods approaches of the UK Department for International Development (DFID),* Care, Oxfam and the United Nations Development.

Carpenter SR and Gunderson, LH, 2001. Coping with collapse: ecological and social dynamics in ecosystem management. *BioScience*, 51: 451-457.

Chambers R and Conway GR, *1992 Sustainable Rural Livelihoods: Practical concepts for the 21st century.* Brighton: Institute of Development Studies.

Cooper CS, Wheeler RR and Sawyer WA, 1957. Meadow grazing: A comparison of gains of calves and yearlings when summering on native flood meadows and sagebrush-bunchgrass range. *Journal of Range Management*, 10: 172-174.

Costanza R, d'Arge R, de Groot R, Farberk S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P and v.d. Belt M, 1997. The value of the world's ecosystem services and natural capital. *Nature*, 387: 253-260.

D' Angelo EM, Karathanasis AD, Sparks EJ, Ritchey SA and Wehr-McChesney SA, 2005. Soil carbon and microbial communities at mitigated and late successional bottomland forest wetlands. *Wetlands*, 25: 162-175.

de Groot R, Stuip M, Finlayson M and Davidson N, 2006. *Valuing wetlands: Guidance for valuing the benefits derived from wetland ecosystem services*. Ramsar Technical Report No. 3CBD Technical Series No. 27. 54p.

DFID *Sustainable livelihoods guidance sheets*: DFID.

Dovie BDK, Shackleton CM and Witkowski ETF, 2006. Valuation of communal area livestock benefits, rural livelihoods and related policy issues. *Land Use Policy*, 23: 260-271.

Dovie BDK, Witkowski ETF and Shackleton CM, 2005. Monetary valuation of livelihoods for understanding the composition and complexity of rural livelihoods. *Agriculture and Human Values*, 22: 87-103.

Dovie BDK, Witkowski ETF and Shackleton CM, 2003. Direct-use value of smallholder crop production in a semi-arid rural South African village. *Agricultural Systems*, 76: 337-357.

Drinkwater M and Rusinow T, 1999. *Application of CARE's Livelihoods Approach*, Presentation for NRAC '99.

Duncan P and D' Herbes JM, 1982. The use of domestic herbivores in the management of wetlands for waterbirds in the Camargue, France. In: Smart M (ed), *Managing wetlands and their birds: a manual for wetland and waterfowl management*. International Waterfowl Research Bureau, Slimbridge, England.

Emerton L and Bos E, 2004. *Value - Counting ecosystems as an economic part of water infrastructure*. IUCN, Gland, Switzerland.

Findlayson M and Moser M, 1991. International Waterfowl and Wetlands Research Bureau, Oxford.

High C and Shackleton CM, 2000. The comparative value of wild domestic plants in home gardens of a South African rural village. *Agroforestry Systems*, 48: 141-156.

Hogan DM, Jordon TE and Walbridge MR, 2004. Phosphorus retention and soil organic carbon in restored and natural freshwater wetlands. *Wetlands*, 24: 573-585.

Howard-Williams C and Thomson K, 1985. The conservation and management of African wetlands. In: Denny P (ed), *The ecology and management of wetland vegetation*. Junk, Dordrecht.

Huang AS, Titchenal CA and Meilleur BA, 2000. Nutrient composition of taro corms and breadfruit. *Journal of Food Composition and Analysis*, 13: 859-864.

Jazairy IM, Alamgir and Pannuccio T, 1992. *The State of the World Rural Poverty. An Inquiry into its Causes and Consequences*. Intermmediate Technology Publications, London.

Kotze DC, Marneweck GC, Batchelor AL, Lindley DS and Collins NB, 2009. *WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands*. WRC Report No. TT 339/09. Water Research Commission, Pretoria.

Kotze DC, Memela B, Fuzani N and Thobela M, 2002. *Utilisation of the Mbongolwane wetland in KwaZulu - Natal*, South Africa, Pretoria, South Africa.

Langenhoven ML, Kruger M, Gouws E and Faber M, 1991. *MRC Food Composition Tables. 3rd Edition. National Programme: Nutritional Intervention*: South African Medical Research Council, Parow.

Layard R and Glaister S, 2003. *Cost-benefit analysis*. 2nd Edition. Cambridge University Press. Cambridge.

Millennium Ecosystem Assessment, 2003. *Ecosystems and human well-being: A framework for assessment*. Island Press, Washington DC.

Miyasaka SC, Hollyer JR and Kodani LS, 2001. Mulch and compost effects on yield and corm rots of Taro. *Field Crops Research*, 71: 101-112.

Morris CD, Boleme TS and Tainton NM, 1989. *Report on investigations into fire and grazing regimes and conservation needs of the eastern alpine catchments of Lesotho*. Department of Grassland Science, University of Natal, Pietermaritzburg.

Navarro AA and Misa M, 1985. *Vegetable crop research*, 1983 -1985.

Oellerman RG, Darroch MAG, Klug JR and Kotze DC, 1994. Wetland preservation valuation, and management practices applied to wetlands. In: Oellerman RG (ed), *Wetland preservation valuation and management practices applied to wetlands; and management plans for Wakkerstroon vlei, Ntabamhlope vlei, Mgeni vlei, Blood River vlei, and Boschoffsvlei.* WRC Report No 501/5/94. Water Research Commission, Pretoria.

Palmer RW, Turpie J, Marnewick GC and Batchelor AL, 2002 *Ecological and economic evaluation of wetlands in the upper Olifants River Catchment, South Africa*. Report No. 1162/1/02, Water Research Commission, Pretoria.

Perez de Mendiguren JC and Mabelane M, 2001. *Economics of productive uses for domestic water in rural areas: A case study from Bushbuckridge, South Africa*, Association for Water & Rural Development (AWARD), Acornhoek, South Africa.

Pollard SR, Perez de Mendiguren JC, Joubert A, Shackleton CM, Walker P, Poulter T and White M, 1998. *Save the Sand: Phase I. Feasibility Study: The Development of A Proposal for A Catchment Plan for the Sand River Catchment*. Unpublished AWARD report submitted to Department of Water Affairs and Forestry, pp280.

Pollard SR, Kotze DC, Ellery WN, Cousins T, Monareng J and Jewitt G, 2005. *Linking water and livelihoods: The development of an integrated wetland rehabilitation plan in the communal areas of the Sand River Catchment as a test case*. AWARD (on behalf of the Save the Sand Programme), Prepared for Warfsa/ Working for Wetlands. 103p.

Pollard SR and Perret S, 2007. *Investigating interactions between biophysical functioning, usage patterns, and livelihoods in the a wetland agro-ecosystem of the Sand River catchment through dynamic modeling.* Draft report to the Challenge Programme on Food and Water.

Pollard SR, Shackleton CM and Carruthers J, 2003. Beyond the Fence: People and the Lowveld Landscape. In: Biggs HC (ed), *The Kruger Experience. Ecology and Management of Savanna Heterogeneity*, Island Press, Washington DC, pp422-446.

Rheinhardt RD, Brinson MM and Farley PM, 1997. Applying wetland reference data to functional assessment, mitigation and restoration. *Wetlands*, 17(195): 215.

Richardson JL and Arndt JL, 1989. What use prairie potholes? *Journal of Soil and Water Conservation*, 44: 196-198.

Rutherford I, Jerie K and Marsh N, 2000. *A rehabilitation manual for Australian streams.* CRC for Catchment Hydrology and Land and Water Resources R & D Corporation, Canberra. Available from www.rivers.gov.au.

Scotney DM and Wilby AF, 1983. Wetlands and agriculture. *Journal of the Limnological Society of Southern Africa*, 9: 134-140.

Shackleton CM and Shackleton SE, 2006. Household wealth status and natural resource use in the Kat River valley, South Africa. *Ecological Economics*, 57: 306-317.

Shackleton CM and Shackleton SE, 2000. Direct use values of savanna resources harvested from communal savannas in the Bushbuckrdige lowveld, South Africa. *Journal of Tropical Forest Products*, 6: 21-40.

Shackleton CM, Shackleton SE, Netshiluvhi TR and Mathabela FR, 2005. The contribution of direct-use values of livestock to rural livelihoods in the Sand River Catchment, South Africa. *African Journal of Range & Forage Science*, 22(2): 127-140.

Shackleton CM, Shackleton SE, Netshiluvhi TR, Mathebula FR and Phiri C, 1999. *The direct use value of goods and services attributed to cattle and goats in the Sand River Catchment, Bushbuckridge*. Report commissioned by the Save the Sand Project. CSIR, Pretoria.

Shackleton CM, Stadler JJ, Jeenes KA, Pollard SR and Gear JSS, 1995. Adaptive Strategies of the poor in Arid and Semi-Arid Lands: In search of Sustainable Livelihoods: a case *study of the Bushbuckridge district, Eastern Transvaal, South Africa*: Wits Rural Facility, University of the Witswatersrand.

Shackleton SE and Shackleton CM, 2005. The contribution of marula (*Sclerocarya birrea*) fruit and fruit products to rural livelihoods in the Bushbuskridge district, South Africa: balancing domestic needs and commercialisation. *Forests, trees and livelihoods*, 15: 3-24.

Smith RD, Ammann A, Bartoldus C and Brinson MM, 1995. *An approach for assessing wetland functions using hydro-geomorphic classification, reference wetlands and functional indices. Technical Report WRP-DE-9*. U.S. Army Corps of Engineers, Wetlands Research Program, Washington, DC

Twine W, Moshe D, Netshiluvhi T and Siphugu V, 2003. Consumption and direct-use values of savanna bio-resources used by rural households in Mametja, a semi-arid area of Limpopo Province, South Africa. *South African Journal of Science*, 99: 467-473.

Wackernagel M and Rees W, 1995. *Our Ecological Footprint: Reducing Human Impact on the Earth*. New Society Publishers, Gabriola Island BC and Philadelphia PA.

WHO, 2005. *Minimum water quantity needed for domestic use*. WHO Technical Note for Emergencies No. 9.

10 Glossary of terms

Benefit Cost Ratio	the ratio between discounted total benefits and costs, and shows the extent to which project benefits exceed costs
Direct (wetland) benefit	something that has worth, quality or importance to humans and is realized by individuals actively using a wetland (e.g. for recreation, or pasture production). This corresponds broadly to the Millennium Assessment description of provisioning andcultural services
Ecosystem services	the benefits that people obtain from ecosystems, including provisioning services such as food and water, regulating services such as flood control, cultural services such as recreational benefits and supporting services, such as nutrient cycling that maintain the conditions for life on earth
Indirect (wetland) benefit	something that has worth, quality or importance to humans but does not require active use of wetlands by individuals in order for the benefits to be realized. Instead, the wider public benefits indirectly from the service that wetlands provide (e.g. purification of water). This category of benefits corresponds broadly with the Millennium Assessment of regulating and supporting services
Internal Rate of Return	the discount rate at which a project's Net Present Value becomes zero
Livelihood	the capabilities, assets (stores, resources, claims and access) and activities required for a means of living. A livelihood issustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global levels in the long and short term.
Net Present Value	the sum of discounted net benefits (i.e. benefits minus costs), and shows whether a project generates more benefits than it incurs costs.
Opportunity cost	the value of that which must be given up to acquire or achieve something
Provisioning services	ecosystem services, including food (for human and livestock use), fiber (e.g. for construction and crafts) and water, which are derived by consumptive use
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
Valuation (economic)	the attempt to assign quantitative values to the goods and services provided by environmental resources. This includes goods and services that have a market value as well as those that are not privately owned and traded in the market

Part 4

The Wetland Rehabilitation Project in the Kromme River Wetlands, Eastern Cape.

Lil Haigh

With contributions from: Pete Illgner, John Wilmot, Japie Buckle, Donovan Kotze and Fred Ellery

1 Introduction and methods

1.1 Aim of report

The Kromme River is one of the most important sources of fresh water for the Nelson Mandela Metropole in the Eastern Cape. Much of the Kromme River basin supports peatlands dominated by palmiet (*Prionum serratum*), and these wetlands are associated with sustained high quality water yield to dams that supply water to this large urban node. However, land-use in the catchment and wetlands is resulting in the degradation of these wetlands through erosion, which threatens both water quality and water security, which in turn has implications for water supply. In order to reduce these impacts and threats, Working for Wetlands (WfWetlands) embarked on an ambitious programme to rehabilitate and stabilise the threatened wetlands in the Kromme River. The aim of this study is to document the rehabilitation interventions, to assess the integrity and ecosystem services of these wetlands (with and without rehabilitation in order to determine the effectiveness of rehabilitation), to capture the views of participants and stakeholders of the rehabilitation process, and to assess the outcomes achieved.

The objectives are to:

- Present a brief general overview of historical land-use changes and the attendant environmental changes of the Kromme River valley wetland system, with an emphasis on changes over time in a selected high-impact area.
- Document rehabilitation interventions in the Kromme River Wetlands undertaken by WfWetlands from 2000 to 2007.
- Report on damage to the wetlands in the valley and to the rehabilitation structures during the floods of 2001, 2006 and 2007.
- Establish likely causes of damage to rehabilitation structures and their effects on wetland health and ecosystem service delivery.
- Present costs of wetland rehabilitation measures that were undertaken since 2000.
- Document rehabilitation procedures and stakeholder opinions on the procedures.

1.2 Study Area and Research Context

The Kromme River Catchment (K90) is situated on the southern coast of the Eastern Cape of South Africa (Figure 1) The river enters the sea at St Francis Bay in the east and is an important water resource for the Nelson Mandela Metropole, which lies to the east of St Francis Bay. The Churchill Dam (34°00'S 24°29'E; capacity 35 710 106 m^3) situated south-east of Kareedouw, and the Mpofu Dam (34° 05'S 24° 42'E; capacity 10 706 106 m^3) situated near Humansdorp below the confluence with the Diep River, deliver about 34% of the water requirements for Port Elizabeth, the major city of the Nelson Mandela Metropole. The wetlands described in this study are situated in sub-catchment K90A. The land-use in the catchment is predominantly private farming (orchards, cultivated crops and pastures) with small areas of nature reserve in the upper-catchment of K90A.

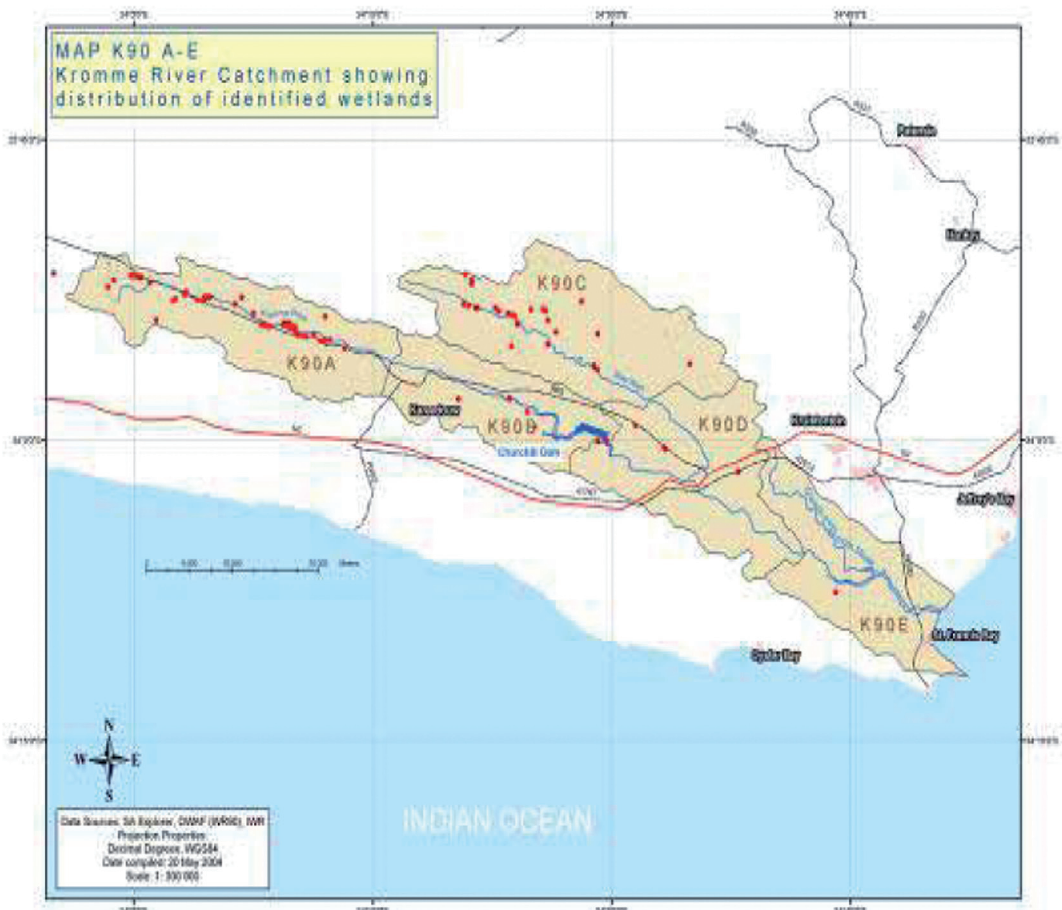


Figure 1: Map of the Kromme River Catchment. The wetlands of the study area are located in catchment K90A

Like so many important rivers in South Africa, the Kromme River and its associated wetlands have shown progressive deterioration with increasing levels of erosion and the encroachment of black wattle (*Acacia mearnsii*). The deterioration of the catchment was posing an increased threat to the water security of Port Elizabeth. As a result, in the mid 1990s, the rehabilitation of wetlands in the Kromme River was proposed. The rehabilitation commenced with the clearing of alien trees through the Working for Water Programme. The clearing of trees along the river course revealed the extent of the deterioration of the rivers and marshes and this precipitated a further series of events:

- A survey of wetlands was conducted by employees of the Cacadu District Municipality (erstwhile Western District Council) Environmental Department together with a group of volunteers in 1997.
- In 1999 the water-resources manager of the Nelson Mandela Metropole formally requested the intervention of the Department of Water Affairs and Forestry (DWAF) of the Eastern Cape.
- A scoping study on the ecological state of the catchment was funded by DWAF and was completed under the auspices of the Institute for Water Research (IWR) at Rhodes University in 2001 (Haigh *et al*., 2001). Much of the information in this document is based on the scoping report.
- The catchment was further surveyed as

part of a wetland inventory conducted by the IWR on the catchments of the Nelson Mandela Metropole (Haigh *et al*., 2004).

- A number of rehabilitation structures were erected at various points along the Kromme River in the K90A catchment during the period 2000-2006.
- Wetland ecosystem-service delivery assessments were conducted in 2006 (prior to the large floods in August 2006) and in 2007 (following the large floods in August 2006).
- Wetland health assessments were conducted after the large flood in August 2006.
- Damage to rehabilitation structures was assessed in 2007.

The wetlands of catchment K90A can be divided into three main sedimentary basins, labelled for convenience, Basin 1, Basin 2 and Basin 3 (Figure 2). For descriptive purposes, the section of the valley upstream of Basin 1 is called Kromdraai or Upper Catchment, and the section of the valley downstream of Basin 3 is called Schaapdrift. In their intact state, as determined from the aerial photographs of 1942, each of these basins had extensive valley-floor marshes linked by meandering channels.

Basin 1 has been subdivided into the Krugersland sub-basin 1 (seasonal and permanent wetland-zones plus channel), Krugersland sub-basin 2 (seasonal to permanent wetland-zones plus channel), Krugersland sub-basin 3 (peat basin with diffuse flow), Krugersland sub-basin 4 (peat basin with diffuse flow) and Companjesdrift sub-basins 1 and 2 (peat basin with diffuse flow; Table 1). Companjesdrift sub-basin 2 is smaller than sub-basin 1, and lies in the zone where a tributary, the Eerstedrif River, enters the floodplain (see Figure 2). This is a naturally high-impact area because the tributary-stream deposits large volumes of sediment on the trunk-valley floor, leading to the narrowing of the valley floor, which increases the power of the trunk stream.

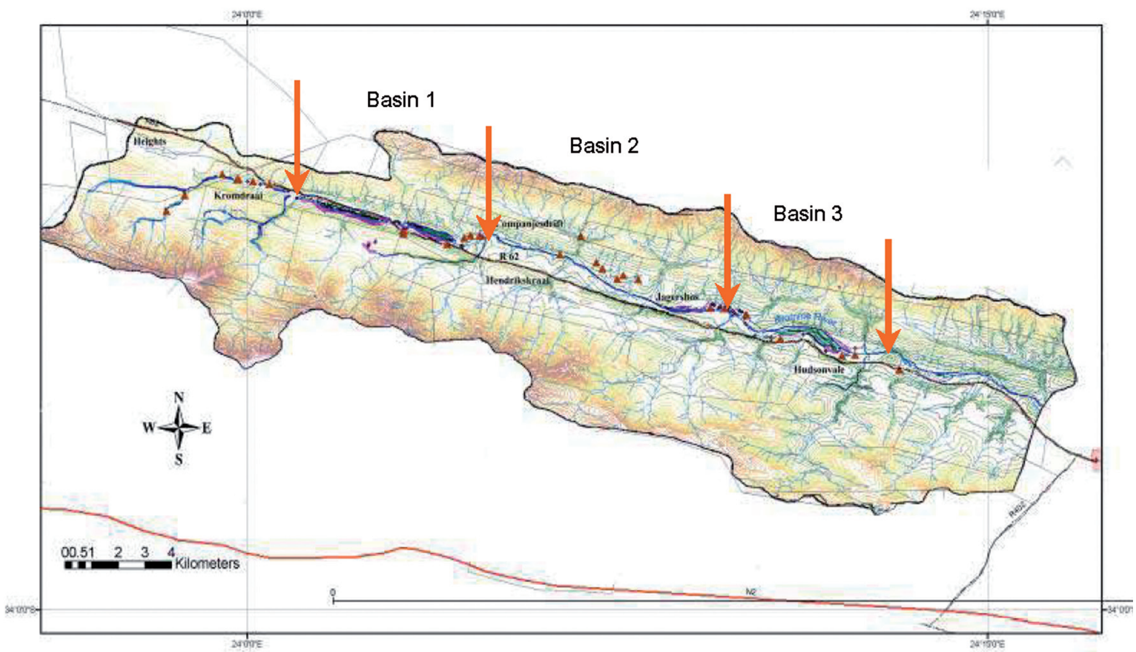


Figure 2: Map of catchment K90A indicating the recorded erosion gullies (triangles) in 1997. Arrows indicate the points at which the basins begin and end.
Data Sources: SA Explorer. DWAF, IWR. Projection properties: Decimal Degrees WG584. Date compiled 20 May 2004. Sacle 1:110 000.

Table 1: The basins and sub-basins of catchment K90A. Also included are farm names, basin boundary tributaries, basin location and erosion control structures, which are labelled according to the sequence of installation. The 1:50 000 maps for this area are Witelsbos 3324CC and Kareedouw 3324CD.

	Sub-basin name	Grant farm	Boundary Tributary	Longitude Latitude	Structures
	Upper catchment	State land & Atomics to Kromdraai.	-	33.8724 S 23.9729 E	A1-4
BASIN 1	Krugersland 1 & 2	Kriegasland, now Kromdraai	Huiskloof	33.8641 S 24.0051 E	A 5-7
	Krugersland 3 & 4	Kriegasland, now Krugersland	Tierkloof	33.8845 S 24.0709 E	-
	Companjesdrift 1 & 2	Companjesdrift / Walletjies	Eerstedrif River	33.8793 S 24.0818 E	B1-3
BASIN 2	Hendrikskraal	Hendrikskraal	Houtkloof & Waterkloof	33.8854 S 24.1029 E	D1-2
	Kammiesbos	Kammiesbos	Ouboskloof	33.8857 S 24.1039 E	D 3
	Jagersbos 1	Jagersbos	Klein River	33.8995 S 24.1256 E	-
BASIN 3	Hudsonvale	Hudsonvale	Witels River	33.9193 S 24.2081 E	C1
	Schaapdrift	Melkhoutkraal	East of Hudsonvale		

1.3 Methods

The research process included the summarizing of existing documents such as the scoping report (Haig *et al*., 2001), use of existing rainfall records to summarise rainfall, analyses of rehabilitation plans and financial records, as well as analysing historical aerial images and interviewing a range of people involved in the project. Although mention is made of land-use changes along the entire Kromme River valley, detailed analysis of changes taking place in the K90A catchment (see Figure 1.1) form the focus of this study. This detailed approach enables better understanding of events and their causes and effects.

1.3.1 Historical land use

A number of sources were used to determine historical land-use practices:

- The National Archives in Cape Town were accessed to determine the dates of early grazing permits, which indicate the timing of land occupation.
- Information was extracted from the travel writings of early explorers.
- Annual reports of the Cape Colony and Cape Province provided information for the nineteenth and early twentieth centuries.
- Interviews were conducted with land-owners and land-users in the study area.

1.3.2 Aerial photograph analysis of land-use change

Portions of aerial photographs from 1942, 1954, 1969, 1986, and 2000 were georectified and captured into a Geographical Information System (GIS) using on-screen digitising methods. These were used to ascertain the degree of transformation of the wetlands (marsh, riparian zone and floodplains) for each of the sub-basins of Basins 1, 2 and 3 from 1942 until 2000. The classification system used to describe the degree of

Table 2: Classification system of the degree of wetland transformation as assessed from aerial photographic images (based on *WET-Health*; Macfarlane *et al*., 2009)

Degree of transformation	Health	Description	Score
None	Intact	No discernible modification or the modification is such that it has no impact on wetland integrity.	*****
Small	Excellent	Although identifiable, the impact of this modification on wetland integrity is small.	****
Moderate	Good	The impact of this modification on wetland integrity is clearly identifiable, but limited.	***
Large	Moderate	The modification has a clearly detrimental impact on wetland integrity. Approximately 50% of wetland integrity has been lost.	**
Serious	Poor	The modification has a clearly adverse effect on this component of habitat integrity. Well in excess of 50% of the wetland integrity has been lost.	*
Critical	Destroyed	The modification is present in such a way that the ecosystem processes of this component of wetland health are totally / almost totally destroyed.	#

transformation of the wetlands accords with impact scores used in *WET-Health* (MacFarlane *et al*., 2009) presented in Table 2.

Furthermore, a more detailed study of the deterioration of a highly impacted zone at Companjesdrift 2 was conducted by classifying the degree of wetland transformation using aerial images from 1954 and 2003. These changes are represented in a series of maps, which can be viewed at *http//www.ru.ac.za/institutes/iwr/wetland group*. The changes are described in as much detail as possible in this document, but the images are not presented here due to printing limitations.

For the period prior to each of the photographs, events with significant environmental impact were ascertained through interviews with residents as well as from rainfall records. Such events include occupation of land, division of farms, development of transport routes and periods of high or low rainfall.

1.3.3 Damage to erosion-control structures and the surrounding environment

A number of rehabilitation structures were damaged during the floods in August 2006. An assessment of the flood damage to the erosion-control structures was undertaken during a site visit on 13 and 14 March 2007. Each structure was visited and observed, with changes upstream and downstream of each structure recorded with respect to the state of the riparian vegetation, sediment deposits and bank erosion. Photographs were taken of each structure. Criteria used in assessing the structure were:

- overall condition of the structure
- state of surfaces and integrity of gabion baskets and concrete walls
- state of banks adjacent to the sidewalls and condition of the sidewalls
- state of the stilling basin and the downstream river area
- degree of damage and the causes of the damage such as undermining due to poor founding because of lack of bedrock or poor soil type
- quality of the construction methods
- suitability of the structure for the estimated flood flows.

1.3.4 Determination of wetland health and ecosystem-service delivery

The ecosystem services provided by the wetland ecosystem subsequent to the erosion control structures being erected were assessed in May 2006 using *WET-EcoServices* (Kotze *et al*., 2009). A similar assessment was undertaken in March 2007 after the large flood-event of August 2006, which damaged or destroyed a number of structures. Also in March 2007, the integrity of the ecosystem was assessed using *WET-Health* (Macfarlane *et al*., 2009).

1.3.5 Rehabilitation project costs

The rehabilitation plans and financial statements were obtained from the Gamtoos Irrigation Board (GIB) and summarised. The main cost-categories that emerged were: implementation fees; transport and fuel costs; equipment rental costs; material costs; staff and staff training costs. It must be noted that the salaries of Mr. Japie Buckle and Mr. Edwill Moore (project managers for Working for Wetlands and Working for Water respectively) were not included in the overall costing of the projects.

1.3.6 Perceptions of rehabilitation procedures and outcomes

In order to document the project implementation, including procedures that were followed, and what benefits were derived from the project, a questionnaire was formulated. The questionnaire had a number of components, each developed for a specific purpose and directed at specific people as follows:

- ***Project initiation, planning and stakeholder involvement*** – for those who initiated the project and steered the process: Working for Wetland (WfWetlands) staff, wetland forums, NGOs, academics, government officials, land owners and land users.
- ***Project implementation*** – for those involved in the construction of the structures: WfWetlands staff, project manager/implementing agent, supervising engineers, contractors and their teams and landowners.
- ***Monitoring and aftercare*** – for the management team, landowners and scientific specialists.
- ***Project outcomes*** – for the project planning and design team, land owners and selected members of the implementation team to establish social outcomes.

2 The history and present state of the upper Kromme River wetlands

2.1 Site description

The catchment of the upper part of the Kromme River (catchment K90A) slopes steeply onto the valley floor. Altitudes on the adjacent Tsitsikamma mountain range to the south reach a maximum elevation of 1251 m above mean sea level (amsl). The Kromme River valley floor has an altitude of 350 m amsl in its upper reaches and a longitudinal slope of 0.6%.

2.1.1 Geology

The catchment is underlain by sandstones and shales of the Cape Supergroup. Of the formations present, the Peninsula, Goudini, Skurweberg and Baviaanskloof are predominantly of sandstone, whereas the Cedarberg and Gydo are mainly shale. The trunk stream within the study area occupies the centre of a syncline within these Cape Supergroup rocks. The formations therefore increase in age north and south from the eastward flowing trunk stream (Toerien & Hill, 1989).

2.1.2 Hydro-geomorphology

The K90A quaternary catchment is structurally controlled and has developed within the Cape Fold Belt. It can be divided into a series of five sedimentary basins, some of which contain extant peat basins. The drainage pattern is a trellis network of six large tributaries and five minor tributaries that enter the main channel from the wetter south side, with seven large and numerous short, mostly temporary tributaries that enter from the northern dry side (Figure 2).

Alluvial fans are evident on the Kromme River valley floor at the distal end of a number of tributaries, extending into and hence limiting the spatial extent of the palmiet (*Prionium serratum*) wetlands, especially at and above Companjesdrift. The rate of sediment delivery to these alluvial fans therefore has important implications for the lateral extent of the wetlands in these areas. For example, if accelerated erosion in the tributary catchments is associated with an increase in sedimentation at the distal ends of the alluvial fans, the lateral extent of the wetlands at these localities will decrease (Gomi *et al*., 2002). Excellent examples of how the growth of alluvial fan deposits may constrain the lateral extent of the palmiet wetlands can be seen at the distal end of the tributaries that drain Tierkloof and Poortkloof (Basin 1). In certain circumstances tributary sediments deposited in the main trunk stream may be associated with a localized downstream increase in channel gradient and hence incision. Alternatively, steep banks may develop when flood events erode the distal ends of the alluvial fans, these in turn contribute to the development of headcuts on the tributary channels. Alluvial fans are therefore an important aspect of the structure of the Kromme wetlands and require careful consideration in relation to the long-term effectiveness of rehabilitation interventions and the level of maintenance that is required to ensure their success. This implies that interventions located at or in close proximity to alluvial fans may require a greater level of maintenance than those located elsewhere.

The wetland system consists of large valley-floor channelled marshes and smaller seeps and riparian marshes on the slopes in the tributaries. Historically the peat basins covered a total area of 547 ha (2.6% of total area) and were situated within catchments K90A and K90B. Sadly very few of these wetlands are still evident. The largest extant marsh, situated in Basin 1 (Krugersland and Companjesdrift; Table 1) comprised 2.5% of the catchment area in 1942 but today only 1.7% is still functional. In the rest of catchment K90A the extant marshes form a very small proportion of the catchment area.

Although the peat basins are dominated by palmiet (*Prionium serratum*), there is nevertheless a mosaic of other wetland plant communities, thus ensuring a diversity of habitats. Peat thickness varies from 0.5 m to 2.8 m with an average of 1.62 m. The inferred peat volume has a total of 12.9 million m^3 which started accumulating approximately 5 600 years ago (Haigh *et al*., 2002). The peat contains some sand and clastic lenses that indicate large flood events in the past. The peat is generally fibrous to fine-grained in texture with charcoal or thin ash horizons indicating the historical occurrence of fire.

2.1.3 Rainfall

Rainfall is not uniformly distributed over the river basin, with the south and south-west experiencing higher rainfall than the north and north-east (Figure 3). Mean annual precipitation for the region, measured at Kareedouw station, is 716.15 mm. This can however, vary considerably, with the region experiencing as much as 1 200 mm in some years and as little as 400 mm in others. The impact of high-rainfall years or high-rainfall events on the wetlands can be high. For example in a high-rainfall year such as 1974, a headcut in the river at Jagersbos II moved back 500 m (resident, *pers.comm.*). The flood of 1996 caused severe damage and the tar road was breached at Hudsonvale. Impacts of high-rainfall on wetlands can be exacerbated by farmers who build

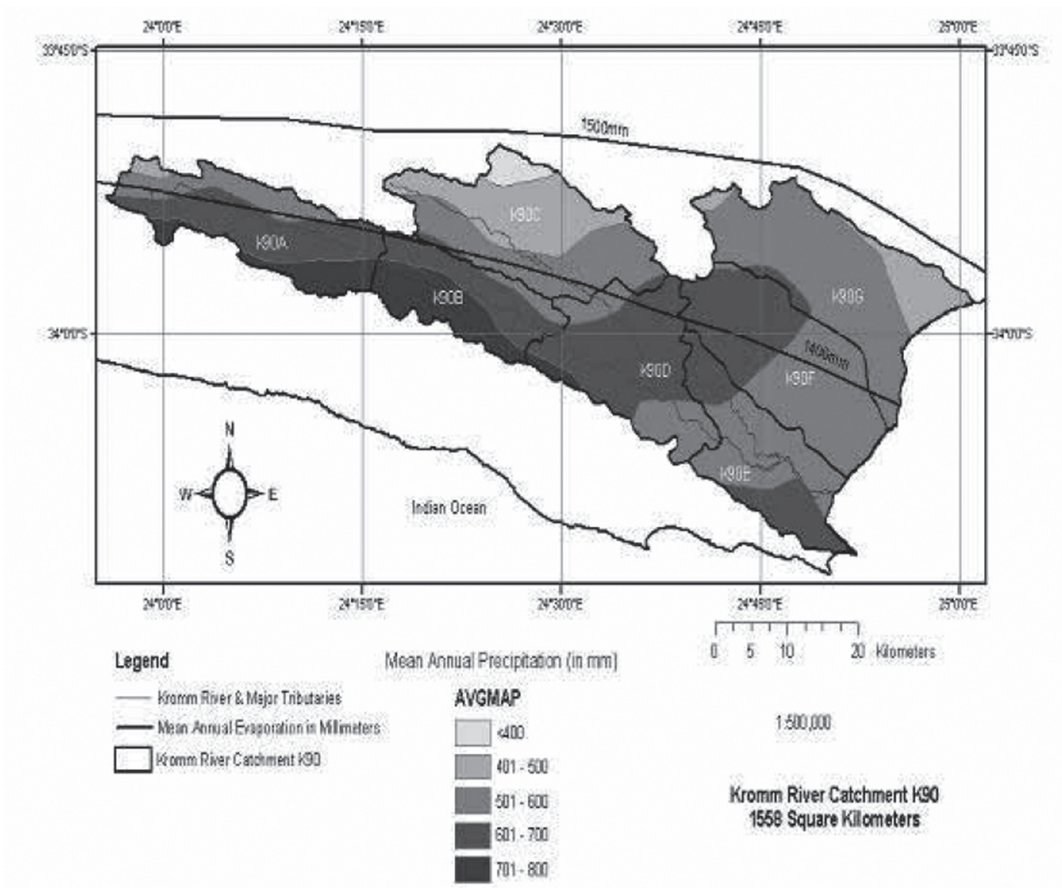


Figure 3: Quaternary catchments of the Kromme River showing the mean annual precipitation

berms on the river banks to prevent the flooding of crops on floodplains adjacent to the valley-floor marshes. For example, following the 1965 floods when water swept away orchards and fences, farmers raised the banks of the river in an attempt to keep flood waters at bay, and laid drainage ditches to preserve the orchards. These earthworks damaged the wetlands and resulted in channel erosion. Furthermore, if a flood occurs during a drought, the damage is likely to be far worse because the vegetation cover is poor. This was the case during the 1980 to 1985 drought when three floods occurred in 1981 (June, August and November), causing severe damage to lands.

2.2 History of occupation and land use

The key events that could have impacted on the freshwater ecosystem in the K90A catchment are presented in this brief history of development in the southern Cape and the Kromme River.

2.2.1 Prior to 1942 (pre-aerial photograph availability)

Eighteenth century

Jagersbos, which is one of the largest units of land in the central K90A valley, was occupied in 1775 when Thomas Ferreira applied for grazing rights. During the same period, settlers occupied the top end of the valley. Between 1787 and 1788 Mosselbaai and Plettenberg Bay (coastal towns to the south west of K90A) were both developed as harbours with a concomitant increase in the logging of indigenous trees and farming development in the hinterland. Records indicate that in 1788, timber was shipped from the Kromme region to Cape Town by sea (Cape Archives).

1800-1940's

In about 1835, Hudsonvale was divided from Jagersbos, indicating a rising population, with the first postal depot established at Jagersbos in 1849. Orchards and grazing were the most common forms of land use in this region in the first half of the twentieth century (Hudson and Rademeyer, *pers. comm.*).

In 1869 the precursor to the National Road, the R62 from Avontuur (west of K90A) to Kareedouw was constructed. The 1878 *General Directory and Guidebook for the South-eastern Province* contains the following:

> *"There has been a marked change for the better in the general state of the roads throughout the district. The dreaded road passing along the Kromme River, which had to be crossed by the old line no less than eight times, some of the drifts being frequently very dangerous to ford, rendered so by the swollen and rapid run of the River, is now being so completely altered that it will now be necessary only to cross twice, namely by bridge (Hudsonvale) and causeway (Companjesdrift) which are almost finished and will shortly be opened for public use".*

Kareedouw, the principal town in the Kromme River Valley, was established in 1905. The railway line, with a halt at Jagersbos, was completed in 1906, improving transport to and from the Port Elizabeth harbour and markets, thus allowing for the intensification of farming activities.

After 1931 when a great flood ripped out the orchards along the river banks and caused massive erosion, many farmers changed to pasture, meat and dairy production. From 1935 onward farmers started planting *kikuyu* as a suitable pasture grass on the floodplain. *Themeda triandra* (rooigras), which occurred in the temporary zones of the floodplain, was ploughed over for the production of grains and vegetables. However, in the greater area more soft-fruit orchards were planted between 1930 and 1940, especially on the fertile floodplains which were previously wetlands.

According to Calvyn Ferreira (*pers. comm.*), after the big flood of 1931, wattle trees appeared in greater numbers all along the course of the Kromme River. After 1945 the wattle bark was harvested for use in the tannery in the town of George, which is south-west of the study area.

2.2.2 Post-1942 (period of aerial photograph availability)

General description of land use

When the first aerial photographs were taken in 1942 the floodplains between Hendrikskraal and the village of Kareedouw were, to a degree, already transformed. After 1942, agricultural activities increasingly moved towards the production of soft-fruit and vegetables, with tens of thousands of tons being produced annually. Dairy and sheep farming remained important income-producing activities. Destructive farming practises such as overgrazing and the draining of floodplains for larger orchards increased as commercialization increased.

Road and bridge construction has an impact on the environment, often through causing erosion gullies and sheet erosion. Extensive road construction activities took place between 1950 and 1970, and included bridge building, re-routing and tarring of roads. Many of the bridges on the Kromme River Valley road are dated between 1950 and 1958. The re-routing and tarring of the R62, which runs through the centre of K90A, was undertaken in the mid-1960s. Side roads leading to Walletjies, Kammiesbos, Jagersbos and Hudsonvale were built from 1983 to 1990. All these activities had a direct impact on the wetlands through an increase in erosion and sedimentation. In one instance a stream was diverted, removing direct water-inputs into the floodplain at Companjesdrift.

Aerial photograph interpretation of the transformation of sub-basins in catchment K90A

It is clear from a study of the aerial photographs that the wetlands in the Kromme river catchment have suffered progressive destruction (Table 3). In Basin 1 of the K90A catchment much of the area that currently appears as degraded shrubland and fynbos was previously wetland and seasonal riparian vegetation. These areas have dried out due to the degradation of the wetland, in particular at Companjesdrift where the river channel had been incised to a depth of at least 3.5 m. In Basins 2 and 3 the degradation has been far greater, especially in areas where the peat was originally shallower and the basins smaller. Here the combination of the inappropriate cultivation of floodplains and the consequent neglect due to depopulation, changes in ownership and/or poverty, followed by the invasion of alien plants (mainly black wattle), has left most floodplains in very poor condition and susceptible to erosion. At present the greatest degree of transformation has occurred between Companjesdrift and Jagersbos, where about 75% of the smaller marshes have disappeared completely.

Table 3: **Aerial photograph assessment of the magnitude of wetland transformation (wetland health) in catchment K90A based on health classes presented in Table 2. (Health classes: ***** = Intact , **** = Excellent, *** = Good, ** = Moderate, * = Poor, and # = destroyed)**

BASIN	SUB-BASIN	YEAR 1942	YEAR 1954	YEAR 1961	YEAR 1969	YEAR 1986	YEAR 2007
Upper catchment	Kromdraai	**	*	#	#	#	#
1	Krugersland 1	***	***	***	#	#	#
1	Krugersland 2	***	***	***	**	*	*
1	Krugersland 3	*****	*****	***	***	**	**
1	Krugersland 4	*****	*****	****	***	***	***
1	Companjesdrift 1	*****	****	****	****	***	***
1	Companjesdrift 2	****	***	**	*	#	#
2	Hendrikskraal	*****	****	***	***	**	*
2	Kammiesbos	***	**	**	**	#	#
2	Jagersbos 1	****	***	**	**	#	#
3	Hudsonvale	****	****	****	***	*	**

Detailed aerial photograph analysis of Basin 1

The magnitude of transformation of the wetlands and surrounds of sub-basins Krugersland 1 to 4 and Companjesdrift 1 and 2 between 1942 and 2003 was determined using aerial photograph analysis. In addition, a more detailed study of the confluence area of the Eerstedrif River with the Kromme River at Companjesdrift 2 was conducted for the period 1954-2003. Figures 4-6 are aerial photographs that provide a visual record of various aspects of wetland transformation during this period. The nature of these transformations are represented in Figures iwr2.5 - iwr2.7 and can be viewed at http//www.ru.ac.za/institutes/iwr/wetland group.

Between 1942 and 2003 the area of wetland in Basin 1 was reduced from 134 ha to 93 ha, which represents a 30% reduction (Table 4). More-detailed descriptions of changes that have occurred during this period are presented in Boxes 1-5.

Table 4: Changes in area of wetland in Basin 1 between 1942 and 2003

Sub-Basin	Size in 1942 (ha)	Size in 2003 (ha)	% destroyed by 2003
Krugersland 1	5.98	0	100
Krugersland 2	1.49 (partly damaged)	0	100
Krugersland 3	35.30	26.27	25
Krugersland 4	34.71	36.41	5 (increased)
Companjesdrift 1	30.65	25.55	16
Companjesdrift 2	25.0	5.0	80
Total area	134	93	30

Box 1 – Aerial photograph 1942

This image is used as the baseline against which later changes are measured.

In 1931 a flood occurred, the consequence of which was the establishment of black wattle over a wide area (C. Ferreira, *pers. comm.*) assisted by the good rainfall in 1935 and 1939. In the immediate vicinity of Basin 1, all alluvial fans were cultivated and the catchment of the Eerstedrif River was extensively transformed. There were six dwellings on the banks of the marsh. The main road ran along the northern bank of the marsh and crossed the wetland at the site of the historical outspan, hence the name Companjesdrift ('ford belonging to the company', the Dutch East India Company.) The wetland was generally in good condition, apart from Basin 2 where several sediment plumes were evident in the western section and the bank below the road east of the ford was denuded. In Basin 1 all the large sub-basins were generally in excellent condition but the smaller sub-basins showed a degree of change and Krugersland 2 had been damaged. In Companjesdrift 2 (detailed study area) the marsh occupied 23 ha which was in excellent to good condition despite the roadway traversing it. About 40% of areas adjacent to the wetlands were transformed, mainly for the purpose of cultivation and grazing.

Box 2 – Aerial photograph 1954.

During several years prior to 1954, the rainfall was unusually high, with an average of 821mm for the entire area, with 1944 and 1952 having the highest rainfall. The rapid filling and overflow (3 weeks) of the newly completed Churchill Dam in 1949 was a noteworthy event. The increase in cultivated areas was indicative of increasing farming activity. In the areas of transformed land, trees had increased in size.

In the Eerstedrif River catchment the wetlands in the upper reaches were channelled, with an increase in the number of orchards established and alien trees planted. In Basin 1, Krugersland 1 and 2, seasonal wetlands were compromised by drains and ploughing. Fortunately the large sub-basins were still in excellent condition and the smaller basins did not show much change.

At Companjesdrift 1 and 2, 26% of the marsh had been sparsely invaded by alien trees but in general the marsh could still be classified as being in good condition. The riparian banks showed signs of bare soils or sediment below the road. At Companjesdrift 2, 63% of the area was valley-floor marsh, all of which was along the main trunk (Kromme) river (Figure iwr2.5). The Kromme River also had a small floodplain area with riparian vegetation at the confluence with the tributary Eerstedrif River.

Box 3 – Aerial photographs 1961-1969

The old road was re-laid and tarred, which caused extensive sedimentation in the wetland. At Eerstedrif River, where a large bridge was constructed, a small catchment stream was re-routed into the main channel above the bridge (see Figure 5, black dot arrow). This increased the discharge in the main channel while effectively drying out the wetland on the eastern bank, allowing for cultivation of this area (Figures 6).

During this period, the large sub-basins in Basin 1 became more compromised, changing from excellent health to good due to alien plant invasion and drains being established in the marginal areas. The smaller basins fared much worse. Krugersland 1 became a field and Krugersland 2 was reduced in size due to cultivation and drainage. The condition of the Krugersland 3 and 4 basins changed from excellent in 1954 to good, due to increased alien vegetation encroachment and a reduction of the seasonal wetland zone.

In the Companjesdrift 2 study area the extent of the transformed area increased from 6ha (1954) to 11ha, with the invaded riparian bank now covering 3.6 ha. Altogether 48% of the wetland area was densely invaded by alien vegetation. The roadway across the river at the ford had fallen into general disuse. The causeway across the wetland at Companjesdrift (Figure 5, light arrow), no longer in use, deteriorated, and appears to have been the major cause of the rapid erosion in this area with the river incising the bed both upstream and downstream.

By 1969, extent of the the Eerstedrif River riparian and floodplain zones had decreased (Figure iwr2.6). In contrast, the Kromme River riparian zone had increased and a small section of valley marshes had been converted to floodplain. The alien vegetation had increased in both extent and in density.

Box 4 – Aerial photographs 1970-1986

The degree of deterioration of wetlands increased markedly during this period (Table 3). Wetlands in Basin 1, Krugersland 1 and Companjesdrift 2 were destroyed and only small patches of wetland vegetation remained in Krugersland 2. The big basins in Krugersland 3 and 4 and Companjesdrift 1 remained in good condition. Nsor (2008) calculated that by 1986, 50% of the valley-floor wetlands had been transformed into floodplains.

In Basin 2, some patches of wetland vegetation remained in the upper portions of Hendrikskraal, but the lower Kammiesbos and Jagersbos wetlands were destroyed during this period. At Companjesdrift 2 the causeway was washed away as no maintenance was performed. According to C. Ferreira (pers. comm.) 1-2 m of bank was lost in a single flood. Today the drainage pipes can still be found in the vicinity.

The condition of sub-basin Hudsonvale was poor as alien invasion was widespread on the floodplain and its growth was becoming increasingly dense.

Box 5 – Aerial photographs 1987-present

During this period the general state of the valley raised alarm bells among municipal water managers and environmentalists. There were widespread, dense stands of black wattle (*Acacia mearnsii*) on the floodplains and in 1998 WfWater started clearing in the valley. A survey in 1998 revealed extensive instream gullying, especially in the peat basins, and stream bank erosion was widespread.

In Basin1, Krugersland 3 had lost 25% of its wetland area since 1942, mainly in the inflow regions where the peat was shallow, Companjesdrift 1 had lost 16% of its wetland area, mainly along the edges. The upper reaches had also been densely invaded by black wattle. In 2003, 52% of the lands adjacent to the marsh wetlands were transformed (Nsor, 2008) while the marsh area had not changed since 2000. In 2006, extant marsh wetlands occurred at Krugersland 3 and 4 while Companjesdrift 1 was in excellent to good condition mainly due to the removal of alien vegetation and the establishment of rehabilitation structures by WfWetlands.

At Companjesdrift 2 matters went from bad to worse. By 2000 the area was invaded by alien vegetation and the marsh was destroyed by gullying to such an extent that by 2003, virtually all of the valley river marshes along the Kromme River were converted to floodplains or riparian zones (Figure 5). However by 2007 the river channel was so deeply eroded that the adjacent valley had become terrestrial land and was no longer a floodplain. During the period of analysis (1954 to 2003) both the Kromme and the Eerstedrif Rivers became less braided and sinuous and generally widened and straightened out. The overall width of the channel doubled.

A small remnant of wetland was extant on Hendrikskraal immediately downstream of Companjesdrift 2. In Jagersbos 1, wetland plants continued to make an appearance. Wetlands on the farm Hudsonvale were in good condition due to kikuyu pastures in the seasonal zone and the rehabilitation structure completed by WfWetlands in 2001.

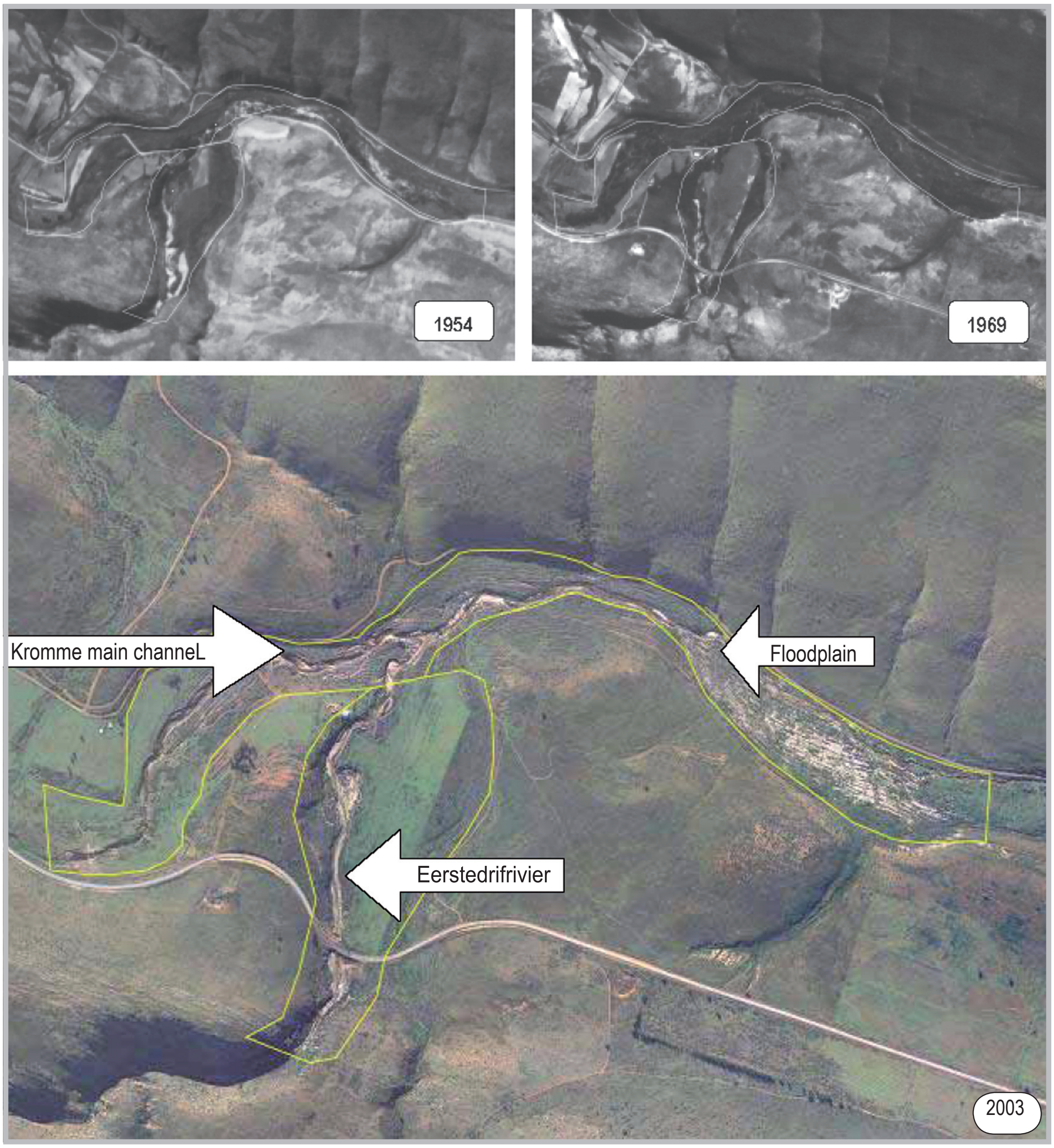


Figure 4: Aerial photographs of the study area in Companjesdrift 2 sub-basin, showing the outline of the area where the detailed analyses were conducted that are portrayed in Figures 2.5 - 2.7 (see website http//.www.ru.ac.za/institutes/iwr/wetland group). Features of note include the increasing extent of channel erosion, sedimentation on the floodplain and the absence of cultivation.

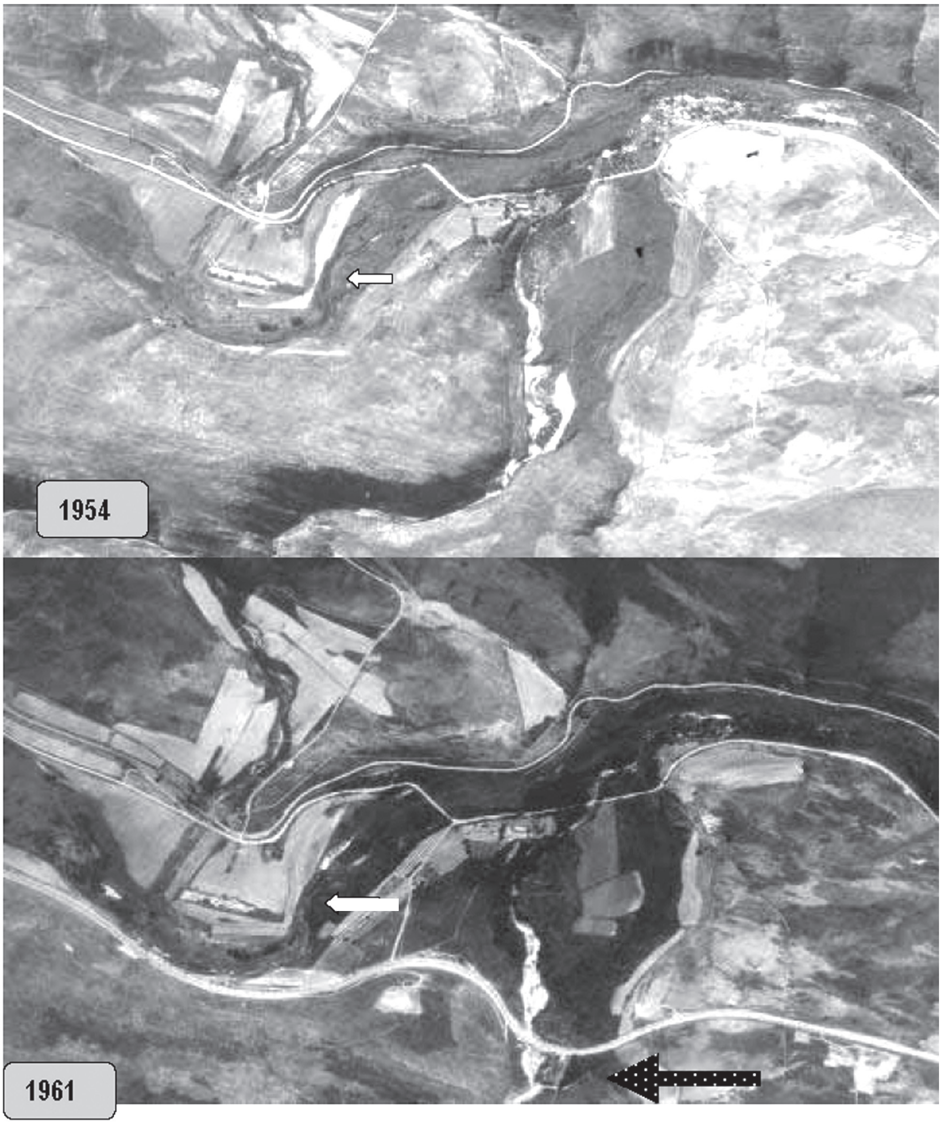


Figure 5: Aerial photographs of the study area in Companjesdrift 2 sub-basin, showing the outline of the area where the detailed analyses were conducted that are portrayed in Figures 2.5 - 2.7 (see website http//.www.ru.ac.za/institutes/iwr/wetland group). Features of note include the increasing extent of channel erosion, sedimentation on the floodplain and the absence of cultivation.

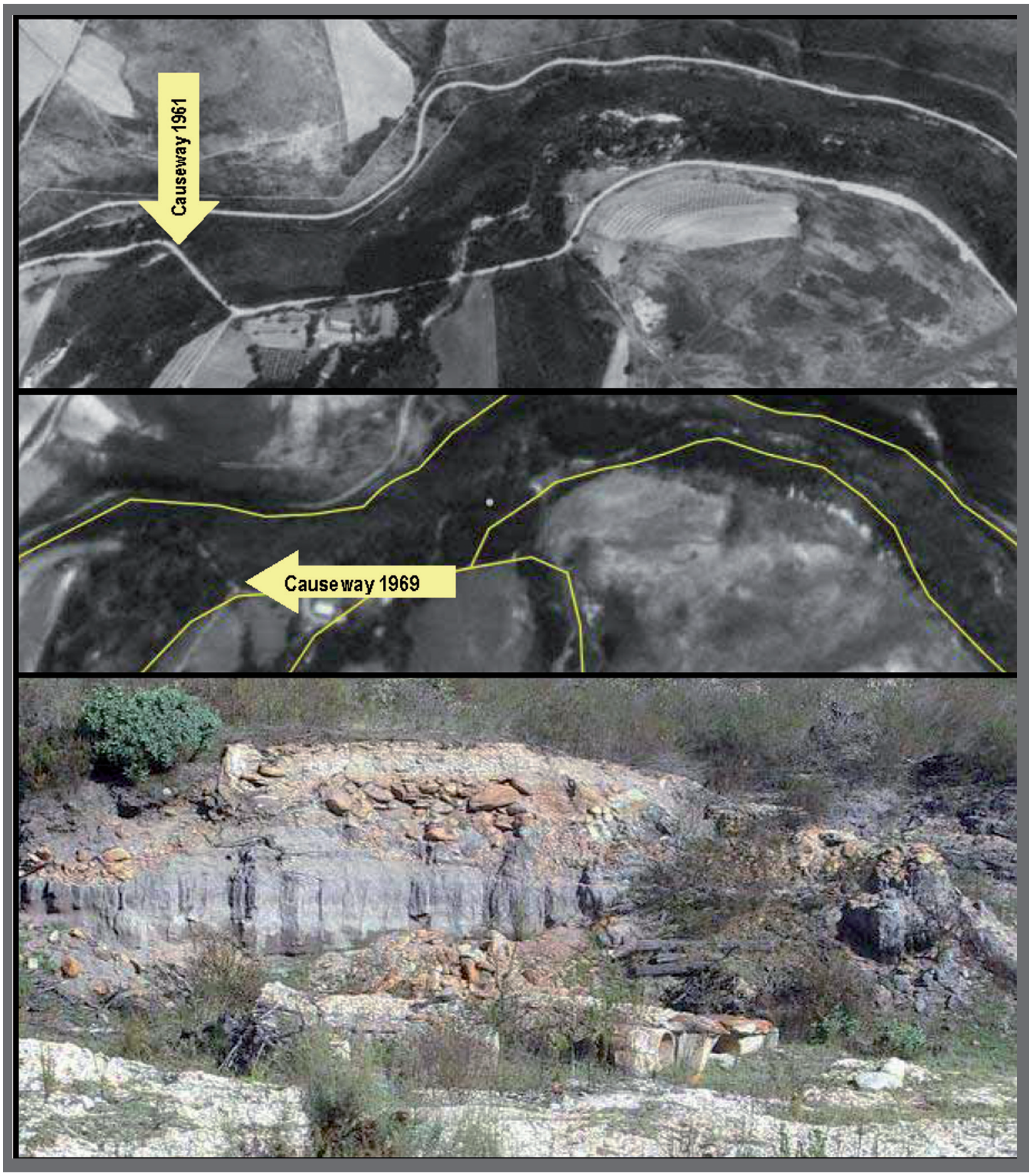


Figure 6: Aerial images of the Companjesdrift 2 study area, showing areas of increasing cultivation in the space of seven years from 1954 to 1961. The increase in sedimentation due the road construction is also visible. The pale arrows indicate the position of the most visible channel in the marsh. Note the change in the character of this feature and evidence of sedimentation downstream of the original channel. The black dot arrow indicates the altered river course.

3 Rehabilitation in the upper Kromme River Wetland

When clearing by Working for Water in 1997 revealed the extent of damage to the wetlands of the Kromme River, and the threats posed to valley-floor peat-basin wetlands, it was considered a priority to undertake gully rehabilitation. Participation and planning on the project was done mainly by staff from the Mondi Wetlands Project, Government agencies (DWAF, Cacadu District Municipality, and Working for Water), the Nelson Mandela Metropolitan Municipality and Rhodes University. Since the inception of the Eastern Cape Wetland Forum in 2001, the forum has played an oversight role in the wetland rehabilitation process. The Gamtoos Irrigation Board (GIB) at Patensie was appointed as implementing agent for the project. Mr. Pierre Joubert, the CEO of the GIB is a civil engineer, and he and other staff have played a significant role in the planning and design of the rehabilitation measures, in collaboration with other expert consultants. Land owners were not involved in the initial rehabilitation planning but were involved in the process at a later stage, after planning of rehabilitation structures had been completed.

3.1 Rehabilitation plan for the Kromme River catchment.

Planning was not done in a systematic manner, but rather as an emergency operation to save the extant peat basins threatened by headcuts. The headcuts that posed an immediate threat to areas in good condition, such as in Basins 1 and 3, were dealt with first. The less-threatening headcuts were then dealt with progressively. The purpose of erecting the erosion-control structures, which began in 2000, was to:

a. prevent further destruction of the peat basins through erosion, by stabilising gully headcuts
b. improve the hydrological functions of the wetlands and thus ensure a sustained supply of water to Churchill and Mpofu Dams (i.e. maintain base flows)
c. decrease the sediment yield from erosion and thus reduce the sedimentation rates within the storage dams (i.e. maintain water quality)
d. protect and conserve the species diversity and habitat diversity of wetlands by raising the water table, thereby ensuring a sustained water-supply to the peat basins
e. ensure flood retention and thus reduce flooding hazard, and
f. relieve poverty and develop skills in contractors and workers.

3.2 The structures

The areas where erosion-control structures were planned and constructed are presented in Table 5.

Table 5: Erosion control structures erected in the Kromme River valley, listed from the top to the bottom of the catchment

Site code, farm name, owner.	Sub-basin	Co-ordinates of erosion site	Problem addressed	Rehabilitation structure type, size, start and completion date.
A1-4. State forestry land above farm *Atomics*.	Upper catchment	33° 51' 40"S 23° 59' 30"E	Erosion gullies in river course.	Series of 4 rock gabions varying in height from 1-2.5m. Started November 2000, completed September 2002 (Figure 7)
A5. *Kromme River Farms*. Owner Andrew Baker	Krugersland	33° 51' 40"S 23° 59' 30"E	General destruction of valley floor wetland, channel incised.	Concrete structure 3.5m high on rock foundation. Spillway 8.5m wide. Started 2001, completed 2003. (Figure 8)
A6. *Kromme River Farms*.	Krugersland	33° 51' 40"S 23° 59' 29"E	Headcut, height 5.5m.	Concrete structure 5.5m high on rock foundation. Spillway section 17.5m wide. Started 2001, completed 2003 (Figure 8)
A7. *Kromme River Farms*.	Krugersland	33° 51' 40"S 23° 59' 28"E	Headcut, height 2.5m.	Concrete structure 2.5m high on rock foundation. Spillway 9.5m wide. Started 2001, completed 2003 (Figure 8)
B1. Walletjes – Companjesdrift. *Klein Rivier Landgoed Pty Ltd*. Manager Mr D.Ferreira	Companjesdrift	33° 52' 56"S 24° 04' 37"E	Largest peat basin under threat. Headcut 3m deep, erosion downstream in bend of river to bedrock.	Gabion above confluence with Eerstedrif River. Started 2000, completed 2002. Original plans for B1 & B2 were abandoned as gabions in bend of river were considered unsuitable (Figure 9).
B2. Keypoint Companjesdrift. *Klein Rivier Landgoed Pty Ltd*. Manager Mr D.Ferreira	Companjesdrift	33° 52' 54"S 24° 03' 0"E	River bed incised to bedrock in valley constriction.	Combined concrete/rockgabion structure below confluence with Eerstedrif River. Started 2003, completed 2004 (Figure 10)
B3. Companjesdrift. *Klein Rivier Landgoed Pty Ltd*. Manager Mr D.Ferreira	Companjesdrift	33° 52' 56"S 24° 04' 36"E	Largest peat basin B1 was too far from the active headcut of 3m depth, 30m width, 100m length.	Combination concrete/rock structure. Spillway and side walls and keyed in section of concrete. Rock gabion weir immediately above gabion B1. Started 2004, completed 2005 (Figures 9 and 10)
D1, D2. *Hendrikskraal*. Mr R. Fick	Hendrikskraal	33° 53' 0"S 24° 06' 0"E	Headcut in extant wetland, channel incised.	2 gabions above confluence of tributary. Completed early 2005.
E. *Kammiesbos*. Mr R Fick, Mr J van Huysteen.	Kammiesbos	33° 53' 0"S 24° 05' 5"E Deduced from map		Concrete gabion structure. Started in 2006 on the site of an old broken gabion, not completed by 2007
C. *Hudsonvale*. East basin. Mr J. van Huyssteen.	Hudsonvale Eastern end of valley	33° 55' 10"S 24° 12' 36"E	Large valley-floor wetland near Witelsrivier tributary threatened by 3 m headcut.	Rock gabion weir on soil foundation. Spillway 21 m wide, 3 m above riverbed. Constructed upstream of tributary confluence. Started 2000 completed 2003. (Figure 11)

Figure 7: Gabion complex A1-4, at left under construction, at right after completion (2001). It was very stable and well vegetated by 2005, and was slightly damaged in the 2006 flood.

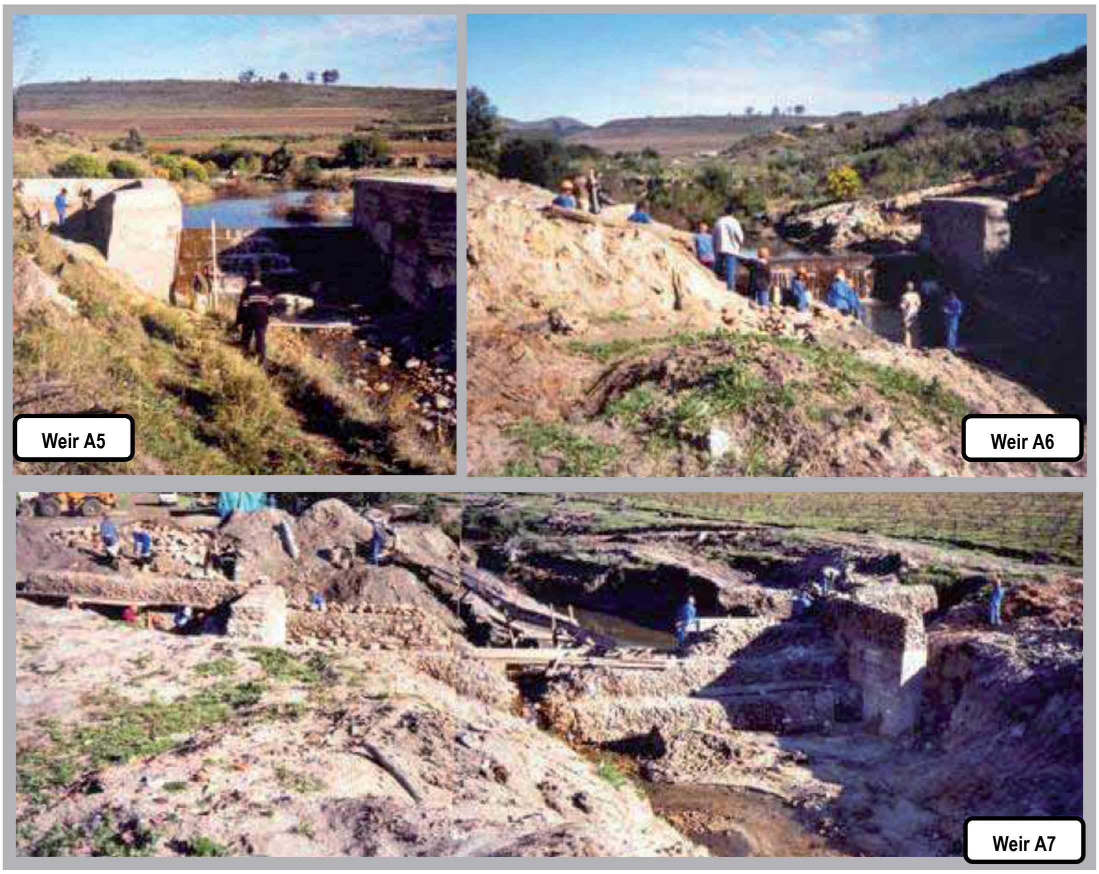


Figure 8: Weirs A5-7 on Kromdraai farm. These were the first concrete structures to be undertaken by the teams. They survived the 2006 floods in reasonable condition and appear to be functioning as intended.

Figure 9: Structures B3 (left) and B1 (right) at Companjesdrift, May 2006. Note the leakage where the concrete abuts the stone gabion on B3. The overflow level on B1 was lowered after the collapse during the 2001 flood.

Figure 10: Weir B3 of concrete and rock gabion in the key point at Companjesdrift, below the confluence with the Eerstedrif River (2004)

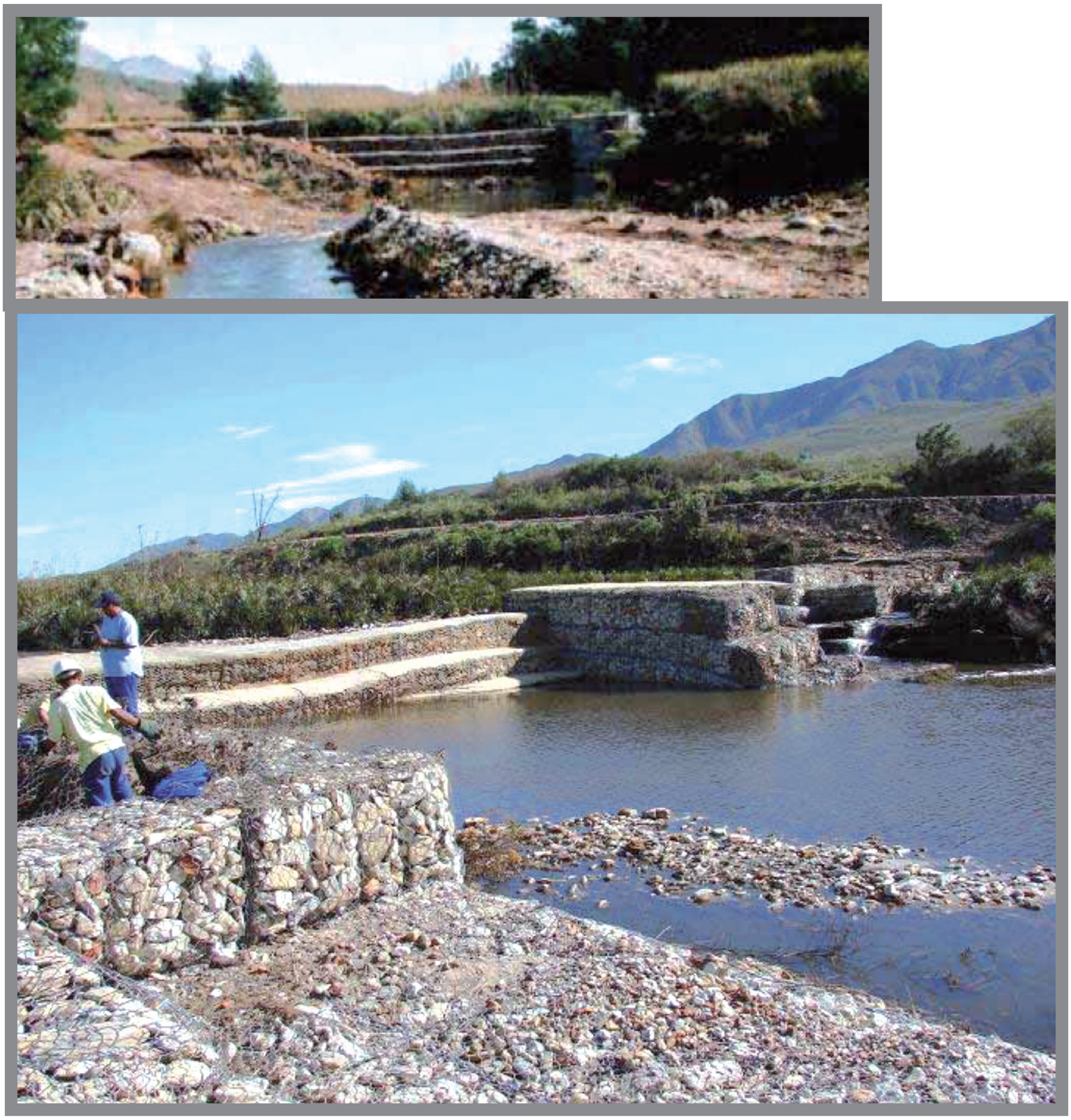


Figure 11: Top: Gabion C at Hudsonvale in 2002.
Bottom: Gabion being mended after the 2006 flood. The structure has two main sections with a central support wall. The structure has been stable and survives cattle using it as a walkway to cross the river.

4 Assessment of flood damage

4.1 Annual daily peak discharges for individual floods and selected return-intervals

Unfortunately no gauge data were available from within the study area to provide an indication of flood magnitude. However, the gauging weir at Churchill Dam lower down in the Kromme River provides some indication of the size of the flood event. Since recording started at the gauging weir in 1955, the highest average daily discharge has exceeded 200 cubic meters per second (cumecs) on only four occasions (30 May 1981 = 212 cumecs; 22 November 1996 = 434 cumecs; 27 July 1983 = 518 and 3 August 2006 = 617 cumecs). Although it is acknowledged that discharges at Churchill Dam will be significantly greater than in the upstream study area, this provides an indication that the high flows of 2006 were significantly higher than all other recorded events. The flood of March 2007 (described below) was significantly smaller than these events with a peak average daily flow recorded on 8 March 2007 of 6.632 cumecs.

The average daily peak discharges for selected return intervals at the gauging station K9H001 at Churchill Dam have been provided in Table 6. These values were calculated using the Log-Pearson Type III distribution as outlined on the Oregon State University website on stream flow evaluations (viz. *//water.oregonstate.edu/streamflow/manipulation/example.htm)*. Note that the August 2006 flood event has a recurrence interval of <50 years and the March 2007 flow a recurrence interval of <5 years. The implication is that gabion structures are likely to require significant ongoing maintenance.

Table 12: A list of return intervals (Tr) and associated discharge-values, based on the data available for the gauging weir K9H001 for the period 1955-2006

Tr	Discharge (cumecs)
2	2.26
5	25.17
10	93.18
25	389.73
50	999.06
100	2366.00
200	5264.15

4.2 Flood of 2001

A number of erosion-control structures were in the process of being built at the time of the moderate 2001 floods. Structure B1 at Companjesdrift was the only structure to be significantly damaged, as water seeped under the gabion instead of overtopping the structure (Figure 12). Overnight subsidence and rotational failure of the spillway followed. The force of the downdraught, as water was sucked under the structure, caused the left bank to collapse and by the following afternoon the escaping water was sediment-laden and the level behind the gabion was dropping. The gabion was rehabilitated and the height of the overflow lowered by 2m. After that the structure remained stable until 2006 (see following section).

Figure 12: The collapse of an unfinished gabion structure B1. It rained on 22-25 July 2001 and at 11h00 on 24 July 2001. The pool behind the structure started filling up, by 12h00 water had reached the top of the gabion (top left). In the following 15 minutes water seeped under the gabion instead of overtopping the structure (top right) as can seen by the surface disturbance. By 13h26 the people standing on top of the structure felt movement and heard groaning and soon afterwards the bank behind the gabion failed (bottom left). Overnight subsidence and rotational failure followed (bottom right). When the gabion was repaired, the height of the overflow was lowered by 2 m. After that the structure remained stable until 2006.

4.3 Flood of 2006

Between 1 and 5 August 2006 the Langkloof area (Companjesdrift) received between 250 and 500 mm of rain. By 2 of August the Kromme River was bank-full and by 4 August the entire valley floor was covered with flood water. The railway line, which had been built above the 100 year flood mark and which had never been compromised since its construction in 1906, was severely damaged in many places. Tables 7 and 8 present an assessment of damage to rehabilitation structures and the likely causes of damage, and Figures 13 to 17 provide photographic evidence of the damage to many structures.

Of the erosion structures installed only those in the very top of the valley were relatively unscathed (Structures A1-7, Figure 13). In Basin 1, Krugersland 3 and 4 and Companjesdrift 2, wetlands were relatively unscathed. However, the damage in the rest of the valley, downstream from gabion B2 at Companjesdrift, was immense. Every part of the wetland and riparian zone where wetland vegetation had been removed over the years and where inadequate plant cover was evident were ripped out. The river course had been altered in many places. The edges of old fields were carved out and new erosion dongas extended into the river bank. Volumes of sandy sediment were dumped from tributaries onto fields and some wetland edges. The river was scoured to bedrock in places and large cobble bars had vanished. The farms with the worst degree of damage were (from west to east): Hendrikskraal with serious erosion along the river course and into adjacent fields; Kammiesbos, where the low water bridge was swept away and the river course was widened; Jagersbos, where many orchards planted in the floodplain were eroded away. Below Kareedouw there was evidence of large sediment plumes. Photographic illustration of the damage to wetlands is presented in Figures 18 to 20.

Figure 13: A view of gabion baskets with clasts missing at the Dwarsrivier structure (A1)

Figure 14: Structures A5-A7 at Kromdraai Farms (Krugersland 1 and 2). Top left: A view of the left bank of the channel at the middle site at Kromdraai (A5). Note the threat posed by erosion to the key wall of the structure.

Bottom left: Collapsed gabions adjacent to the right bank of the channel (A6).

Top Right: A view of the 'wing wall' on the left bank of the river (A7). Note the loss of sediment between the wing wall and river bank.

Table 7: A brief description of each of the erosion control structures after the August 2006 flood in relation to selected geomorphological aspects and flood damage and an assessment of their erosion- control efficacy based on the condition of the upstream banks and the state of the area immediately adjacent to the structure. The structures have been listed in order of increasing distance downstream.

Site & Location	Catchment Area (ha)	Slope (%)	Geomorphological Notes	Comment	Efficacy
A1-4 Dwarsrivier	402.3	3.6	Bedrock present.	There has been loss of stones from some gabion baskets (Figure 13).	Excellent
A5 Kromdraai (upper)	1507.7	1.5	No bedrock present. Channel banks were unstable downstream of the structure.	Erosion adjacent to structure and immediately downstream of structure. Erosion adjacent to the shoulder wall may cause outflanking of the structure if left. Limited scour evident at the base of at least one shoulder wall. The association between these features and flood events is unknown.	Excellent
A6 Kromdraai (middle)	1601.2	1.5	No bedrock present. The channel banks downstream are unstable. For example, on the right-hand bank there has been an arcuate rotational failure adjoining the downstream end of the structure (Figure 12)	Gabion baskets that formerly joined the structure have toppled over. The key walls on the left bank were inadequate, which increased the risk of the structure being outflanked by future floods should the size of the eroded space between the structure and the channel bank be increased (Figure 14).	Excellent
A7 Kromdraai (lower)	1644.7	1.5	Bedrock present. Channel banks downstream of the structure were unstable.	Erosion had occurred on the left bank between the structure and the adjacent slope (Figure 14). Further loss of sediment in this area could lead to outflanking of the structure by the stream. The key wall on this bank is too short which increases the aforementioned risk.	Excellent
B1, B3 Companjesdrift (upper)	5535.5	0.8	Bedrock present a short distance downstream of the structures. Channel banks downstream of the structures were unstable. Headcuts were present upstream of the structures. An incised overflow channel was present on the left bank. The structures were located adjacent to the Poortkloof alluvial fan and a short distance upstream of the Eerstedrifrivier alluvial fan. Unvegetated sand deposits were present adjacent to the wetland.	The site of two large gabion structures, B1& B3, were located in close proximity to each other. Both structures were damaged in the August 2006 flood event (Figure 15). The older, lowermost structure, subsided on a prior occasion and was repaired (Figure 12). Flood damage to the structures included inter alia extensive subsidence (lower structure), movement of clasts within gabion baskets (upper structure) and erosion of unconsolidated sediment adjacent to the structures (both structures, Figure 15). An incised overflow channel on the left bank represented a significant threat to the structures, as continued headward retreat may result in both structures being outflanked by the river.	Poor (upstream structure) Moderate

B2 Kompanjiesdrif (lower)	7138.5	0.8	The structures were located immediately downstream of the Eerstedrifrivier alluvial fan.	The structure was damaged by the August 2006 flood event. The gabion weir was pushed over in the downstream direction but the concrete section was intact. The structure was in the process of being repaired at the time of the site visit (Figure 16).	Moderate
D1 Hendrikskraal (upper)	7498.0	0.9	Located within a Palmiet wetland a short distance upstream of the confluences of the Kromme River with two tributaries, the Waterkloof on the right bank and Houtkloof on the left bank.	The structure was located on the left flank of the wetland below the railway line. Flood debris (e.g. log) was present on top of the gabion. The wire of at least one basket had been broken, possibly by trees snagged in the basket during a flood event.	Moderate
D2 Hendrikskraal (middle)	7502.3	0.9	Bedrock present, with the strike orientated parallel to the valley. The channel banks downstream were unstable. Unvegetated sand deposits present.	Upper gabion baskets pushed downstream by the force of flood waters.	Excellent
D3 Hendrikskraal (lower)	9728.1	0.4	Bedrock present. Unvegetated sand deposits present.	A new structure was being built at the site of an earlier one.	
C Hudsonvale	15145.4	0.4	The structure is located immediately upstream of the confluence of the Witelsrivier with the Kromme River.	The gabion baskets had subsided at the terminal end of one of the shoulder walls (Figure 17). The cement apron downstream of the main wall had been damaged by flood waters. The latter damage is believed to have occurred at the time of the more recent flood, on Monday 5 March, 2007 and during the previous week. Erosion of unconsolidated sediment had taken place adjacent to the structure.	Good

Table 8: Summary table of assessment of problems at each of the structures and the action recommended. An explanation for each problem is presented as a bulleted list at the bottom of the table. Present state rating for each structure is given in brackets after the name (1 = poor, must be rebuilt; 2 = severe problems, needs urgent attention; 3-3.5 = reasonable, needs repairs; 4 = good, minor repairs; 5 = excellent, no damage.)

Structure	**Problems**	**Comments/ recommendations**							
	Poor founding	Gabion packing method	Gabion construction	Key walllength	Shoulder walls	Concrete capping	Stilling basin design	Impervious membrane	
A1-4 (4)		X							Repair the stilling basin by placing a concrete sill downstream of the reno mattress
A5 (3.5)					X (left needs attention)				Downstream shoulder wall to be extended in concrete or as gabions
A6 (3)					X (both si des need attention)			Gabion slipped	Shoulder requires extensive wall repairs and replacement on both sides
A7 (4)					X				Requires extension of right shoulder wall
B3 (1)	X			X		X	X	X	Intensive exploration needs to find bedrock. Depending on availability of good founding conditions, weir should be extended beyond previous length. The current gabion needs to be built in a stepped fashion to river bottom level, and an appropriate sized stilling basin should be included in the design. Key wall should be extended to protect the gully formed downstream and to divert water into the main channel.
B1 (1)	X	X	X		X	?		X	A firm foundation needs to be found. A basement with a reno mattress which includes a heel and cutoff toe wall needs to be included beneath the toe wall of the stilling basin. These will prevent scour beneath the basement and sliding of the structure. The whole structure should be protected by a geotextile membrane between gabion and soil. Folds should be made in the water-proofing material to accommodate movement of the structure and to prevent tearing.

B2 (2)	X	X	X			X	X	X	Adequate foundation material needs to be located and a concrete mass gravity-weir should be constructed across the entire river width. A stilling basin of the correct dimensions should be built.
D1 (3)		X				X		X	The top gabion should be unpacked and repaired, the spillway raised to the level of the headcut. The sidewall should be extended to a step structure. An appropriate stilling basin should be created and capped with concrete 100 mm thick.
D2 (3)		X	X	Concrete poor					The gabions should be repacked and repaired. They should be extended across the floodplain as far as the south bank of the floodplain. The gabion should be raised by 1 m to compensate for vegetation and sediment build-up.
D3					X (Upstream wing too short)			X	Adequate rock foundation should be found. The existing shoulder wall should be extended to prevent scour by trapped water.
C1 (3.5)		X				X	X	X	The current central sidewall should be moved towards the railway line to prevent the gully forming underneath the north basin due to deepening and undercutting the gabion. The steps that were damaged after the March 2007 flood should be repaired and the exposed side wall erosion covered. Stilling basin should be repaired. All structures should be capped with 150 mm concrete. The suggestion was that concrete should be laid in the gabions before the wire basket lid is secured.

- Poor founding. Refers to the foundations that were built for a structure. In sandstone dominated areas valley floors often have consolidated sands which may appear suitable, but under severe stress they will give way. This was the case at structure B3. Exploration for suitable foundation material should be undertaken.
- Gabion construction. Better training and supervision is required to produce a more densely packed structure.
- ·Gabion packing stones. More angular, flatter, less rounded stones should be selected for the outer skin of the gabion.
- Vegetation type must be taken into consideration. Its distribution makes a difference to the height of the freeboard, which must always be higher than for an unvegetated upstream area. Reeds are more flexible than palmiet, which therefore require a higher freeboard.
- Impervious membrane for water proofing on the upstream side of the gabion weir needs to be at least 500 µm (such as orange Hyperlastic from Gundle Plastics). In addition, the membrane must be installed below the foundation into an impervious layer such as clay, to prevent seepage beneath the structure. This prevents the fine material present in the soil from being washed out.
- Key-wall length and shoulder walls should be longer and better protected as this should protect the investment. Shoulder walls should be keyed into the river bank on both the up- and downstream sides to prevent scour.

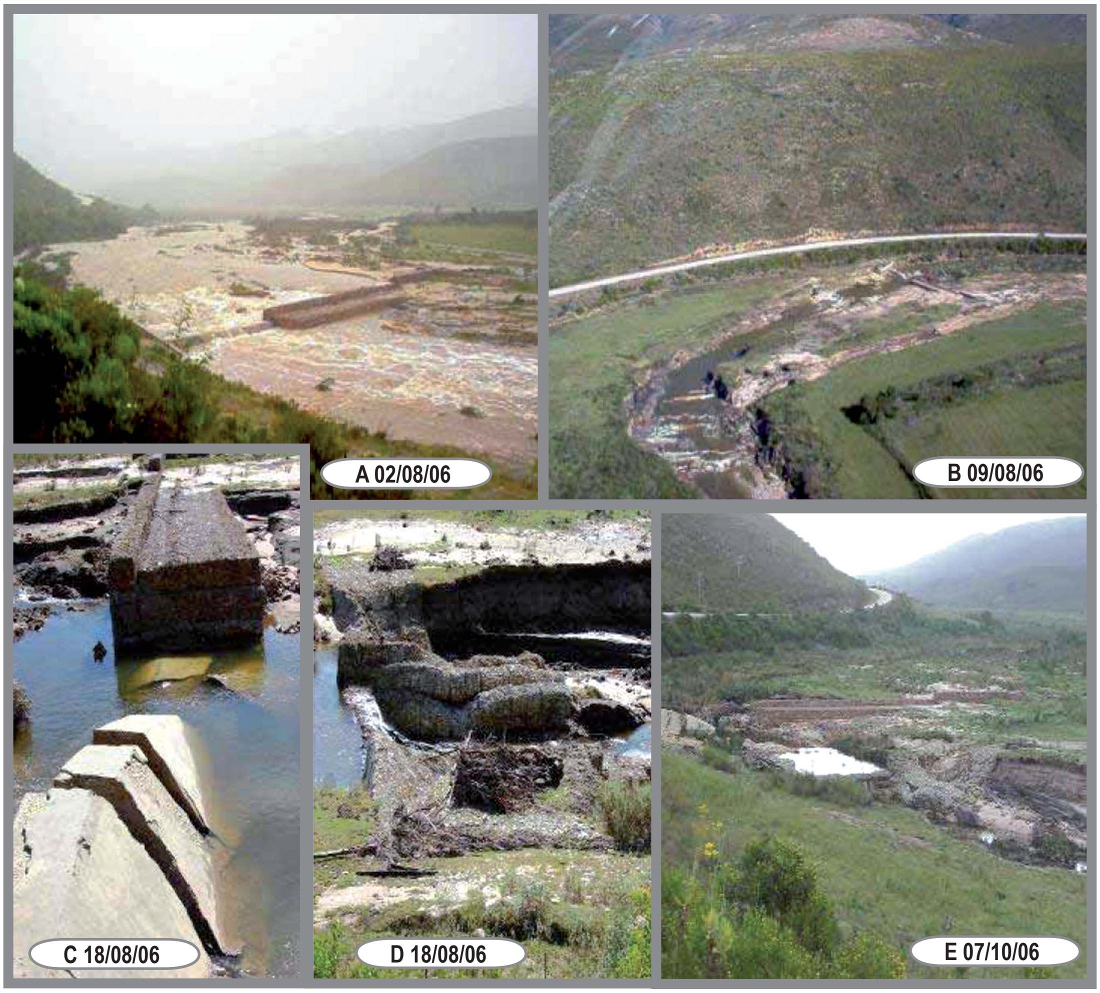


Figure 15: Sequence of events at the weirs B1 and B3 at Companjesdrift on the Kromme River, August 2006.

A: Midway through flood, gabion B3 still entire.

B: Four days after flood showing damage to both weirs and a new gully through the field on the north bank (arrowed).

C: Close-up of concrete section weir B3.

D: Mangled but functioning remains of gabion B1.

E. General view of devastation approximately one month after the event.

Figure 16: Flood damage at weir B2, August 2006.

Top left – weir from south bank.

Top right – weir form the air.

Bottom right – weir from north bank.

The arrow indicates the river course prior to the flood. The concrete section of the weir trapped a large volume of silt, which resulted in water finding an alternative route through the stone gabion. The central section in the direct route of the water was distorted and pushed over by the force of water.

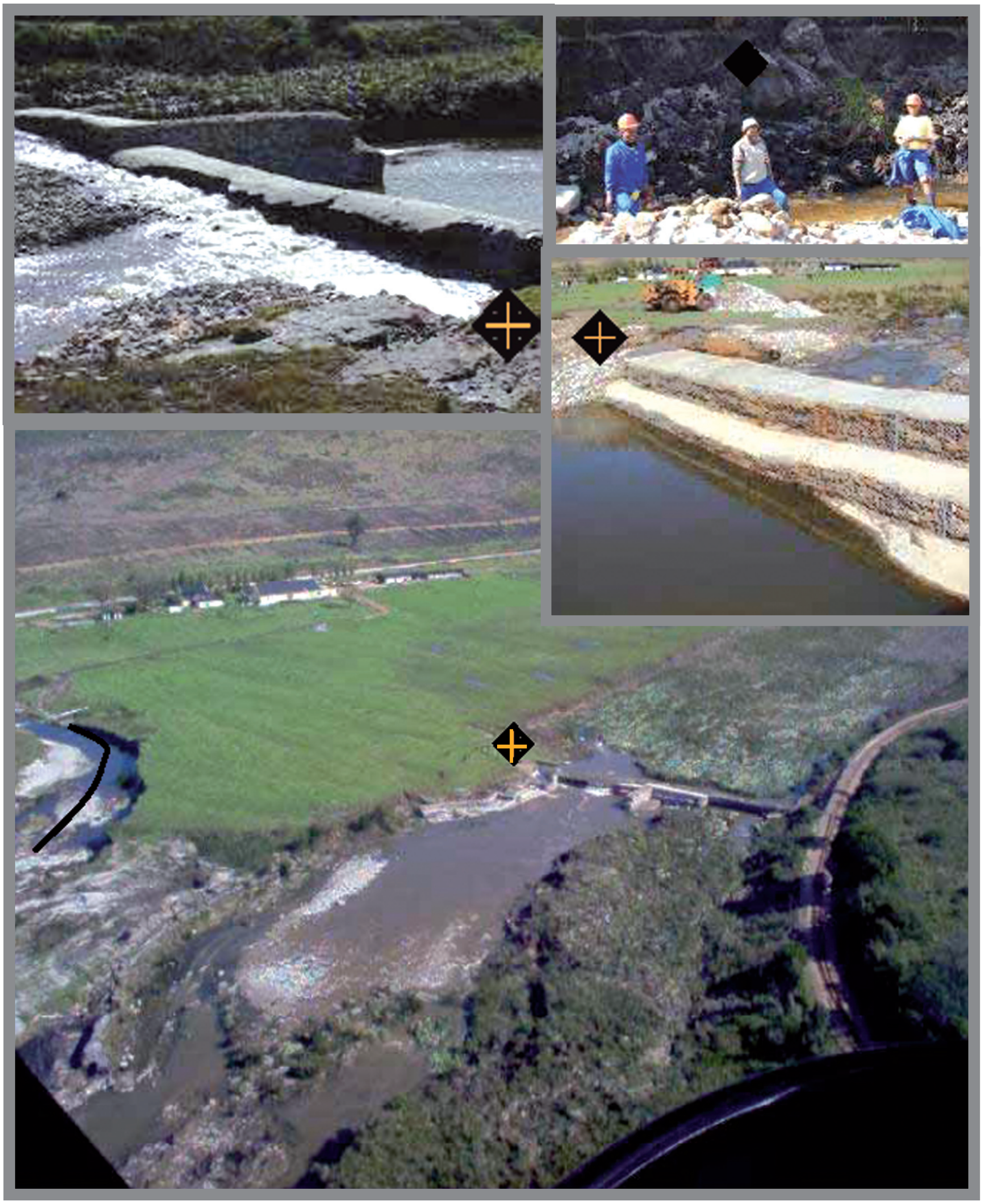


Figure 17: Flood damage at gabion C at Hudsonvale. The water forced past the southern arm of the gabion. The cross marks approximately the some spot in each photograph.

- Top left – view from the bank where the break through took place.
- Top right – gabion being mended by extending the key wall on the south side. Note the depth of the peat layer in this position.
- Middle right – state of the gabion as viewed from the northern bank.
- Bottom – view from the air looking west, 9/08/06 four days after the flood. The river was still very full. The gabion had survived relatively unscathed. The arrow indicates the Wit Els tributary where the bank had been substantially altered as shown by the dark line.

Figure. 18: Above - view of the floodplain at Kammiesbos after the 2006 flood. Right - aerial photograph of the same area taken in 2003. In both photographs the R62 roads is on the left and the railway line on the right. The wetland vegetation was beginning to establish after the area had been cleared of alien vegetation in 2000. It appears that the river course had shifted closer to the road in 2006 as it is more deeply incised. The roadbridge across the river was washed away in the 2006 flood.

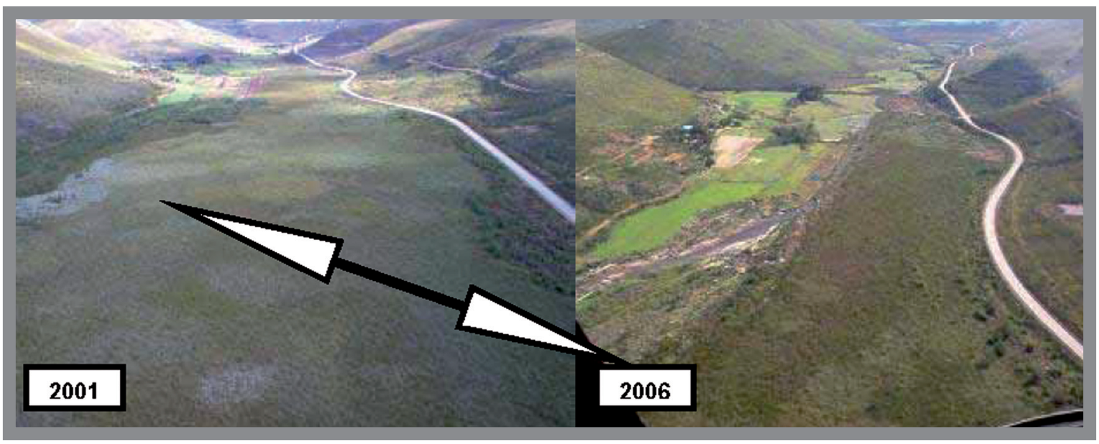


Figure 19: View of the marsh at Companjesdrift looking west in 2001 (left) and in 2006 (right) after the flood. Note that the scoured area (arrowed) is in the artificial pasture on the edge of the marsh, which had formerly been a riparian area.

Figure 20: Floodplain at Companjesdrift.

Left – view of the unvegetated sediment deposits on the left bank of the wetland above the uppermost structure.

Right – view about 100m downstream on the same side. An incised overflow channel represents a significant threat to structures if left unattended.

4.4 Flood of 2007

Most of the damage that has been reported in this study is assumed to be associated with the flood event that occurred in August 2006. The smaller flood in early March 2007 may have exacerbated the earlier flood damage or have caused new damage to the rehabilitation structures. In the absence of accessible baseline data, such as photographs taken at regular time-intervals, it has not been possible to unequivocally attribute the reported damage to any specific flood event. Some of the damage (e.g. scour at the foot of structures) may also represent the cumulative effect of smaller flood-flows. However, as at least some of the damage to the concrete apron at Hudsonvale can be attributed to the smaller flood event in March 2007 (Mr J. Buckle, *pers.comm.*), the magnitude of this flood has been used in the analysis of return intervals for assessing potential, future flood-related damage to rehabilitation structures (see Section 4.1).

5 Ecosystem services and wetland health assessments

5.1 Ecosystem services assessments pre- and post-flood.

In their intact state, the Kromme River wetlands have little direct economic value to inhabitants as the grazing potential is low and the wetlands are not directly utilised for their products. Consequently the wetlands and riparian zones have been extensively transformed for the cultivation of pastures and fruit orchards, especially in Basins 2 and 3 between Hendrikskraal and Hudsonvale. This transformation greatly threatens the palmiet-dominated peat basins and has resulted in the poor condition of these areas. A further contribution to the poor state is the erosivity of the sandy soils. Ecosystem services such as flood attenuation, stream flow regulation, and sediment trapping in the catchment areas of the two dams in the lower part of the Kromme River system, are important in terms of protecting the water resource and ensuring a sustained supply of good-quality water to Port Elizabeth.

A rapid assessment of ecosystem service delivery of the wetlands, based on the framework outlined in the *WET-EcoServices* tool (Kotze *et al*., 2009), was undertaken in May 2006 and repeated in March 2007 in the upper K90A catchment of the Kromme River, including Basins 1, 2 and 3. These results are presented in Table 9.

The scores for delivery of ecosystem services in Basin 1 in 2006 were intermediate to high (>=2), with the exception of cultivated foods and cultural significance. The scores for cultural significance consistently scored 0 for all sites and all dates, and will therefore be ignored for all assessments described below. The scores for several ecosystem services were high (>=3), namely toxicant removal, erosion control, carbon storage, maintenance of biodiversity, water supply for human use and education and research. Ecosystem service delivery in Basin 1 generally improved between 2006 and 2007, with nine of the services improving or remaining the same and only six declining (Table 9). None of those that declined did so to a large degree except for education and research, which went from a score of 3.3 to one of 2.0, due to the cessation of research work done in the area in 2007.

Except for streamflow regulation and carbon storage, ecosystem service scores in Basin 2 in 2006 were intermediate (2 to 3), but none were higher than 3. In Basin 2, scores for eight ecosystem services declined from 2006 to 2007 and the scores for six, increased over the same time period. Only a single score (sediment trapping) was greater than 3.0 in 2007, and one had dropped to less than 1 (carbon storage). Scores for nitrate removal and erosion control had dropped from above 2 in 2006 to below 2 in 2007.

Scores for ecosystem services in Basin 3 were intermediate or high (>=2) in 2006. The scores largely showed an improvement or they stayed much the same from 2006 to 2007. Eight ecosystem services stayed the same and only six ecosystem service scores declined somewhat – again only by a relatively small amount.

Given these differences it is clear that Basin 2 suffered most during the flood period with eight of the ecosystem services declining, including erosion control, carbon storage and nitrate control, which all declined by a large amount. Unlike Basin 1, which had ten structures (A1-7 and B1-3), Basin 2 had only three structures (D1-3), which clearly were not sufficient to maintain ecosystem service delivery for a flood such as experienced in 2006.

Threats posed to wetlands in Basins 1 and 2 were high in both 2006 and 2007 (scores of 3 to 4), while in Basin 3 they were intermediate in both years (scores of 2 to 3). However, opportunities for conservation and rehabilitation were generally lower with scores being 2 or less in Basins 2 and 3 in both 2006 and 2007. The opportunities for conservation and rehabilitation in Basin 1 were higher in 2007 (score of 3), but declined over the year to 2.

Table 9: Assessment of ecosystem service delivery in 2006 and 2007 (pre and post flood) in catchment K90A

	Basin 1		Basin 2		Basin 3	
Ecosystem service	**2006**	**2007**	**2006**	**2007**	**2006**	**2007**
Flood attenuation	2.5	2.4	2.0	2.1	2.4	2.3
Streamflow regulation	2.8	3.2	1.7	1.8	2.3	2.3
Sediment trapping	2.4	2.6	2.7	3.3	3.0	3.0
Phosphate trapping	2.5	2.7	2.8	2.5	2.8	2.8
Nitrate removal	2.8	3.2	2.3	1.7	2.3	2.3
Toxicant removal	3.0	3.2	2.5	2.0	2.6	2.6
Erosion control	3.3	3.4	2.7	1.5	2.5	2.5
Carbon storage	4.0	3.7	1.7	0.3	2.0	1.7
Maintenance of biodiversity	3.5	3.2	2.9	2.2	2.4	2.5
Water supply for human use	3.5	3.0	2.3	2.5	2.6	3.2
Natural resources	2.0	2.4	2.8	2.6	2.0	1.8
Cultivated foods	1.2	1.6	2.6	2.4	2.4	2.2
Cultural significance	0.0	0.0	0.0	0.0	0.0	0.0
Tourism and recreation	2.3	2.0	2.0	2.4	2.4	2.3
Education and research	3.3	2.0	2.0	2.4	2.4	2.3
Threats	3.0	4.0	4.0	4.0	2.0	2.0
Opportunities	3.0	2.0	1.0	2.0	2.0	2.0

1=moderately low; 2=intermediate; 3=moderately high; 4= high
Shaded cells indicate an improvement in service delivery

5.2 Wetland health assessment in 2007 (post-flood)

The results of the *WET-Health* assessment (Macfarlane *et al*., 2009) of the upper catchment (K90A) of the Kromme River Wetland following both the 2006 and 2007 floods are presented in Table 10.

Table 10: Summary table of WET- Health assessment results for all three basins of the Kromme River in catchment K90A

	Basin 1	Basin 2	Basin 3
Hydrological	1*	8	5
Geomorphological	2	8	6
Vegetation	1	10 (see 18% below)	6
Integrated health score**	1.3	8.6	5.6
Percentage of wetland and its condition	83% un-impacted 17% critically impacted	18% un-impacted 53% seriously or critically impacted 29% channel	43% moderately impacted 57% seriously or critically impacted
Area of extant wetland (ha)	101	28	18

*Score: 0 = no discernible modification; 10 = critically impacted (see Macfarlane *et al*. (2009) for the rationale and scoring system).

A large proportion of the wetlands in Basin 1 were still intact and their overall health was very good such that the score for integrated-health was 1.3, which indicates that the area was largely natural with few modifications. This basin had the largest volume of peat and was in the best condition of the three basins. Erosion control structures A1-7 had clearly been very useful in maintaining wetland integrity despite the floods. The collapse of structures B1-3 however, which were further downstream than the aforementioned structures, contributed to the destruction of wetlands in the lower part of Basin 1 such that 17% had been critically impacted.

Basin 2 was in the worst health condition of the three basins (integrated score of 8.6, which in WET-Health is regarded as being critically impacted) with 53% of the wetlands being seriously or critically impacted. This was the result of a number of factors including:

- the collapse of structures B1-3 upstream, in the upper part of Basin 2,
- the presence of few structures in Basin 2 (D1-3) and
- poor land management practices in the catchment and wetland.

Basin 3 scored somewhat better than Basin 2. Although a large proportion of the wetlands (57%) in Basin 3 were largely, seriously or critically impacted, the integrated health score of 5.6 represents a large impact with a large change in ecosystem processes and loss of natural habitat and biota. These impacts were largely the result of insufficient erosion-control structures as well as poor land-management practices in the catchment and the wetland.

5.3 Predicted effect on health and ecosystem service delivery should the headcuts proceed

Headcut erosion is one of the biggest threats to the wetlands in the upper Kromme River catchment. This section describes an assessment in each of the Basins of the likely loss of health and ecosystem service delivery should the advance of these headcuts not be halted through the use of rehabilitation structures.

5.3.1 Basin 1

The likely loss of health/integrity (Tables 11 and 12) and the associated loss of ecosystem-service delivery (Table 13) that would result should the headcuts proceed throughout the Companjesdrift and Krugersland basins have been assessed, based on the erosion of peat and its subsequent oxidation as illustrated schematically in Figure 21.

Table 11: Predicted level of health of the Basin 1 (Krugersland/Companjesdrift peat basin) likely to be secured if headcut erosion through this basin is halted

Integrity component	Score	Rationale
Hydrological integrity before further advancement of the headcut through the wetland.	1/10	The hydrology of the wetland is relatively unimpacted. However, low to moderate levels of water abstraction occur in the wetland's catchment, which somewhat reduces the volume of water inputs to the wetland.
Hydrological integrity should the headcuts proceeded unhindered through the affected area.	7/10	The deeply incised channel will have a pronounced draining effect on the wetland. Lag deposits of cobbles, sand and other coarse material in the peat predispose the remaining peat to dry out. However, lateral tributary inputs are likely to lessen the desiccation effect. Reduced surface roughness associated with the loss of palmiet will diminish the extent to which flows are slowed down in the wetland.
Geomorphic integrity before the advancement of the headcut through the affected area.	2/10	Impacts on the geomorphic integrity of the wetland are minimal. The major peat deposit is currently intact. The extent of mineral sediment deposits have increased slightly due to increased sediment from human activities in the catchment.
Geomorphic integrity after the advancement of the headcut through the affected area.	8/10	A considerable loss of peat would occur through direct erosion. Further loss of peat is likely to occur as a result of the drying out and oxidation of remaining peat. Overall, the basin will be converted from an aggrading system to a system with a high net loss of sediment.
Vegetation integrity before the advancement of the headcut through the affected area.	1/10	Most (95%) of the area of the wetland comprised largely pristine vegetation, and the remaining 5% was cleared of alien plants a few years ago, and is now dominated by pioneer species
Vegetation integrity after the advancement of the headcut through the affected area.	7/10	Re-establishment of vegetation in the incised channel is very limited owing to the high scouring-velocities. Although palmiet will persist on the lateral areas of remaining peat, there is likely to be invasion by terrestrial species.

Score: 0 = completely natural (pristine), 10 = integrity completely lost

Note: it is predicted that the decline in vegetation integrity will take place over an extended period (possibly several decades) following advancement of the headcut through the wetland.

The scores for these three respective components (hydrology, geomorphology and vegetation) can be integrated based on a weighted average ratio of 3: 2: 2, given that hydrology is considered to have the greatest contribution to health. The integrated score for the current state is ((1 x 3) + (2 x 2) + (1 x 2))/7 = 1.3 (Table 12). This translates to a hectare health equivalent score of (10-1.3)/10 x 101 ha) = 87.9 hectares of healthy wetland. The integrated score for the eroded state if rehabilitation does not take place is ((7 x 3) + (8 x 2) + (7 x 2))/7 = 7.3. This translates to a hectare health equivalent score of (10-7.3)/10 x 101 ha) = 27.2 hectares of healthy wetland. Therefore rehabilitation will secure 87.9 – 27.3 = 60.6 hectares of healthy wetland.

Table 12: Summary of hectare equivalents of healthy wetland secured by rehabilitation for Basin 1 (101 ha), Basin 2 (28 ha) and Basin 3 (18 ha)

		Basin 1	Basin 2	Basin 3	Total
With rehabilitation	Integrated health score[1&3]	1.3	8.6	5.6	
	Hectare equivalents[2]	87.9	3.9	7.9	
Without rehabilitation	Integrated health score[1&3]	7.3	10	8.7	
	Hectare equivalents[2]	27.3	0	2.3	
	Secured hectare equivalents	60.6	3.9	5.6	70.1

1 0 = pristine, 10 = completely destroyed

2 Hectare equivalents = (10 – health score)/10 x area of rehabilitation in hectares.

3 The scores for these three respective components are integrated based on a weighted average ratio of 3: 2: 2, given that hydrology is considered to have the greatest contribution to health. For example, if hydrology, geomorphology and vegetation

Table 13 highlights that a substantial loss of ecosystem service delivery is expected for 5 of the 15 ecosystem services considered if the erosion continues. This loss would be averted through rehabilitation.

Table 13: Loss of ecosystem services likely to result from headcut erosion through Basin 1, and which could be averted by halting the headcut erosion through rehabilitation measures

Ecosystem service	Score	Comments
Flood attenuation	**	1. Flows will be afforded less opportunity to be spread across the wetland as the un-channelled valley bottom becomes deeply incised. 2. Roughness will decline greatly as the dense cover of palmiet vegetation is diminished
Streamflow regulation	**	Level of wetness (currently mainly semi-permanent) will be reduced greatly as a result of the desiccating effect of the erosion gully
Sediment trapping	**	See comments for flood attenuation
Phosphate assimilation	*	Afforded fairly limited opportunity for assimilating this element
Nitrate assimilation	*	Afforded fairly limited opportunity for assimilating this element
Toxicant assimilation	*	Afforded fairly limited opportunity for assimilating this element
Erosion control	*	Considerable direct loss of peat through erosion
Carbon storage	**	Considerable loss of peat through erosion and oxidation
Biodiversity maintenance	**	Significant loss of habitat anticipated given the decline in health reported in Table 10. This has added significance given the high cumulative impact to which palmiet wetlands have already been subjected
Water supply for human use	*	Currently, limited use made of water directly out of the wetland. However, there is substantial value outside the catchment
Natural resources	#	Currently very limited use of natural resources
Cultivated foods	#	Currently not used for this purpose
Cultural significance	#	Currently not used for this purpose
Tourism and recreation	#	Currently not used for this purpose
Education and research	#	Currently limited use for this purpose. Information of climate changes trapped in peat will be lost

Score for Individual services (# = no significant loss anticipated; * = slight loss anticipated; ** = substantial loss anticipated).

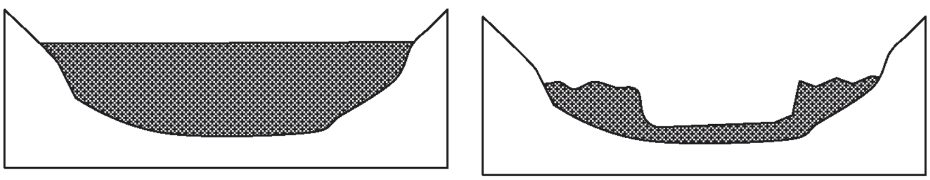


Figure 21: Schematic cross-section through the Krugersland/Companjesdrift peat basin, showing the current situation (a) compared with an incised situation (b). Given the present state of the channel at the distal end of the basin and the drop in level (2-3m to bedrock) that has occurred since that year, the threat to the basin has increased considerably.

If Basin 1 is considered for the purposes of assessing the possible efficacy of the structures it appears that their positive influence is considerable.

5.3.2 Basin 2

Given that Basin 2 is in relatively poor health for hydrology, geomorphology and vegetation (Table 14), securing health or improving health by the construction of additional structures produces relatively small improvements in wetland health. This is reflected in the small value obtained for hectare equivalents of healthy wetland secured in Basin 2 (Score = 3.9; Table 12). Similarly, Table 15 highlights that a substantial loss of ecosystem service delivery is not expected for any of the 15 ecosystem services considered if the erosion continues. This loss would be averted through rehabilitation.

Table 14: Predicted level of integrity likely to be secured if headcut erosion through Basin 2 could be halted or reduced

Integrity component	Score	Rationale
Current hydrological integrity i.e. before further advancement of the headcut through the affected area	8/10	Only a small portion (18%) of the wetland was secured by gabions. The hydrological regime has been severely altered to a broad channel for more that 80% of the basin.
Hydrological integrity should the headcuts proceeded unhindered through the affected area	10/10	The deeply incised channel will destroy the remainder completely.
Geomorphic integrity before the advancement of the headcut through the affected area	8/10	Impacts on the geomorphic integrity of the wetland have been severe for a considerable time (refer Table 3).
Geomorphic integrity after the advancement of the headcut through the affected area	10/10	There has been considerable loss of peat through direct erosion. Further loss of peat will occur due to a lack of structure-maintenance.
Vegetation integrity before the advancement of the headcut through the affected area	10/10	Approximately 18% of the area of the wetland is extant.
Vegetation integrity after the advancement of the headcut through the affected area	10/10	Establishment of vegetation in an incised channel will be limited owing to high scouring-velocities.

Score: 0 = completely natural (pristine), 10 = integrity completely lost

Note: it is predicted that the decline in vegetation integrity will take place over an extended period (possibly several decades) following advancement of the headcut through the wetland.

Table 15: Loss of ecosystem services due to headcut erosion through Basin 2

Ecosystem service[1]	Score	Comments
Flood attenuation	#	1. Flows are afforded less opportunity to spread across the wetland due to the deeply incised channel in the valley bottom.[2] Roughness has declined greatly as the dense cover of palmiet vegetation has vanished.
Streamflow regulation	#	2. Level of wetness is reduced greatly
Sediment trapping	#	3. None
Phosphate assimilation	#	4. Afforded limited opportunity for assimilating this element
Nitrate assimilation	#	5. Afforded limited opportunity for assimilating this element
Toxicant assimilation	#	6. Afforded limited opportunity for assimilating this element
Erosion control	#	7. Limited to 18% of basin 2. If there had been no erosion control, the entire basin would have been eroded and there would have been even more direct loss of peat
Carbon storage	#	8. Large loss of peat through erosion and oxidation
Biodiversity maintenance	#	9. There has been significant loss of biodiversity services of the wetland habitats due to soil erosion linked to loss of riparian vegetation before the 2006 flood
Water supply for human use	*	10. Currently, limited use is made of water directly from the wetland. However, this is an important source of water for nearby cities and towns
Natural resources	#	11. Currently very limited use of natural resources
Cultivated foods	#	12. Floodplain had been previously used for cultivated fields, now washed away
Cultural significance	#	13. Reed harvesting considered a cultural practice
Tourism and recreation	#	14. Currently not used for this purpose
Education and research	#	15. Currently not used for this purpose

Score for Individual services (# = no significant loss anticipated; * = slight loss anticipated; ** = substantial loss anticipated).

[1]If erosion structures had been instituted in 2001 some of the ecoservices could have been conserved.

[2]Score for Individual services (# = no significant loss anticipated; * = slight loss anticipated; ** = substantial loss anticipated).

The chances of regaining the transformed wetland areas in Basin 2 through rehabilitation are small as they are of more value to the land users as cultivated fields. Rehabilitated areas have been transformed to kikuyu pastures, which are of considerable economic value to the land owner.

5.3.3 Basin 3

Although the wetland combined hydrological, geomorphologic and vegetation health score for Basin 3 indicates large impacts (score of 5.6, Table 12), the predicted overall health if headcut erosion proceeds would be at critical levels (score of 8.7; Table 12). This is based on the analysis in Table 16. Table 17 highlights that a substantial loss of ecosystem service delivery is expected for 7 of the 15 ecosystem services considered if the erosion continues. This loss would be averted through rehabilitation.

Table 16: Predicted level of integrity likely to be secured if headcut erosion through Basin 3 is halted

Integrity component	Score	Rationale
Current hydrological integrity (i.e. before further advancement of the headcut through the affected area).	5/10	Benefits of on-site gabions are significant in terms of securing the hydrological regime upstream. Downstream the hydrological regime has been severely altered and could threaten the structure. Moderate levels of water abstraction occur in the wetland's floodplain but have little effect on the volume of water available due to rapid return flows.
Hydrological integrity if the headcuts proceeded unhindered through the affected area	9/10	A deeply incised channel will have a pronounced draining effect on the wetland. Lag deposits of cobbles, sand and other coarse material occur in the peat predispose the remaining sections of peat to drying out. Reduced surface-roughness associated with loss of palmiet will diminish the extent to which flows are slowed down in the wetland.
Geomorphic integrity before the advancement of the headcut through the affected area	6/10	Impacts on the geomorphic integrity of the wetland are significant due to the poor condition of Basin 2 further upstream. The extent of clastic sediment deposition will increase and may affect the vegetation and cause surface drying.
Geomorphic integrity after the advancement of the headcut through the affected area	8/10	A substantial loss of peat through direct erosion, drying out and oxidation is likely. Overall, the basin will be converted from an aggrading system to a system with a high net loss of sediment.
Vegetation integrity before the advancement of the headcut through the affected area	6/10	Approximately 50% of the area of the wetland is secured by a combination of wetland vegetation and kikuyu pasture, and the remaining 50% is poorly vegetated with a mixture of alien invasives and pioneer species.
Vegetation integrity after the advancement of the headcut through the affected area	9/10	Re-establishment of vegetation in the incised channel is very limited owing to the high scouring-velocities. Although palmiet will persist on the remaining peat, there is likely to be an invasion by terrestrial species, especially black wattle.

Score: 0 = completely natural (pristine), 10 = integrity completely lost

Table 17: Ecosystem services likely to be lost if the headcut erosion is allowed to progress through Basin 3

Ecosystem service	Score	Comment
Flood attenuation	**	Good at present. The incised gully will rapidly incise to bedrock because of the condition of the downstream channel. Roughness due to vegetation will be drastically reduced.
Streamflow regulation	**	Level of wetness (currently semi-permanent in central portion) will be reduced greatly as a result of the desiccating effect of the erosion gully
Sediment trapping	**	All sediment generated from Basin 2 is likely to be deposited here and then transported through to downstream areas
Phosphate assimilation	*	Afforded fairly limited opportunity for assimilating this solute
Nitrate assimilation	*	Afforded fairly limited opportunity for assimilating this solute
Toxicant assimilation	*	Afforded fairly limited opportunity for assimilating this solute
Erosion control	**	Considerable loss of peat through erosion
Carbon storage	*	Considerable loss of peat through erosion and oxidation
Biodiversity maintenance	**	Significant loss of habitat is anticipated given the decline in health. This has added significance given the high cumulative impact to which palmiet wetlands have already been subjected.
Water supply for human use	**	
Natural resources	#	Currently very limited use of natural resources takes place
Cultivated foods	**	Use as grazing by cattle on the floodplain will be lost
Cultural significance	#	Currently not used for this purpose
Tourism and recreation	#	Currently not used for this purpose
Education and research	#	Currently limited use for this purpose but has great potential. Information of climate changes trapped in peat will be lost

Score for Individual services (# = no significant loss anticipated; * = slight loss anticipated; ** = substantial loss anticipated).

5.4 Summary of ecosystem-service delivery and health

It seems clear that the erosion control structures have not only secured a number of wetland ecoservices and ensured a healthy condition in those areas where they were put in place, but that the neglect to repair them after the 2006 flood and maintain them in perpetuity might result in the loss of many ecoservices. Additional structures of a suitable nature should be considered in key points below C1 (Basin 3) and in the Jagersbos key point (Basin 2). However, the forces at play in these positions are considerable and it would be advisable to engage professional dam engineers to design such weirs.

6 Rehabilitation project costs

6.1 Costs of rehabilitation structures (2000 – 2005)

The annual cost of the wetland-rehabilitation measures that have taken place in the upper catchment (K90A) of the Kromme River valley, are detailed in Table 18. Table 19 gives a summary of the annual costs and provides an indication of the structures that were built using these funds.

Table 18: Annual costs of rehabilitation in the upper catchment of the Kromme River valley

	Budget items	Cost (R)	Percentage of budget
YEAR 1	**2000-2001**		
STRUCTURES	**Site A1-4: Rock gabions built to address gullies in upper catchment tributary of the Kromme River. Site B: Rock gabions (3 planned) to stabilize the headcut at the mouth of the upper peat basin threatening the entire basin. Site C: Rock gabion built to stabilize the second largest extant peat basin threatened by a headcut.**		
	Implementation fees		
	Transport	1 199	2.3
	Materials	10 176	19.7
	People costs (contractors, teams, consultants)	40 072	76.9
	Municipal & other services	187	0.63
	TOTAL	**51 634**	
YEAR 2	**2001-2002**		
STRUCTURES	**Sites A1- 4: Rock gabions (to be completed). Sites A5-8 - Kromdraai concrete weirs. Site B: Companjesdrift1 rock gabion to be completed. Site D: Hudsonvale rock gabion to be completed.**		
Person days 14800	Implementation fees GIB	77 827	3.3
No. people = 74	Transport	177 692	7.5
	Equipment costs (rental / purchase)	477 034	20.2
	Materials	167 592	7.1
	People costs (contractors, teams, consultants)	1 456 523	61.7
	Training	2 956	0.1
	TOTAL	**2 359 624**	**100**
YEAR 3	**2002-2003**		
STRUCTURES	**Sites A5-A7: Completion of 3 concrete structures on rock foundation started 2001. Completion of structure at Site C started in 2000.**		
	Implementation fees	84 663	4.7
	Transport	147 363	8.2
	Materials	270 806	15.0
	Equipment costs (rental / purchase)	372 235	20.6
	People costs (contractors, teams, consultants)	910 715	50.5
	Training	17 942	1.0
	TOTAL	**1 803 724**	**100**

11 WET - OutcomesEvaluate Part 2152 152 21/07/2009 08:28:35 PM

YEAR 4	**2003-2004**		
STRUCTURES	**Site B: Planning and construction of concrete/rock gabion structure B2 below the confluence with the Eerstedrifrivier.**		
	Implementation fees	90 754	8.4
	Transport	167 063	15.4
	Equipment costs (rental/purchase)	243 849	22.5
	Materials	149 948	13.8
	People costs (contractors, teams, consultants)	431 419	39.7
	Training	2 963	0.3
	TOTAL	**1 085 996**	
YEAR 5	**2004-2005**		
STRUCTURES	**Site B: Planning and construction of combined concrete and rock gabion B3, above the original rock gabion B1. The head cut had not stabilised adequately. Maintenance of B2 and C due to flood damage.**		
	Implementation fees	58 377	5.2
	Transport	160 062	14.1
	Materials, equipment costs	367 122	32.4
	People costs (contractors, teams, consultants)	529 179	46.8
	S&T	12 885	1.1
	Training	4 380	0.4
	TOTAL	**1 132 005**	
YEAR 6	**2005-2006**		
STRUCTURES	**Site D: Hendrikskraal 2 gabions in the wetland below gabion B2. (No details available)**		
YEAR 7	**2006-2007**		
STRUCUTRES	**Site E: One gabion to be constructed on the site of a much older broken weir on border of Hendrikskraal/Kammiesbos. (No details available)**		

Table 19: Annual costs of rehabilitation and structures built

YEAR	COST	A1-4	B1	C	A5-7	B2	B3	D	E
2000	51 634	X	X	X					
2001	2 359 624	X	X	X	X				
2002	1 803 724			X	X				
2003	1 085 996					X			
2004	1 132 005					X			
2005	Not available						X	X	
2006	Not available							X	X
Total	6 432 983								

6.2 Maintenance costs

Since 2003 each annual business plan for rehabilitation included cost items for maintenance. While it was not possible to separate the maintenance cost in the analyses of the accounts, Table 20 shows the estimated costs and maintenance measures proposed in each year. Maintenance was usually necessary due to flood damage or some aspect of the gabion structure showing weakness.

6.3 Earnings of emerging contractors

One stated aim of the WfWetlands programme is poverty alleviation. One of the ways this was achieved was through the use of emerging contractors who employ members of the local community as labourers. The income they derive as labour brokers is then distributed to their teams. The income distribution in terms of poverty alleviation for this project is summarised in Table 21.

Table 20: Maintenance of structures and estimated costs as included in each business plan

Year	Site/structure	Material requested	Estimated labour costs	Total estimated cost
2003	C (completion)	Gabions, rock, clay	R25 000	R45 560
2004	B2 Maintenance	Gabions, rock, clay, geotextile	R18 000	R48 294
2004	C1 Maintenance	Gabions, rock, clay, geotextile	R18 000	R42875

Table 21: Earnings of emerging contractors in rand (% of total annual personnel costs)

Year	Minor Contractors	Contractor 1	Contractor 2	Contractor 3	Contractor 4
2001-2002	143 688 (6.09%)	264 762 (11.22%)	256 736 (10.88%)	258 525 (10.95%)	86 013 (3.65%)
2002-2003	28 836 (2.18%)	196 349 (10.89%)	59 274 (3.29%)	236 817 (13.13%)	206 783 (11.46%)
2003-2004	23 629 (2.18%)		8 736 (0.8%)	172 485 (15.88%)	173 948 (16.01%)
2004-2005			46 051 (4.07%)	178 366 (15.76%)	161 048 (14.23%)

6.4 Cost-comparison of concrete and gabion weirs

There is an ongoing debate regarding the cost-effectiveness of concrete weirs compared to gabions. In the 2003-2004 year both types were constructed, which makes it possible to compare costs (Table 22). If both structures are of a similar size, it appears that rock gabions are less expensive to make as the materials cost less, but they may be less durable.

Table 22: Proportion of cost per structure for 2003-04

Structure type	Item	Cost (Rand)	% of annual cost
Rock gabion (Contractor 3)	Labour	198 954	18.3%
	Transport	46 516	4.3%
	Materials	49 339	4.5%
	Equipment hire	103 968	9.6%
	TOTAL	398 777	36.7%
Concrete weir (Contractor 4)	Labour	202 499	18.6%
	Transport	73 209	6.7%
	Materials	88 409	8.1%
	Equipment hire	119 584	11.0 %
	TOTAL	483 701	44.5%
		45 534	4.2%

7 Rehabilitation project procedures and benefits

7.1 Introduction

Wetland rehabilitation is a relatively new field in South Africa. In addition to environmental rehabilitation these projects also alleviate poverty and provide socio-economic benefits. This section presents research results that attempted to establish what participants had learnt from the rehabilitation process.

The rehabilitation team consisted of two groups of people, the expert consultants, on a part-time contract basis, and the implementation team, on a long-term contract basis (Tables 23 and 24). Members of the consulting team may be part of the implementation team or can be independent and contracted as needed. Members of the implementation team can be employed variously by the implementing agent or by the state through WfWetlands. The labourers are employed by the contractors according to a range of poverty-relief criteria.

Table 23: Rehabilitation team members in the Kromme River Valley Wetland Project

Consultant experts	Task
Environmentalists, GIS experts, computer modelers, biologist, geomorphologist	Siting of structures, wetland assessment, monitoring, serving on wetland forums
Engineer	Design structure, occasionally oversee construction, estimation of quantities
Machine operators	Excavation
Lawyer	Contracts, deal with legal problems
Doctor	Injuries and illness
Trainers	Provide life skills, health and safety and financial training
Implementation team	**Task**
WfWetlands staff, provincial coordinators, project managers	Plan and initiate rehabilitation provincially,oversee and monitor construction and completed structures, serve on wetland forums, report to national office
Gamtoos Irrigation Board (GIB)	Project management, technical supervisory and financial services for WfWetlands
Engineering technician, site managers	Order supplies & machinery, oversee construction, estimate quantities, train contractors
Financial manager	Billing and payments, order supplies
Building contractors	Oversee construction, engage and manage workers
Workers	Build structures on site

Table 24: Implementation team responsibilities and costing implications

Task	Responsibility	Account item
Coordination	GIB	Implementation costs
Financial management	GIB	Admin, implementation costs
Equipment rental	GIB	Diverse, equipment hire
Transport (materials)	GIB, suppliers,contractors	Consumable stores, transport
Transport (workers)	Contractors	Transport
Transport (management)	GIB	Transport private/hired
Supervision and training	GIB, WfWetlands	Implementation cost (salaries)
Salaries	GIB	Implementation costs, administration
Wages	Contractors	Emerging contractors
Construction	Contractors	Emerging contractors
Materials purchase	GIB	Consumable stores

A multipurpose questionnaire was used to obtain information on the project process and also the opinions of various participants with regard to the rehabilitation-project process. The positions of all the interviewees are presented in Table 25. The feedback from the interviews has been grouped under two headings (Project procedures and Project outcomes) and is presented as far as possible in a narrative style that both describes the project process and includes relevant comments made by individuals.

Note: The sections labelled *Additional Comment* are the opinion of the author, Lil Haigh.

7.2 Results of project procedure interviews.

7.2.1 Respondents to the questionnaire

Three main groups of respondents were interviewed: members of the management and planning team (named M1, M2 and M3), contractors (C1 and C2) and workers in the field (W1, W2, W3, W4 and W5), and landowners (L1) on whose land work was being undertaken.

7.2.2 Project planning

(a) Wetland assessment and rehabilitation prioritisation

The motivation for choosing the wetland system for rehabilitation in this particular study included the need to a) prevent further gully erosion and further size reduction of the peat basins, b) raise the water levels in the extant wetland, c) create silt traps to prevent further siltation of Churchill Dam, to ensure good quality water for human consumption. Further motivation included ensuring the security of wetland habitats and rare species. Once the wetland system had been chosen, within-system prioritisation of sites was guided by the health and size of the wetland, the size of the headcut and the possible influence of a large flood on the headcut.

There was general agreement that prioritisation should be done professionally, and that the use of prioritisation and assessment manuals such as the tools developed in the *WET-Management* series should be utilised.

Respondents were asked to rate the effects of various land use activities on the integrity and functioning of a wetland. Impacts were rated from 1-5, where 1 represented the lowest risk and 5 represented the highest risk. There was general agreement among respondents that roads and bridges (mean = 4.9), alien vegetation (4.1) especially in riparian zones, erosion gullies (3.8) and cultivation (3.5) were the main factors leading to wetland degradation. Grazing and excavation of drainage ditches were also mentioned as posing a great threat to wetland integrity.

(b) Design Selection

The designs that were selected were guided by technical input from various consultants and engineers.

(c) Communication Strategies and the Participatory Process

Communication during the project was by telephone, personal visits, brochures, circulars and workshops. Regular contact was made with civil servants in the relevant departments and with NGOs. Communication on organized field visits was encouraged, and proved to be a good method of keeping people up to date with progress of the project. WfWetlands advisory monthly meetings, which included community representatives, the implementing agent, landowners and municipal representatives from both the Nelson Mandela Metropole and the Kouga municipality, were used for feedback.

7.2.3 Project implementation

(a) Procedure for project planning

Meetings for the prioritisation of rehabilitation structures were held at Wetland Provincial Forum meetings where the catchments were prioritised according to set criteria. In the selected catchment site surveys, assessments and visits by technical staff (engineering, geomorphological and GIS mapping teams) were followed by drafting of plans and costing. Plans were forwarded to the WfWetlands head office for review and were then returned to provincial-forum meetings for acceptance.

(b) Construction team selection

Each month-long (20 days) contract quotation stipulated: transport and wage costs, equipment costs (protective clothing, tools), administration and profit margins. A contractor was responsible for the day-to-day planning and implementation of the construction to ensure that the correct amount of material on time, that time sheets were completed and correct site building procedures were observed. Each site had a worker who was trained as a health-and-safety officer.

C1's team had 5 men, 7 women and 7 youths (total = 19). C2's team started with 15 but was reduced to 12 due to financial constraints but it was felt that 15 would be better as the workload was high and there were always odd jobs to do around the site, such as cleaning. Concrete structures can be built at the rate of 3.5 tons per day on good weeks. Work can be interrupted and slowed down by weather and worker absenteeism as well as mechanical failures of equipment.

(c) Materials and equipment-use

Materials were sourced and provided by the implementing agent (M1) who followed the procurement procedures and policies of DWAF and WfWetlands. They generally tried to use previously-disadvantaged suppliers (M3). Specialist vehicles and equipment (wetland walking digger) were supplied by the implementing agent or by local builders. Every-one agreed that sourcing suitable packing stones for building gabions was difficult as they tried not to use stone from the river.

(d) Planning on-site management

The two contractors provided their perspective of the on-site planning process:

C1: Get the people together and discuss the project. Go to the site, then unpack the equipment, prepare the tent and place the toilet. Plan and clean the site. Clean trenches, prepare gabion baskets. At the start of the day give a 5 minutes report-back to the team. New teams have to have code of conduct spelt out to them.

C2: The run–up to the start of a project is always very short. It can be a matter of hours from being notified to be on site. The timing of project initiation is not always suited to an area where seasonal fruit picking is the main source of income. Many people would earn occasional income this way.

(e) Project implementation

The major constraints to the various phases of the project management was inconsistent funding streams which often did not take into consideration seasonal cycles and unexpected out of season floods.

(f) Data capture and management

A daily/weekly record sheet as well as notebooks and diaries were kept by both contractors on the project. The safety report was kept by the safety officer. The reports went to the GIB who processed the information. These reports then went to WfWetlands at SANBI and to DWAF. The information was stored at SANBI (M1).

> **Additional comment:** *There is no consistency in the information storage system. It proved very difficult to retrieve the information due to changes from one department to another and systems that changed. Hopefully the new web based submission system will improve matters.*

(g) Key constraints to implementation and solutions

In general, untimely and unexpected flooding was a major concern to all. These concerns were addressed through improved seasonal-planning (M3). At the outset of the project problems with unreliable contractors were experienced but these became less troublesome as the less-suitable people were sidelined.

Delays in financial streaming and payment, and lack of approval to start work (especially at the start to the project) were mentioned by all interview respondents as problems. For the project managers, the time allocated for budgeting and funding cycles were of concern, as delay in these caused bottlenecks. Delays in funding allocation were particularly unfair for the employees on these projects as most of them were extremely poor. It was mentioned (M1) that funding streams improved once WfWetlands moved from DWAF to SANBI and a business unit was created. However, the switch from DWAF to SANBI did cause some confusion as the financial manager had to learn the new systems and procedures.

7.2.4 Training and skills development

(a) Types of training

The entire management team received various forms of training. The training offered to each of these groups was tailored to the specific activities undertaken by each. Table 25 details the types of training offered.

(b) Evaluation of training by participants

The specialist training was deemed adequate to good, especially by the management team, but the general training provided to contractors and teams was considered to be adequate to poor. In general the education and training offered to the labourers was regarded as inadequate, inappropriate and with insufficient skills development to allow for increased future employment opportunities. The main reason given by GIB for these trends was the difficulty in finding trainers, and when the Department of Labour took over, the situation worsened as there were insufficient numbers of certified trainers.

The team workers and contractors expressed the need for small business skills training, personal finance, health counselling and computer skills. They also felt they should receive certification for skills acquired.

> **Additional comment:** *Opportunities for the raising of awareness of environmental issues were not fully utilised, in particular as two Environmental Education units in nearby tertiary institutions could have contributed to the process. I also feel that although the education and training offered to the project team (workers) was deemed to be generally useful it could have been enhanced with better supervision on the quality of the basic economic life-skills education, and the enhancement of health education to include dietary training. The area where education was truly lacking was in business and entrepreneurship development for project contractors.*

7.2.5 Monitoring and aftercare

(a) Plans, methods and implementation

The monitoring and aftercare, which was budgeted for, was the responsibility of WfWetlands and the implementing agent (GIB). Monitoring the structures was done by the provincial project technical advisor who contacted the implementer to discuss maintenance needs as they arose. The implementer then undertook the necessary maintenance work.

Currently, follow-up visits are undertaken by both the project implementing agent and the WfWetlands provincial manager, in particular to monitor the structures after each major flood event. Follow-up and monitoring includes rectifying and securing the gabion baskets after floods. Concrete slabs were often placed over gabion structures to prevent the baskets from breaking.

Table 25: Training undergone by the various groups involved in the construction of the rehabilitation structures

Type of training	Position of the trainee(s)
WfWetlands procedures	Managers
Structure design	Managers
Wetland values and function	Managers
Catchment processes	Managers
Gabion packing	Managers, contractors, field workers
Safety procedures	Managers, contractors. Specialist training was given to the safety officer. Aspects covered included protective clothing training, safety rules, site inspections, safety at the workplace. Assessment in the form of written tests.
Project Financial management	Managers
Personal Financial management	Managers, contractors and field workers
Health	Managers, contractors and field workers. Aspects covered included sexual disease education and disease control.
Life skills	Managers, contractors and field workers
Conflict resolution	Managers (some)
Other	Advanced Driving Courses, Vehicle Inspection Procedures, Site Management, Toolbox talks, Debriefing of teams

The revegetation of bare soil in the areas behind the gabions proved to be problematic as the irrigation infrastructure used after planting, to give the plants time to take root and establish, was stolen. As a result, the plants died and the affected areas did not revegetate as quickly as they should have.

(b) Data capture and documentation

> **Additional Comment:** *As far as I am aware no regulated photo monitoring process has been implemented. Photo monitoring points should be decided on and intervals for visits should be agreed on with special visits during and after flood events. A special database for storing this information should be instituted. Valuable information can be garnered from such a process especially if accompanied by on-line reports gathering some of the information mentioned above.*

7.3 Results of project outcome interviews

7.3.1 Social value of project

(a) Financial benefits

From the questionnaire it was clear that there was a general improvement in the lives of the contractors and their teams as they were able to purchase household equipment to make their lives easier and improve their social standing. More important they emphasised the ability to educate their children, including having the opportunity to send their children to better schools:

C1: *Education was made possible for a special-needs child, and another child went to a Model C school, which is an excellent investment.*

C1: *I purchased a new truck that has enabled me to trade and transport goods.*

(b) Other benefits

Being involved in the project proved to have benefits for the contractors and workers that extended beyond the project itself:

C2: *Enabled me to tender for private work. I can now read plans and plan and do a job on my own.*

W1: *I will now be able start my own spaza shop. Education: I got my safety certificates. I feel that I knew nothing when I left school. The project taught me about work, how to build gabions, what hard work means. I could now tackle anything and I know how to manage personal finances and budget better.*

W2: *Learnt how to make my own garden as I can handle a spade and fix my own fence and stuff around the house. Although I am the safety representative I have no certificates yet. I gained in terms of self esteem and confidence*.

W4: *Learnt to spend money responsibly and no longer dependant on parents.*

W5: *It changed my social life; I can keep my children at school and keep my family happy.*

(c) Key Lessons Learnt from the Project

> **Additional Comment:** *One contractor was fairly critical of the project management and procedures. It seems that he/she would have liked to be more involved in the earlier stages and in planning. It appears that there was poor communication between the GIB and the contractors during the off season; they felt out of the loop. It also appears that the exit strategy had not been communicated to contractors. Similarly some managers had no idea of the rehabilitation planning prioritisation, especially as GIB staff did not attend ECWF meetings.*

It appears that communication from project managers could be improved. Some managers appeared to be especially elusive, as they did not answer e-mails or return phone calls.

Overall, it appears that social improvement was significant. Individuals were promoted, workers became contractors and the Irrigation Board has subsequently employed some of the workers.

7.3.2 Environmental value of project

(a) Assessment of structures and the delivery of planned benefits

All planned rehabilitation measures were implemented. However it is still too early in the life of the programme to assess whether the structures have delivered the planned benefits.

In response to the question "*Did the rehabilitation measures achieve the intended outcomes?*":

M1: *In 80% of cases, yes. Where not, additional measures were implemented. Companjesdrift has proved the most problematic (B1, B2: Figure 12). Untimely floods caused sagging of the gabion B1 before the construction was completed. The lack of bedrock at a reasonable depth has caused subsidence of some structures. Adaptations to the plans included lowering the height of the gabion B1 to reduce water weight and then gradually build it up again as it stabilised in order to lift the water table. A second structure has since been put in upstream of the problematic one as the headcut had also not stabilised.*

C1: *Water storage and erosion control have been improved.*

C2: *Dubious about the stone-concrete combination weirs, the interface looks rather shaky.*

W1: *Yes, in my opinion the rehabilitation measures achieved their goal as the headcut has stabilised the erosion rate below the gabion. The key-point gabion has stopped silt movement downstream. I think the engineers learnt a lot from building these structures.*

Table 26 (opposite) is a summary of M1's evaluation of the design of the structures in terms of achieving certain stated objectives.

Complaints were received about a landowner's care of the wetland, particularly with respect to clearing vegetation along the perimeter of the wetland by bulldozer. The landowner explained that the stumps and roots of wattles that had been cut down on the edges of the wetland had caused hazards for his stock by trapping them. He was clearing these stumps when the WfWetlands helicopter observed the actions.

Problems were observed with the construction of the gabions, especially gabion B2. The gate from the tar road was often left open and cattle wandered onto the road, which is very serious.

L1: *It is hard to keep animals out of areas where there is good grazing unless the fences are very good.*

(b) Key environmental lessons learnt from the project

It appears one of the main lessons learned from the project is that a good understanding of the processes that underpin river and wetland structure and function should be well understood for effective structures to be built and for effective rehabilitation to take place.

Table 26: M1's evaluation of the design in terms of achieving the specified objectives

Structure	Atomics A1-4	Kromme River Farms A5-7	Companjes-drift B1	Key point at B2	Companjes-drift B3	Hudsonvale C
Aim						
Prevent further wetland reduction	Good	xx	Moderate	Moderate	xx	Excellent
Stop erosion gully	Excellent	Good	Initially poor after second structure improvement	Moderate	xx	Excellent
Create a silt trap	Excellent	Good	Good	Not flooded yet. Design problems fixed	Excellent	Excellent
Raise water level	Good	Excellent	Good	Unsure	Good	Good
Secure good quality water	Good	Unsure	Unsure	Unsure	unsure	Unsure
Secure wetland habitats	Unsure	Unsure	Excellent	Excellent	xx	Good
Bank stability	Good	Improved	Cattle trampling	Improved	Moderate	Cattle trampling
Species diversity	Not monitored	Not monitored	Not monitored	Not monitored	xx	Not monitored

xx = not relevant

Additional comment: For most structures it is still too early to assess the outcomes. M1 answered some of the questions again in 2007 and it is now clear that some of the expectations were not achieved

8 Conclusions and final assessment of the rehabilitation programme in the Kromme River valley

8.1 Introduction

In the course of the research of this rehabilitation project many discussions were held with project planners, implementers, workers and people with specialist expertise. Differing opinions have been heard on the wisdom of the project and the appropriateness of erosion-control structures. During the seven years of the project, the area experienced several floods of varying magnitude, which enabled first hand assessment of their effect on both the structures and the environment. Unfortunately, high quality data, such as accurate rainfall figures, were not available. Furthermore, accurate monitoring by fixed-point photography had not been instituted.

8.2 Approach to planning

The project started on an ad hoc "fix the worst problems first" basis which worked well initially but over time this approach was not ideal. The tools *WET-Prioritise* and *WET-RehabPlan* should be used extensively in future. Appropriate amelioration measures should only be considered once an accurate Digital Elevation Model of the catchment and wetland has been created, and the possible flow paths and forces operational during various levels of discharge events determined. Hydrological and hydraulic modelling in the case of large systems and costly interventions may also need to be considered.

It is generally advisable that a thorough analysis of the geohydrology of a catchment be undertaken before structures are designed and positioned.

Such an expert should either be on the staff of WfWetlands or on a register of service providers.

Observations indicate that the key to successful erosion control in Basin 1 lies at the site of structure B2, which is at a key point where discharge-forces are concentrated. This structure, if correctly designed and built, could act as a silt trap and reduce the force of the water, thus reducing the impact of the flood water downstream. The correct design and materials were clearly not selected given that the structure was severely damaged in 2007. The structure that was built acted as a silt trap behind the concrete instream section, and once it was full, water found an alternative route and the force simply pushed over the gabion sections. As a result the channel is now wider, having moved north, possibly leading to damage to the railway line.

Questions that will assist in further planning:

- What value does the water quantity and quality have to the end user, the Nelson Mandela Metropole?
- How much silt was deposited in the Churchill Dam during the last flood and to what degree has the volume of the storage dam decreased?
- Why did the gully and headcut at the top of Companjesdrift 1 slow down where it did, when the erosion had progressed easily through the S bend between 1986 and 1997?

Other questions about the approach to the project that remain are:

- How appropriate is the use of unskilled construction labour in a problematic situation where there are highly erodible soils? Given that the aim of the programme is one of poverty alleviation, which is largely affected through the upgrading of skills, should the focus not be on using more skilled people in the training programs?
- What research exists relating to successful interventions in similar situations in other parts of the world?

8.3 Summary effects of the floods in 2006 and 2007 and resultant recommendations

The following observations stem from surveys after the 2006 and 2007 floods. Some recommendations have also been made.

1. The structures at the bottom of Basin 1 (B1-B3) were not able to withstand the magnitude of the 2006 floods. The smaller flood in 2007 damaged some of the already weakened structures in different places. Two were badly damaged and one was destroyed. However, they did protect the basin above it (Basin 1) and below it (Basin 2) to a great degree.
2. Rehabilitation should take land-use practices into consideration. Measures appropriate for farming are not necessarily suited to measures for conservation areas. In this instance kikuyu protected the seasonal areas well against erosion and, although not indigenous, is a good pasture to grow in floodplains. Given that this area is primarily used for grazing, kikuyu is of more value to the land users than palmiet. However, *kikuyu* failed to protect the wetland at the edge of the field in the Witels confluence area on Hudsonvale. Here a bank of palmiet might have given better protection.
3. If palmiet is given the correct growing conditions it is able to withstand significant flood events, as seen in Basin 1. Large areas of palmiet planted below and around the structures where the water table is high enough could be the most appropriate vegetation adjunct to erosion control structures.

The question of what are appropriate species for rehabilitation in this area remains to be answered (see the section on bioengineering in *WET-Methods*). At Companjesdrift, planting of wetland species was attempted but did not succeed.

4. The contrast in the environmental conditions between the three basins is marked. Table 27 highlights the main differences between them in terms of wetland vegetation, catchment cover and surface condition prior to the flood. A range of other factors have a bearing on the present state of the three basins; their position in the valley, the size of the tributaries feeding into them and the resultant discharge and variation in discharge. Discharge is of particular importance. Given that there are six structures above the Eerstedrif River tributary catchment, which is a large tributary, and only three below it, it is hardly surprising that Basin 2 suffered much damage. In addition, the pre-flood state of vegetation cover of the floodplains was different. In Basin 2 the vegetation cover was poor and the amount of agriculture on the floodplains was considerable, especially at Jagersbos, where several orchards were being replanted at the time of the flood. In contrast, the damage seen in Basins 1and 3 was relatively low.
5. In designing structures a 1:50 year flood return period is preferable to a 1:20 year return period in steep narrow catchments.
6. In construction, gabion packing of the highest quality is essential in areas where topography and climate conspire to produce flash floods. The longest possible sidewalls and key walls for the amount of funding available are advisable.
7. With respect to land management in the Working for Water programme, ecologists and geomorphologists that visited the area felt that the Working for Water approach to alien clearing in floodplains should be changed. Debris of cut wood and especially tree trunks should not be left on site despite the increased costs that will be incurred to remove and stack them elsewhere. Debris dams that form during flood events are hazards to people and infrastructure, and the power of the water, silt and debris combined increases the level of devastation in downstream areas when a debris dam breaks.
8. The people involved in project management who were interviewed were generally pleased to have been involved with the work, and all experienced positive personal outcomes from their involvement. However, from an external observer's perspective the lack of training and further qualifications achieved by the contractors were somewhat problematic. If the programme is to have long-term upliftment effects, the downtime between periods of intensive work should be used for certified training. Contact should be made with accredited educational institutions and suitable local service providers to ensure that training is available.

Table 27: Summary of the environmental condition in the three sedimentary basins and the post flood outcome.

	BASIN 1	BASIN 2	BASIN 3
Feature/ structure	**Condition**	**Condition**	**Condition**
Wetland vegetation	Healthy, dense. Riparian vegetation patchy but generally good.	Largely destroyed. Riparian vegetation sparse.	Poor to good. Riparian vegetation destroyed in places. Good kikuyu pasture above the structure.
Catchment cover	Excellent to good. Upper catchment comprises dense indigenous vegetation, orchards and grazing in stable state.	Mediocre to sparse. Some fields in the floodplain were unvegetated. Orchards in the floodplain were being replaced, leaving bare soil. River banks unstable.	Mediocre to sparse. Fields on floodplain and marsh areas in bottom half of the basin were well vegetated.
Micro-topography	Relatively flat	Sheet and gully erosion on the valley bottom. Berms across floodplain.	Sheet erosion in places and bare soil. Berms across floodplain.
Rehabilitation structure location	Six in place, 3 above and 3 below large wetland with 1 in the key point.	Two in the very top of the basin.	One above key point at the toe of the basin.
Structure condition post flood	Three above slightly damaged, 3 below largely destroyed.	Mediocre, needs rehabilitation.	Slightly damaged and needs attention.
Environmental condition post flood	Good	Poor. Has lost the largest degree of ecoservices.	Good to mediocre. Ecoservices slightly reduced.
Threat	Threat level increased	Threat level has always been high	Threat level remains medium

9. Bibliography

Historical research references

Cape Archives. Receiver of Land Revenue Folios (handwritten records of grazing permits, rents etc).

Cape Colony General Directory (Eastern Province), 1876, 1878, 1900.

Cape of Good Hope Almanac, 1858.

Cape of Good Hope, 1895. Topographical Map of the Colony of the Cape of Good Hope and neighbouring territories compiled from the best available information [Map] / Stanford's Geographical Establishment London : Stanford's Geographical Establishment, 1895 1 sheet

Cullinan P, 1992. Gordon, Robert J. 1743-794. *The man and his travels at the Cape.* Struik, Cape Town

Eastern Cape Directory Almanac, 1848, 1849, 1862.

Eastern Province Yearbook, 1862.

Forbes VS, 1965. *Pioneer travellers in South Africa: a geographical commentary upon routes, records, observations and opinions of travellers at the Cape, 1750-1800.* Balkema, Netherlands.

Goldblatt R, 1984. *Postmarks of the Cape of Good Hope.* Reijger Publishers (Pty.) Ltd., Cape Town.

Le Valliant F, 1790. 1753-1824. *Travels from the Cape of Good Hope, into the interior parts of Africa including many interesting anecdotes.* Translated by E. Helme, William Lane, London.

Moir SM, 1963. *Twenty-four inches apart.* The Oakwood Press.

Noble J, 1886. *Official handbook of the Cape of Good Hope, its history productions and resources.* Juta, Cape Town.

Scott JB, 1968. *The Eastern Cape 1700 to 1800. A General Survey.* Theses in fulfilment for the degree of Magister Artium, University of Port Elizabeth.

Sellick WSJ, 1904. *Uitenhage past and present. Souvenir of the centenary 1804-1904.* Uitenhage Times, Cape Colony.

Theal GM, 1905. *Records of the Cape Colony, Vols. I-V,* Cape Town 1897-1899

Thompson G, 1967. *Travels and adventures in southern Africa (1796-1889).* VS Forbes (ed and notes), Van Riebeeck Society, Cape Town.

Thunberg CP, 1986. *Travels at the Cape of Good Hope 1772-1775:* Edited by VS Forbes. Translated from Swedish, revised by J & I Rudner. Van Riebeeck Society, Cape Town.

Van der Merwe PJ, 1938. *Die trekboere in die Geskiedenis van die Kaapkolonie (1675-1842).* Nationale Pers Bpk., Kaapstad.

General references

Bergh JS and Visagie JC, 1985. *The Eastern Cape frontier zone, 1660-1980: a cartographic guide for historical research*. Butterworth, Durban.

Bullock A and Acreman M, 2003. The role of wetlands in the hydrological cycle. *Hydrology and Earth System Sciences*, 7(3): 358-389.

Coastal and Environmental Services, 2005. *Kromme/ Seekoei Catchments Reserve Determination Study - Technical Component.* EWR Report. Prepared for Department of Water Affairs and Forestry, South Africa. Report No. RDMEWR001/RR004/CON/ CES/1105

Department of Water Affairs and Forestry, 2005. *A practical field procedure for the identification and delineation of wetlands and riparian areas*. Edition 1. Department of Water Affairs and Forestry, Pretoria.

Gomi T, Sidl RC and Richardson JS, 2002. Understanding processes and downstream linkages of headwater systems. *BioScience,* 52(10): 905-916.

Haigh EH, Grundling P-L and Illgner PM, 2002. *Report on the scoping study on the status of the Kromme River peatland complex and recommended mitigatory measures.* Department of Water Affairs and Forestry, Project X832633.

Johnson MR, 1976. *Stratigraphy and Sedimentology of the Cape and Karoo Sequences in the Eastern Cape Province.* PhD thesis, Rhodes University.

Kotze DC, Marneweck GC, Batchelor AL, Lindley DS and Collins NB, 2009. *WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands.* WRC Report No. TT 339/09. Water Research Commission, Pretoria.

Kotze DC, Breen CM, Nxele IZ and Kareko J, 2009. *WET-ManagementReview: The impact of natural resource management programmes on wetlands in South Africa.* WRC Report No. TT 335/09. Water Research Commission, Pretoria.

Kotze DC, Ellery WN, Rountree M, Grenfell MC, Marneweck G, Nxele IZ, Breen DC, Dini J, Batchelor AL and Sieben,E, 2009. *WET-RehabPlan: Guidelines for planning wetland rehabilitation in South Africa.* WRC Report No. TT 336/09. Water Research Commission, Pretoria.

Macfarlane DM, Kotze DC, Ellery WN, Walters D, Koopman V, Goodman P and Goge MC, 2009. *WET-Health: A technique for rapidly assessing wetland health.* WRC Report No. TT 340/09. Water Research Commission, Pretoria.

Macvicar CN, Loxton RF, Lambrechts JJN, LeRoux J, DeVilliers JM, Verster E, Merryweather FR, Van Rooyen TH, and Harmse H, 1977. *Soil Classification: a binomial system for South Africa.* The Soil and Irrigation Research Institute, Dept of Agricultural Technical Services, Pretoria South Africa.

McCarthy TS and Rubidge B, 2005. *The story of earth and life. A southern African perspective on a 4.6-billion-year journey. Struik Publishers, Cape Town.*

Meyer JL, Kaplan LA, Newbold D, Strayer DL, Woltemade CJ, Zedler JB, Beilfuss R, Carpenter Q, Semlitsch R, Watzin MC and Zedler PH, undated. *Where rivers are born: the scientific imperative for defending small streams and wetlands.* Fact sheet. Sierra Club and American Rivers.

Midgley DC, Pitman WV and Middleton BJ, 1994. *Surface water resources of South Africa.* WRC Report 298/4.1/94 Appendices; Vol. VI.

Nsor CA, 2008. *Assessment of current plant species diversity and threats to the peat basins of the Kromme River Catchment, Eastern Cape Province of South Africa.* Masters Thesis: Rhodes University.

Ramsar Convention Secretariat, 2004a. *Designating Ramsar sites. Handbook 7*. 2nd Edition. Ramsar handbooks for the wise use of wetlands. Ramsar Convention Secretariat, Gland, Switzerland.) (see http://www.ramsar.org/).

Ramsar Convention Secretariat, 2004b. *Managing wetlands. Handbook 8.* 2nd Edition. Ramsar handbooks for the wise use of wetlands. Ramsar Convention Secretariat, Gland, Switzerland.) (see http://www.ramsar.org/).

Ramsar Convention Secretariat, 2004c. *Wise use of wetlands. Handbook 1.* 2nd Edition. Ramsar handbooks for the wise use of wetlands. Ramsar Convention Secretariat, Gland, Switzerland.) (see http://www.ramsar.org/).

Russel WB 2009. *WET-RehabMethods: National guidelines and methods for wetland rehabilitation.* WRC Report No. TT 341/09. Water Research Commission, Pretoria.

Rountree MW, Thompson M, Kotze DC, Batchelor AL, and Marneweck GC, 2009. *WET-Prioritise: Guidelines for prioritising wetlands at national, regional and local scales.* WRC Report No. TT 337/09. Water Research Commission, Pretoria.

Semlitsch RD, 2000. Size does matter: the value of small isolated wetlands. *National Wetlands Newsletter*, January-February, 5-13.

Toerien DK and Hill RS, 1989. *The Geology of the Port Elizabeth Area.* Government Printer. Pretoria

Part 5:

An assessment of the effect of rehabilitation interventions on the health of Dartmoor Vlei, KwaZulu-Natal Midlands

DC Kotze, WN Ellery, B Patrick and O Bambus

1 Introduction

Dartmoor Vlei, in the Karkloof, KwaZulu-Natal, had been impacted upon by artificial drainage channels dug several decades ago. Rehabilitation interventions were undertaken by Eastern Wetlands on behalf of Working for Wetlands in 2004 and early 2005. These interventions consisted primarily of nine concrete weirs (Figure 1) that act as plugs in the drains and reduce the loss of water from the wetland, and the excavation of spreader channels extending from immediately upstream of five of the plugs. The spreader canals act to spread water over the wetland and promote diffuse flow.

This study aimed to evaluate the effectiveness of rehabilitation interventions in the Dartmoor Vlei by investigating the effectiveness of individual structures in raising the water table and promoting diffuse flow, and then to develop a procedure for evaluating the cumulative effect of all of the structures for the wetland as a whole.

The intention here was not to evaluate outputs and their survival, as this is something that Working for Wetlands does very well. Therefore, no attempt was made here to evaluate whether the structures themselves are intact or not. Our intention was to evaluate outcomes of rehabilitation interventions in terms of wetland health. An evaluation of the outcomes at Dartmoor in terms of ecosystem services is given as an example in Cowden and Kotze (2009).

2 Methods

2.1 Assessing the effectiveness of individual structures

In order to appraise the effectiveness of individual structures, two typical structures (structures 7 and 9; Figure 1) were chosen in the Dartmoor Vlei. A series of auger holes was excavated upstream and downstream of the structures (weirs), and the elevation of each hole was measured using a dumpy level and staff. This provided information such that a number of cross-sectional and longitudinal profiles could be plotted showing the elevation of the channel bed, banks, surface water and groundwater. The location of the weirs was also plotted.

2.2 Assessing overall effectiveness of rehabilitation interventions

Wet-Health (MacFarlane *et al*., 2009) was used as a basis for assessing the hydrological, geomorphological and vegetation health of Dartmoor Vlei under three scenarios:

- pre-rehabilitation health (based on the inherent biophysical characteristics of the wetland, interpretation of aerial photographs, interviews with local informants, and previous visits to the wetland prior to rehabilitation),
- post-rehabilitation health based on visits during the wet and dry seasons of 2005, and
- post-rehabilitation health following the predicted outcomes of further minor rehabilitation interventions that are recommended on the basis of this study as follows:

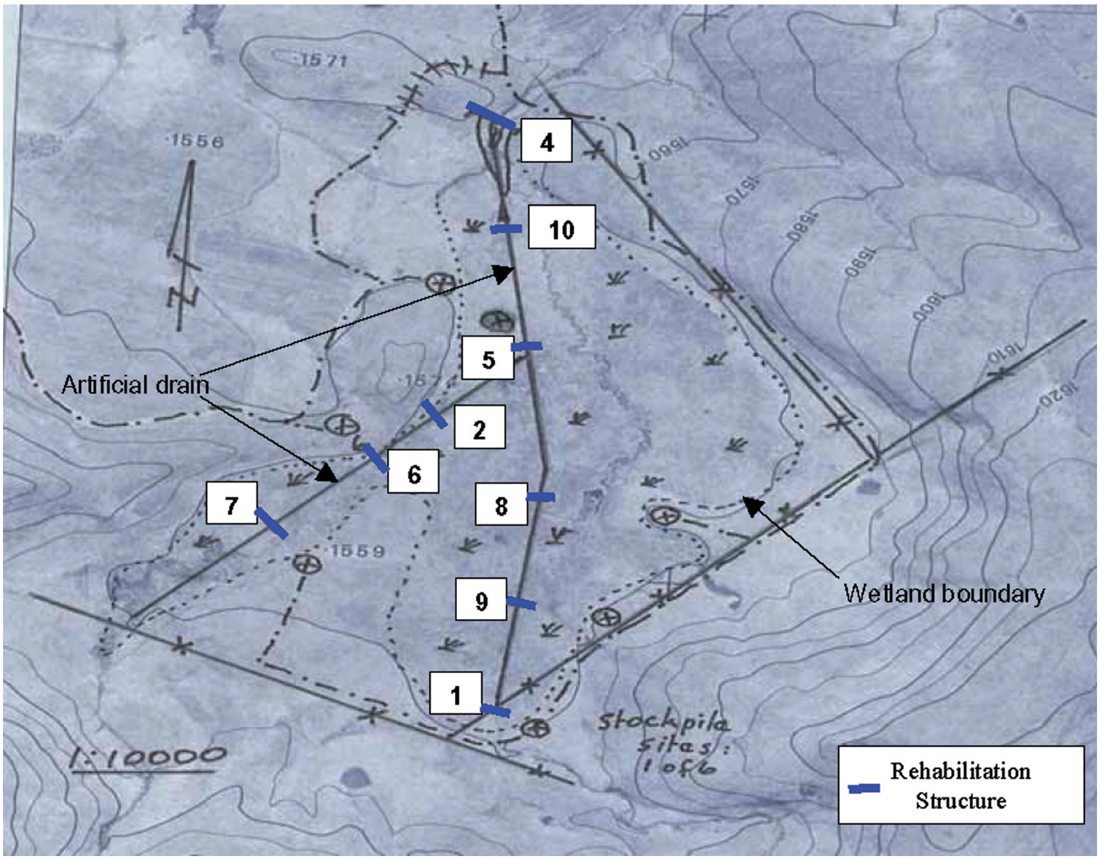


Figure 1: Dartmoor Vlei showing the location of artificial drains and rehabilitation structures

- Modify existing structures 6 and 9, which are strategically placed, so as to much more effectively spread low flows from these structures (at the time of the assessment in 2005, two of the eight plugs effectively spread low flows out of the drainage channels).
- Stabilise the toes of those structures that are being undermined.
- Include additional structure/s in the section of channel between structures 4 and 5, so as to stabilize this section against erosion through the creation of a head of water to act as a 'water cushion' in the channel.
- Clear the American bramble (*Rubus cunneifolius*) from the wetland.

3 Results

3.1 Assessing the effectiveness of individual structures

3.1.1 Weir 7

The right bank in the vicinity of weir 7 has a slope of approximately 0.45% (Figure 2), the left bank has a slope of approximately 0.46% (Figure 3), while the bed of the channel has a slope of 0.54%. Thus, the slope of the bed of the channel is steeper than the banks, suggesting that ongoing erosion of the bed of the channel is likely to occur since the slope of the bed of the channel is typically lower than that of the bank.

In the case of weir 7, the elevation of surface water in the channel is horizontal upstream of the weir, and drops a height of approximately 0.8m across the weir

(Figure 2 and 3). Below the weir, the water surface is just above the bed of the channel over a distance of approximately 80m, at which point the effect of the next weir downstream is evident as the water surface in the channel again becomes horizontal despite the channel bed continuing to slope down the valley. This is a consequence of the damming effect of the next weir downstream.

The elevation of the water surface in the channel above the weir is slightly lower than the elevation of the land surface at the location of the weir, as a consequence of the elevation of the spillway (Figures 2 and 3). This reflects the purpose of the weir design, to promote lateral flow of water along spreader canals located upstream of the weir and oriented at a high angle (close to 90° to the channel). The orientation of these spreader canals is slightly down the valley in order to facilitate movement of water into the wetland, where it can flow as diffuse flow through the wetland downstream of the weir.

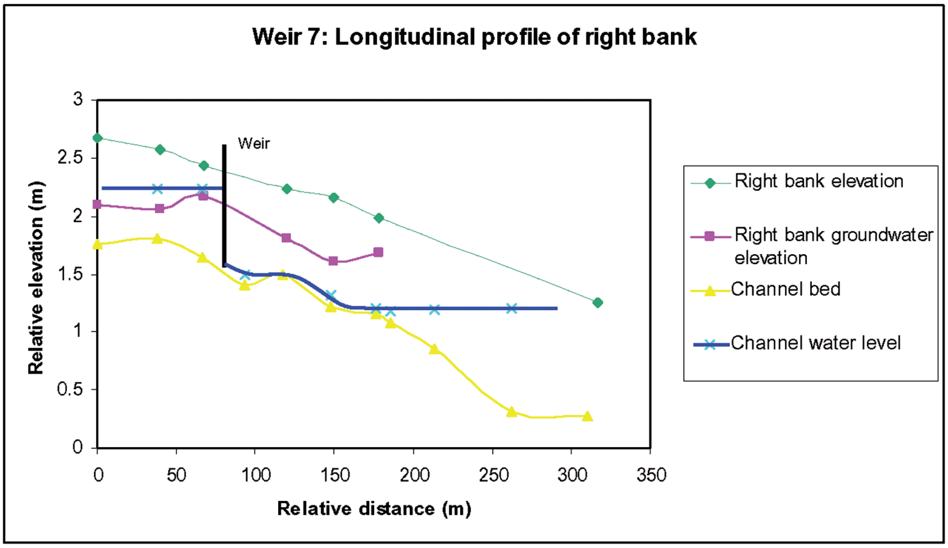


Figure 2: Longitudinal profile of the right bank and channel bed of Weir 7, Dartmoor Vlei

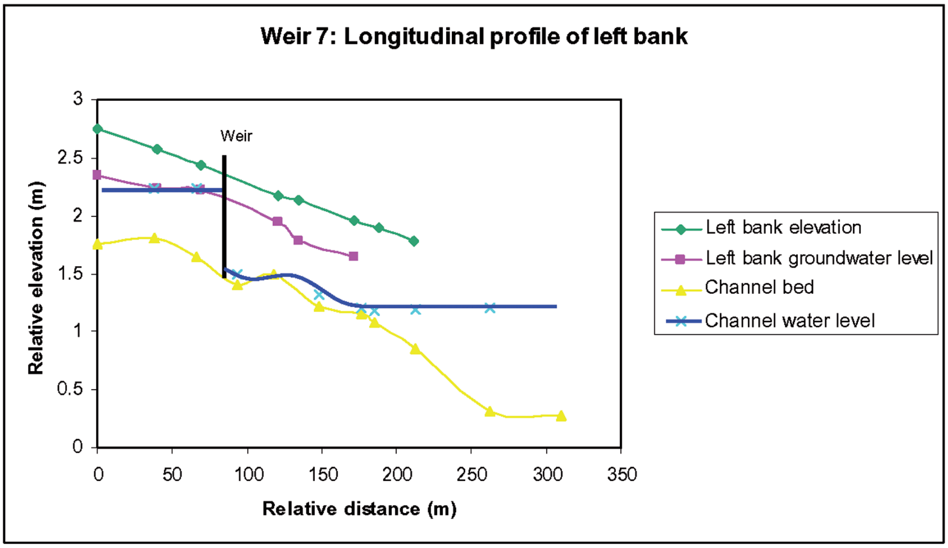
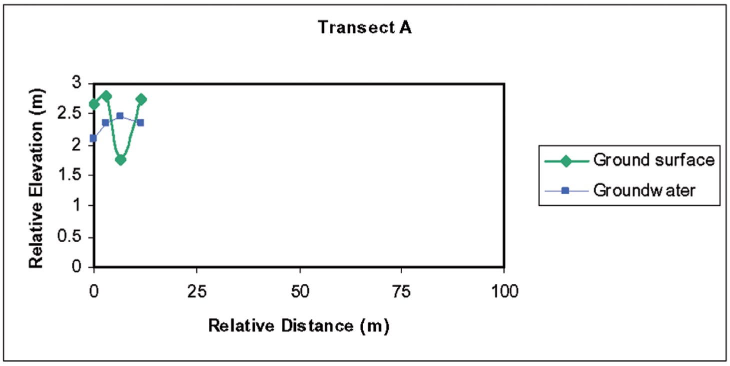
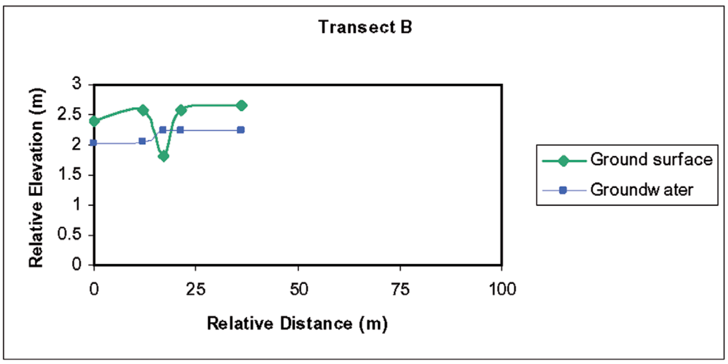


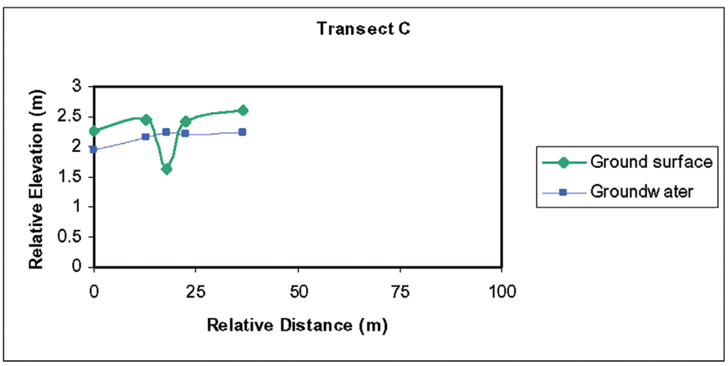
Figure 3: Longitudinal profile of the left bank and channel bed of Weir 7, Dartmoor Vlei

The elevation of the water surface in the channel above the weir is higher than the surrounding groundwater on either side of the channel (Figure 4: Transects A, B and C), suggesting that the weir is effectively raising the elevation of surface water in the channel, which sustains groundwater recharge upstream of the weir. However, immediately downstream of the weir, the reverse applies as the elevation of surface water in the channel is lower than in the surrounding wetland (Figure 4: Transects D, E and F). Thus, below the weir there is groundwater discharge from the wetland into the channel until the damming effect of the next weir downstream becomes effective.

Since the purpose of the structure was to raise the water table and promote diffuse flow of water through the wetland, it is clear that this is being achieved to a large extent above the weirs where there is clear evidence of groundwater recharge from the channel. However, this is not happening below the weirs where there is groundwater discharge into the channel from the surrounding wetland.







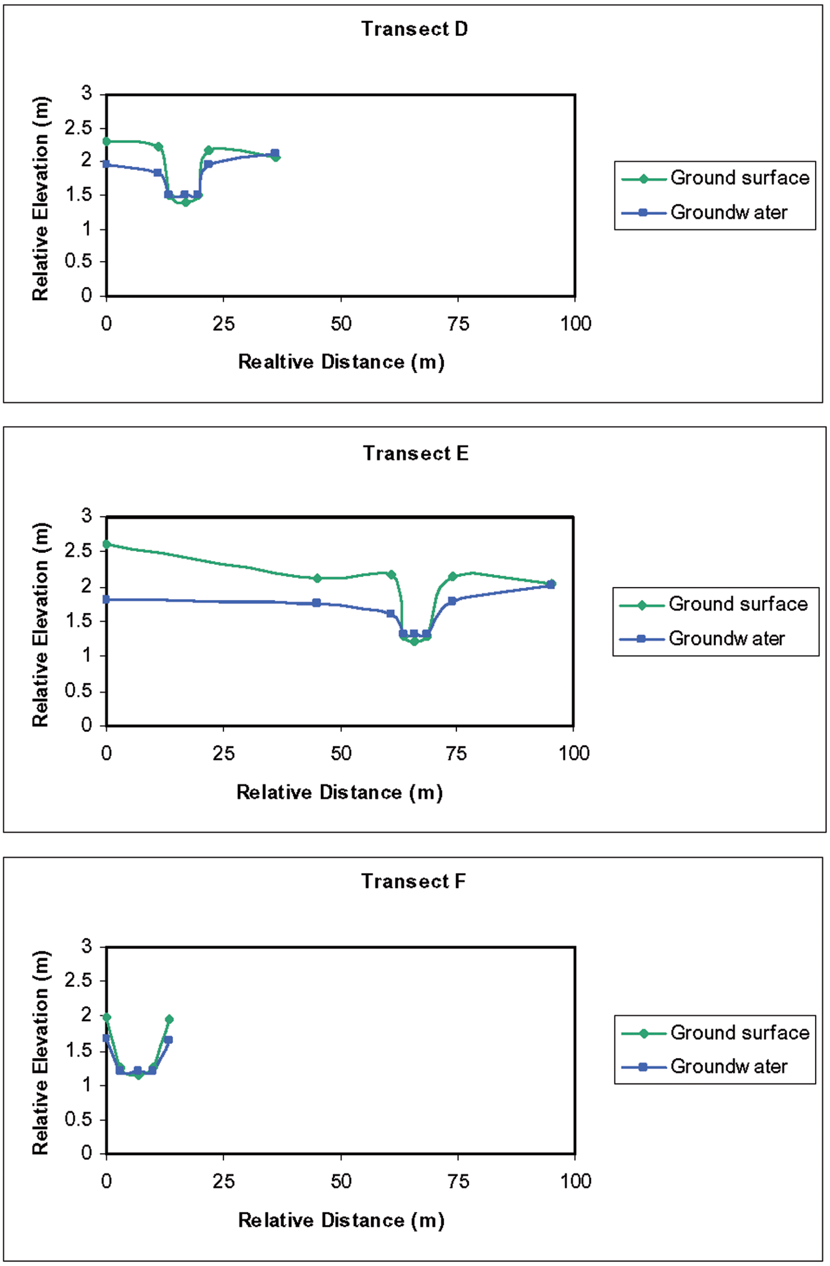


Figure 4: Cross-sectional profiles across the channel upstream (Transects A, B, C) and downstream (Transects D, E, F) of weir 7, Dartmoor Vlei.

3.1.2 Weir 9

The results for weir 9 are very similar to those for weir 7. The right bank in the vicinity of weir 9 has a slope of approximately 0.47% (Figure 5), the left bank has a slope of approximately 0.51% (Figure 6), while the bed of the channel has a slope of 0.36%. Thus, the slope of the bed of the channel is lower than that of the bank, suggesting that the channel bed is likely to be stable (non-erosional).

The elevation of the surface water in the channel is horizontal upstream of weir 9, and drops across the weir a height of approximately 0.6m (Figures 5 and 6).

Below the weir, the water surface is also horizontal due to the damming effect of the next weir downstream, despite the channel bed continuing to slope down the valley.

The elevation of the water surface in the channel above the weir once again reaches an elevation close to the land surface on both the right and left banks (Figures 5 and 6), which again reflects the purpose of the design of the weir to promote lateral movement of water along spreader canals upstream of the weir. The spreader canals are oriented to promote movement of water into the wetland, where it can flow as diffuse flow.

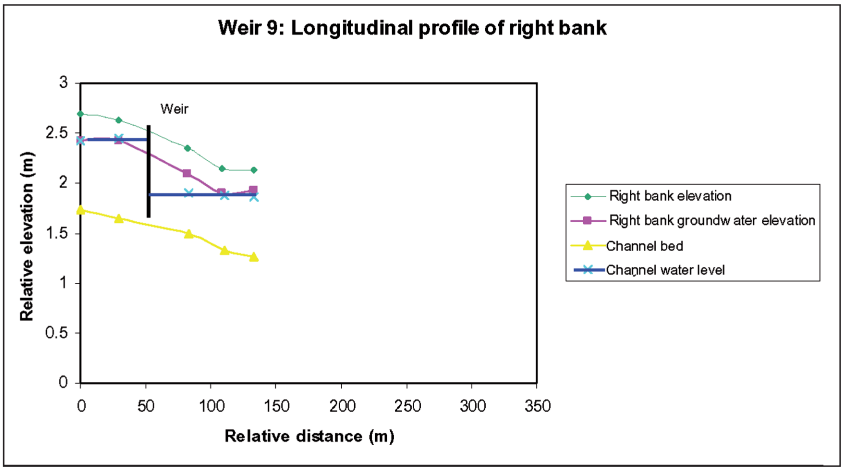


Figure 5: Longitudinal profile of the right bank and channel bed of weir 9, Dartmoor Vlei

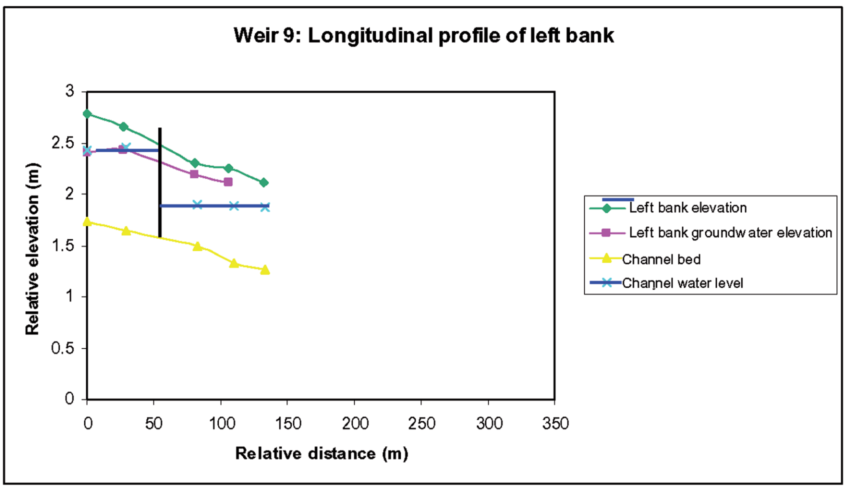
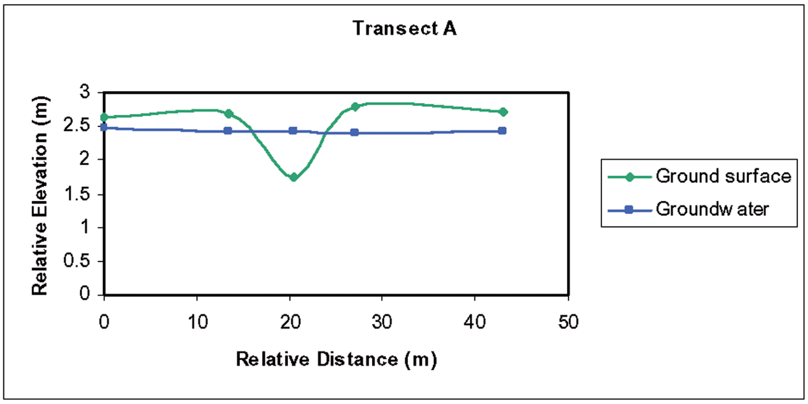
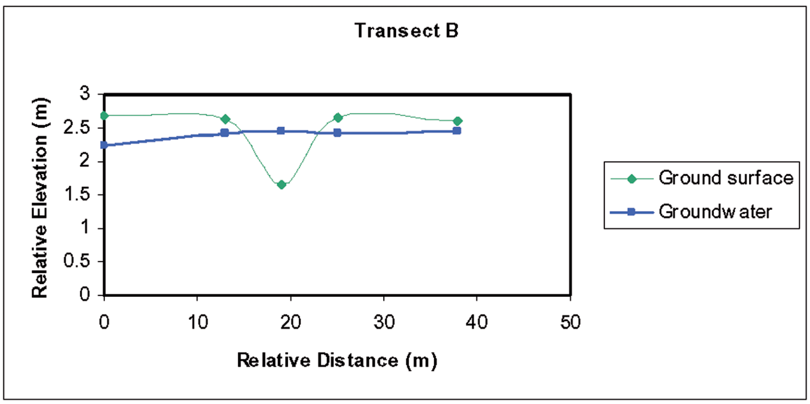


Figure 6: Longitudinal profile of the left bank and channel bed of weir 9, Dartmoor Vlei

The elevation of the water surface in the channel above the weir is at a slightly higher elevation than the surrounding groundwater on either side of the channel (Figure 7; Transects A and B) suggesting that the weir is effectively raising the elevation of surface water in the channel, which sustains groundwater recharge upstream of the weir. However, immediately downstream of the weir, the reverse applies as the elevation of surface water in the channel is lower than in the surrounding wetland Figure 7: Transects D and E). Thus, below the weir there is groundwater discharge from the wetland into the channel until the damming effect of the next weir downstream becomes effective.

Since the objectives of the rehabilitation were to raise the water table and promote diffuse flow of water through the wetland, the data once again demonstrates this is happening upstream of each structure. However, below the structure there is groundwater discharge from the wetland into the channel.





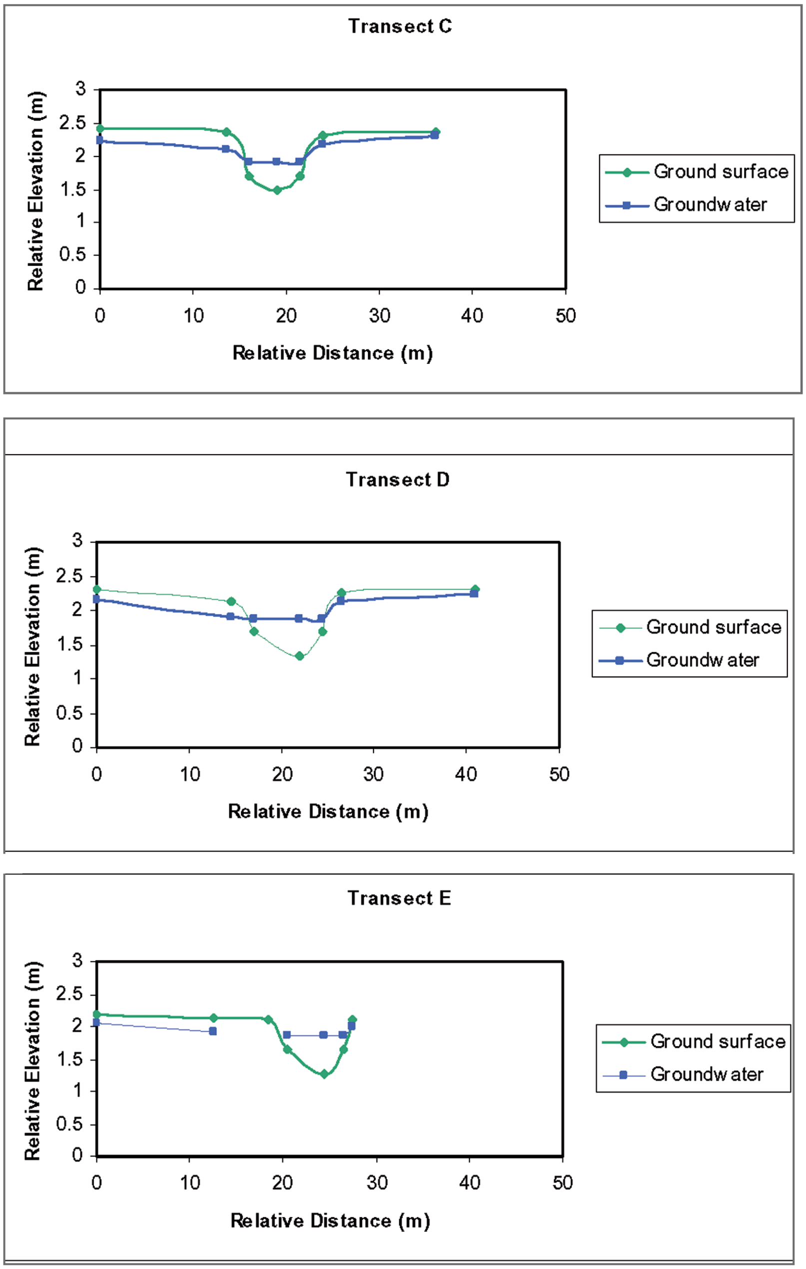


Figure 7: Cross-sectional profiles across the channel upstream (Transects A and B) and downstream (Transects C, D, E) of weir 9, Dartmoor Vlei

3.1.3 Discussion of the effectiveness of individual structures

Prior to any rehabilitation intervention the drains would have readily moved water from the wetland downstream into the stream into which the wetland ultimately discharges. This is simply due to the hydraulic efficiency of the drains, which move water downslope at 2-3 orders of magnitude faster than would be the case for diffuse flow of surface water within the wetland. Given this hydraulic efficiency of the drains, surface water would have entered the drain as it encountered the drain on its passage down the valley. Nevertheless, due to the orientation of the drains along the main hydraulic slope, little surface water would have entered the drain. The greater effect of the drain on wetland water supply is typically caused by localized lowering of the water table, leading to the flow of groundwater into the drain – as can be seen below each of the weirs where the elevation of the water table is higher than that of the surface water in the drain. Since water moves downslope, it can be expected to flow into the drainage ditches and out of the wetland.

The rate of water flow (velocity and discharge) from the wetland into the drain will be affected primarily by the hydraulic slope on the water table surface and the hydraulic conductivity of the soils. Based upon a brief investigation of the hydraulic properties of the soils, it appears that they have very low hydraulic conductivities, such that the velocity of water flow through the soil is likely to be very low. Therefore, we anticipate that the impact of the drains on wetland water supply is not particularly great – as indicated by the high health of vegetation in the wetland – even in close proximity of the drains.

These insights allow us to evaluate the effectiveness of each structure (weir) in improving the hydrological health of the wetland. It is clear that the structures prevent the rapid drainage of some water from the wetland, thereby increasing the residence time of water in the wetland. Furthermore, they promote recharge of groundwater upstream of each structure, possibly lifting the elevation of the water table downstream of the structure to some extent.

Although each weir is likely to promote increased wetness locally, together they are likely to reinstate considerable hydrological health to the wetland. The next section attempts to assess the effectiveness of all of the structures for the Dartmoor Vlei as a whole.

3.2. Assessing the effectiveness of all rehabilitation interventions at Dartmoor Vlei

3.2.1 Hydrological health

The effect of catchment activities on hydrological input timing and volume to Dartmoor Vlei is negligible. Almost the entire catchment of the wetland is under natural vegetation in moderate to good condition. There is no abstraction and there are no tree plantations in the wetland's catchment and only one small dam is present. The principle hydrological impacts in the wetland are from two major artificial drainage channels running through the wetland. A comparison of Figures 2 with 3 and Figures 5 with 6 show that the principle effect of the artificial channels has been to reduce water retention and the spread of flow in the wetland.

Prior to the creation of the artificial drainage canals there were essentially eight different flow supplies to Dartmoor Vlei, four of which supplied diffuse flow (Inputs C, F, G and H; Figure 8), and four of which supplied direct flow through stream channels (Inputs A, B, D and E; Figure 8). As a result of the artificial canals, input A continues along its natural course for a short distance through the wetland before being captured by an artificial drainage channel (Figure 9). Input B and Inputs D and E, which provide the greatest volumes, are captured almost immediately after they enter the wetland. In contrast, Inputs C, F, G and H, continue to supply the wetland largely without disruption and through diffuse flow, although their supply volumes are relatively low when compared with Inputs B, D and E.

Figure 10 shows the distribution and intensity of impact resulting from the drainage channels. It can be seen that prior to rehabilitation, 40% of the wetland has been subject to a large intensity of impact and a further 20% to a moderate intensity of impact (i.e. a total of 60% had been impacted), and the remaining 40% of the wetland was largely unaffected by the artificial drains. The effect of the rehabilitation interventions has been to lower the magnitude of impact on the wetland. In the 2005, post-rehabilitation situation, areas subject to large impacts have been improved, those areas subject to moderate impacts were 30% in extent, those areas close to natural 30%, with areas largely unaffected remaining at 40%. These percentage areas are used to determine the extent of the impact from artificial drainage on hydrological conditions of the wetland. Table 1 is a pre-rehabilitation analysis of the area subject to impact from the drains, Table 2 provides a description of the derived impact scores and Table 3 is an assessment of this area post-rehabilitation. These three tables are from chapter 2 in *WET-Health* (Macfarlane *et al*., 2009), which focuses on hydrology.

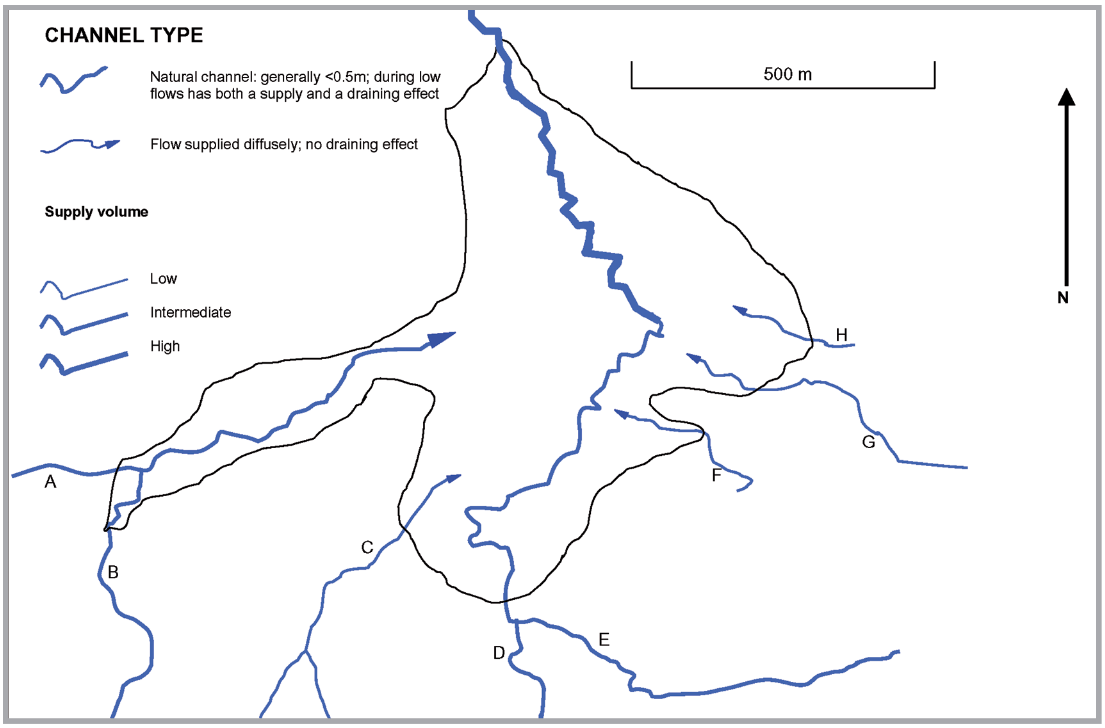


Figure 8: The natural flow pattern in Dartmoor Vlei prior to artificial drainage

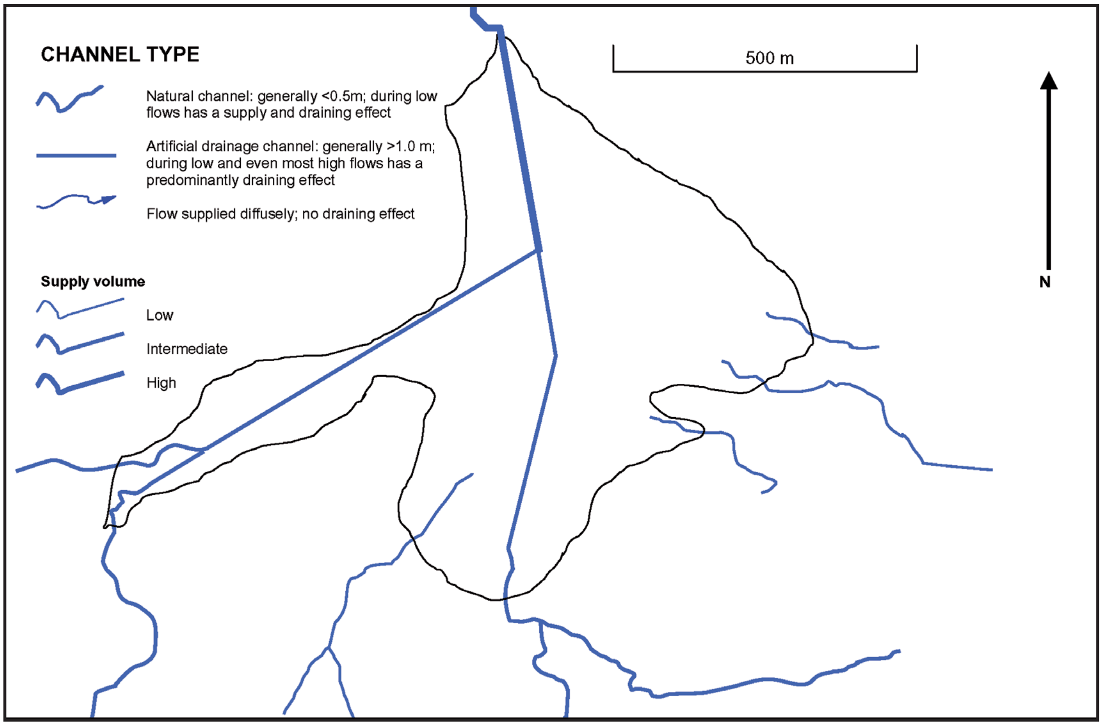


Figure 9: The flow pattern in Dartmoor Vlei following artificial drainage and prior to rehabilitation

Health classes
Unmodified, natural
Close to natural with few modifications
Moderately modified
Largely modified
Extensive loss of habitat and function
Critical

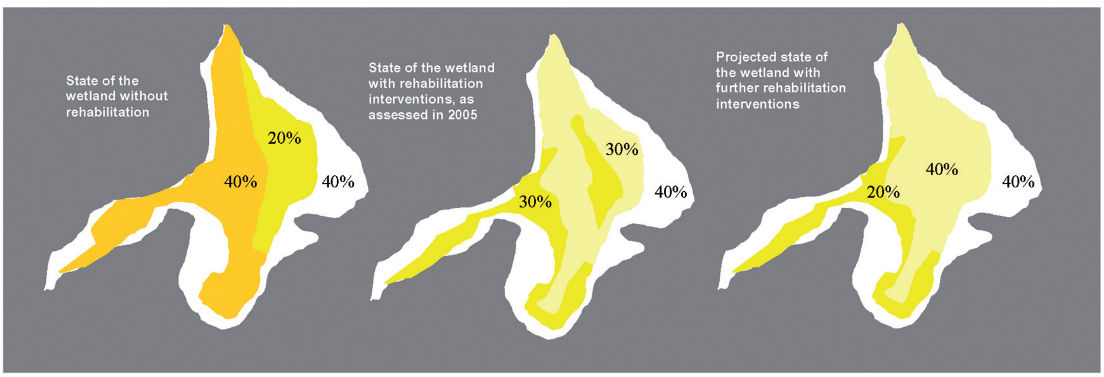


Figure 10: The hydrological state of Dartmoor Vlei under pre- and post rehabilitation scenarios

Table 1: **Wetland characteristics affecting the impact of canalisation on the distribution and retention of water in Dartmoor Vlei – prior to rehabilitation**

Extent of HGM unit affected by canalisation	**ha**	**60 %**

Factors	**Low**				**High**	**Score**
	0	**2**	**5**	**8**	**10**	
	Characteristics of the wetland					
(1) Slope of the wetland	<0.5%	0.5-0.9%	1-1.9%	2-3%	>3%	2
(2a) Texture of mineral soil, if present	Clay	Clay loam	Loam	Sandy loam	Sand/loamy sand	
(2b) Degree of humification of organic soil, if present	Completely amorphous (like humus)	Somewhat amorphous	Intermediate	Somewhat fibrous	Very fibrous	2
(3) Natural level of wetness	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	10
	Characteristics of the drains/gullies					
(4) Depth of the drains/ gullies	<0.20 m	0.20-0.50 m	0.51-0.80 m	0.81-1.10	>1.10 m	10
(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	2
(6) Location of drains/gullies in relation to flows into and through the wetland. Drains/ gullies are located such that flows are:	Very poorly intercepted	Moderately poorly intercepted	Intermediate	Moderately well intercepted	Very well intercepted	5
(7) Obstructions in the drains/ gullies	Complete obstruction	High obstruction	Moderate obstruction	Low obstruction	No obstruction	10
Calculate the mean score for factors 1, 2a or 2b, 3, 4 and 5						5.2
Multiply the score for factor 6 by the vulnerability factor = 0.9 from Table 2.1 in WET-Health						4.5
Mean score for above two scores						4.9
Intensity of impact for canalization: divide the score for factor 7 by 10 and multiply this by the mean score derived in previous row						4.9
Magnitude of impact of canalization: extent of impact/100 × intensity of impact calculated in the row above						2.9

Based on the score (Score =2.9) derived in Table 1, the susceptibility of the wetland to desiccation by drainage channels is considered 'moderate' (Table 2). This is due to a number of factors. Firstly, the slope is gentle, which means water will not drain very efficiently via the drains. Secondly, the substrate consists of a 1 m highly amorphous peat layer, below which is a clay layer that is impermeable to water. This makes the hydraulic conductivity of the soil low, limiting the effectiveness with which drains can lower the water table. Thirdly, the density of drains and their ability to intercept water is low. Fourthly, the wetland has a low mean annual rainfall to potential evaporation ratio such that rain falling onto the wetland is an important source of water, which means that the wetland has a low vulnerability score to activities that deprive the wetland of surface inputs and reduce residence time (a value of 0.9 in Table 1).

When the wetland is scored again for the same factors as in Table 1, but after the rehabilitation structures have been put in place, the impact score is considerably reduced (Table 3), which places it in an impact category of 'small impact'. This score reduction is based on the fact that the rehabilitation structures act very effectively in reducing the speed of through-flows in the wetland, thereby reducing the ability of the drains to effectively drain water from the wetland.

Given the above analysis it is clear that the magnitude of impact of artificial drainage of the wetland was moderate (a score of 2.9 out of a maximum impact score of 10), and that rehabilitation has improved the hydrological health of the wetland by reducing the magnitude of impact of the artificial drains to a small impact (a score of 1.5).

Table 2: Guideline for interpreting the magnitude of impact on the hydrological health of a wetland (from the WET-Health document)

Impact category	Description	Impact score range
None	No discernible modifications, or the modifications are of such a nature that they have no impact on the hydrological health.	0-0.9
Small	Although identifiable, the impact of the modifications on the hydrological health are small.	1-1.9
Moderate	The impact of the modifications on the hydrological health is clearly identifiable, but limited.	2- 3.9
Large	The impact of the modifications is clearly detrimental to the hydrological health. Approximately 50% of the hydrological health has been lost.	4-5.9
Serious	Modifications clearly have an adverse effect on the hydrological health. 51% to 79% of the hydrological health has been lost.	6-7.9
Critical	Modifications are so great that the hydrological functioning has been drastically altered. 80% or more of the hydrological health has been lost.	8-10

Table 3: Wetland characteristics affecting the impact of canalisation on the distribution and retention of water in Dartmoor Vlei – after rehabilitation

Extent of HGM unit affected by canalisation	ha	60%

Factors	Low				High	Score
	0	2	5	8	10	
	Characteristics of the wetland					
(1) Slope of the wetland	<0.5%	0.5-0.9%	1-1.9%	2-3%	>3%	2
(2a) Texture of mineral soil, if present	Clay	Clay loam	Loam	Sandy loam	Sand/loamy sand	
(2b) Degree of humification of organic soil, if present	Completely amorphous (like humus)	Somewhat amorphous	Intermediate	Somewhat fibrous	Very fibrous	2
(3) Natural level of wetness	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	10
	Characteristics of the drains/gullies					
(4) Depth of the drains/gullies	<0.20 m	0.20-0.50 m	0.51-0.80 m	0.81-1.10	>1.10 m	10
(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	2
(6) Location of drains/gullies in relation to flows into and through the wetland. Drains/ gullies are located such that flows are:	Very poorly intercepted	Moderately poorly intercepted	Intermediate	Moderately well intercepted	Very well intercepted	5
(7) Obstructions in the drains/ gullies	Complete obstruction	High obstruction	Moderate obstruction	Low obstruction	No obstruction	5
Calculate the mean score for factors 1, 2a or 2b, 3, 4 and 5						5.2
Multiply the score for factor 6 by the vulnerability factor = 0.9 from Table 2.1 in *WET-Health*						4.5
Mean score for above two scores						4.9
Intensity of impact for canalisation: divide the score for factor 7 by 10 and multiply this by the mean score derived in previous row						2.5
Magnitude of impact of canalisation: extent of impact/100 × intensity of impact calculated in the row above						1.5

3.2.2 Geomorphological health

Loss of sediment through erosion

The overall geomorphic characteristics of a wetland can be summarized by locating a wetland in relation to two variables: longitudinal slope in relation to wetland area (Macfarlane *et al*., 2009). In the case of Dartmoor Vlei, the area of the wetland is 40 ha and the longitudinal slope is 0.5% (Edwards 2008). Thus, the wetland is located approximately on the threshold slope in Figure 11 and it is unlikely to be easily eroded. Prior to construction of the drains, it therefore appears that the wetland was not eroding, which is confirmed by observations in the wetland and based on aerial photography. However, as indicated in this report, the concentration of flow along drainage ditches has resulted in erosion, some of which is still active. Therefore, the geomorphic assessment in this report focuses on erosion prior to rehabilitation (Tables 4 and 5) and after rehabilitation (Table 7). These tables have been taken directly from Chapter 3 of *WET-Health*, which focuses on geomorphology.

Although artificial drainage channels showing signs of erosion (which are taken as gullies for the purposes of this assessment) occupied most of the wetland length, they occupy a small proportion in relation to width, giving an extent of erosional impact of 25% prior to rehabilitation (Table 4). Due to this relatively low extent of erosional impact, as well as to the fact that the gullies were of moderate depth, low width and given that there are only two headcuts in the wetland (Table 5), the geomorphic impact score even prior to rehabilitation was 'small' (Score 1.06; Table 6).

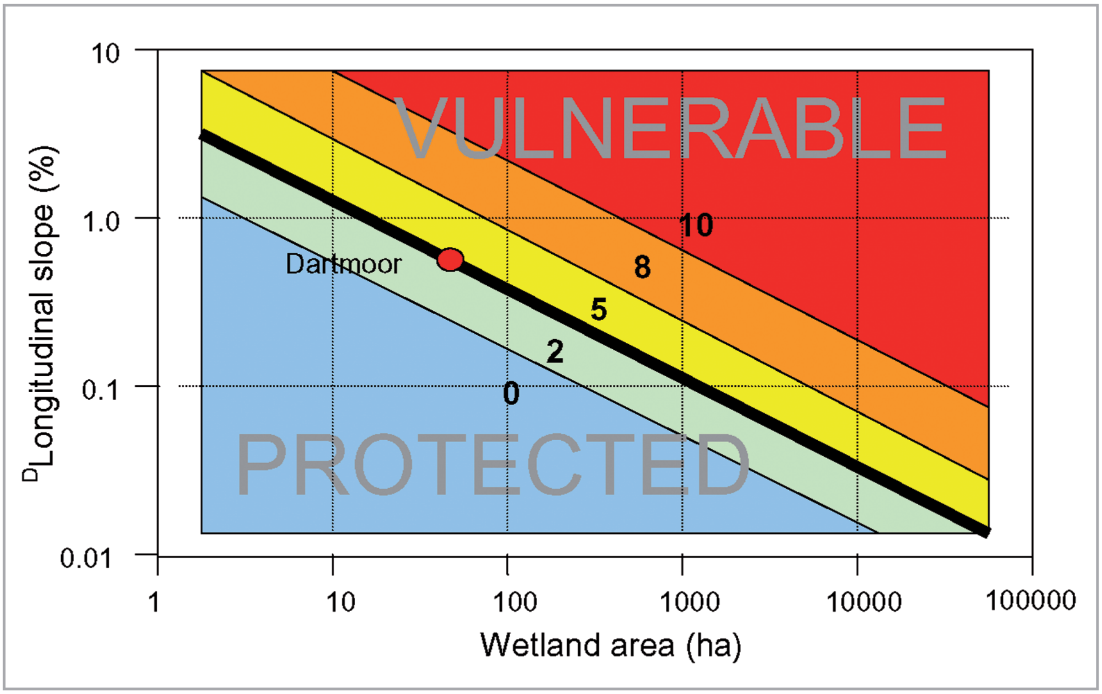


Figure 11: Vulnerability of Dartmoor Vlei to geomorphological impacts based on wetland size (a simple surrogate for mean annual runoff) and wetland longitudinal slope. The dark line between scores 2 and 5 approximates the equilibrium slope for a wetland of a given size.

In the geomorphological analysis done for the period after rehabilitation, the extent of gully impact remained at 25% (Table 4), but the overall impact was reduced as the scaling factors relating to sedimentation rates (all sediments being deposited within the wetland) and re-vegetation (high re-vegetation of the bed and sides of the gullies) were low (Table 7). This resulted in an overall geomorphic impact score of 'none' (Score 0.53; Table 6).

Table 4: Estimation of extent of impact of erosional features at Dartmoor Vlei prior to rehabilitation

		Length of wetland occupied by gully/ies as a percentage of the length of HGM				
		0-20%	21-40%	41-60%	51-80%	>80%
Average gully width (sum of gully widths if more than 1 gully present) in relation to wetland width	< 5%	5%	10%	15%	20%	25%
	5-10%	10%	15%	25%	35%	45%
	11-20%	15%	25%	40%	55%	65%
	21-50%	20%	30%	50%	70%	80%
	>50%	25%	40%	60%	80%	100%

Table 5: Intensity and magnitude of impact of erosional features at Dartmoor Vlei prior to rehabilitation

Factor	**2**	**4**	**6**	**8**	**10**	**Unscaled Score**
Mean depth of gullies	<0.5 m	0.5-1.0 m	1.01-2.0 m	2.0-3.0 m	>3.0 m	6
Mean width of gullies	<2 m	2-5 m	5.1-8 m	8.1-16 m	>16 m	4
Number of headcuts present	1	2	3	4	>4	4
Unscaled intensity of impact score: mean score of above 3 rows						4.7
Scaling factor	**0.4**	**0.5**	**0.7**	**0.9**	**1.0**	**Factor**
Extent to which sediment from the gully is deposited within the HGM or wetland downstream of the HGM unit (as opposed to being exported)	Entirely deposited	Mainly deposited	Intermediate	Mainly exported	Entirely exported	0.9
Extent to which the bed and sides of the gully have been colonized by vegetation and/or show signs of natural recovery	Complete	High	Moderate	Low	None	0.9
Scaling factor score: mean of above 2 rows (value is between 0 and 1)						0.9
Scaled intensity of impact score = unscaled intensity of impact score x scaling factor score						4.23
Magnitude of impact score for erosional features: (extent of impact score (see Table 4)/100) × scaled intensity of impact score						1.06

Table 6: Description of Present Geomorphic State in relation to Impact Scores and Present Geomorphic State Categories for a wetland

Impact score range	Description	Impact category
0-0.9	Unmodified, natural.	None
1-1.9	Largely natural. A slight change in geomorphic processes is discernable but the system remains largely intact.	Small
2-3.9	Moderately modified. A moderate change in geomorphic processes has taken place but the system remains predominantly intact.	Moderate
4-5.9	Largely modified. A large change in geomorphic processes has occurred and the system is appreciably altered.	Large
6-7.9	Greatly modified. The change in geomorphic processes is great but some features are still recognizable.	Serious
8-10	Modifications have reached a critical level as geomorphic processes have been modified completely.	Critical

Table 7: Intensity and magnitude of impact of erosional features at Dartmoor Vlei after rehabilitation

Factor	2	4	6	8	10	Unscaled Score
Mean depth of gullies	<0.50 m	0.50-1.00 m	1.01-2.00 m	2.00-3.00 m	>3.00 m	6
Mean width of gullies	<2 m	2-5 m	5.1-8 m	8.1-16 m	>16 m	4
Number of headcuts present	1	2	3	4	>4	4
Unscaled intensity of impact score: mean score of above 3 rows						**4.7**
Scaling factor	0.4	0.5	0.7	0.9	1.0	Factor
Extent to which sediment from the gully is deposited within the HGM or wetland downstream of the HGM unit (as opposed to being exported)	Entirely deposited	Mainly deposited	Intermediate	Mainly exported	Entirely exported	0.4
Extent to which the bed and sides of the gully have been colonized by vegetation and/or show signs of natural recovery	Complete	High	Moderate	Low	None	0.5
Scaling factor score: mean of above 2 rows (value is between 0 and 1)						**0.45**
Scaled intensity of impact score = unscaled intensity of impact score x scaling factor score						**2.12**
Magnitude of impact score for erosional features: (extent of impact score (see Table 4)/100) × scaled intensity of impact score						**0.53**

It is useful at this point to consider the rehabilitation structures themselves. The rehabilitation structures within Dartmoor Vlei have been well keyed in to the banks. In addition, in the upstream portion of the wetland, approximately 70% of the length of these channels has been back-flooded by the plugs, providing a water cushion for much of the flow that would be potentially re-entering the channel. However, in most cases within Dartmoor Vlei, the downstream structure floods back short of the next structure upstream (see Box 1). Thus, most structures are lacking a water cushion to protect their toe and active undermining of the toe is occurring, particularly downstream of Structure 9. Thus, from an erosion-control point of view, the structures have been partially successful in the upstream portion of the wetland in deactivating erosion within the drains.

The downstream portion of the wetland consists of a 400 m section of drain with a single concrete weir plug at its downstream end. Owing to the gradient in this channel, this plug floods back no more than 50 m up the channel. Thus, the remaining 350 m of this channel up to the toe of Structure 5 is without a water cushion.

Structure 5 and its associated spreader channel have very effectively spread flow, and at the end of the dry season in August 2005, almost all of the flow was being directed along the spreader canal. The increased soil saturation that has resulted from this spreading of flow appears to have led to slumping of the channel banks, which are not supported by any water in the channel (see Box 1). Overall, therefore, although the erosion associated with the drainage channels has been decreased in some channel portions, there has probably been a slight localized increase in the impact from erosion when compared with the pre-rehabilitation condition. However, if the undermining of the toes of the structures could be addressed and if an additional plug was included downstream of Structure 5 to retain water in the channel between structure 4 and 5, then the impacts of erosion on geomorphic health are likely to be significantly reduced. A structure (Structure 10 shown in Figure 1) was, in fact, constructed in 2006, and has successfully addressed the principle threat to the geomorphic health of the wetland.

Box 1: Potential effect of 'plugs' on erosion in artificial drainage channels

By slowing down the velocity of water flow within an artificial drainage channel, concrete weirs used as plugs within a drain have the potential to greatly reduce the threat of future erosion taking place within the drain. However, for these plugs to be most effective in controlling erosion, each plug needs to be well keyed into the channel banks and should cause flooding back to the toe of the next structure upstream. This flooding provides a 'water cushion' for water flowing over the toe of the upstream structure, which helps to prevent erosion at the toe of the structure. This erosion may undermine the toe of the structure, and if this continues to an advanced state, it could potentially lead to the complete failure of the structure.The increased level of water in an artificial drainage channel resulting from the plugs also acts as a cushion to water flowing from the surface of the wetland into the drainage channel. The greater the extent to which water has been spread across the wetland, the greater is the volume of water potentially re-entering the drainage channel, and the more important it would be from an erosion-control perspective to have a good water cushion in the channel. Furthermore, re-wetting of the channel banks may contribute to their reduced stability, leading to possible slumping, unless water is present in the channels to give them support.

Loss of sediment through increased oxidation of organic sediments

The overall geomorphology of the Dartmoor Vlei was examined by Edwards (2008), and there is approximately 1m of peat present across the entire wetland. However, this peat is well humified and has hydraulic properties of a clay-rich soil. Desiccation of the wetland is likely to lead to further oxidation of the peat present, and the study therefore also focused on the loss of organic sediment. Only indirect indicators of the impact of desiccation were used since there are no direct indicators of organic sediment being consumed in peat fires (Tables 8-11; derived from the geomorphic chapter in *WET-Health*). The intensity of impact score prior to rehabilitation (Table 9) was 'small' (Score 1.25) and was reduced to 'nil' (Score 0.2) after rehabilitation (Table 11).

Table 8: Extent of impact of the loss of organic sediment for direct indicators (A) and indirect indicators (B) for Dartmoor Vlei prior to rehabilitation

A.	Extent of impact score based on direct indicators (if present)	None present
B.	Additional extent of impact score based on indirect indicators (if present)	25%

Table 9: Indirect indicators (not clearly visible) reflecting the intensity of diminished health of organic sediments in Dartmoor Vlei prior to rehabilitation

	0	2	5	8	10	Intensity score
Level of desiccation of the region of the HGM unit in which peat accumulation is taking place	Unmodified	Largely natural	Moderately modified	Largely modified	Seriously / critically modified	5
Magnitude of impact score: extent of impact score (Table 8)/100 × intensity of impact score						**1.25**

Table 10: Extent of impact of the loss of organic sediment for direct indicators (A) and indirect indicators (B) for Dartmoor Vlei after rehabilitation

A. Extent of impact score based on direct indicators (if present)	None present
B. Additional extent of impact score based on indirect indicators (if present)	10%

Table 11: Indirect indicators (not clearly visible) reflecting the intensity of diminished health of organic sediments in Dartmoor Vlei after rehabilitation

	0	2	5	8	10	Intensity score
Level of desiccation of the region of the HGM unit in which peat accumulation is taking place	Unmodified	Largely natural	Moderately modified	Largely modified	Seriously / critically modified	2
Magnitude of impact score: extent of impact score (Table 10)/100 × intensity of impact score						**0.2**

Table 12: **Derivation of overall magnitude-of-impact scores for geomorphology through combining the scores obtained from individual assessments**

Impact category	Score before rehabilitation	Score after rehabilitation
1. Magnitude of impact of dams		
2. Magnitude of impact of channel straightening		
3. Magnitude of impact of infilling		
4. Magnitude of impact of changes in runoff characteristics		
5. Magnitude of impact for erosional features (Tables 5 and 7)	1.06	0.53
6. Magnitude of impact for depositional features		
7. Magnitude of impact for loss of organic sediment (Tables 9 and 11)	1.25	0.2
Overall Present Geomorphic State = Sum of three highest scores	**2.31**	**0.73**

Combined effect of erosion and oxidation of organic sediments

The combined effects of impact for erosion and for loss of organic matter have been summarized and are presented in Table 12. The overall geomorphic state has been reduced from 'moderate' (impact score of 2.31) to 'nil' (impact score of 0.53) through rehabilitation. It is likely the value of 0.53 would be reduced even further if the problem of the undermining the toe of the structures is addressed as suggested in the previous section on erosion.

3.2.3 Vegetation health

Prior to rehabilitation, Dartmoor Vlei was still dominated by indigenous hydric plants. Ruderal (weedy) species characteristically occurring in wetlands of the region (e.g. *Verbena bonariensis*) were present at a relatively low abundance (<10% cover). A baseline description of the wetland vegetation prior to drainage does not exist. However, based on the authors' experience of nearby wetlands with a similar altitude and hydro-geomorphic setting, (e.g. Mgeni vlei), it would appear that immediately prior to rehabilitation, the vegetation composition of the wetland had generally not been greatly altered except in localized disturbed areas immediately adjacent to the drainage channels. It is important to note that particularly in high rainfall areas, vegetation composition may be very slow to respond to a reduction in the level of wetness of a wetland, which appears to be the case for Dartmoor.

After rehabilitation, approximately 25% of the wetland remained invaded by American bramble (*Rubus cuneifolius*) (Table 13) as the rehabilitation did not include any clearing of alien plants. Infestation was confined mainly to near the drainage channels (particularly immediately adjacent to the channel, but also having spread in some areas) and on some of the margin of the wetland. Within the invaded area, the aerial cover of bramble is approximately 30%. Thus, the intensity of impact resulting from moderate invasion of the American bramble and the presence of ruderal native species results in an overall magnitude of impact score for vegetation (based on information from the vegetation chapter of *WET-Health*) of 1.3, which rates as 'small' (Table 14). Increased wetting of the areas adjacent to the drainage channel may potentially result in a certain level of replacement of the ruderal species by the original hydric species. However, although vegetation composition generally responds more quickly to increased wetness than to decreased wetness (van der Valk, 2005, *Pers. comm.*) the effect of re-instated hydrology on vegetation requires at least a few years before a meaningful assessment can be undertaken. Thus, given that the rehabilitation is very recent, it is not yet possible to assess its full effect on vegetation. However, it is concluded that at the very least, the rewetting of the wetland area adjacent to the main channel will limit the expansion of the American bramble, thereby making a positive contribution to vegetation health but with little effect in the naturally drier portions of the wetland.

Table 13: Calculation of Dartmoor Vlei magnitude of impact score for vegetation after rehabilitation

Disturbance class	Disturbance class extent (% of wetland)	Intensity of impact score (from Table 14.5 in *WET-Health*)	Magnitude of impact score*	Factors contributing to impact
1	25	5	1.3	Moderate invasion of American bramble in close proximity of the drains and presence of ruderal native species
2				
3				
4				
5				
HGM Magnitude of impact score**			1.3	

* Magnitude of impact score is calculated as extent / 100 x intensity of impact
** Overall magnitude of impact score for the HGM unit = sum of magnitude scores for each disturbance class.

Table 14: Impact categories for assessing the intensity of impacts on vegetation health within disturbance classes

Impact category	Description	Impact scorerange
None	Vegetation composition appears entirely natural.	0-0.9
Small	A very minor change to vegetation composition is evident at the site (e.g. abundance of ruderal, indigenous invasive slightly higher than would be the case naturally).	1-1.9
Moderate	Vegetation composition has been moderately altered but introduced; alien and/or increased ruderal species are still clearly less abundant than characteristic indigenous wetland species.	2-3.9
Large	Vegetation composition has been largely altered and introduced; alien and/or increased ruderal species occur in approximately equal abundance to the characteristic indigenous wetland species.	4-5.9
Serious	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
Critical	Vegetation composition has been almost totally altered, and in the worst case aall indigenous vegetation has been lost (e.g. as a result of a parking lot).	8-10

Table 15: Impact scores for health of Dartmoor Vlei prior to and after rehabilitation

Componentsof health	Two different rehabilitation scenarios	
	Without rehabilitationInterventions	With rehabilitation interventions
Hydrology	2.9 (moderate)	1.5 (small)
Geomorphology	2.3 (moderate)	0.7 (none)
Vegetation	2.0 (moderate)	1.3 (small)

Note a score of 0 represents no impact (totally natural) and a score of 10 represents maximum impact (totally transformed).

3.2.4 Overall summary of the health of Dartmoor Vlei pre- and post-rehabilitation

From Table 15, it can be seen that despite having been subjected to artificial drainage, the wetland was in a generally good state prior to rehabilitation, although clearly with scope for improvement. Following rehabilitation, improvements in hydrological geomorphic and vegetation health were achieved. By implementing other rehabilitation interventions, further improvements in wetland health can be achieved, particularly for geomorphology (by stabilizing important sections of the drain) and vegetation.

4 Conclusion

Individual weirs are effectively reducing water loss from the wetland by plugging artificial drains, and they are therefore contributing to improved wetland health. However, due to the inherent biophysical characteristics of the wetland, including high rainfall and relatively low potential evapotranspiration from the site, as well as the low hydraulic conductivity of soils in the wetland, the impact of the drains on wetland health is likely to have been low. As such the overall impact of rehabilitation has been modest.

By considering the impact of rehabilitation on the basis of area of improved wetland health, it is possible to assess the effectiveness of rehabilitation interventions for the wetland as a whole. It also then becomes possible to assess the cost-effectiveness of rehabilitation between different wetlands. To this end the concept of 'hectare equivalents of intact wetland' is useful and which is described in greater detail in *WET-RehabEvaluate* (Cowden and Kotze, 2009) and in Part 1 of this document.

5 References

Edwards R, 2008. *A dolerite controlled valley bottom wetland system: the origin and evolution of Dartmoor Vlei in the KwaZulu-Natal Midlands, South Africa.* Unpublished MSc thesis, University of KwaZulu-Natal, Durban.

Cowden C and Kotze DC, 2009. *WET-RehabEvaluate: Guidelines for the monitoring and evaluation of wetland rehabilitation projects.* WRC Report No. TT 342/09. Water Research Commission, Pretoria.

Kotze DC, Ellery WN, Rountree M, Grenfell MC, Marneweck G, Nxele IZ, Breen DC, Dini J, Batchelor AL and Sieben E, 2009. *WET-RehabPlan: Guidelines for planning wetland rehabilitation in South Africa.* WRC Report No. TT 336/09. Water Research Commission, Pretoria.

Macfarlane DM, Kotze DC, Ellery WN, Walters D, Koopman V, Goodman P and Goge M. 2009. *WET-Health: A technique for rapidly assessing wetland health.* WRC Report No. TT 340/09. Water Research Commission, Pretoria.

Part 6:

Evaluating the effect of rehabilitation of Kruisfontein Wetland (KwaZulu-Natal) on its health and delivery of ecosystem services

DC Kotze

1 Introduction

When evaluating the ecological outcomes of a project, whether for prioritizing potential wetland rehabilitation projects or for evaluating existing projects, it is of little value to simply report on the spatial area rehabilitated. It may be, for example, that the health of a large rehabilitated area has been only very slightly improved, or conversely, the health of a small rehabilitated area has been considerably improved. Area of wetland also provides no indication of the delivery of ecosystem services. Thus, when evaluating rehabilitation outcomes it is important to examine the level to which the health of the rehabilitated wetland area and its delivery of ecosystem services is affected by rehabilitation. This can be done by assessing and comparing two scenarios, the situation without rehabilitation (i.e. no intervention) and the situation with rehabilitation. Sometimes, it may be necessary to assess several alternative rehabilitation scenarios. The approach and 'currency' used is that of 'hectare equivalents' of healthy wetland as described in Part 1 of this document.

2 Effect of rehabilitation on the health of Kruisfontein Wetland

Kruisfontein is an eighteen hectare wetland situated in the Midlands of KwaZulu-Natal east of Mooi River. It has been extensively desiccated through two very effective cut-off furrows that were dug on either side of the wetland, and a series of ridges and furrows covering almost the entire surface of the wetland. Most of the wetland had been cleared of indigenous vegetation, and prior to rehabilitation (which took place in 2005) it was dominated by an alien pioneer species, *Paspalum dilitatum*, and the facultative non-wetland species *Cynodon dactylon*. In 2007, pioneer hydric species, notably *Juncus effusus*, had started to colonise the wetter portions of the 6 ha of the floodplain now being supplied with low flows.

The state of health of Kruisfontein wetland was assessed for the 2005 situation prior to any rehabilitation and for the 2007 situation subsequent to the rehabilitation interventions. Following the 2007 assessment, it was identified that several further interventions (e.g. the construction of more berms) should be undertaken to enable the rehabilitation objectives to be better achieved. A third situation was therefore assessed, that of the projected situation that would exist should the additional identified interventions be undertaken.

Figure 1 represents the flow patterns in the wetland under the three situations described. It can be seen that the rehabilitation interventions have considerably increased the extent of the wetland subject to flood flows and low flows, and that additional rehabilitation interventions would most likely increase these still further. These flow patterns have a direct bearing on the health of the wetland, which is represented in Figure 2. The health classes in Figure 2 were derived from analyses based on *WET-*

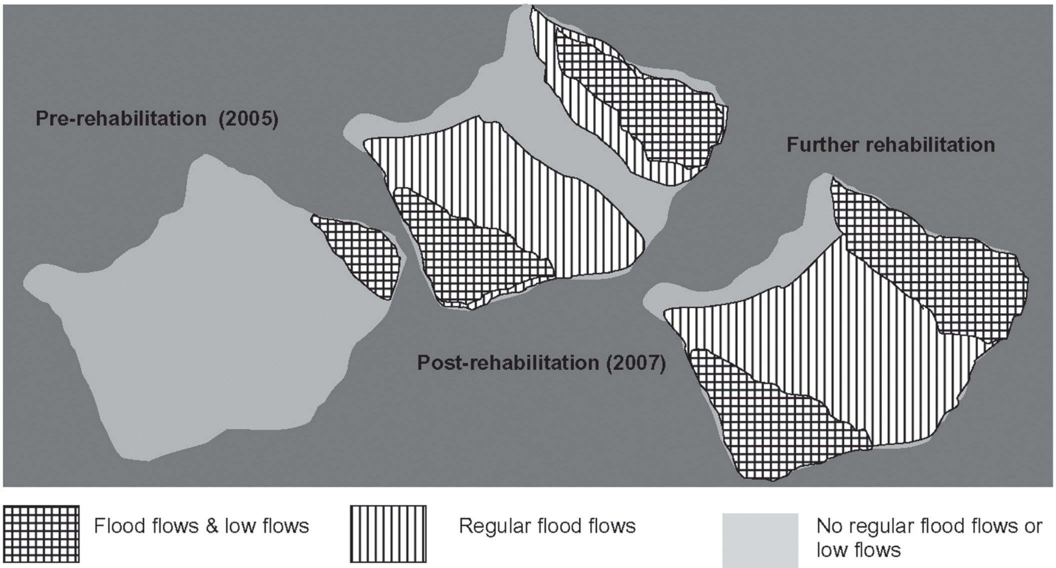


Figure 1: The general pattern of waterflow in Kruisfontein Wetland under three different situations

Health (Macfarlane *et al.*, 2009). The area for each particular health class was converted to hectare equivalents of healthy wetland as shown in Table 1. Based on the calculated health given in Table 1, in functional terms, the rehabilitation interventions completed at Kruisfontein Wetland in 2007 is equivalent to fully re-instating the hydrological health of 2.9 ha of wetland (6.1 ha-3.2 ha). If the further rehabilitation interventions identified were also to be undertaken then the combined effect of these and the current interventions would be equivalent to fully re-instating the hydrological health of 6.0 ha of wetland (9.2 ha-3.2 ha).

Impact category	Health class description	Impact score
None	Unmodified, natural.	0-0.9
Small	Largely natural with few modifications.	1-1.9
Moderate	Moderately modified.	2-3.9
Large	Largely modified.	4-5.9
Serious	Extensive loss of habitat and function	6-7.9
Critical	Critical	8-10

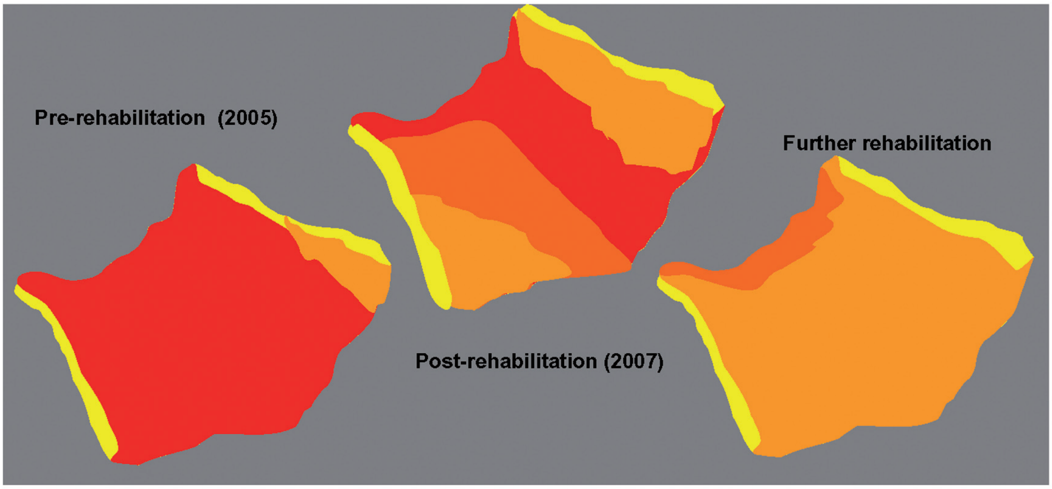


Figure 2 The health of Kruisfontein Wetland under three different situations

Table 1: Hydrological health of the Kruisfontein Wetland before and after rehabilitation and for a projected situation with further rehabilitation interventions, expressed in hectare equivalents of intact wetland

Health classes and score	Pre-rehabilitation (2005)		Post-rehabilitation (2007)		Projected situation with further rehabilitation	
	Area under a particular health class	Hectare equivalent1	Area under a particular health class	Hectare equivalent1	Area under a particular health class	Hectare equivalent1
Unmodified, natural (0.5)	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha
Largely natural (1.5)	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha
Moderately modified (3.0)	1.5 ha	1.1 ha	1.5 ha	1.1 ha	1.5 ha	1.1 ha
Largely modified (5.0)	1 ha	0.5 ha	6 ha	3 ha	15.5 ha	7.8 ha
Extensive modification (7.0)	0 ha	0 ha	4.5 ha	1.4 ha	1 ha	0.3 ha
Critical (9.0)	15.5 ha	1.6 ha	6 ha	0.6 ha	0 ha	0 ha
Total area	18.0 ha	3.2 ha	18.0 ha	6.1 ha	18.0 ha	9.2 ha

1 Hectare equivalents = (10 – health score)/10 x area of rehabilitation in hectares.

As indicated previously, prior to rehabilitation the two lateral drainage furrows effectively cut off the wetland from most of its inflows. Therefore, a key aspect of rehabilitation has been to distribute some of the water in these channels across the surface of the wetland by constructing obstructions in the furrows. The western drainage furrow is fed by a much larger catchment and therefore is subject to much larger flood discharges than the eastern drainage furrow, and is considerably more deeply incised, particularly in its upper sections. It is therefore a considerably simpler task to construct an obstruction in the eastern furrow than the western channel. An obstruction to flow was in fact put in place by the landowner soon after the 2005 assessment through the construction of a small earthen berm in the furrow (structure a; Figure 3). Distributing the water out of the western furrow has been achieved by means of a weir in the upper, most deeply incised portion of the channel and a concrete-clad diversion berm in the lower portion of the channel (structures b and c respectively; Figure 3). The spillway of the weir is about 0.3 m lower than the banks of the channel, resulting in only the highest of flows overtopping the banks. During the wet season of 2005/6, overtopping occurred on only two occasions.

Impact category	Health class description	Impact score
None	Unmodified, natural	0-0.9
Small	Largely natural with few modifications	1-1.9
Moderate	Moderately modified	2-3.9
Large	Largely modified	4-5.9
Serious	Extensive loss of habitat and function	6-7.9
Critical	Critical	8-10

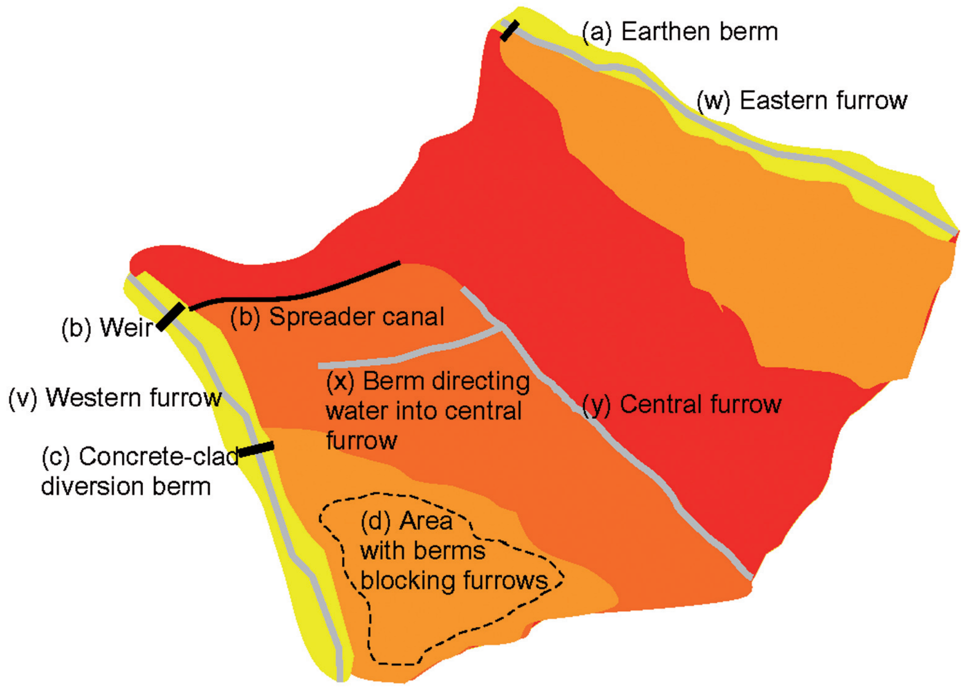


Figure 3: Kruisfontein Wetland, showing rehabilitation interventions (a to c), features associated with artificial drainage (v to y) and the hydrological health of different portions of the wetland (see Figure 2).

Once water had been forced onto the floodplain, the next challenge for rehabilitation was to neutralize the impact of the ridge and furrow system. In the eastern portion of the wetland this has not been fully achieved, and flow is contained mainly within the furrows, slowing down the flow of surface water. Nevertheless, it can already be observed that after two years of re-wetting, vigorous growth of vegetation has established in the eastern and western furrows, and they are becoming less efficient hydraulically. Over time, as both organic and minerogenic sediments accumulate in the furrows, they will become progressively shallower and ultimately much less effective in conveying water out of the wetland. In the western portion, short berms at regular intervals across the furrows have distributed flow well throughout the area (intervention d; Figure 3).

Thus, it is recommended that short berms also be constructed in the eastern portion to help speed up the process of recovery. As indicated earlier, the storm discharges are likely to be less severe in the eastern portion than in the western portion, and therefore the berms will probably not need to be constructed as high, and could be done by the landowner. It has been observed by the landowner that when water is distributed towards the central portion of the floodplain during a high flow event, the long berm and central furrow (features x and y respectively; Figure 3) act to gather water and convey it out of the wetland. Thus, the berm needs to be broken at intervals and a few short berms constructed across the central furrow.

In addition to the berms recommended above, the health of the wetland and its delivery of ecosystem services are likely to be further enhanced if the spillway of the weir in the western channel is raised slightly to increase the frequency of overspill by high flow events. It should, however, be emphasized that levels should still be low enough such that low flows are not spilled over the banks. If the area of wetland across which low flows are distributed is increased greatly from the 2007 situation, it is likely to make the wetland wetter than it was naturally, given that the wetland is assumed to have consisted of a channelled portion (associated with the western input channel, which supports high flood discharges) and an unchannelled portion (associated with the eastern input channel, which supports lower flood discharges).

3 Delivery of ecosystem services

The next question to examine is: what are the implications of the increased health in terms of altered delivery of ecosystem services. The fact that a wetland is currently delivering a high level of goods and services does not automatically make it a good candidate for rehabilitation. Rather, it is the level to which the delivery of ecosystem services are affected by rehabilitation that is most important. This can be done by predicting the level of delivery of ecosystem services under a rehabilitated state compared with the level of delivery without any rehabilitation. This prediction is based on the extent to which rehabilitation will affect key characteristics determining the delivery of services, as elaborated upon in *WET-EcoServices* (Kotze *et al*., 2009). For example, the pattern of low flows in a wetland has an important effect on the wetland's effectiveness in assimilating pollutants (the more diffuse the flow, the better). If by plugging drains, for example, the flow patterns in a wetland can be converted from a very concentrated situation to a very diffuse one, then the effectiveness of the wetland in assimilating pollutants is likely to be markedly enhanced.

If a vision and objectives exist for the catchment in which wetlands are being prioritised then particular attention should be given to those ecosystem services relevant to the vision and objectives. For example, the supply of good quality water may be very important in a particular catchment, requiring that particular attention be given to the hydrological services assessed by *WET-EcoServices*. In another case, biodiversity may be the most important consideration.

From Table 2 it can be seen that through rehabilitation, there is a noticeable increase in the delivery of several hydrological services, with nitrate removal having the greatest improvement. In Kruisfontein, without rehabilitation, several features (e.g. the pattern of flow and hydrological zonation) are at their lowest level in terms of the effectiveness of the wetland in supplying hydrological services. Thus, there is much that can be done to improve the effectiveness of the wetland. This has in fact been achieved in Kruisfontein by restoring a much more diffuse pattern of low flows and a much higher level of wetness. Furthermore, the wetland has provided opportunity for assimilating nutrients because it occurs downstream of a dairy and fertilized pastures.

Table 2: Delivery of ecosystem services by Kruisfontein wetland, under three situations, prior to rehabilitation, in 2007 following rehabilitation interventions, and a projected situation if further rehabilitation interventions identified in the assessment were carried out

Ecosystem services		Without rehab (2005)	With rehab (2007)	Additional rehab
Hydrological services	Flood attenuation	2.0	2.6	2.6
	Streamflow regulation	1.8	2.2	2.4
	Sediment trapping	1.5	2.0	2.0
	Phosphate trapping	1.8	2.6	2.6
	Nitrate removal	1.6	2.7	3.0
	Toxicant removal	1.6	2.4	2.6
	Erosion control	2.6	3.0	3.0
	Carbon storage	1.3	2.0	2.3
Maintenance of biodiversity		1.5	2.2	2.4
Provisioning & cultural services	Water supply for human use	0.3	0.7	0.9
	Natural resources	1.0	1.6	1.6
	Cultivated foods	0.4	0.4	0.4
	Cultural significance	0.0	0.0	0.0
	Tourism and recreation	0.9	1.6	1.6
	Education and research	1.5	2.0	2.0

Level of importance of ecosystem service	<0.5Low	0.5-1.2 Moderately low	1.2-2.0 Intermediate	2.1-2.8 Moderately high	>2.8High

The wetland provides fairly limited provisioning and cultural services, which are generally not greatly affected by rehabilitation. However, given that the Kruisfontein property is run as an ecotourism farm, the increased birds that are likely to be attracted to the wetland will contribute positively here. In addition, some of the farm labourers use *Juncus punctorius* for weaving, a natural resource that is likely to increase in abundance through rehabilitation.

Comparing the current rehabilitated situation with the projected situation following additional rehabilitation interventions, it can be seen that while some ecosystem services (e.g. nitrate removal and carbon storage) will be further enhanced, others such as flood attenuation will be little affected. In the case of flood attenuation, the positive effective of the additional berms, would be negated by increasing the level of wetness of the area, which in turn would reduce the flood storage capacity of the wetland.

4 Conclusion

Use of *WET-Health* can provide useful insights into the effectiveness of wetland rehabilitation for individual wetlands to compare different rehabilitation interventions and even different wetlands, since it makes use of the currency of 'hectare equivalents' of healthy wetland. *WET-EcoServices* provides a means of demonstrating the improvement in wetland ecosystem services within a wetland for different scenarios of rehabilitation, but it cannot be used to compare different wetlands since it does not make use of a currency that is area-based. This study nevertheless illustrated the usefulness of these tools in considering rehabilitation effectiveness, and it was clearly demonstrated that both health and delivery of ecosystem services were improved through rehabilitation.

5 Acknowledgements

The keen observations and inputs of the landowner of Kruisfontein, Sandy and Peter Ward, have contributed towards this assessment. Doug McCullough and Craig Cowden of LRI and Erwin Sieben are also thanked for their assistance in conducting the field work, and Karen Ellery provided useful editorial help.

6 References

Kotze DC, Marneweck GC, Batchelor AL, Lindley DS and Collins NB, 2009. *WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands*. WRC Report No. TT 339/09. Water Research Commission, Pretoria.

Macfarlane DM, Kotze DC, Ellery WN, Walters D, Koopman V, Goodman P and Goge M, 2009. *WET-Health: A technique for rapidly assessing wetland health*. WRC Report No. TT 340/09. Water Research Commission, Pretoria.

Part 7:

Evaluation of the effect of rehabilitation interventions on the health and ecosystem service delivery of the Wakkerstroom Vlei, Mpumalanga province

WN Ellery, DC Kotze and R Joubert

1 Introduction

Wakkerstroom Vlei is situated in the upper reaches of the Tugela catchment in the province of Mpumalanga, although the outlet of the wetland is situated in KwaZulu-Natal. It is a large (950 ha) unchannelled valley-bottom wetland that lies immediately west of the town of Wakkerstroom. Peat deposits, limited in depth and extent, are known to occur in Wakkerstroom Vlei (Begg, 1989).

The vlei is surrounded by Ecca Shale of the Volksrust Formation and a Karoo dolerite dyke crosses the outlet of the vlei, making it tempting to conclude that the wetland is a consequence of the arrested erosion of the Thaka River valley.

The aim of managing the Wakkerstroom Vlei is to sustainably optimize the direct benefits that different users derive from the wetland without compromising the indirect benefits of the vlei for the local community and for society more generally (Kotze *et al*., 1994). Direct benefits include grazing of livestock, bird watching, water use, hunting and reed harvesting, and the most important indirect benefits include hydrological values (water purification, sustaining base flow and water storage), erosion control and ecological value provided through the provision of habitat for wetland dependant species. The Wakkerstroom Vlei is viewed as ecologically significant and there are plans to proclaim it as a Ramsar site.

2 Objectives of rehabilitation

Rehabilitation of the Wakkerstroom Vlei was undertaken in order to stop headward erosion along an existing gully and to raise the water table in the gully and adjacent wetland (Working for Wetlands Programme, 2003). The goal was to maintain wetland health and the delivery of ecosystem services in the Wakkerstroom Vlei, rather than to reinstate the health or ecosystem services.

The intention of this study is to carefully examine headward erosion that is taking place along the gully in the Wakkerstroom Vlei in order to determine its threat to the wetland as a whole. It is further designed to document the health and ecosystem services that are secured through rehabilitation.

3 Methods

Several cross-sections were measured at intervals across the Wakkerstroom Vlei (Figure 1; Transects 1, 2 and 3) and a longitudinal section was also measured down the length of Wakkerstroom Vlei using a dumpy level that is accurate to 0.1 m. Depth to bedrock was measured from locations of known relative elevation using gouge coring equipment.

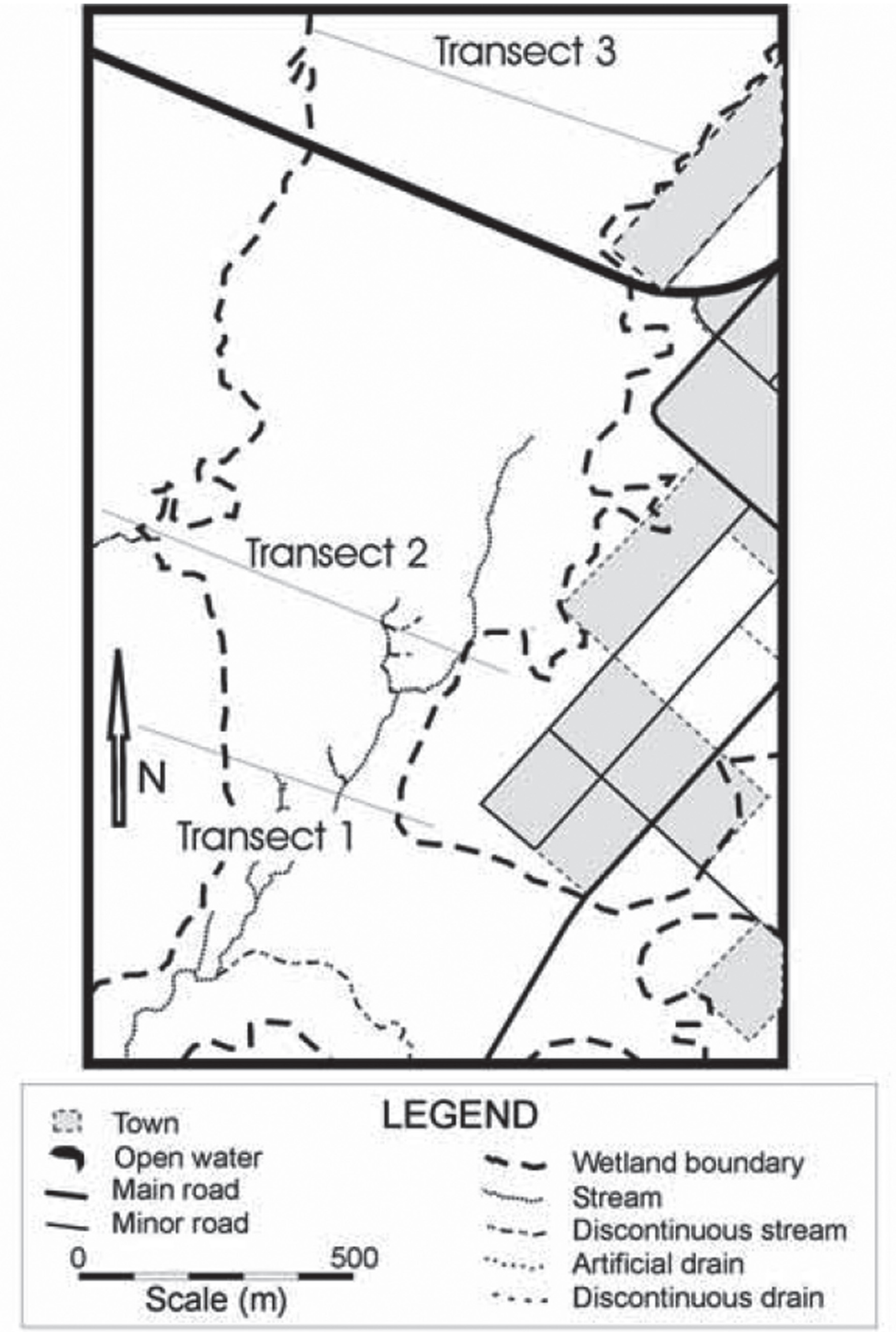


Figure 1: Location of transects used in this study to determine wetland cross-sectional morphology and depth to bedrock

Aerial photographs taken in 1938, 1954 and 2004 were interpreted with an emphasis on the dimensions, continuity and size of erosion gullies, channels and drains. The resolution of the photography imposed some limitations on interpretation as the resolution was best in the 1938 photography and worst in the 2004 photography. Nevertheless, the validity of the overall findings is sound.

WET-Health (Macfarlane *et al.*, 2009) and *WET-EcoServices* (Kotze *et al*., 2009) were used to determine the health and provision of ecosystem-services prior to and after rehabilitation, forming the basis for an evaluation of the benefits of rehabilitation.

In general there seems to be a decrease in sediment thickness downstream such that in the lower reaches the bed of the channel is on bedrock, but this is not true of the small channel further upstream.

The longitudinal profile, conducted for the entire Wakkerstroom Vlei (the location of Transects 1, 2 and 3 are indicated) shows that the longitudinal slopes of the wetland surface and bedrock are remarkably similar at 0.22%, and 0.21% respectively (Figure 3). However, the bed of the channel has a steeper longitudinal slope of 0.26%. It is of interest that the gully has developed in the vicinity of the region of the lower part of the wetland where the surface of the wetland is steepest (0.24%).

4 Results

a. Wetland morphology

The cross-sections of the lower part of the Wakkerstroom Vlei are presented in Figure 2. All elevations are relative to the thalweg (the lowest point on the floor of a stream or gully at any location along its length) or the lowest point on the floor of the valley when a stream or gully is absent. The floor of the valley is remarkably flat in cross-section, as is the elevation of bedrock. There is no channel present in the middle reaches of the wetland (Transect 3 in Figure 1), there is a small channel present in Transect 2 further south, and the channel gets progressively larger downstream. The channels are not associated with significant levees suggesting that they are not important in transporting and /or depositing sediment.

b. Aerial photograph interpretation

The focus of the aerial photographic interpretation was to document the presence of active channels and drains (for the purposes of this report the word ‘channel’ will be used to refer to features that might be also be interpreted as gullies). It was not intended to interpret the wetland boundary, development of infrastructure or growth of the town of Wakkerstroom. Therefore, the boundary of the wetland was mapped from the highest resolution photography (1938), which was used throughout the sequence. Similarly, the extent of the town as mapped from the 2004 photographs was used to indicate the extent of the town. However, the channels and drains have been accurately mapped and their activity interpreted as carefully as possible given the constraints of the photographs’ resolution.

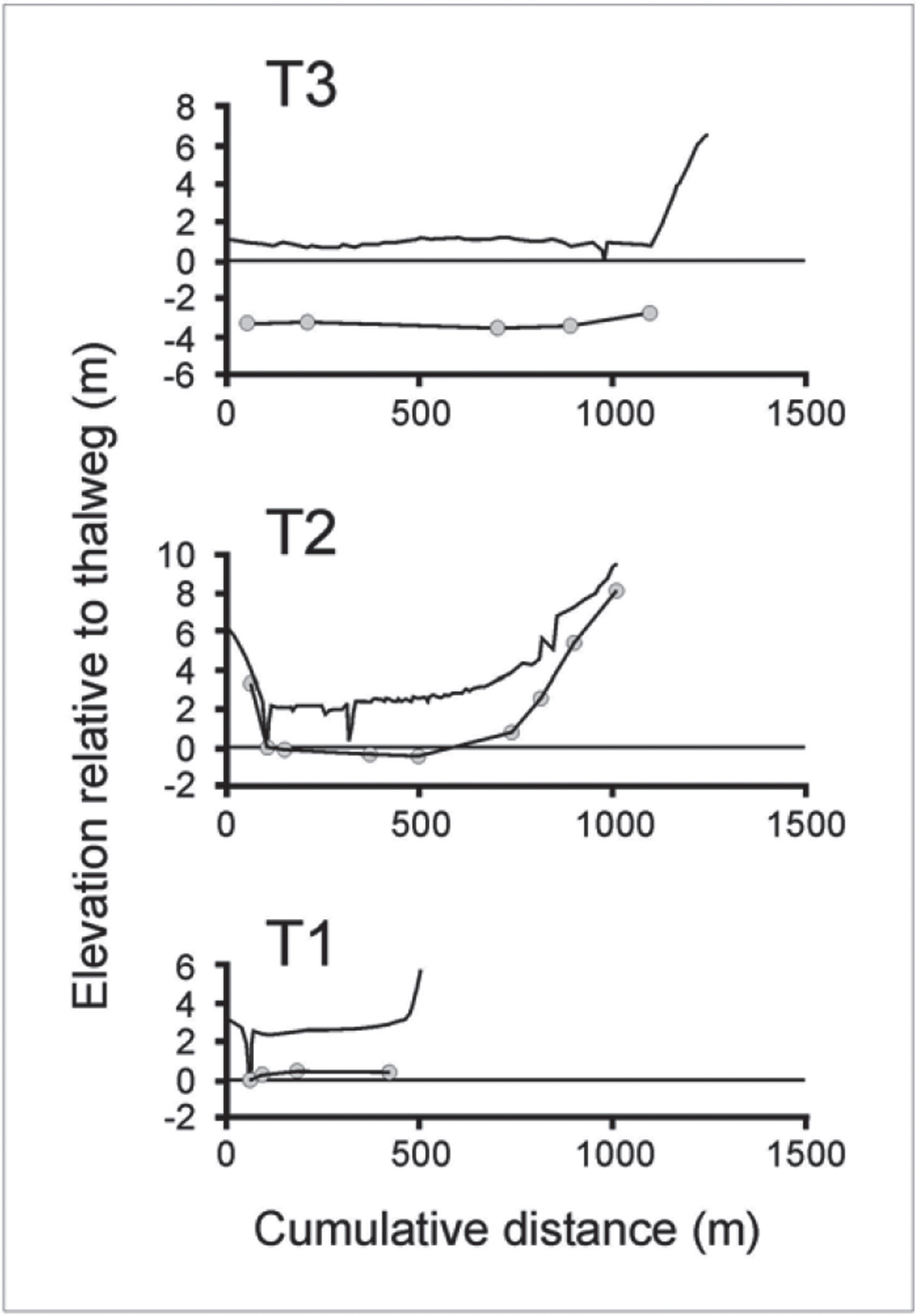


Figure 2: Cross-sections of the lower Wakkerstroom Vlei showing wetland morphology, channel dimensions and depth to bedrock

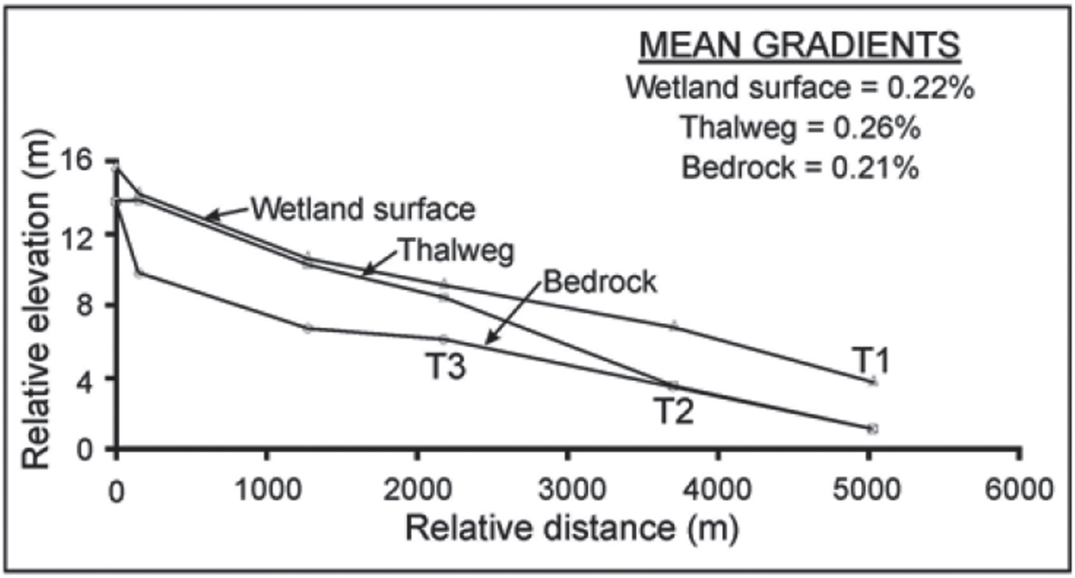


Figure 3: Longitudinal profile of the Wakkerstroom Vlei showing the mean elevation of the wetland surface, the elevation of the lowest point in the valley (or thalweg) and elevation of bedrock

The 1938 aerial photographs showed that a large number of active channels were evident in the southern part of the wetland (Figure 4), some of which were isolated within the wetland (not connected to a stream that leads into the outflow), and some of which were discontinuous (linear or oval areas of open water that are stream-like in appearance but lack continuity as they are interrupted by patches of emergent vegetation). There were also three areas of open water that had the appearance of former oxbow lakes, although the two northernmost lakes had a somewhat angular and artificial appearance casting doubt on their possible origin.

There were also a large number of artificial drains leading into the wetland and perpendicular to it (particularly from the town in the north of the study area), while along the fringe of the wetland they were oriented sub-parallel to the valley. Some of the drains oriented down the valley were sufficiently extensive to form areas of open water.

The photograph taken in 1954 (Figure 5) showed a smaller number of active channels, and some of the active channels present in 1938 had become discontinuous (inactive) in 1954. The areas of open water had disappeared, although signs of their presence were evident in the photographs. Most drains were not visible in the photography, except for a small number leading from town properties into the wetland.

The road from Volksrust to Wakkerstroom (R543) was constructed between 1938 and 1954, and it crosses the wetland in the study area. Although the road could potentially impact the wetland there are a large number of culverts beneath the road and its impact may therefore be small (Kotze *et al.*, 1994).

The 2004 aerial photographs (Figure 6) showed a similar number of channels to the 1954 photographs, but some of the previously discontinuous channels were continuous, suggesting that they were active again. In comparison to the 1938 photographs, the 2004 photographs showed no increase in the number or collective length of channels.

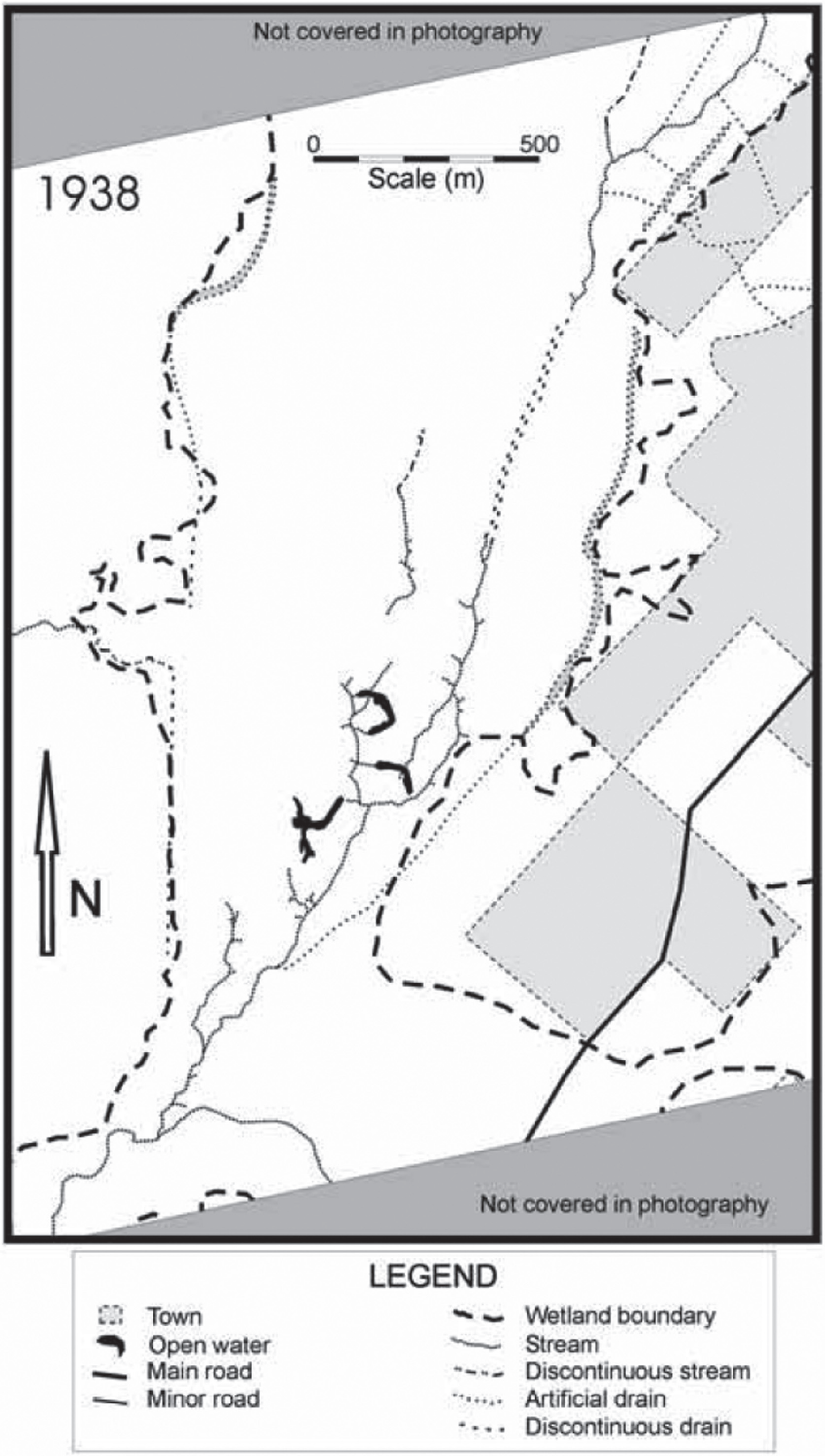


Figure 4: Distribution and activity of channels and drains in the lower Wakkerstroom Vlei based on the interpretation of aerial photographs taken in 1938

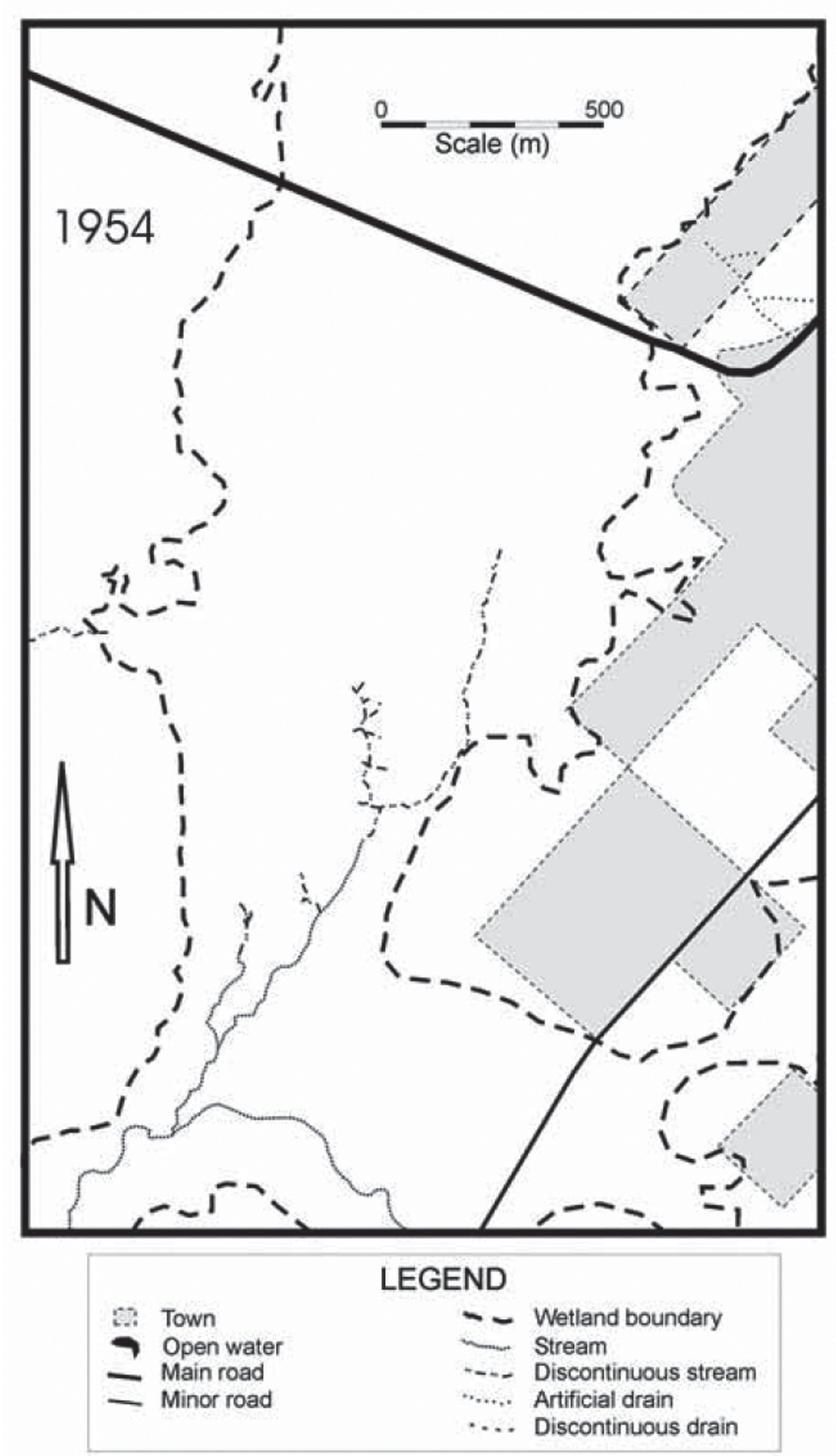


Figure 5: Distribution and activity of channels and drains in the lower Wakkerstroom Vlei based on the interpretation of aerial photographs taken in 1954

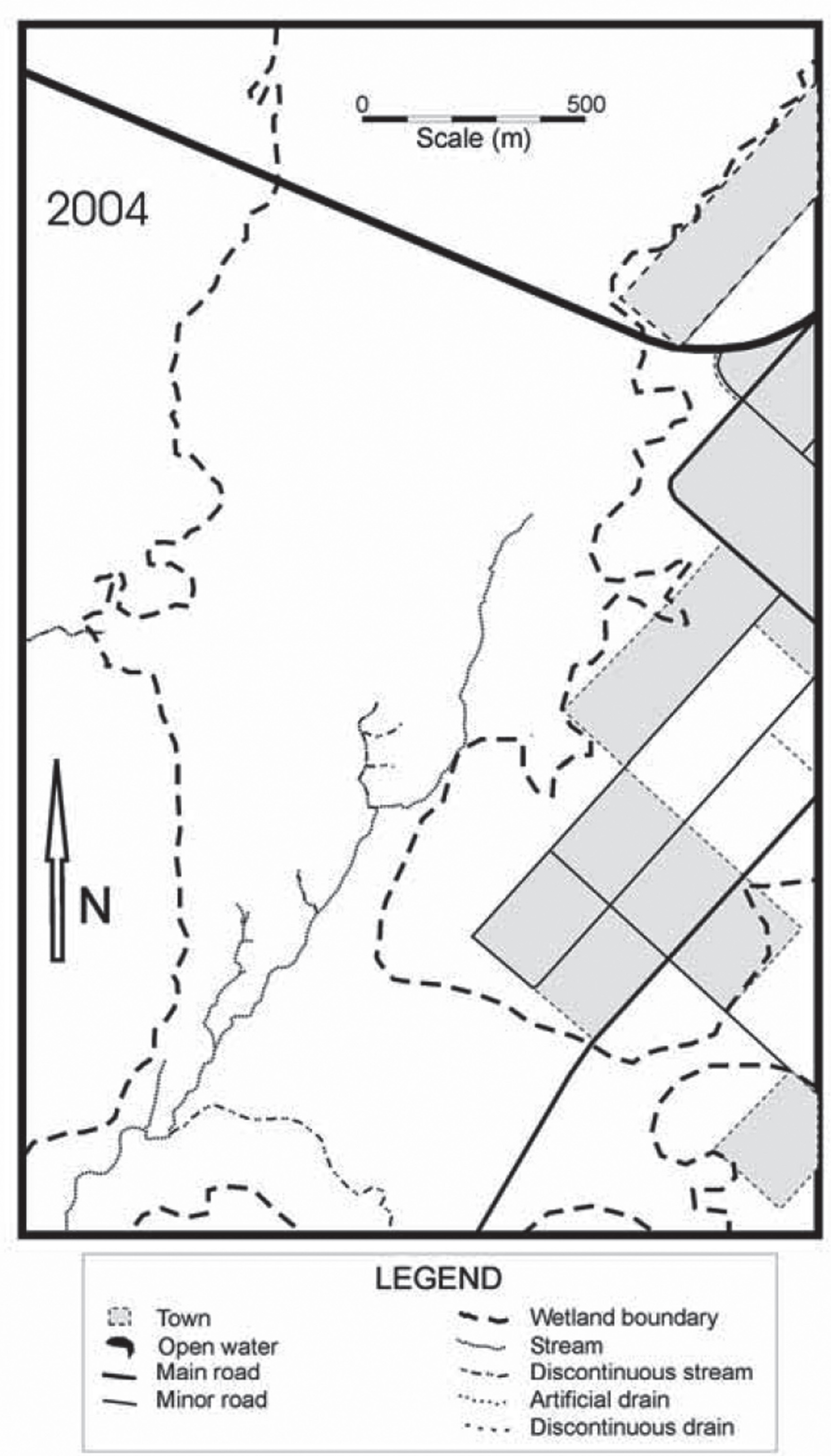


Figure 6: Distribution and activity of channels and drains in the lower Wakkerstroom Vlei based on the interpretation of aerial photographs taken in 2004

c. Wetland Health

The area in this study considered to potentially be affected by gullies extends downstream from the road that crosses the wetland, as the elevation of the spillways of the culverts beneath the road will prevent headward erosion into the area upstream of the road. The wetland area below the road, which is 71 ha in extent, was thus the focus of the rehabilitation intervention. An assessment of the health of this 71 ha area was conducted for the planning of rehabilitation interventions. Two situations were compared: an un-eroded situation, where water flow through the 71 ha remains predominantly diffuse, and an eroded situation, which would result if the channels present in the south-western part of the area were to extend throughout the area through headward erosion. Rehabilitation structures were constructed by Working for Wetlands in the channels in order to minimize the risk of their advancing through headward erosion.

From Table 1, the hydrological health of the wetland in an eroded situation (if rehabilitation did not take place) is likely to be 6, which indicates a seriously impacted wetland (Table 2). The factors that contribute to this low state of health are the headward erosion along two gullies as far upstream as the road crossing, which will carry most of the flow in the wetland. However, in the rehabilitated state, the health is likely to be 1, where the impacts are small and the modification to the health of the wetland is also small. This means that a large degree of health is secured through the rehabilitation interventions.

Table 1 shows that the geomorphic health of the Wakkerstroom Vlei without rehabilitation is likely to be 2.5, which indicates a moderately impacted wetland (Table 2). This rating is despite the gully extending all the way through the relevant section of the wetland. However, the width of the gully is very small in relation to the width of the wetland such that the inpact on the geomorphology of the wetland is not great. With rehabilitation the wetland can be considered to be in a natural state with a health score of 0.5. Thus, rehabilitation is beneficial to the wetland's geomorphic health.

The vegetation health of the wetland without rehabilitation is likely to be largely impacted (health score = 5.0), due to the desiccating effect of drainage caused by the gully. After rehabilitation, the health score is likely to be 1.5, which reflects a small degree of alteration due to some desiccation caused by the gully in its present state.

Headward erosion, if it occurred and was allowed to proceed unchecked, would have a significant impact on wetland health.

Table 1: Predicted level of health of the of the lower unchannelled portion of the Wakkerstroom Vlei under a rehabilitated state (i.e. any erosion headcut advance is halted through erosion control) compared with an un-rehabilitated state (i.e. where headcuts would advance through the entire portion of wetland)

Health component	Score	Rationale
Hydrological health for the eroded situation	6/10	The hydrological health has been impacted only slightly by: 1. upstream dams and water abstraction (low relative to the mean annual runoff); and 2. the upstream road crossing (which includes several culverts, minimizing its impact on flow through the wetland). Impacts from the upstream catchment remain as above. Assuming that two of the arms of the headcut each connect as an erosion gully with one of the culverts under the road, this will work together with the road to effectively cut off flow to the lower unchannelled valley bottom area. This cutting off of flow will, however, not be complete because, although the two connected culverts will be the ones carrying the most flow, there will be some flow through the 'unconnected' culverts, particularly during the wet season, as well as inflow from a right hand tributary situated below the road crossing. The two gullies will be moderately effective in draining away the diffuse flow passing through the affected area, given the moderate depth of the gullies (0.8 m), the very gentle slope of the wetland surface, and the low hydraulic conductivity of the wetland soil that will restrict the amount of seepage into the gullies.
Hydrological health with rehabilitation	1/10	The hydrological health has been impacted only slightly by: 1. upstream dams and water abstraction (low relative to the mean annual runoff); and 2. the upstream road crossing (which includes several culverts, minimizing its impact on flow through the wetland). Onsite impacts on hydrological health are slight and result from trampling by cattle
Geomorphic health for the eroded situation	2.5/10	The extent of the lower unchannelled portion affected by the gullies is taken as 25%, given the fact that the gullies will extend its entire length but collectively will be <5% of the wetland width, which is greater than 1000 m. The intensity of this impact is moderate given the depth of the gully (0.8 m), its width of ~10 m, multiple headcuts, and the fact that an intermediate level of sediment deposition and vegetation establishment in the gully is anticipated.
Geomorphic health with rehabilitation	0.5/10	Impacts on the geomorphic health of the wetland are low. Localised erosion is present at the transition between natural diffuse flow and natural channel flow. However, a comparison of the airphoto series dating from 1938, shows that although there have been some changes in the pattern of the channels, involving both advance and retreat, overall there has been no net advance of the channels into the unchannelled portion since 1938.
Vegetation health with reahbilitation	5/10	The health of the vegetation will decline as the hydrology dries out the area, but some of the dominant hydric species such as *Carex acutiformis* are likely to persist given their tolerance to a very wide range of wetness conditions.
Vegetation health for the rehabilitated situation	1.5/10	The vegetation of the affected area is largely intact and is dominated by indigenous hydric species. However, its health has been diminished somewhat by the presence of some alien species, notably *Phalaris arundinacea* and *Persicaria hydropiper* and the high abundance on the margins of the area of pioneer species such as *Eragrostis planiculmis*.

Score: 0 = health is completely natural (pristine); 10 = health is completely lost.

See Macfarlane *et al*. (2009) for the rationale underlying the scoring system.

Table 2: **Guideline for assessing the magnitude of impact on wetland health**

Impact category	Health description	Impact score range
None	No discernible modification or the modification is such that it has no impact on wetland health.	0-0.9
Small	Although identifiable, the impact of this modification on wetland health is small.	1-1.9
Moderate	The impact of this modification on wetland health is clearly identifiable, but limited.	2-3.9
Large	The modification has a clearly detrimental impact on wetland health. Approximately 50% of wetland health has been lost.	4-5.9
Serious	The modification has a clearly adverse effect on this component of habitat health. Well in excess of 50% of the wetland health has been lost.	6-7.9
Critical	The modification is present in such a way that the ecosystem processes of this component of wetland health are totally / almost totally destroyed.	8-10

d. Provision of ecosystem services

The effect of rehabilitation on the delivery of ecosystem services is also appreciable if it is assumed that headward erosion will propagate upstream in the wetland as far as the road crossing. Recall that the tool *WET-EcoServices* (Kotze *et al*., 2009) scores the delivery of ecosystem services on a scale from 0 to 4. Those ecosystem services that are secured to a large degree by rehabilitation (ecosystem service scores increase in value by 3 or 4) include biodiversity maintenance, erosion control and carbon storage. Rehabilitation improves the delivery of streamflow regulation, sediment trapping, and tourism and recreation to a moderate extent (ecosystem service scores increase in value by 2). Flood attenuation, phosphate assimilation, nitrate assimilation, toxicant assimilation and education and research are modestly improved (ecosystem service scores increase in value by 1). Rehabilitation has no effect on water supply for human use, cultivated crops and cultural significance. Due to the impact of rehabilitation on the wetness of the area, areas that would become accessible to livestock if erosion was allowed to proceed, will be reduced. As such the impact of rehabilitation on the use of the wetland for livestock grazing, is negative.

Table 3: Anticipated difference in the delivery of ecosystem services by the lower unchannelled portion of Wakkerstroom wetland under an eroded situation compared with a rehabilitated situation

Ecosystem service	Difference between the eroded situation and rehabilitated situation1	
	Score[1]	Rationale for the score
Flood attenuation	+1	In the eroded situation, the gullies will contain some of the flood flows, but because the dimensions of the gully are not great, major stormflows are likely to overtop the gullies and spread across the surface of the wetland. Thus, the extent of the area over which flood flows can spread will be the same in the rehabilitated situation compared with the eroded situation, but the frequency with which this occurs will be less in the eroded situation. The surface roughness will be lower in the eroded situation, particularly if the *Phragmites* reeds are lost because of the drier conditions. The higher level of wetness in the rehabilitated situation, by reducing the volume of floodwaters that can be stored in the wetland's soils, will counteract to some extent its potentially greater positive contribution to flood attenuation. Downstream floodable property is very limited in both situations.
Streamflow regulation	+2?	The wetland is fed primarily by surface water inputs, and thus its potential influence in regulating the discharge of sub-surface water is limited. In the rehabilitated situation, its potential to store incoming water and release this during low flow periods would be enhanced by the fact that extensive frosting back of vegetation occurs in winter that would significantly reduce evapo-transpiration. However, the potential storage of water is probably limited by the very low hydraulic conductivity of the clay-rich soil. The hydrology of Wakkerstroom vlei is poorly understood, and thus a low confidence is attached to the score assigned.
Sediment trapping	+2	The sediment supplied to the lower unchannelled portion from upstream in the main body of the wetland is likely to be naturally very low given that most of the sediment carried down the main body of the wetland would have already been deposited further upstream because of the very gentle gradient and great length of the main body of the wetland. The main supply of sediment would be from the right hand tributary. While this sediment would continue to be deposited in the rehabilitated situation, its deposition would be somewhat disrupted in the eroded situation.
Phosphate assimilation	+1	The effectiveness of a wetland in trapping phosphates is generally closely associated with its effectiveness in trapping sediment (Hemond and Benoit, 1988). Therefore, the rehabilitated situation will be more effective in assimilating phosphates than the eroded situation. However, the potential sources in the wetland's catchment are limited and thus the wetland is not afforded a high opportunity to assimilate phosphates.
Nitrate assimilation	+1	The rehabilitated situation will be more effective in assimilating nitrates than the eroded situation owing to: (1) its higher level of wetness, which enhances denitrification; (2) more favourable flow patterns, which provide for greater contact between water and sediment; and (3) greater accumulation of soil organic matter (Hammer, 1992; Reddy and Patrick, 1984). However, the opportunity for the wetland will remain relatively low as there are limited sources of nitrates in the catchment.
Toxicant assimilation	+1	The rehabilitated situation will be more effective in assimilating toxicants than the eroded situation owing to: (1) its higher level of wetness (2) more favourable flow patterns, which provide for greater contact between water and sediment; and (3) greater accumulation of soil organic matter and sediment. The opportunity afforded to the wetland is very limited as there are few sources of toxicants in the catchment, the most important source probably being potential wash into the wetland of toxicants spilled onto the main road.
Erosion control	+3	The eroded situation, by its very nature, would contribute very little to erosion control. In contrast, the rehabilitated situation has been designed specifically to control erosion. However, the erosion potential of the site is not inherently high, and therefore it would not score +4
Carbon storage	+3	The much higher level of wetness in the rehabilitated situation (extensive permanently saturated areas exist) compared with the eroded situation favours a greater accumulation of soil organic matter (Tiner & Veneman, 1988).

Biodiversity maintenance	+4	Hydrology is the most important determinant affecting the biota in a wetland (Mitsch and Gosselink, 1986). Therefore, the rehabilitated situation, where the hydrology is much more intact than the eroded situation, will provide a greater contribution to biodiversity maintenance. Of particular significance is that the area in its rehabilitated state provides non-breeding habitat to the critically endangered White-winged flufftail (*Sarothrura ayres*) (although their occurrence at the site is sporadic) and is also used for breeding by Crowned Crane (*Balearica regulorum*), both of which require a high level of wetness. Therefore, in its eroded state the area would be rendered unsuitable for these and other species requiring a high level of wetness.
Water supply for human use	0	By significantly increasing the retention of water, the rehabilitated situation results in water being much more readily available for domestic use. Local people are, however, only dependent on this supply, when their piped water scheme fails, which lessens the importance of the wetland.
Natural resources	-1	In its rehabilitated state the area is used regularly for livestock grazing, but the high level of wetness renders extensive areas inaccessible for grazing. The increased level of wetness resulting from rehabilitation would reduce the accessibility for grazing. Very little harvesting of reeds or sedges takes place.
Cultivated foods	0	The wetland is not cultivated.
Cultural significance	0	Although a channelled part of the upper portion of the wetland has cultural significance for baptisms, no such cultural values have been reported for the lower unchannelled portion.
Tourism and recreation	+2	The value of Wakkerstroom wetland for tourism derives mainly from the birdlife associated with the wetland and the scenic value of its extensive area of the wetland adjacent to Wakkerstroom town. Both of these elements would be diminished in the eroded situation. Although the lower unchannelled portion of the wetland is not a key area for viewing birds, it is immediately adjacent to the main entrance road to the wetland (i.e. birds can be easily viewed).
Education and research	+1	The wetland has been the subject of several research projects, but the research value of the wetland does not rest specifically on the unchannelled lower portion remaining intact.

[1] Difference in level of ecosystem delivery between the un-rehabilitated (i.e., eroded) situation and the rehabilitated situation (0=none/ negligible; 1=moderately low; 2=intermediate; 3=moderately high; 4= high) + =improvement, - =decline

5 Discussion

The assessment shows that if erosion progressed unchecked, the Wakkerstroom Vlei would degrade and its delivery of ecosystem services would decline. These impacts are viewed as appreciable and provide justification for rehabilitation.

However, the analysis of wetland morphology and the aerial photograph interpretation revealed that channels (or gullies) in the Wakkerstroom Vlei are located in the region of the wetland where the slope of the wetland surface is steepest. Also, they are dynamic in that they do not remain continuously active, and they can be reactivated. These data suggest that the gullies are unlikely to extend further upstream by headward erosion as the slope upstream of their present extent is too low for erosion to occur. Therefore, the assumption that headward erosion will proceed is questionable, although it is recognized that the road crossing could be contributing to increasing the likelihood of future erosion in the downstream area. Questions such as these are examined in the MSc thesis written by Joubert (2008) in which the reasons for the existence of the Wakkerstroom Vlei are described.

6 References

Joubert R, 2008. *The origin of Wakkerstroom Vlei, Mpumalanga Province, South Africa.* MSc Thesis, School of Environmental Science, University of KwaZulu-Natal. In Preparation.

Begg GW, 1989. *The wetlands of Natal (Part 3). The location, status and function of the priority wetlands of Natal.* Natal Town and Regional Planning Report 73.

Hammer DA, 1992. *Creating freshwater wetlands.* Lewis Publishers, Baco Raton.

Hemond HF and Benoit J, 1988. Cumulative impacts on water quality functions of wetlands. *Environmental Management,* 12: 639-653.

Kotze DC, Breen CM and Klug JR, 1994. A management plan for Wakkerstroom vlei. In: Breen CM, Kotze DC, Klug JR, Darroch MAG and Oellermann RG (eds), *Wetland preservation valuation and management practices applied to wetlands; and management plans for Wakkerstroon vlei, Ntabamhlope vlei, Mgeni vlei, Blood River vlei, and Boschoffsvlei.* WRC Report No 501/5/94. Water Research Commission, Pretoria.

Kotze DC, Marneweck GC, Batchelor AL, Lindley DS and Collins NB, 2009. *WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands.* WRC Report No. TT 339/09. Water Research Commission, Pretoria.

Macfarlane DM, Kotze DC, Ellery WN, Walters D, Koopman V, Goodman P and Goge M. 2009. *WET-Health: A technique for rapidly assessing wetland health.* WRC Report No. TT 340/09. Water Research Commission, Pretoria.

Reddy KR and Patrick WH, 1984. Nitrogen transformations and loss in flooded soils and sediments. *CRC Critical Reviews in Environmental Control,* 13: 273-309.

Tiner RW and Veneman PLM, 1988. *Hydric soils of New England.* University of Massachusetts Cooperative Extension, Massachusetts.

Working for Wetlands Programme 2003. *Working for Wetlands Programme Rehabilitation Plan 2003/2004: Wakkerstroom.*