Assessment of the long-term response to rehabilitation of two wetlands in KwaZulu-Natal, South Africa.

Thesis submitted in fulfilment of the requirement for the degree of Master of Science in Environmental Science, Rhodes University, Grahamstown.

by

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ABSTRACT

Assessing the outputs and outcomes of wetland rehabilitation activities is recognised by the 'Working for Wetlands' programme in South Africa as important, but to date has been limited. An assessment of the ecological outcomes and the structural outputs of the Working for Wetlands rehabilitation implemented in the Killarney and Kruisfontein wetlands, KwaZulu-Natal, in 2005 was undertaken. The assessment of outcomes included an evaluation of the changes in terms of ecological integrity and the supply of ecosystem services, using WET-Health and WET-EcoServices assessment techniques respectively, and vegetation composition. Improvements in hydrological and geomorphic integrity were recorded in both wetlands, resulting in improved ecosystem services delivery. However, investigation of vegetation composition using the Wetland Index Value and Floristic Quality Assessment Index showed that, seven years after rehabilitation, Killarney's vegetation composition had improved, but Kruisfontein's vegetation was still largely dominated by pioneer species and appeared to be stable, but in a severely transformed state. The response of these wetlands has shown that sites for rehabilitation should be screened before work begins, and wetlands requiring intensive management of vegetation recovery should be assessed in terms of the objectives and the anticipated benefits of the project. The assessment of the outputs included an evaluation of structural integrity, survival and cost-effectiveness. Limited issues, mostly relating to deviations from the designs during construction, were identified with regards to the structural outputs at each of the wetlands. However, the spreader canals at both Killarney and Kruisfontein wetlands were not functioning as intended and concentrated flows from the spreader canals were evident in both wetlands. The use of spreader canals should therefore be carefully planned and implemented for future wetland rehabilitation projects. Consideration of ZAR per hectare equivalent re-instated/secured provided a useful initial means of determining the cost-effectiveness of the wetland rehabilitation. However, additional factors need to be considered, such as, the nature of the rehabilitation activities, the type and size of the problem being addressed, rehabilitation of priority wetlands, limitations imposed by funders, and risks that need to be addressed by the rehabilitation strategy. Furthermore, the evaluation of the Killarney and Kruisfontein wetlands

highlighted the need to revise the Water Research Commission's Wetland Management Series, especially those documents or guidelines relating to rehabilitation planning (WET-RehabPlan), interventions (WET-RehabMethods), and monitoring and evaluation (WET-RehabEvaluate).

DECLARATION

This thesis is based largely on a WRC funded Research Program entitled "The long-term response of two wetlands to wetland rehabilitation undertaken by Working for Wetlands (K5/2035)". One of the outcomes of funding of research by the Water Research Commission, is the training of scientists through training of senior postgraduate students. This thesis is being submitted to support the achievement of this outcome.

I therefore wish to confirm that I was responsible for the writing of the proposal for the research project (K5/2035), funded by the Water Research Commission, and was project leader and principal scientist for the project that formed the basis of this Master of Science thesis. A part of this thesis (Chapters 1 and 4) has been published in a peer reviewed journal (see below), and the material in these chapters has been based (and reproduced) from this publication. The remainder of the thesis are based partly on a WRC Report (*WRC Report No. 2035/1/13*). Again, the details of the relationship of this thesis with that WRC report are clearly spelled out below.

Chapters 1, 2, 3 and 5 incorporate information derived from a Water Research Commission document published as: *Cowden C, Kotze D, and Pike T. 2013. Assessment of the long-term response of two wetlands to Working for Wetlands rehabilitation. WRC Report No. 2035/1/13, Water Research Commission, Pretoria*.

I was the project leader for the study, undertook the fieldwork and analysis, and wrote the majority of the report. Due to the multi-disciplinary nature of the research, expert engineering input was received from Mr. T Pike in terms of the assessment of the structural interventions, and Dr D Kotze assisted with the vegetation sampling. Both co-authors contributed to the writing and editing of aspects of the document and where use of the work of the co-authors has been made in this thesis, this is acknowledged according to academic ethical standards as based on the Ethics Policy for Researchers of Rhodes University (www.ru.ac.za/research/ethics).

Chapters 1 and 4 incorporate information from a scientific paper published as: *Cowden C, Kotze DC, Ellery WN and Sieben EJJ. 2014. Assessment of the long-term response to rehabilitation of two wetlands in KwaZulu-Natal, South Africa. African Journal of Aquatic Science, Vol. 39*, No. 3.
I was the lead author on this scientific paper and can claim that the three co-authors (two of whom are academic co-supervisors of this thesis), did nothing more than offer academic advice to me in conceptualising the study, collecting, analysing and interpreting the data, writing, submitting, editing and addressing comments from the reviewers relating to the paper. The co-authors contributed to the published manuscript as follows: Dr D Kotze contributed towards writing and editing of the document; Prof W Ellery acted as advisor, offering suggestions as well as editorial changes; and Dr E Sieben assisted with aspects of the preliminary statistical analysis.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

LIST OF ABBREVIATIONS

Acronym	Explanation
DWAF	Department of Water Affairs and Forestry
EKZNW	Ezemvelo KwaZulu-Natal Wildlife
EPWP	Expanded Public Works Programme
FQAI	Floristic Quality Assessment Index
GIS	Geographic Information System
Ha equiv.	Hectare Equivalents
HGM	Hydrogeomorphic
KZN	KwaZulu-Natal
NEMA	National Environmental Management Act (107 of 1998)
NWA	National Water Act (36 of 1998)
NNR	Ntsikeni Nature Reserve
SANBI	South African Biodiversity Institute
USA	United States of America
WfWet	Working for Wetlands
WIV	Wetland Index Value
WRC	Water Research Commission

CHAPTER 1 - INTRODUCTION

1.1 Background

Wetlands are important ecosystems within the landscape as they provide ecosystem services directly related to water quantity and quality (Kotze et al. 2007). Nel and Driver (2012) estimate that in excess of 65% of South Africa's wetlands are under threat, 48% of these are critically endangered. Wetlands in KwaZulu-Natal (KZN), including the priority wetlands of KZN as described by Begg (1989), have been subjected to high levels of modification and destruction (Kotze et al. 1995; Macfarlane et al. 2012). The factors contributing to the degradation of wetland systems vary greatly, but the predominant impacts include urbanisation, abstraction, dams, cultivation, drainage and over-grazing (Macfarlane et al. 2012). At a regional level, the loss of wetland habitat is of concern considering the contributions of wetland habitat towards maintaining and enhancing water quantity and quality, and supporting unique biological diversity and other ecosystem services (Kotze et al. 2007).

The recognition of benefits associated with wetland ecosystems and the need to reverse ecosystem degradation has resulted in the initiation of wetland restoration projects amongst individuals and organisations across the globe (Ramsar Convention 2002). Ecosystem restoration is defined as the planned activities that assist the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER 2004). Although often used in similar contexts, Grenfell et al. (2007) describe the terms restoration and rehabilitation from the perspective of interventions within South African wetlands. For this study, the term rehabilitation was considered to be appropriate as it is consistent with the objectives of Working for Wetlands, the statutory agency responsible for most wetland rehabilitation in South Africa. Thus, rehabilitation is defined as "the process of reinstating natural ecological driving forces within part or the whole of a degraded wetland to recover former or desired ecosystem structure, function, biotic composition and ecosystem services" (Grenfell et al. 2007 p. 49).

Within South Africa, national legislation highlights the importance of having a protected environment for the benefit of present and future generations. In an attempt to address historic impacts on wetland ecosystems, the Working for Wetlands (WfWet) programme was initiated in 2000. When this research was undertaken, the WfWet programme was a combined initiative of the statutory Department of Environmental Affairs, Department of Tourism, Department of Agriculture Forestry and Fisheries, and Department of Water Affairs. The WfWet programme was housed within the South African National Biodiversity Institute (SANBI), which falls under the umbrella of the Department of Environmental Affairs. The approach adopted by the Working for Water programme, and similarly by WfWet, has been compared with the concept relating to payments for ecosystem services, where voluntary payment, in this case government funding, is made in order to deliver defined ecosystem services (Turpie et al. 2008). However, WfWet uses wetland rehabilitation rather than alien invasive plant clearing as the mechanism to achieve the overriding objectives of the programme. The purpose of the WfWet programme is described as follows: "to champion the protection, rehabilitation and sustainable use of South Africa's wetlands through co-operative governance and partnerships" (WfWet 2005a p.4).

The majority of WfWet's funding originates from the treasury as a component of the Expanded Public Works Programme (EPWP) and as such, WfWet is bound by limitations imposed by the funding agent, which include defined labour components for planned wetland rehabilitation. The intensive rehabilitation planning undertaken by WfWet, to provide adequate details to project teams during implementation, also serves to reduce funds available for monitoring and evaluation. To date monitoring and evaluation within the WfWet programme has been limited to information required for their own administrative processes and for the reporting of specific data of importance to the EPWP regarding the implementation of the programme. These data include costs, compliance with the programmes best management practices, employment details (relating to target groups and remuneration), and training that has been undertaken. Such information is reported for each project implemented by WfWet. Despite spending in excess of ZAR 80 million annually on the rehabilitation of wetlands, as yet the formal evaluation of the long-term ecological outcomes of WfWet's investment has been very limited.

The need to undertake such evaluations of completed wetland rehabilitation is considered critical to inform our understanding of system response in order to inform future rehabilitation efforts. WfWet have acknowledged the need to develop a comprehensive monitoring and evaluation framework to support learning and report on the ecological outcomes of their rehabilitation activities based on broad-scale and strategic research across multiple WfWet sites. In addition to the WfWet programme, wetland rehabilitation is being undertaken by organisations and individuals, generally as a consequence of complying with conditions of authorization in terms of the National Environmental Management Act No 107 of 1998 (NEMA) and the National Water Act No. 36 of 1998 (NWA), as a means of mitigating the impacts associated with a proposed activity with an environmental impact. Restoration on this basis needs to be assessed to determine whether compliance has been achieved.

Rutherford et al. (2000) state that without the formal evaluation of project success, rehabilitation techniques are unlikely to be improved as there is limited understanding of the need for improvement. This highlights the importance of revisiting wetland rehabilitation projects, especially by those individuals undertaking wetland rehabilitation planning, in order to 'close the loop' of continually improving wetland rehabilitation by documenting lessons learnt (Figure 1.1). Such reflection on lessons learnt in past wetland rehabilitation projects serves to document rehabilitation efforts in a way that is consistent with the 'learning by doing' approach, which has generally been adopted to a limited extent by wetland rehabilitation practitioners in South Africa. In an effort to stimulate an approach to learn through past rehabilitation activities, an expert-system 'tool', WET-RehabEvaluate (Cowden and Kotze 2009) was designed, which presented guidelines for monitoring wetland rehabilitation. Subsequently, monitoring of rehabilitation has been confined almost entirely to an assessment of the extent to which rehabilitation plans were adhered to (rehabilitation 'outputs'), but little attention has been paid to assessing the extent to which rehabilitation outcomes such as ecosystem integrity or the delivery of ecosystem services have been achieved. There was a clear need to evaluate the outcomes of rehabilitation projects in order to support and strengthen the implementation and science of wetland rehabilitation in South Africa.

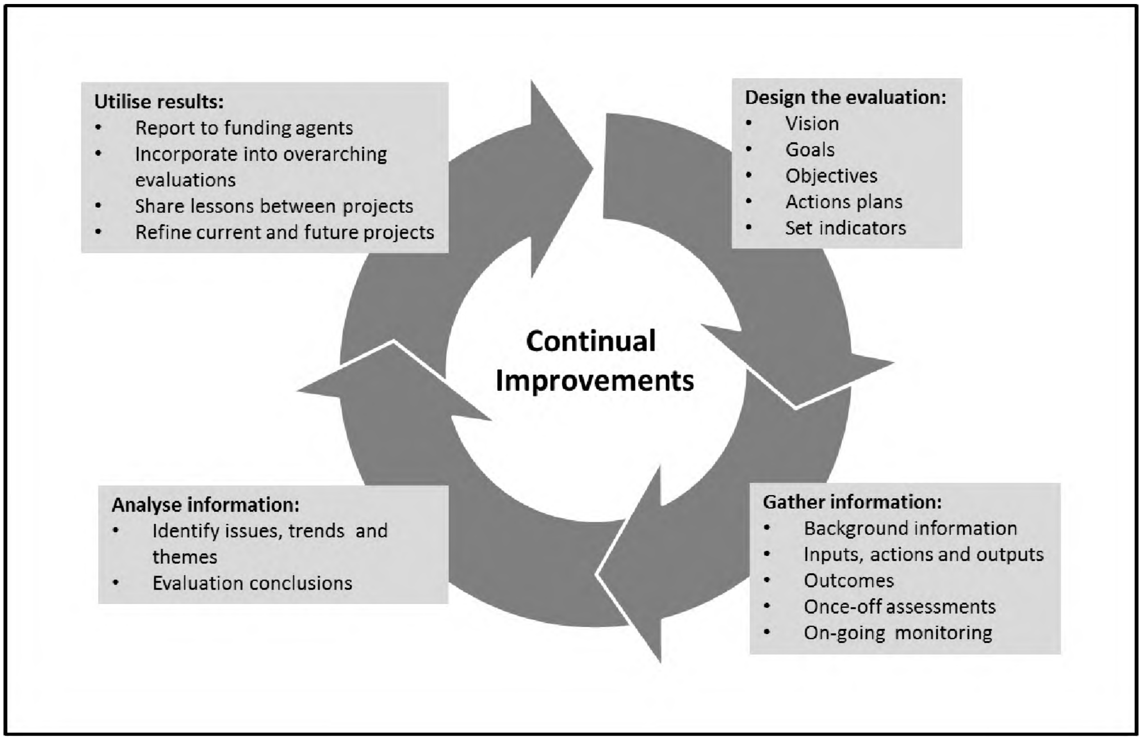

Figure 1.1. Evaluation process ultimately resulting in continual improvement of wetland rehabilitation projects (adapted from Woodhill and Robins 1998)

1.2 Aim and objectives

The aim of this study was to assess the ecological outcomes of the rehabilitation of two contrasting wetland sites with similar objectives. The two wetland sites, the Killarney and Kruisfontein wetlands in KwaZulu-Natal, described in more detail in Section 4.1, were rehabilitated by the WfWet programme in 2006. Killarney wetland is a valley-bottom (as per Kotze et al. 2007; Ollis et al. 2013) tributary of the Ntsikeni Vlei, a proclaimed Ramsar site. Kruisfontein wetland includes valley-bottom and seepage wetland areas (as per Kotze et al. 2007; Ollis et al. 2013) associated with the confluence of two minor tributaries and the Mooi River and was historically modified for cultivation purposes. In both wetlands the rehabilitation focussed on reinstating the hydrological regime by promoting more frequent flooding and redirecting flows to desired areas. It was anticipated that the reinstated hydrology would facilitate the re-establishment of wetland plant species, specifically those associated with seasonal and permanent wetness.

Given the aim of the study, the following objectives were identified for the Killarney and Kruisfontein wetlands:

1) Determine the ecological outcomes of the rehabilitation interventions, including wetland ecological integrity, ecosystem services, and vegetation composition for each wetland;
2) Determine the structural integrity, survival of the rehabilitation interventions, and cost of the interventions at each site (i.e. the effectiveness of rehabilitation outputs); and
3) Document lessons learnt from monitoring as described in the first two objectives for future practices – from project inception, rehabilitation planning, project implementation and the long-term monitoring of wetland rehabilitation efforts.

1.3 Study areas

The study areas were the Killarney wetland in south-western KZN and the Kruisfontein wetland in the KZN Midlands (Figure 1.2), both of which are channelled valley-bottom wetlands in accordance with the hydrogeomorphic (HGM) types defined by Kotze et al. (2007) and Ollis et al. (2013).

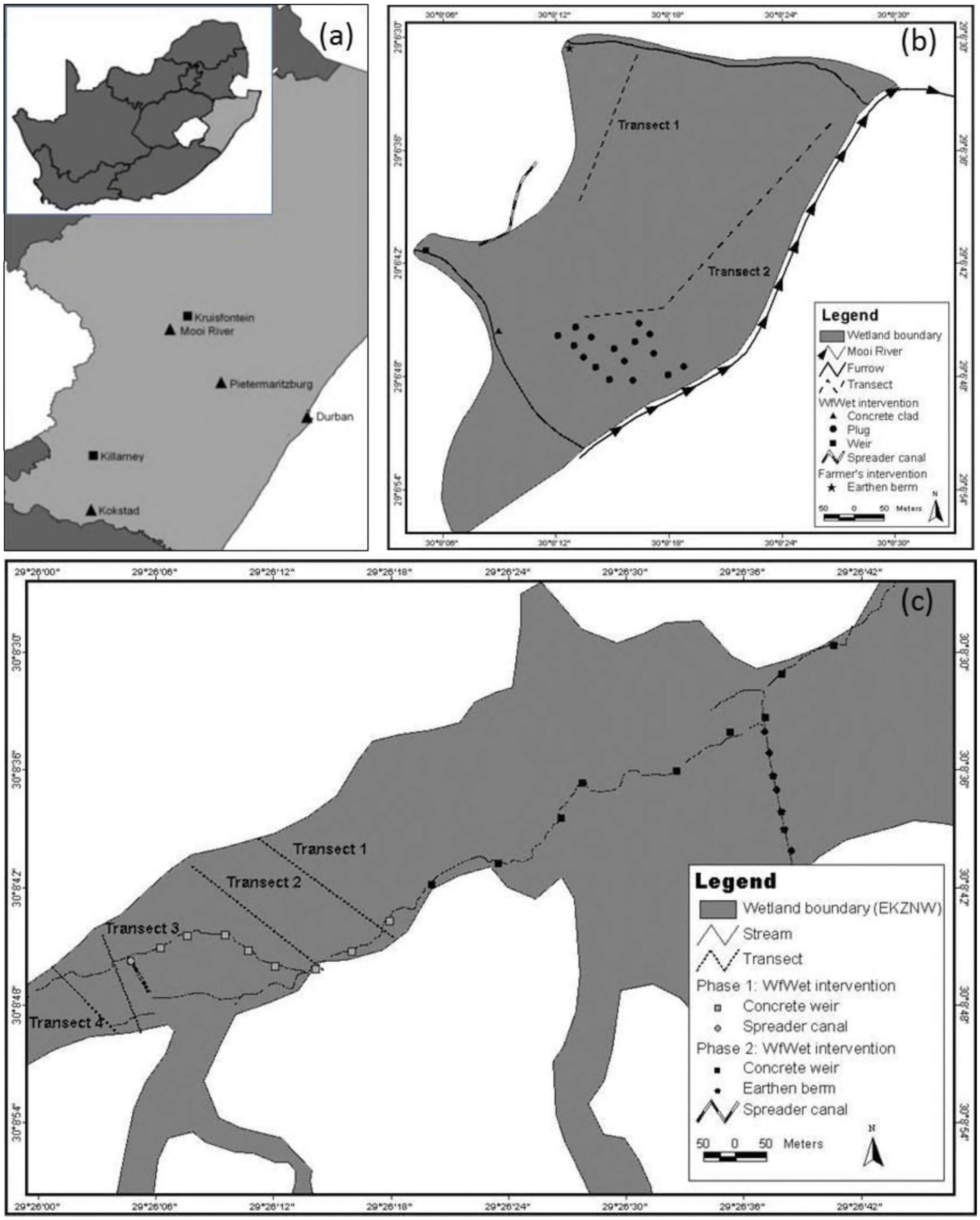

Figure 1.2. Study sites, showing (a) location of wetlands within KwaZulu-Natal, South Africa in relation to major cities, (b) Kruisfontein and (c) Killarney wetlands with sampling, survey and intervention locations.

1.3.1 Killarney wetland

The Killarney wetland (30°08'44" S, 29°26'10" E) is a tributary of the main body of the Ntsikeni Vlei within the Ntsikeni Nature Reserve (NNR), a proclaimed Ramsar site managed by Ezemvelo KZN Wildlife (EKZNW). The wetland drains into the upper reaches of the Lubhukwini River. The NNR originally consisted of farmlands that were proclaimed as a nature reserve in 1978, but was subject to illegal occupation by local communities for an extended period thereafter (Begg 1989). During the period of illegal occupation the area lacked a management plan, and was characterised by the presence of a combination of large- and small-scale gullies, promulgated by a combination of increased runoff, from poorly managed grassland areas, and a poorly planned road crossing. The Killarney wetland was identified for rehabilitation by WfWet in 2005 with the intention being to stabilise the main gully within the system and promote more frequent flooding of the valley-bottom, thereby promoting the re-establishment of plant species associated with the seasonally and permanently wet zones. Rehabilitation was undertaken in 2006.

1.3.2 Kruisfontein wetland

The Kruisfontein wetland (29°06'45" S, 30°08'13" E) includes valley-bottom and seepage wetland areas, located at the confluence of two tributary streams with the Mooi River. The wetland is on privately-owned farmland, approximately 17 km north-east of the town of Mooi River in the KZN Midlands. The Kruisfontein wetland was historically greatly modified for cultivation purposes. Two cut-off drains had been excavated along the north-eastern and south-western boundaries of the wetland, and ridge-and-furrow agriculture had been undertaken across the majority of the wetland. Ownership of the farm changed approximately 10 years ago, at which time cultivation of the Kruisfontein wetland ceased and the land owner attempted to rehabilitate the north-eastern portion of the system in 2004. The Kruisfontein wetland was subsequently identified as a priority for wetland rehabilitation by WfWet in 2005, with the focus being to reinstate the hydrological regime in the south-western and central portions by redirecting the flows from the drainage channels across the site. It was anticipated that the redistribution of flows would be adequate to support the re-establishment of hydric plant species. Rehabilitation took place in 2006.

1.4 Structure of the thesis

The thesis comprises of five chapters, which have been arranged as follows:

- **Chapter 1 - Introduction:** briefly introduces key topics from a South African perspective, including a) what is wetland rehabilitation? ; b) why wetlands are rehabilitated? ; and c) who undertakes wetland rehabilitation? The chapter further describes the importance of monitoring of rehabilitation outcomes as integral to continued learning and therefore to the continual improvement of wetland rehabilitation activities. The aim and objectives of the study and study areas were also described.
- **Chapter 2 - Literature review:** reviews available literature relating to the research objectives, namely, a) assessing structural integrity of rehabilitation interventions; b) investigating ecological outcomes of rehabilitation interventions; and c) reviewing ecological outcomes in relation to the costs of rehabilitation interventions in order to promote learning and thus improve the effectiveness of rehabilitation practices nationally.
- **Chapter 3 – Description of structural outputs:** provides the approach and findings relating to the assessment of the integrity, survival and costs of the rehabilitation interventions.
- **Chapter 4 – Description of ecological outcomes:** provides detailed descriptions of the approach and findings from the investigation of the ecological outcomes of the rehabilitation interventions, including ecological integrity, ecosystem services, and vegetation composition.
- **Chapter 5 - Conclusions and recommendations**: reviews the findings of the study and discusses the implications of these findings in order to evaluate the wetland rehabilitation interventions undertaken at the Killarney and Kruisfontein wetlands. In addition, the chapter reviews the ecological outcomes of the rehabilitation interventions in relation to

the costs of the interventions, taking account of the specific context of the rehabilitation. The chapter also includes recommendations for amendments to existing guideline documents, adaptive management requirements, and changes to wetland rehabilitation practice in South Africa.

CHAPTER 2 - LITERATURE REVIEW

Cowden and Kotze (2009) describe how wetland rehabilitation attempts to achieve a number of results, but distinguish between outputs and outcomes of the project/s. Outputs are engineered modifications of the physical, chemical and biotic environment, including earth-moving and/or construction of physical structures or biotic interventions, which are designed to alter the distribution and/or pattern of water and sediment flow, and the distribution of biota in the landscape. Outputs are therefore those activities and interventions that immediately modify the structure of the physical environment, and which are carried out by practitioners in order to modify natural processes for purposes that achieve longer term perceived benefits. Outcomes are the perceived positive changes to the physical, chemical and biotic characteristics of the system, which are achieved as a longer term consequence of short-term engineered interventions. Generally the intention of rehabilitation is to change the condition of an ecosystem so that it more closely resembles its natural state i.e. the state prior to anthropogenic impacts. In this particular study, the research has focussed on assessing the ecological outcomes of wetland rehabilitation, specifically the influences on the wetland health and the provision of ecosystem benefits and services. However, the research has also focused on assessing the outputs in terms of structural integrity of planned engineered interventions. It is important to note that due to the nature of wetland rehabilitation, reporting is often a mixture peer-reviewed journal articles, monitoring and project reports, and unpublished manuscripts. In a review of articles on wetland restoration in Southwestern USA, Ramstead et al (2012) identified that only 52% appropriate articles were from peer-reviewed journals.

2.1 Wetland rehabilitation practice in South Africa

As described in the introduction, the level of degradation of wetland ecosystems recorded internationally has led to support for wetland rehabilitation initiatives globally. The Ramsar Convention, initiated by an international treaty, serves to promote the conservation and wise use of wetlands globally, especially those of international importance. As a component of its operations the Ramsar Convention produces strategic plans, including wetland restoration, which are governed by specific principles and guidelines (Ramsar Convention 2002). Societies, such as the Society of Wetland Scientists (SWS) and the Society of Ecological Restoration (SER) have also contributed towards the initiative by defining principles and providing guidance regarding wetland rehabilitation (SWS 2001, SER 2004).

In the implementation of wetland rehabilitation the following principles apply as derived from Kotze et al. (2009), SER (2004), Ramsar Convention (2002), and SWS (2001):

- Stakeholder engagement should be an integral aspect of the rehabilitation planning, potentially including land users and broader stakeholders, and rehabilitation should not be undertaken without long-term commitment of relevant stakeholders towards sustaining wetland integrity.
- The conservation, wise use and rehabilitation of wetland ecosystems should be integrated in any management programme. Wetland rehabilitation is unlikely to succeed without integration into a long-term management plan for the wetland and its catchment and as highlighted by the Drivers Pressures State Impacts Response (DPSIR) framework (Smeets and Weterings 1999), addressing identified impacts on a system is not necessarily limited to rehabilitation but may also need to include preventative measures, e.g. reduction in livestock numbers.
- The rehabilitation should be integrated into the existing landscape, and should be cognisant of broader objectives, such as catchment and biodiversity conservation targets.
- Foremost for the rehabilitation would be the elimination of existing and potential threats to the wetland, promoting a system that is resilient to natural disturbance and self-sustaining, as much as possible. In some instances this may require adopting an alternative stable state, as described by Walker et al. (2006), rather than ‘forcing’ the natural/reference condition which may no longer be stable or resilient.
- Rehabilitation plans should include clear objectives, aligned with the guidelines provided by WET-RehabEvaluate (Cowden and Kotze 2009), and should be developed by a multi-disciplinary team incorporating ecological and engineering skills.

- As far as possible, rehabilitation objectives should be aligned with natural processes, promoting a system dominated by indigenous species with a diversity and community structure similar to that of identified reference sites and the presence of functional groups necessary for long-term stability, with system functioning aligned with the normal or reference conditions and the ability to sustain populations.

While principles are important to guide the wetland rehabilitation, practitioners rely on practical guidelines, which in a South African context is provided by the documents within the Wetland Management Series (Dada et al. 2007), especially WET-RehabPlan (Kotze et al. 2009). Since the publication of the Wetland Management Series, wetland rehabilitation has largely followed the approach illustrated in Figure 2.1.

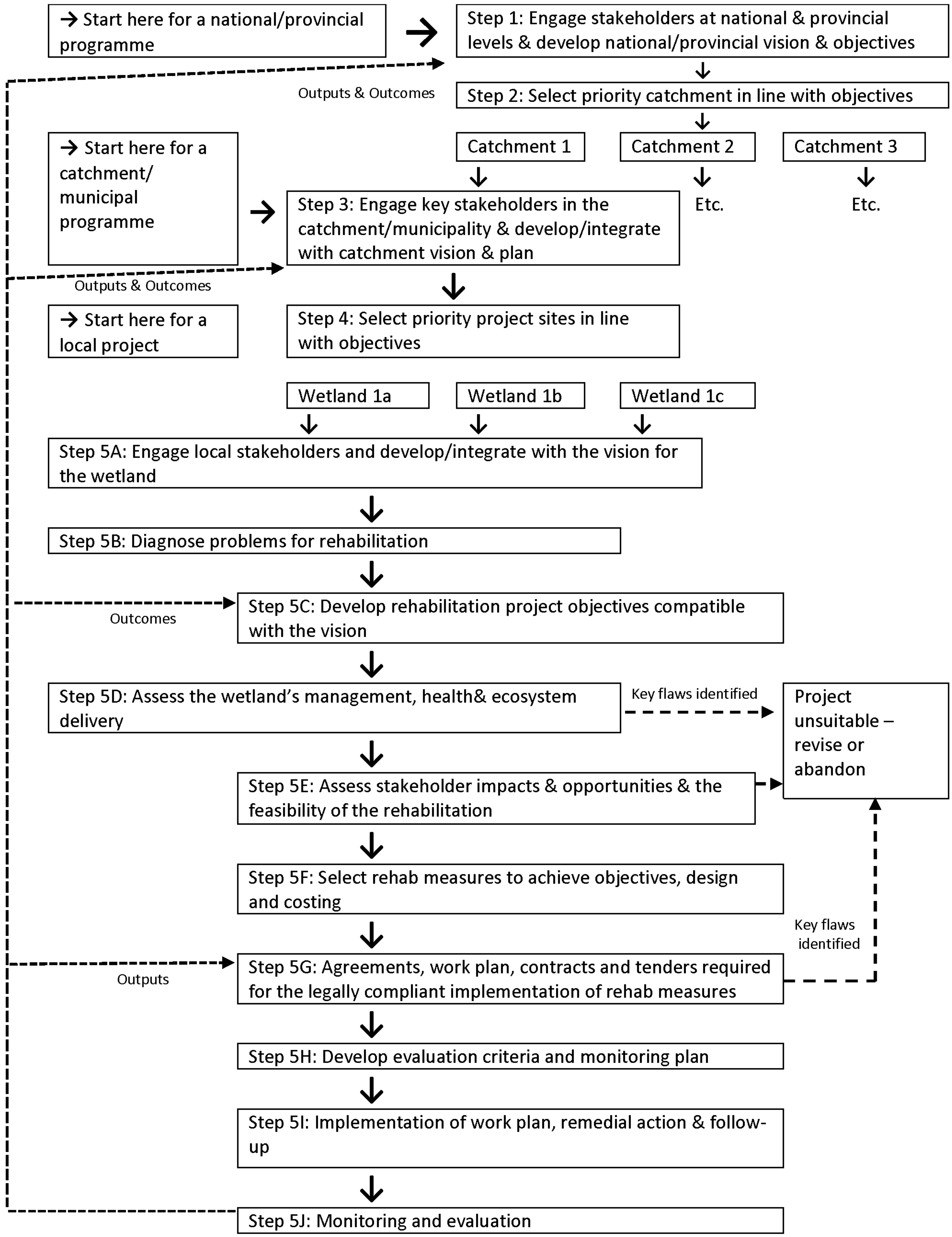

Figure 2.1. Framework for planning wetland rehabilitation modified from Kotze et al. (2009).

2.2 *Structural outputs of wetland rehabilitation*

The outputs of wetland rehabilitation include the engineered interventions and activities that are implemented in accordance with the rehabilitation strategy and to ultimately achieve the project objectives. Outputs include structural interventions such as, concrete weirs across a drainage canal or earthen embankments to redirect surface flows. The interventions adopted vary greatly depending on the particular project being considered and consequently the monitoring of outputs varies too, as described in the following sections.

2.2.1 *Structural wetland rehabilitation*

As described by Hayes et al. (2000) wetland rehabilitation requires the long-term re-establishment of favourable site conditions, based on the careful consideration of site characteristics, and the site's unique construction and management requirements. In some instances funding requirements, such as the preferences for labour-based approaches in the WfWet programme, dictate the nature of the approach adopted for the rehabilitation of the candidate wetland systems. Accordingly, wetland rehabilitation planners and implementers require guidance when considering structural interventions for different project sites.

Internationally, guidelines have been compiled for the appropriate rehabilitation of wetland ecosystems (Hayes et al. 2000), with guidelines for particular wetland types in some instances, such as peatlands (Schuman and Joosten 2008). In South Africa, the selection and design of structural interventions for wetland rehabilitation was initially largely informed by approaches for stabilising erosion, as advocated by agricultural land management practices (Co-ordinated Extension Committee of KwaZulu-Natal 1999). Subsequently, with elevated awareness and prioritisation of wetland ecosystems, specific guidelines emerged for rehabilitating wetland ecosystems, notably the Wetland-Fix series (Wyatt 1997). With the emergence of WfWet, a government-funded wetland rehabilitation programme, more comprehensive guidelines were compiled by Kotze et al (2001) to assist with the planning, implementation and monitoring of wetland rehabilitation. The most recent and appropriate guidelines for the selection and design of wetland rehabilitation structural interventions were developed as a component of the Wetland Management Series, particularly in WET-RehabMethods (Russell 2009). The WET-RehabMethods guidelines provide detailed practical rehabilitation guidance for the selection and design of wetland rehabilitation structural interventions, including principles and step-by-step guidelines to be followed during rehabilitation planning. Of particular importance for assessing rehabilitation outputs would be the guidance provided by WET-RehabMethods for selecting appropriate interventions and the details relating to the aftercare of interventions.

2.2.2 Monitoring outputs of wetland rehabilitation

Wetland rehabilitation interventions, i.e. artificial or man-made structures within a dynamic natural system, by their nature are subject to risk and/or damage over time. Hayes et al. (2000) suggest that our limited knowledge of wetland systems limits the assurance that project objectives will be met in their entirety. As such, monitoring of the integrity of structural interventions is paramount to the implementation of a wetland rehabilitation strategy. Monitoring of the interventions also assists in identifying successful measures that should be adopted within the wetland rehabilitation field of practice. Jensen (1999) noted that the ineffective and low levels of information exchange on the approaches and/or techniques adopted for wetland rehabilitation is of particular concern, which may translate into duplicated mistakes and ineffective spending of limited funding. Ramstead et al (2012) also note the limited publication and/or sharing of information relating to successes and failures of wet meadow restoration projects amongst managers and practitioners in Southwestern USA.

Cowden and Kotze (2009) describe the monitoring of outputs in terms of survival, based on the assessment of the integrity and the survival of interventions in relation to specified events e.g. floods or flow levels. While Hayes et al. (2000) make reference to a number of common reasons for the failure of different intervention types, Cowden and Kotze (2009) provide a list of criteria (Table 2.1) to be considered when monitoring the structural integrity of wetland rehabilitation interventions. The criteria in Table 2.1 were largely derived from the description of aftercare for structural interventions compiled by Russell (2009).

Table 2.1. Criteria used for monitoring structural integrity of wetland rehabilitation interventions relevant to the research sites[1]
(Modified from Cowden and Kotze 2009).

Concrete work:	**Earthen Structures (incl. berms and diversions):**
• Dimensions according to specifications • Authorised deviations from plan • Evidence of sliding, tilting, slumping or overturning of the structure • Tunnelling pipes under or around the intervention • Cracks evident within the structure • Scouring downstream • Evidence of outflanking or poor compaction around the intervention • Concrete mixed to specifications i.e. no signs of corrosion or segregation of the aggregate • Quality of workmanship	• Dimensions according to specifications • Authorised deviations from plan • Erosion on the bank • Tunnelling pipes under or around the intervention • Establishment of vegetative cover • Scouring downstream • Evidence of outflanking • Adequate compaction of soil i.e. no slumping or excessive settling of the soil (> 10% of overall height) • Damage by livestock • Quality of workmanship
Spreader Canals: • Dimensions according to specifications • Authorised deviations from plan • Erosion of the lip of the canal i.e. concentrated outflow points • Free passage of water through the canals • Scouring within the canal • Quality of workmanship	

2.2.3 Costs of wetland rehabilitation interventions

Zentner et al. (2003) highlight the scarcity of published literature relating to the costs of wetland rehabilitation and it was evident that the availability of such publications is still limited. Furthermore, costs reported are often project costs estimated during the planning phase of the project rather than actual costs calculated following project completion. An additional

[1] It should be noted there was no means of verifying that the spillway levels were according to the original plan as survey benchmarks were not utilised during the setting out of the interventions.

confounding issue is costs of a wetland rehabilitation project can be calculated including dissimilar components. For example, guidelines for the wetland restoration and/or compensation process published by Alberta Environment (2007) illustrate wetland rehabilitation costs as including land acquisition, wetland rehabilitation activities, maintenance, monitoring, and project administration. Costs are also often reported against different time periods, for example, Streever (1997) reported costs of wetland rehabilitation projects in Australia per annum rather than from initiation to completion. For comparative purposes, reported costs in available literature were considered to make broad comparisons to locally derived wetland rehabilitation cost estimates (Table 2.2). Where appropriate, costs were adjusted to account for exchange rates and inflation where project implementation occurred in different years and to exclude land acquisition.

Table 2.2. Wetland structural rehabilitation costs per region represented in ZAR per hectare

Region	Cost (ZAR)/hectare	Source
Canada		
Alberta	R 8 800	Alberta Environment (2007)
Ontario	R 133 342	Pattison et al. (2011)
United States		
Florida	R 664 856	Baca et al (1994)
Georgia	R 619 489	Baca et al (1994)
South Carolina	R 540 637	Baca et al (1994)
Maryland	R 3 538 368	Hayes et al. (2000)
Texas	R 215 051	Hayes et al. (2000)
Iowa	R 222 850	Tyndall and Bowman (2016)
California-Tidal wetland	R 122 496 to R 287 867	Zentner et al. (2003)
California-Permanent wetland	R 479 783 to R 679 873	Zentner et al. (2003)
California-Seasonal wetland	R 336 871 to R 857 489	Zentner et al. (2003)
South Africa		
Northern Cape	R 81 774	Black and Turpie (2016)
KwaZulu-Natal	R 65 448 to R 223 163	Kotze and Ellery (2009)
Eastern Cape	R 100 946	Kotze and Ellery (2009)
Limpopo	R 947 382	Kotze and Ellery (2009)

Despite the variation in project costs shown in Table 2.2, the associated wetland rehabilitation was generally considered valuable for each particular project. It is, however, important to note that the wetland rehabilitation projects in Table 2.2 represent different socio-economic contexts, funding avenues and priorities that may limit direct comparison.

As for donor-funded programmes generally, WfWet requires a means of justifying expenditure, which is generally based on the standards described by WET-RehabPlan (Kotze et al. 2009) for assessing the so-called cost-effectiveness of a wetland rehabilitation project. This approach for assessing cost-effectiveness is based on costs in relation to the hectares of functional wetland gained or secured as a result of the rehabilitation (Table 2.3).

Table 2.3. Cost-effectiveness of rehabilitation interventions (Kotze et al. 2009, p. 47)

Cost of rehabilitation interventions per hectare of reinstated / 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 - 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 - 500 000 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.

The use of cost-effectiveness was viewed as an appropriate means of reviewing the outcomes of the rehabilitation interventions for each wetland in relation to the costs of those interventions, considering the adoption of the approach by Kotze and Ellery (2009) to evaluate the outcomes of five WfWet rehabilitation sites. It is important to note that, as indicated by Kotze et al. (2009), these ballpark thresholds / standards were derived mainly from costings of planned rehabilitation projects rather than historical projects which had already been implemented. As standards, they have therefore not been fully tested. Furthermore, it is acknowledged by Kotze et al. (2009) that different types of rehabilitation problems will be more costly than others. But no further elaboration and no specific guidance is given by Kotze et al. (2009) in terms of how to account for differences in site context in order to refine the preliminary cost-effectiveness assessment provided. Accounting for differences in site context in relation to cost-effectiveness has been considered in Section 5.1, taking into consideration the findings of this study.

However, the use of costs per hectare equivalent in isolation may not accurately reflect the contribution of the wetland rehabilitation, as highlighted by Kotze and Ellery (2009) who also subjectively considered the cost-effectiveness of rehabilitation in terms of the delivery of ecosystem services for the Manalana wetland. This appears to be an important consideration in those instances where provisioning services are supplied by the wetland to adjacent communities. It should be noted that detailed cost-effectiveness studies, including comparisons of alternatives as undertaken by Black and Turpie (2016), or cost-benefit analyses considering value to society as undertaken by Dubgaard (2003) and Pattison et al. (2011) are required for wetland rehabilitation in South Africa. Additional research in this regard would allow practitioners to more accurately reflect the value and/or contribution of wetland rehabilitation undertaken in the country.

2.3 Outcomes of wetland rehabilitation

Interventions undertaken as a core activity in wetland rehabilitation may be designed to achieve a range of longer term benefits, such as to return an ecosystem to as near a natural state as possible, perhaps in order to enhance conservation of biodiversity. Alternatively, it may have a more pragmatic focus, such as the delivery of ecosystem services of benefit to human well-being.

A central focus of this study was to assess such outcomes of wetland rehabilitation, specifically the influence on wetland health and the provision of ecosystem benefits and services. Available assessment tools consider the hydrology, geomorphology and vegetation of the wetland, aligned with the focus of the review undertaken by Ramstead et al (2012), but the dearth of research considering the biotic response of wetlands to impacts in southern Africa, limits the opportunity to use biotic indices until further research has been undertaken. As such, the response of the vegetation component was considered in greater detail, with vegetation indices investigated for adoption in South Africa.

2.3.1 Assessment of ecological outcomes: ecosystem integrity

The use of biological assessments to specify the health or integrity of a wetland is common practice internationally, as illustrated by the comprehensive review of international assessment methods undertaken by Ollis and Malan (2014). An example in the United States of America (US), is the series of documents developed by the Environmental Protection Agency (EPA) to evaluate the overall ecological condition of wetlands based on biological assessments as described by the US EPA (2002a). While these approaches may be applicable, Kotze et al. (2011) highlight that the variability of environmental conditions and the range of wetland systems in southern Africa, are likely to affect the applicability of international approaches.

In an attempt to circumvent these challenges, an assessment approach referred to as WET-Health (Macfarlane et al. 2007), has been widely adopted in southern Africa to assess ecosystem integrity (Kotze 2011; Walters et al. 2011; Macfarlane et al. 2012). Although other assessment methods exist within South Africa, alongside the Wetland-Index of Habitat Integrity (DWAF 2007), Ollis and Malan (2014) describe WET-Health as the most advanced assessment method to determine wetland condition. Considering this, and the fact that WET-Health includes a comprehensive level of assessment and has been adopted by the WfWet programme (Ollis and Malan 2014) as prescribed by Kotze et al. (2009), the method was viewed as an appropriate means of assessing the changes in ecosystem integrity based on the impacts of anthropogenic activities, including rehabilitation.

To inform the assessment, a wetland is initially classified in accordance with a hydrogeomorphic (HGM) unit classification, modelled on the system developed by Brinson (1993) and later adapted by Smith et al. (1995). As explained by the US Department of Agriculture (2008), this approach focuses on geomorphic and hydrological features of the wetland, rather than solely on the biotic characteristics, and as such assists in gaining an understanding of how the wetland works rather than merely its appearance. Similar to the assessment technique developed by Price et al. (2007) for Australian wetlands, WET-Health considers the overall health of a wetland, documenting and taking into consideration human-related impacts in the HGM unit and its catchment. Given that WET-Health identifies human activities and their impacts, it is particularly useful in identifying management needs. The disturbance within the wetland is mapped, and then used to inform the assessment of wetland integrity for a prescribed scenario of activities, such as comparing pre- and post-rehabilitation states of the biophysical components of the wetland, including:

- Hydrology - defined as the supply of water to wetland and the distribution and movement of water through the wetland.
- Geomorphology - defined as the distribution and retention patterns of sediment within the wetland; and
- Vegetation - defined as the vegetation structural and compositional state.

Each component of the wetland (hydrology, geomorphology and vegetation), has a number of sub-categories which are considered during the assessment, and impacts are scored on a scale of 0-10 (Macfarlane et al. 2007) and the magnitude of impact score is used to derive the Present State Category for each component, reflecting the extent to which human stressors have impacted wetland condition (Table 2.4). These are represented as Present State Categories as outlined in Table 2.4. The adoption of Present State Categories is advocated by DWS, to inform decision-making and management of South Africa's wetland ecosystems.

Table 2.4. Impact scores and present state categories for describing the integrity of wetlands (MacFarlane et al. 2007 p.138)

Impact Category	Description	Impact Score Range (0-10)	Present State Category
None	Unmodified, natural.	0-0.9	**A**
Small	Largely natural with few modifications. A slight change in ecosystem processes is discernible and a small loss of natural habitats and biota may have taken place.	1-1.9	**B**
Moderate	Moderately modified. A moderate change in ecosystem processes and loss of natural habitats has taken place but the natural habitat remains predominantly intact.	2-3.9	**C**
Large	Largely modified. A large change in ecosystem processes and loss of natural habitat and biota has occurred.	4-5.9	**D**
Serious	The change in ecosystem processes and loss of natural habitat and biota is great but some remaining natural habitat features are still recognizable.	6-7.9	**E**
Critical	Modifications have reached a critical level and the ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota.	8-10	**F**

MacFarlane et al. (2007) describe how the scores for each of the components hydrology, geomorphology and vegetation can then be integrated into a composite impact score, using the predetermined ratio of 3:2:2, respectively for the three components. This composite impact score is then used to derive a health score, providing the basis for the calculation of hectare equivalents, introduced by Kotze and Ellery (2009) as a means of measuring how wetland ecosystem integrity has changed in response to wetland rehabilitation. Kotze and Ellery (2009) also refer to hectare equivalents as "functional area", i.e. the health of a wetland expressed as an area such that it represents a common 'currency' to measure the gains for the three biophysical drivers associated with wetland rehabilitation. A common currency allows direct comparisons between wetland systems and as such the ability to determine which rehabilitation efforts have been more cost-effective and/or valuable.

2.3.2 Assessment of ecological outcomes: ecosystem services

As outlined by Dada et al (2007), the development of the Wetland Management Series was funded by the Water Research Commission (WRC) and included both the WET-Health (Macfarlane et al. 2007) and the WET-EcoServices (Kotze et al. 2007) assessment frameworks. Similar to the assessment of the ecological condition of wetlands, a number of tools exist internationally for the assessment of wetland functioning, for example Smith et al. (1995), which defines an approach for assessing wetland functioning in the USA.

As for WET-Health, WET-EcoServices was developed to be applicable to South African conditions. WET-EcoServices focusses on the assessment of the extent to which a wetland delivers particular ecosystem services - it does not assess wetland integrity. As for WET-Health, application of WET-EcoServices also requires the classification of the wetland based on HGM unit/s. The assessment technique assesses fifteen ecosystem services that wetlands are capable of providing (Table 2.5) in terms of the extent to which a benefit is being supplied by the wetland habitat, based on both:

- The opportunity for the wetland to provide the benefit; and
- The effectiveness of the particular wetland in providing the benefit.

Table 2.5. Ecosystem services supplied by wetlands

(Kotze et al. 2007, p. 14)

<table>
<tr><td rowspan="16">Ecosystem services supplied by wetlands</td><td rowspan="9">Indirect benefits</td><td rowspan="9">Regulating and supporting benefits</td><td colspan="2">Flood attenuation</td><td>The spreading out and slowing down of floodwaters in the wetland, thereby reducing the severity of floods downstream</td></tr>
<tr><td colspan="2">Stream flow regulation</td><td>Sustaining stream flow during low flow periods</td></tr>
<tr><td rowspan="5">Water quality enhancement benefits</td><td>Sediment trapping</td><td>The trapping and retention in the wetland of sediment carried by runoff waters</td></tr>
<tr><td>Phosphate assimilation</td><td>Removal by the wetland of phosphates carried by runoff waters</td></tr>
<tr><td>Nitrate assimilation</td><td>Removal by the wetland of nitrates carried by runoff waters</td></tr>
<tr><td>Toxicant assimilation</td><td>Removal by the wetland of toxicants (e.g. metals, biocides and salts) carried by runoff waters</td></tr>
<tr><td>Erosion control</td><td>Controlling of erosion at the wetland site, principally through the protection provided by vegetation</td></tr>
<tr><td colspan="2">Carbon storage</td><td>The trapping of carbon by the wetland, principally as soil organic matter</td></tr>
<tr><td colspan="3">Biodiversity maintenance</td><td>Through the provision of habitat and maintenance of natural process by the wetland, a contribution is made to maintaining biodiversity</td></tr>
<tr><td rowspan="6">Direct benefits</td><td rowspan="3">Provisioning benefits</td><td colspan="2">Provision of water for human use</td><td>The provision of water extracted directly from the wetland for domestic, agricultural or other purposes</td></tr>
<tr><td colspan="2">Provision of harvestable resources</td><td>The provision of natural resources from the wetland, including livestock grazing, craft plants, fish, etc.</td></tr>
<tr><td colspan="2">Provision of cultivated foods</td><td>The provision of areas in the wetland favourable for the cultivation of foods</td></tr>
<tr><td rowspan="3">Cultural benefits</td><td colspan="2">Cultural heritage</td><td>Places of special cultural significance in the wetland, e.g. for baptism or gathering of culturally significant plants</td></tr>
<tr><td colspan="2">Tourism and recreation</td><td>Sites of value for tourism and recreation in the wetland, often associated with scenic beauty and abundant birdlife</td></tr>
<tr><td colspan="2">Education and research</td><td>Sites of value in the wetland for education or research</td></tr>
</table>

The abovementioned ecosystem services, which include direct and indirect benefits to society and the surrounding environment, were assessed by rating various characteristics of the wetlands and their surrounding catchments based on the following scale:

- Low (0);
- Moderately Low (1);
- Intermediate (2);
- Moderately High (3); and
- High (4)

Similar to WET-Health, the WET-EcoServices assessment framework can be undertaken for prescribed scenarios, such as pre- and post-rehabilitation. However, it should be noted that the rehabilitation activities are generally designed to improve the effectiveness of the wetland in providing ecosystem services, and as such it is important to separately report scores for both opportunity and effectiveness recorded by WET-EcoServices.

2.3.3 *Assessment of ecological outcomes: vegetation response*

Further to changes in ecosystem integrity and the provision of ecosystem services, this study examined vegetation composition as an index of post-disturbance recovery in the form of both: 1) the dominance of ruderal species that would be expected to dominate immediately after a disturbance, and which would decline in abundance as an ecosystem recovered from such a disturbance, and 2) the presence and contribution of plants other than hydrophytic species, given that disturbance often leads to desiccation and therefore invasion by dryland species. WET-Health does make use of an index similar to the first index described above, but it does so rather crudely in that the contribution of ruderal species is the only basis for assessment. The use of vegetation to measure wetland ecosystem response to anthropogenic and restoration / rehabilitation impacts is well documented (Ruiz-Jaen and Aide 2005; US EPA 2002b; Walters et al 2006). Ruiz-Jaen and Aide (2005) highlight that the use of vegetation to measure ecosystem response to restoration / rehabilitation is linked to the assumption that the recovery of ecosystem processes and associated fauna follows re-establishment of the desired vegetation. Therefore, measuring vegetation response provides a means of directly quantifying an important component of biodiversity as well as providing an indirect means of quantifying changes in physical features of a wetland, particularly the hydroperiod.

In the interests of investigating additional tools to assist wetland rehabilitation practitioners and managers, and in an attempt to simplify the interpretation of vegetation data, indices were considered in this study. The indices to be considered needed to address the common questions surrounding the response of wetland ecosystems to rehabilitation efforts, namely:

- To what extent has there been a shift from vegetation indicating terrestrial conditions to vegetation indicating hydric (wetland) conditions?
- To what extent has there been a shift from vegetation strongly dominated by pioneer / ruderal species to vegetation dominated by native vegetation?

As such, this study considers two vegetation indices to measure the wetlands' response to the rehabilitation activities, namely:

- Wetland Index Value (WIV) in order to address the question of whether the vegetation had shifted to a more hydric state; and
- Floristic Quality Assessment Index (FQAI) in order to address the question of whether the vegetation had shifted away from domination by ruderal / pioneer species.

2.3.3.1 Wetland Index Value

The use of the Wetland Index Value, derived from vegetation survey data to show rehabilitation success has been demonstrated by numerous studies (Wentworth and Johnston 1986; Carter et al. 1988). WIV provides a useful means of addressing the query relating to whether the system has recovered to a point where there is functional wetland vegetation, based on wetland indicator status (also referred to as ecological index) of the respective plant species recorded. In this instance wetland indicator status of the recorded vegetation was determined based on the classes as defined by Van Ginkel et al. (2010), as follows:

- Obligate wetland species (i.e. always occurs in wetlands);
- Facultative positive wetland species (i.e. usually occurs in wetlands);
- Facultative wetland species (i.e. occurs in wetland and non-wetland);
- Facultative negative wetland species (i.e. usually does not occur in wetlands); and
- Non-wetland or terrestrial species (i.e. always does not occur in wetlands).

Initially, all the plant species recorded during the vegetation surveys would need to be assigned to one of the five abovementioned classes, which is included in Appendix 1, and would be assigned an ecological index ranging from 1 (obligate) to 5 (non-wetland).

Similar to Carter et al. (1988) the following thresholds recommended by Wentworth and Johnson (1986) were considered in the analyses and interpretation of the derived WIV scores:

- WIV <2.5 is designated as wetland,
- WIV 2.5 to 3.5 is designated as transitional,
- WIV >3.5 is designated as non-wetland.

It is anticipated that WIV scores recorded for plots in areas of the wetland influenced by the rehabilitation activities, such as areas with reinstated hydrology, would generally change from non-wetland to wetland, considering the abovementioned WIV classes.

2.3.3.2 Floristic Quality Assessment Index

The Floristic Quality Assessment Index (FQAI), as developed by Swink and Wilhelm (1979), was considered to assess vegetation condition, but due to the prevalence of alien invasive plant species in South African wetlands the adapted version of FQAI, as defined by Miller and Wardrop (2006), was seen to provide a more reliable estimate of habitat quality and a means of addressing the query relating to whether the system has recovered to a point closer to the benchmark based on the abundance of weedy, pioneer or alien invasive plant species. The recorded plant species would be assigned a 'coefficient of conservatism', a subjective rating of the plant species' preference for non-degraded natural communities, ranging from 0 to 10, with the higher values assigned to those species less tolerant of degradation (Miller and Wardrop 2006). In this instance, the assigned coefficient of conservatism was based on professional opinion in accordance with the following classes adapted from Miller and Wardrop (2006):

- Alien invasive plants (0)
- Ruderal or weedy plants (1)
- Occasionally ruderal or weedy plants (5)
- Plant species intolerant of disturbance (10)

CHAPTER 3 - STRUCTURAL OUTPUTS IN TERMS OF INTEGRITY, SURVIVAL AND COST

Structural interventions associated with wetland rehabilitation projects are subject to damage and failure, and as such require monitoring and maintenance to ensure their survival and the achievement of the wetland rehabilitation strategy. Cowden and Kotze (2009), describe structural interventions as outputs of wetland rehabilitation and prescribe monitoring according to what they describe as "Level 1 monitoring". This is typically included in the monitoring guidelines that accompany rehabilitation plans. The long-term monitoring of the wetland rehabilitation outputs is therefore focussed on the assessment of the structural integrity of the interventions, survival of interventions and effectiveness of the rehabilitation strategy.

3.1 Methods

The rehabilitation of the Killarney and Kruisfontein wetlands included the construction of structural interventions to achieve the objectives of the rehabilitation strategy. A number of different structural interventions, as described by Russell (2009), were used to rehabilitate the wetlands, including:

- Killarney wetland
    - A series of seventeen concrete weirs in the main channel deactivating the channel and promoting overbank topping.
    - A single spreader canal to divert water out of the main channel into the adjacent wetland.
    - A series of earthen plugs deactivating a lateral drain within the system.
- Kruisfontein wetland
    - A concrete weir in the main channel to promote flows into the spreader canal.
    - Two spreader canals diverting flows out of the main channel into the adjacent wetland.
    - A concrete-covered earthen diversion berm to divert a portion of the flows out of the main channel.
    - A series of sixteen earthen plugs within the ridge-and-furrow drainage network.

The following photographs show examples of the wetland rehabilitation interventions implemented at the two wetlands, including concrete weirs (Plate 3.1), spreader canals (Plate 3.2), concrete-covered earthen berm (Plate 3.3) and earthen berms (Plate 3.4).

Plate 3.1. Concrete weir in the main channel of the Killarney (left) and Kruisfontein (right) wetlands.

Plate 3.2. A spreader canal diverting a portion of the base flows out of the main channel in the Killarney wetland

Plate 3.3. A concrete-covered earthen berm diverting flows out of the main channel in Kruisfontein wetland

Plate 3.4. A series of earthen berms used to deactivate the ridge-and-furrow drainage in Kruisfontein wetland.

These structural interventions were assessed in this study based on monitoring approaches defined by Cowden and Kotze (2009) for both structural integrity and the survival of specified flood levels, in addition to the aftercare of interventions as specified by Russell (2009). The effectiveness of the wetland rehabilitation at both sites was assessed based on determining the costs of the rehabilitation, reviewing the rehabilitation strategy and considering alternatives to meeting the defined objectives.

3.1.1 Structural integrity

To provide a guide for assessing whether the various structural interventions within the two wetlands were appropriate for the particular setting onsite, the WET-RehabMethods (Russell 2009) decision tree for the selection of appropriate rehabilitation measures to address erosion gullies and/or drainage channels in wetlands (Figure 3.1) were applied for both sites.

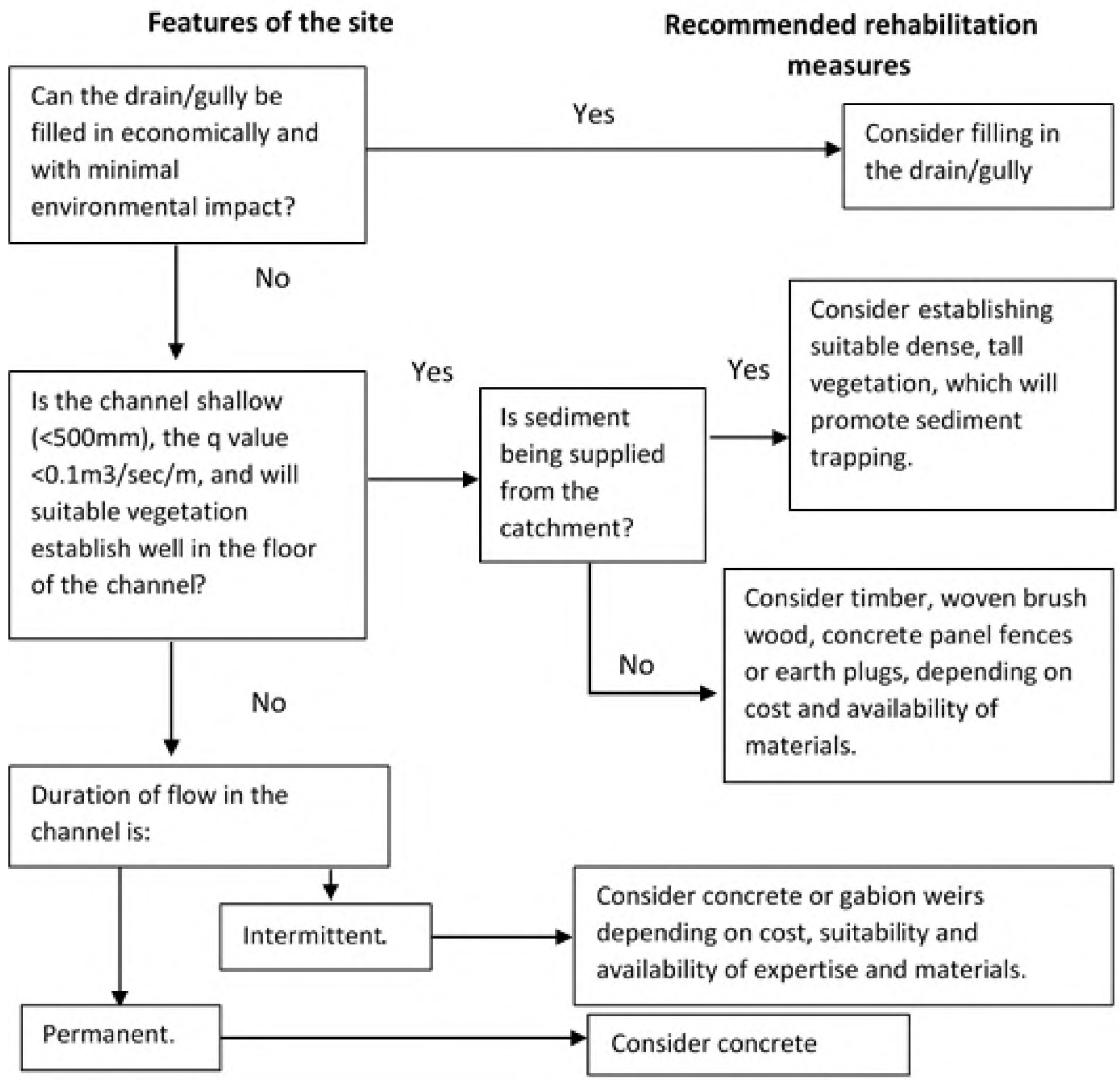

Figure 3.1. Decision tree for choosing appropriate rehabilitation interventions for erosion gullies and drainage canals in wetlands (Russell 2009, p.35)

WET-RehabMethods are the national guidelines for wetland rehabilitation methods compiled to guide wetland rehabilitation planning, and it is important to note that the rehabilitation planning at both Kruisfontein and Killarney wetlands was undertaken prior to the publication of these guidelines. The assessment of the structural integrity focussed on the long-term integrity of the interventions and the likelihood of achieving the stated objectives. This assessment was intended to identify weaknesses or strengths of the selected interventions within the two wetlands.

3.1.2 Survival of specified flood events

The wetland rehabilitation interventions specified for the Killarney and Kruisfontein wetlands were designed to withstand 1 in 20 year flood events. Flood events of this magnitude would require a daily rainfall in excess of 100mm within the Killarney and Kruisfontein catchments. Unfortunately, the lack of rainfall stations near the rehabilitated wetlands was a limitation in terms of accurately estimating the occurrence of the specified flood event since implementation. For the purposes of this study, daily rainfall data from 2005 to 2012 were sourced from Department of Water Affair's rainfall stations in the towns of Matatiele and Mooi River, and were used to determine whether daily rainfall in excess of that required to generate a 1 in 20 year flood event may have occurred in the vicinity of the study sites during that period.

3.1.3 Effectiveness of the wetland rehabilitation strategy

The rehabilitation strategies for both wetlands, including the specific interventions adopted, were reviewed in terms of effectiveness and in terms of providing insights for future rehabilitation planning, based on the following key questions:

- Have the objectives of the interventions or the rehabilitation plan been achieved by the current interventions?
- Could the same level of outcomes have been achieved with less costly interventions?

3.2 Results

The application of the WET-RehabMethods decision tree (Figure 3.1) confirmed that the earthen and concrete interventions adopted for the rehabilitation of the Killarney and Kruisfontein wetlands, were used in appropriate settings (Appendix 2). Based on field observations, minor issues relating to construction rather than 'catastrophic failure' of the interventions, were identified at both wetlands (Appendix 2). It appears that the adoption and implementation of available guidelines and best practice during the planning and design phase assisted in the low failure rate recorded at these sites. However, discrepancies relating to the construction phase, especially relating to the dimensions of the constructed interventions were identified (Appendix 2), but can be easily addressed with the implementation of maintenance.

3.2.1 Rehabilitation outputs: Killarney wetland

3.2.1.1 Overview of structural interventions

Concrete weirs

The concrete weirs were constructed across the main channel, with the spillway levels set close to the top of the banks. This allowed for the water level in the main channel to be maintained close to the surface of the wetland (in order to minimise the drawdown effect of the channel on the water table), as well as to encourage overbank flow during storm events. The weirs were spaced relatively close to one another down the length of the channel, which ensured that the backwater from one structure flooded back to approximately halfway up the spillway of the upstream weir. The high level of the spillways relative to the top of the banks, together with the close spacing of the weirs down the length of the channel not only improved the hydrology of the wetland, but also ensured that an effective water cushion was created along the entire length of the channel. The water cushion ensured that lateral erosion of the banks of the channel, as a result of the re-entry of diverted flows into the main channel, was minimised.

The spacing of the weirs was therefore critical to the success of the rehabilitation strategy of the Killarney wetland. Not only did the close spacing of the structures allow for a significant improvement in the hydrology of the system, but also reduced vertical incision of the channel and reduced the energy associated with moving water in the system as a whole. This was verified by means of surveyed cross sections of the channel, which showed minimal change to the channel profile from the cross sections that were surveyed previously (Cowden et al. 2009). It should be noted that the frequent spacing of interventions does, however, have cost implications which have been discussed in Section 3.3.

Spreader canal

A single spreader canal was constructed across the upper portion of the wetland to divert a portion of the base flows out of the main channel upstream of a concrete weir intervention. The spreader canal allowed for a continual supply of water to be available for improving the hydrology within the wetland area adjacent to the main channel. The site inspection revealed that the end of the spreader canal had breached and the majority of the water was flowing out of the end of the canal rather than being spread across the wetland. The water that was being discharged at the end of the spreader canal was flowing into a secondary channel on the right hand side (facing downstream) of the wetland. The point of entry of the water into the secondary channel was showing signs of erosion with the development of numerous small nick points. Plate 3.5 shows the erosion developing as a result of flows originating from the spreader canal.

Plate 3.5. Photographs showing the development of erosional nick points where water from the spreader canal enters the secondary channel

Earthen diversion berms

A series of earthen diversion berms were constructed across a lateral drain on the side of the main channel. The earthen berms are located in a low energy environment and are showing no signs of erosion. The berms were well vegetated, stable and did not require maintenance at the time of the site inspection. The berms have been successful in deactivating the drain and are considered to be a cost effective solution for rehabilitating the drains in a low energy environment.

3.2.1.2 Structural integrity

The investigation of the structural integrity of the concrete weirs identified only one of the seventeen weirs as requiring maintenance, where tunnelling had occurred (Plate 3.6), which directly affects the likelihood of the intervention achieving the specified objectives. A number of interventions appear to have been modified, with the overflow / spillway wall having been lowered to account for deviations from the plan during implementation. In addition, a number of issues relating to implementation were identified, e.g. 'honeycombing' of concrete, limited freeboard, key walls incorrectly constructed. However, the modifications to the interventions were not impacting on the integrity of the interventions, and should be monitored during future site visits to ascertain if corrective measures may be required in future. Although serving to redistribute flows from the main channel, the spreader canal was identified as requiring corrective measures, mainly in order to address the breaching of the canal's endpoint. Currently, flows are unequally distributed across the spreader canal's length and concentrated flows are entering a secondary channel initiating erosion, as described in the previous section. The earthen berms within the lateral drain were considered to be built in an appropriate setting in accordance with the plan, and they appeared stable and well-vegetated, with no corrective measures identified.

Plate 3.6. View from downstream of an intervention in the Killarney wetland with no water flowing over the spillway as a result of tunnelling that has occurred allowing base flows to pass under the structure.

3.2.2 Rehabilitation outputs: Kruisfontein wetland

3.2.2.1 Overview of structural interventions

Concrete weir

The concrete weir was designed to divert flows from large storm events into the wetland on a regular basis. From discussions with the landowner, together with an inspection of the site, it appears that overbank-topping does not occur on a regular basis. Ideally the spillway should be raised to increase the frequency of overbank topping during storm events and of storm flows being redirected into the wetland. In terms of the structural integrity, the weir was showing no sign of failure. Minor corrosion of the concrete had taken place and the steel reinforcing was exposed in places, however neither of these issues are an immediate threat to the integrity of the structure.

Spreader canals

Spreader canals were constructed in the wetland with the intention of diverting a portion of the base flows out of the main channel and into the adjacent wetland. The spreader canals were not functioning as intended, as flows were not being spread in a diffuse manner across the wetland. A single discharge point had developed along each spreader canal, resulting in the development of preferred flow paths within the wetland, which should be addressed to ensure the interventions are operating optimally i.e. flows filling the spreader canal and decanting along a specified length of the intervention.

Concrete-covered earthen berm

The concrete-covered berm has been effective in diverting flows out of the main channel and did not require maintenance at the time of the site inspection. The integrity of the structure can be attributed to the concrete covering that was strategically placed in the direct line of the receiving flows.

Earthen plugs used to deactivate the ridge-and-furrow drainage network

The deactivation of the ridge-and-furrow drainage network was in the form of a series of earthen plugs that were constructed across the furrow portions. The deactivation of the ridge-and-furrows has had limited success as flows were not being diverted in a diffuse manner across large portions of the wetland. Despite flows being more diffuse than previously, a preferred flow path has developed along the furrows and consequently a smaller portion of the wetland has been positively influenced by the rehabilitation than planned. Further interventions will be required to successfully deactivate the ridge-and-furrow drainage network and the erosion that initiated where the preferred flow path enters the Mooi River (Plate 3.7)

Plate 3.7. Headcut erosion as a result of concentrated flows discharging over the bank of the Mooi River

3.2.2.2 Structural integrity

The investigation of the structural integrity of the mass gravity drop-inlet concrete weir revealed numerous discrepancies between the design dimensions and the built dimensions. In terms of the implementation of the design, the right hand wing wall is located approximately midway along the shoulder wall and not at the end of the shoulder wall as specified in the design. Two buttresses along the wing wall (which were not specified in the design) were added in the construction phase. Despite these 'as built' discrepancies, the structure appeared to be structurally stable and no remedial actions are proposed to improve the structural integrity of the weir; however signs of poor workmanship were identified.

An additional intervention, a concrete buttress weir, which was originally included in the wetland rehabilitation plan, was not constructed. It is unclear if the concrete buttress weir was deemed unnecessary or if the availability of funds during the project cycle was a limiting factor. Considering the rehabilitation strategy adopted for the wetland i.e. the reliance on spreader canals and earthen berms to redistribute flows, it is unlikely that the additional weir across the stream channel would have contributed towards achieving the project objectives. Should future rehabilitation be considered, efforts should focus on the ridge-and-furrow areas rather than raising the water level in the channel.

The concrete-covered earthen berm is located within the lower reaches of the stream channel and serves to divert flows from the channel. The berm is structurally stable and there is no evidence of erosion along the structure. A slightly incised channel (approximately 300mm deep) is located on the upstream side of the berm, but this does not currently pose a risk to the intervention's structural integrity. No corrective actions are therefore proposed for the berm in terms of securing its structural integrity.

Two spreader canals were identified on the site, one downstream of the concrete weir and one upstream of the concrete-covered diversion berm. The upstream spreader canal did not contain water at the time of the site inspection and there was no evidence that flows were directed into the canal on a regular basis. The canal appeared stable and no corrective actions are therefore proposed for the spreader canal in terms of securing its structural integrity. The downstream spreader canal, receiving flows from the concrete-covered diversion berm, has breached close to the entry point of the water from the diversion berm. The breach in the canal has resulted in the development of a single preferred flow path downstream of the intervention. The spreader canal is therefore not meeting its original objective of spreading flows across the wetland. If it is a requirement that diffuse flows are to be promoted, the breach should be repaired and functioning of the spreader canal should be re-instated in order to allow for spreading of water across a wider portion of the wetland.

A total of 16 earthen plugs were identified onsite, and at the time of the site inspection, the majority of the earthen plugs contained standing water on the upstream side. The earthen plugs were all structurally intact and showed no signs of erosion. No corrective actions are therefore proposed for the plugs in order to secure their structural integrity.

3.2.3 Survival of specified flood events

The evaluation of the interventions in terms of structural integrity highlighted that the interventions within Killarney and Kruisfontein are generally stable, but it is important to consider the survival of the interventions taking into account the occurrence of flood events in excess of the respective design specifications since implementation. If the interventions within the wetlands were exposed to flood events beyond their design specifications, the likelihood that there would be a number of issues relating to structural integrity are assumed to be higher than if the converse were true. Based on the rainfall recorded at nearby Department of Water and Sanitation (DWS) rainfall stations, it is anticipated that the interventions in the Killarney wetland would have been exposed to a flood event beyond their design specifications. While the interventions within the Kruisfontein wetland have been exposed to high flows, rainfall has not exceeded the amounts that would be equivalent to the flood event accounted for in the design specifications. In addition, the rehabilitation strategy adopted at Killarney wetland needs to be acknowledged as successful, with concrete weirs being planned with water from the downstream interventions back-flooding halfway up the interventions upstream (Plate 3.8). Currently, the same cannot be said for the interventions within the Kruisfontein wetland as flows have not exceeded the design specifications, although the interventions have withstood elevated flows.

Plate 3.8. View of water back-flooding to the base of an intervention in Killarney wetland

3.2.4 *Effectiveness of the wetland rehabilitation strategy*

The review of the interventions, in terms of effectiveness, was supported by the assessment of the ecological responses of the systems in Chapter 4. In terms of meeting the stated objectives of reinstating the near-natural hydrological conditions, the interventions in the Killarney wetland were considered to have performed better than those in the Kruisfontein wetland. The primary reason for this is the discrepancies recorded between the planned rehabilitation interventions and the interventions that were actually built in the Kruisfontein wetland (Appendix 2). However, it should be noted that with nominal additional costs it is anticipated that the rehabilitation effectiveness could be improved.

With regards to the rehabilitation strategy adopted for the Killarney wetland, the use of numerous structures to raise the water level thereby deactivating the channel was deemed an effective approach. The lack of sediment accumulation in the channel, largely due to a lack of sediment supply within the catchment, precluded relying on sediment accumulation to deactivate the channel. The redistribution of water flows using the spreader canal and diversion pipe increased the area influenced by base flows within the wetland, actively driving the hydrological and vegetation response downstream of these interventions. The hydrological response was also facilitated by the increased frequency of overtopping and high water levels maintained in the channel due to the frequency of interventions along the length of the channel. The benefits of the adopted rehabilitation strategy in the upper reaches of the system are evident, but one may question if the interventions further downstream have been as effective. The question of intervention effectiveness, that is could similar outcomes have been achieved with fewer and/or less costly outputs, was raised for the downstream areas of Killarney wetland based on the observations by Cowden et al (2009) that the wetland appears to be less dependent on the flows originating from the channel. It was noted during the assessment of the interventions that the key walls were potentially higher than necessary, and it is likely that this was adopted to account for the lack of freeboard (i.e. the height between spillway level and the crest of an intervention) in the intervention designs. The use of gabions as an alternative material to construct the weirs within the wetland would have been inappropriate due to the perennial flows within the channel and the potential corrosion of gabion wire, based on the intervention selection criteria defined by Russell (2009).

The issues identified in the assessment of structural integrity (Appendix 2) contributed to the ecological response being less than anticipated for the Kruisfontein wetland. With the implementation of corrective action addressing the identified issues, especially those relating to redirecting flows in the upper reaches of the system and additional key interventions, the efficacy of the rehabilitation would be improved. While the earthen berms have worked well to trap water within the ridge-and-furrowed areas of the wetland, the size of the earthen plugs, with 1m freeboard, could have been substituted for a greater number of smaller earthen plugs (<0.5m freeboard) for the equivalent budget. The adoption of this approach towards the western channel is likely to have increased the area affected by the rehabilitation, however, this would need to be considered in relation the increased risks and potentially maintenance costs associated with the erosion or breaching of the smaller interventions. The nature of the flows in the channel, with perennial flows and a relatively large catchment, limits opportunities to reduce the size of the concrete interventions.

3.3 Discussion

The process of rehabilitation planning relies on documenting the lessons learnt from previously implemented interventions and the manner in which interventions address the identified problems, as described by Cowden and Kotze (2009). Reflecting on lessons learnt potentially assists the wetland rehabilitation practitioners in improving the effectiveness of selected interventions in various settings. Improving the effectiveness of interventions is of particular importance to WfWet, where limited budget is a constraint to the objectives of the programme.

3.3.1 Modification of the checklist used to assess rehabilitation outputs

Prior to the application in this study of the WET-RehabEvaluate checklist (Table 2.1), amendments were suggested (Mr T Pike 2011, pers. comm., April 2011). Subsequent to the assessment of the rehabilitation interventions at both wetlands, it was evident that further amendments to the monitoring of structural outputs would benefit the WET-RehabEvaluate guideline document. These amendments would need to focus on the following key aspects:

- Differentiate between issues that relate to risk, integrity and/or damage to the structures and those issues that relate to deviations from design, which are generally addressed by post-construction audits. Monitoring of structural integrity would focus on issues similar to the tunnelling recorded at the intervention in Killarney wetland, whereas post-construction monitoring of interventions would focus on issues relating to location, construction materials, and deviations from design.
- Update the monitoring of structural integrity in WET-RehabEvaluate to include any structural integrity issues that may have been identified by experienced practitioners for different interventions types since the publication of WET-RehabMethods. For example,

considering if an undesirable decant point has developed along the length of a spreader canal, an issue identified at both the Killarney and Kruisfontein wetlands.

- Incorporate clarifying and/or explanatory details in the checklist, to clearly define the issues needing to be considered when assessing structural integrity. For example, the original guidance provided by WET-RehabEvaluate refers to 'adequate shoulder walls', which may be unclear without clarification of the indicators that assist in identifying the issue, such as erosion of the stream banks downstream of the intervention.
- Incorporate guidance on reviewing the rehabilitation strategy adopted, in terms of effectiveness and potential amendments / enhancements in terms of meeting the stated objectives. While the concrete weir in Kruisfontein wetland stabilised the headcut erosion, high flows were not being frequently re-directed, and thus the objectives of the intervention were only partially being achieved. In order to achieve the interventions objectives potential amendments would need to be considered and should be guided by WET-RehabEvaluate.
- Incorporate guidance on assessing unanticipated consequences of the interventions on the wetland integrity, as was recorded in Kruisfontein wetland where erosion has initiated at the point that redirected flows enter the Mooi River.

The limited issues relating to structural integrity, identified during the assessment of the rehabilitation interventions in the Killarney and Kruisfontein wetlands, is deemed to be associated with the adoption of best practice (refer to Figure 3.1). Of the issues identified (Appendix 2), the differences between the designs and dimensions of the interventions were the dominant concern and these are easily addressed through maintenance activities. It should be noted that the incorporation of activities into WfWet's operations, which are not included in existing planning guidelines, has reduced the likelihood of future rehabilitation projects recording similar discrepancies. In terms of the construction of interventions, WfWet's operations now include an engineer responsible for setting out any interventions and then 'signing off' and documenting any variations in the final 'as-built' structures following completion of the rehabilitation project.

3.3.2 Suitability of rehabilitation interventions

With regards to the types of interventions adopted within the Killarney and Kruisfontein wetlands, the concrete weirs were considered to be particularly stable, with a low level of failure or maintenance requirements being recorded. Therefore, while concrete interventions may be associated with potentially higher costs initially, the low long-term maintenance requirements may well outweigh the on-going need and cost of maintenance that may be required for interventions constructed with alternative materials. The discussion regarding the success of the evaluated interventions also needs to take into consideration the fact that the interventions in Killarney are likely to have withstood flows in excess of the design specifications. The impermeable nature of the concrete also contributed towards the success of the interventions in terms of retaining and redistributing flows within both wetlands. Based on these observations, the use of concrete interventions may be a preferred approach for rehabilitation strategies involving the retention and redistribution of flows within a wetland, but this would need to be verified across a larger number of sites. The berms implemented within the wetlands were also considered to be successful, with the integrity of the berms being attributed to the low energy environment in which they were utilised. In particular, the concrete-covered earthen diversion berm in the Kruisfontein wetland has been successful in diverting flows out of a channel in a relatively high energy environment. The integrity of the intervention suggests that the practice should be considered for future wetland rehabilitation projects as the concrete-capped berm appears to have durability similar to that of an entirely concrete intervention. In addition, the concrete-covered earthen diversion berm has the advantage of being labour intensive (due to the earthen core), which is more suited to EPWP where labour-based activities are an important consideration. The spreader canals at both Killarney and Kruisfontein were not functioning as intended and concentrated flows from the spreader canals were evident in both wetlands. The use of spreader canals is likely to greatly enhance rehabilitation efforts in particular settings, but the success of these interventions is strongly dependant on project engineer oversight during the construction phase i.e. implementation of these interventions needs to be carefully managed.

3.3.3 *Benefits of monitoring rehabilitation outputs*

Although only minor issues were identified with the interventions within the Killarney and Kruisfontein wetlands, the assessment of the survival of the interventions served to highlight the importance of intervention monitoring in the long-term. On-going monitoring has numerous benefits which include:

- Informing those entrusted with land management of the wetland system being rehabilitated of all activities and their desired outcomes. For example, the conservation agency Ezemvelo KZN Wildlife (EKZNW) highlighted the need to evaluate the wetland rehabilitation at Killarney wetland to determine if the desired outcomes are still being achieved (EKZNW 2011);
- Early detection of maintenance requirements, which would reduce the potentially costly nature of major repairs if a failure were to occur that could have been prevented;
- Highlight the need for additional interventions and/or modifications to be carried out to enhance the functioning of the interventions in terms of meeting the rehabilitation objectives; and
- Informing the intervention selection process for future planning.

3.3.4 *Effectiveness of the rehabilitation strategy*

In addition to the integrity of the interventions, an important aspect of the success of wetland rehabilitation projects relates to the rehabilitation strategy adopted to address the identified problems. The durability of the Killarney concrete interventions is deemed to be due to a combination of the materials used, the small-scale of the interventions, frequent spacing along the length of the system and the management of the flow of water in the channel, so that stream power is appropriate for the grade of the channel and unable to erode any further. The costs of the frequent spacing interventions, however, would need to be adequately motivated based on the anticipated outcomes. Where deactivation of a channel was required but sediment yield in the catchment was low, the rehabilitation approach adopted in the Killarney wetland would also be seen as the preferred option as the water, rather than sediment or vegetation, serves the purpose of deactivating the channel. While the earthen plugs used at Kruisfontein were stable, the approach to deactivating the ridge-and-furrow areas should be revised for future wetland rehabilitation planning. The plugs were only partially successful in terms of spreading flows across the wetland and a preferred flow path had developed through the wetland as a result of the general topography of the site. The earthen plugs served to create a series of small damlets within the wetland, which has improved habitat diversity within the system to some extent.

Within the Killarney wetland, modifications to the spreader canal will be required to prevent further erosion from occurring, and an additional intervention would be required in the Kruisfontein wetland at the identified sites of headcut erosion, in order to prevent the erosion from advancing headwards into the wetland system. The unanticipated consequences of rehabilitation measures, such as re-directed flows potentially leading to erosion, are difficult to anticipate and adaptive management, informed by monitoring, is an important consideration in wetland rehabilitation.

CHAPTER 4 - ECOLOGICAL OUTCOMES OF REHABILITATION: INTEGRITY, ECOSYSTEM SERVICES AND VEGETATION COMPOSITION.

Despite guidelines existing for monitoring wetland rehabilitation, monitoring of the ecological outcomes of wetland rehabilitation in South Africa has typically not included detailed assessments. It was therefore considered critical that further research be undertaken to support and strengthen the implementation and science of wetland rehabilitation. Therefore, this chapter investigated the long-term ecosystem response of two wetland systems to rehabilitation activities, and included assessments of ecological integrity and ecosystem services, and a detailed investigation of the response of vegetation to rehabilitation interventions.

4.1 Methods

Baseline studies (i.e. pre-rehabilitation) were undertaken in 2005 during the research by Cowden et al. (2009) and Kotze (2009), using the framework of Cowden and Kotze (2009), and included rapid and comprehensive assessments of the wetland rehabilitation outcomes as determined by the objectives. These studies included the establishment of three transects across the Killarney wetland (Figure 1.2) and two transects across the Kruisfontein wetland (Figure 1.2), which formed the basis for the collection of data linked to vegetation composition. The Killarney rehabilitation was implemented by WfWet in multiple phases, and at the time of establishing the baseline monitoring, i.e. that recorded by Cowden et al. (2009), only the initial phase of rehabilitation in the upper reaches of the system (Figure 1.2) had been planned, limiting the extent of the baseline monitoring. Follow-up fieldwork (i.e. post-rehabilitation) for each site was conducted during the rainfall season, with the Killarney site visit being undertaken in January 2011 and the Kruisfontein site visit being undertaken in February 2012.

4.1.1 <u>Assessment of ecological outcomes: ecosystem integrity</u>

An assessment of ecosystem integrity was undertaken using WET-Health (Macfarlane et al. 2007). Kotze et al. (2012) describe WET-Health as a wetland assessment method that records the amount of deviation from the natural reference condition for three components of health: namely hydrology, geomorphology and vegetation. Kotze et al. (2012) also state that ecosystem integrity, as described in WET-Health, is aligned with the description of naturalness or intactness by Anderson (1991), where an ecosystem's reference natural condition excludes impacts from human activities. The disturbance units, portraying the extent of different types of disturbance within the wetlands, were mapped using aerial imagery, pre- and post-rehabilitation, in the QGIS software package, a Geographic Information System (GIS). These disturbance units were then used to inform the assessment of wetland integrity for the pre- and post-rehabilitation conditions. The scores for each of the WET-Health components were integrated into a composite impact score, using the predetermined ratio of 3:2:2 (MacFarlane et al. 2007), for the hydrology, geomorphology and vegetation components respectively. This composite impact score was used to derive a health score that then provided the basis for the calculation of hectare equivalents as follows (Kotze and Ellery 2009):

Hectare Equivalents = (10 – Composite impact score)/10 x (Size of HGM Unit (ha))

Hectare equivalents provide a means of deriving a common "currency" to measure gains or changes in ecosystem integrity in response to the various rehabilitation interventions.

4.1.2 Assessment of ecological outcomes: ecosystem services

The likelihood of specified ecosystem services being supplied by the wetlands was assessed using WET-EcoServices (Kotze et al. 2007), an assessment method that relies on indicators to rate various functionally-relevant characteristics of the wetlands and their surrounding catchments (e.g. surface roughness of the wetland), rather than directly measuring the level of ecosystem service supplied. Pre-rehabilitation levels of ecosystem service delivery were compared to the post-rehabilitation levels, specifically focusing on how the rehabilitation activities have improved the effectiveness of the wetlands to provide ecosystem services.

4.1.3 Assessment of ecological outcomes: vegetation outcomes

The objectives of the rehabilitation of both wetlands focussed on re-establishing near-natural hydrological conditions and promoting the re-establishment of native hydric plants (Cowden et al. 2009, WfWet 2005b). Thus, vegetation surveys were undertaken at both wetlands. A control (i.e. an area unaffected by rehabilitation) was only present within the Kruisfontein wetland. In an attempt to identify trends between affected and unaffected areas of the Killarney wetland, an additional transect unaffected by rehabilitation (Transect 4) was included upstream of the rehabilitation in the post-rehabilitation survey.

Vegetation surveys were conducted based on species composition collected in plots, which were 4 m x 4 m for Killarney and 4 m x 1 m for Kruisfontein, along the existing transects. Different quadrat dimensions were used at the two sites in order to account for heterogeneity in micro-topography. The interpretation of the vegetation data was based on the use of indices, selected to address key questions surrounding the response of wetland ecosystems to rehabilitation efforts, namely 1) to what extent has there been a shift from vegetation indicating terrestrial conditions to vegetation indicating hydric (wetland) conditions?; and 2) to what extent has there been a shift from vegetation strongly dominated by pioneer / ruderal species to native undisturbed vegetation?

4.1.3.1 Wetland index value

The Wetland Index Value (WIV) addresses whether the system has recovered to a point where there is functional wetland vegetation, based on wetland indicator status (Wentworth and Johnston 1986, Carter et al. 1988). In this instance, the wetland indicator status of the recorded plant species was determined based on the classes defined by Van Ginkel et al. (2010). Based on the approach defined by Carter et al. (1988) WIV calculations were undertaken such that each of the abovementioned indicator classes would be assigned an ecological index ranging from 1 (obligate) to 5 (non-wetland). The proportional abundance values recorded for each of these indicator classes at each plot would then be summed and entered into the following equation, which makes use of a weighted average, to calculate the WIV score for the plot:

WIV = (1 x PA:O/100)+(2 x PA:FP/100)+(3 x PA:F/100)+(4 x PA:FN/100)+(5 x PA:NW/100)

Where:
WIV = Wetland Index Value
PA:O = Sum of the proportional abundance of plants of the obligate indicator status recorded in the plot
PA:FP = Sum of the proportional abundance of plants of the facultative positive indicator status recorded in the plot
PA:F = Sum of the proportional abundance of plants of the facultative indicator status recorded in the plot
PA:FN = Sum of the proportional abundance of plants of the facultative negative indicator status recorded in the plot
PA:NW = Sum of the proportional abundance of plants of the non-wetland indicator status recorded in the plot.

To clearly illustrate the approach adopted, two hypothetical vegetation plots are shown in Table 4.1.

Table 4.1. Derivation of WIV for two hypothetical vegetation plots

Species	Indicator Status	Ecological Index	Plot 1 (% cover)	Plot 2 (% cover)
Carex acutiformis	Obligate	1	82	0
Eleocharis dregeana	Obligate	1	10	0
Pennisetum thunbergii	Facultative positive	2	5	0
Themeda triandra	Non-wetland	5	0	65
Hyparrhenia dregeana	Facultative negative	4	0	15
Eragrostis plana	Facultative	3	0	17
WIV			**1.02**	**4.36**

The rehabilitation activities did not affect water flows across the individual sites uniformly, allowing for different "treatments" to be identified, e.g. at Kruisfontein wetland, areas where low- and high flows had been reinstated could be distinguished from areas where only high flows had been re-instated. Thus, to determine the response of the wetland system to the rehabilitation activities, the samples were grouped according to "treatments", similar to the approach adopted by Campbell et al. (2002). The Kruskal-Wallis test, a non-parametric alternative to a one-way ANOVA (Ashcroft and Pereira 2003), was used to determine if significant differences existed between the means for the different "treatments". For Killarney wetland, data were grouped according to transects, as it was anticipated that the response of the system to rehabilitation was likely to vary longitudinally down the length of the system. Within Kruisfontein wetland, data were grouped according to the nature of the flows received by the areas, as it was anticipated that the response of the system to rehabilitation was likely to vary in accordance with different areas (WfWet rehabilitation high flows only; WfWet rehabilitation high, moderate and low flows; Transformed control; Untransformed; Farmer's rehabilitation). In the event that statistically significant differences ($P<0.05$) were identified by the Kruskal-Wallis test, t-tests were undertaken to compare different areas. For the Killarney wetland, t-tests were undertaken to compare transects before and after rehabilitation, showing the change over time. For the Kruisfontein wetland where a control was available, namely the group described as the "Transformed control", control t-tests were used to compare the different "treatments" to the control in addition to the t-tests to compare the groups before and after rehabilitation. All analyses were conducted using PractiStat software (Ashcroft and Pereira 2003).

4.1.3.2 Floristic quality assessment index

The Floristic Quality Assessment Index (FQAI) as defined by Miller and Wardrop (2006) addresses whether the system has recovered to a point closer to the reference natural condition based on the abundance of weedy, pioneer or alien invasive plant species. The recorded plant species were assigned a "coefficient of conservatism", a subjective rating of the plant species' preference for non-degraded natural communities, ranging from 0 to 10, with the higher values assigned to those species less tolerant of degradation (Miller and Wardrop 2006). The assigned coefficient was based on professional opinion, with reference to species descriptions (Van Ginkel et al. 2010) and in accordance with: alien invasive plants (0); ruderal or weedy plants (1); occasionally ruderal or weedy plants i.e. plants that can equally occur in disturbed and undisturbed areas (5); and plant species with a low tolerance of disturbance (10). As for WIV, all the recorded plant species were assigned to one of the five abovementioned classes, which is shown in Appendix 1. The recorded vegetation data at each plot were entered into the following equation to calculate the FQAI score for the plot:

FQAI = (C/10) x (√N/ √S) x 100

Where:
C = Mean coefficient of conservatism (as determined by dividing the sum per plot by the indigenous species richness)
N = Indigenous species richness
S = Total species richness

To clearly illustrate the approach adopted, two hypothetical vegetation plots are shown

Table 4.2.

Table 4.2. Derivation of FQAI for two hypothetical plots

Species	Coefficient of conservatism	Plot 1	Plot 2
Carex acutiformis	10	10	-
Eleocharis dregeana	10	10	-
Pennisetum thunbergii	10	10	-
Leersia hexandra	5	5	
Paspalum dilatatum	0	-	0
Hyparrhenia dregeana	5	-	5
Conyza sp.	1	-	1
Eragrostis plana	5	-	5
Total species richness		**4**	**4**
Indigenous species richness		**4**	**3**
Sum of coefficient of conservatism		**35**	**11**
Mean coefficient of conservatism		**8.75**	**3.67**
FQAI		**87.50**	**31.75**

A FQAI score for each plot was derived based on the weighted average approach outlined by Miller and Wardrop (2006). Statistical analyses of the derived FQAI data was undertaken in the same manner as the approach adopted for the WIV scores.

4.2 Results

4.2.1 Assessment of ecological outcomes: ecosystem integrity

Impacts to ecosystem integrity in the Killarney wetland was limited primarily to channel incision, leading to the desiccation of the upstream areas of the system linked to reduced frequency of overtopping of the channel and a draw-down effect directly adjacent to the channel. The wetland had not been subjected to cultivation or removal of natural vegetation. In contrast, the Kruisfontein wetland was subjected to extensive ridge-and-furrow agriculture, artificial drainage channels, and active erosion. These disturbances included the alteration of both the vegetation and hydrological components to critical levels, with the almost total loss of indigenous vegetation cover and altered water flows and retention patterns within the system. It is evident from the assessments of pre-rehabilitation ecological integrity (Table 4.3) that in comparison to the Killarney wetland, Kruisfontein wetland had been impacted upon to a greater extent by land use activities.

Table 4.3. The impact scores* for the three components of ecological integrity, and hectare equivalents recorded for both wetland systems, pre- and post-rehabilitation

	Killarney		Kruisfontein	
	Pre-rehabilitation	**Post-rehabilitation**	**Pre-rehabilitation**	**Post-rehabilitation**
Hydrology	3.0	1.0	9.0	7.5
Geomorphology	1.6	0.5	2.5	1.8
Vegetation	3.6	2.1	8.2	6.7
Overall impact score	***2.8***	***1.2***	***6.9***	***5.6***
Hectare equivalents**	30.7	37.5	8.2	11.5
Hectare equivalents reinstated***	**6.8**		**3.3**	

* Impact score is from 0 (pristine) to 10 (critical) derived through the application of "WET-Health"

** Hectare equivalents were determined as follows: Total wetland area X (10 - Overall impact score)/10. For Killarney the total wetland area was 42.4 ha and for Kruisfontein it was 26.4 ha.

*** Hectare equivalents reinstated were determined as follows: (Post-rehabilitation hectare equivalents) – (Pre-rehabilitation hectare equivalents)

The assessments of the post-rehabilitation conditions showed that both wetlands have improved in terms of ecosystem integrity. These improvements were primarily linked to improvements in the hydrological component of each of the wetlands (Table 4.3), with the scores for hydrology changing the most. The major changes recorded in the Killarney wetland were linked to reversal of the impacts of the incised channel, i.e. rewetting areas of the wetland that had become desiccated. Reversing the impacts of the channel also served to stabilise the identified erosion and promote the re-establishment of wetland plant species, improving the geomorphic and vegetation components of the Killarney wetland, respectively. Similarly, the redirection of base flows across portions of the Kruisfontein wetland, served to improve the hydrological regime, especially in those areas receiving moderate and low flows. Improvements in the vegetation component, however, were largely limited due to inadequate recovery of the vegetation, with the alien plant *Paspalum dilatatum* remaining dominant within the system at the expense of native plant species (as reported in the detailed assessment of the vegetation in section 4.3.3). Within Kruisfontein wetland the geomorphology improved as a result of the stabilisation of active erosion.

Based on the recorded impact scores, the Killarney wetland improved from 30.7 hectare equivalents (ha equiv.) to 37.5 ha equiv., while the Kruisfontein wetland improved from 8.2 to 11.5 ha equiv. (Table 4.3). The improvement in ecosystem integrity of the Killarney and Kruisfontein wetlands was less than the improvements in hectare equivalents predicted originally, which were approximately 8 hectare equivalents (Cowden et al. 2009) and 6 hectare equivalents (Kotze 2009), respectively.

4.2.2 Assessment of ecological outcomes: ecosystem services

Post-rehabilitation WET-EcoServices assessments generally reflect improvements in the effectiveness of the rehabilitated wetland in providing particular ecosystem services. Improvements in the effectiveness scores recorded, for both the Killarney and Kruisfontein wetlands, were strongly linked to changes in hydrology as a result of the rehabilitation (Table 4.4). Thus, increases in the perceived effectiveness of the systems to assimilate phosphates, nitrates and toxicants, improved integrity and opportunities for water supply and carbon storage were recorded (Table 4.4). It is important to point out that although the effectiveness of the Killarney wetland in delivering regulatory services has generally been enhanced, the opportunity / demand for carrying out these services is very limited, mainly because of the near-pristine nature of the wetland's catchment. This contrasts markedly with Kruisfontein, which has a catchment that is much more intensively used for dairy production.

Table 4.4. Pre-and post-rehabilitation scores for the ecosystem services assessed at Killarney and Kruisfontein wetlands.

Ecosystem Services	Killarney Wetland		Kruisfontein Wetland	
	Pre-rehabilitation	Post-rehabilitation	Pre-rehabilitation	Post-rehabilitation
Flood attenuation	1.6	1.7	1.3	1.6
Stream flow regulation	2.7	3.2	2.5	2.7
Sediment trapping	2.0	1.9	1.3	1.5
Phosphate trapping	2.1	2.2	2.4	2.7
Nitrate removal	2.1	2.6	2.6	2.9
Toxicant removal	2.0	2.3	2.0	2.4
Erosion control	2.4	2.5	2.5	2.7
Carbon storage	1.7	2.7	2.0	2.3
Biodiversity maintenance	3.1	3.4	1.8	1.9
Water supply	0.9	1.8	1.1	1.4
Source of harvestable resources	1.3	1.3	0.7	0.7
Source of cultivated resources	1.3	1.3	0.7	0.7
Socio-cultural significance	0.0	0.0	0.0	0.0
Tourism and recreation	1.9	2.1	0.0	0.1
Education and research	0.5	0.8	0.8	1.0

Within the Kruisfontein wetland, the poor recovery of vegetation composition had implications for provisioning services supplied by the wetland. Specifically, some of the labourers on the farm use the wetland-dependent rush *Juncus punctorius* for weaving. In its pre-rehabilitation state, the extent of *J. punctorius* was very limited, translating into low provisioning scores being recorded. Given that *J. punctorius* is adapted to permanently or near-permanently saturated conditions, it was anticipated that this species would increase in abundance through rehabilitation in response to the increased extent of the permanent zone. However, the 2012 vegetation survey showed no such increase. In contrast, *Juncus effusus* was relatively abundant in some of the wetter rehabilitated portions of Kruisfontein.

4.2.3 Assessment of ecological outcomes: vegetation outcomes

Dominant plant species within different areas of each wetland (Tables 4.5 and 4.6) highlight the changes in dominance over time in response to the rehabilitation. Within the Killarney wetland, Transects 1 and 2 show *Eleocharis dregeana,* an obligate wetland species, as increasing in dominance together with other obligate wetland species, thereby reducing the dominance of facultative positive wetland species, such as *Pennisetum thunbergii* (Table 4.5). *Eleocharis dregeana* also appears to have displaced *Themeda triandra*, a non-wetland species, as the most dominant species in Transect 3 (Table 4.5). Within Kruisfontein, Table 4.6 shows how obligate wetland species such as, *Paspalum distichum* and *Schoenoplectus paludicola*, have increased in abundance in response to the high, moderate and low flows when compared to the dominance of facultative and facultative positive plant species within the control area. Nonetheless, it is also clear that the alien grass *Paspalum dilatatum* has remained dominant over most of the wetland since rehabilitation. In addition, the dominant plant species within the area affected by the farmer's interventions (prior to 2005) has not changed between 2005 and 2011 (Table 4.6).

Table 4.5. Dominant plant species identified for each of the transects for the pre- and post-rehabilitation within Killarney wetland. Species are ranked in order of abundance. Transect 4 was included in 2011 due to the lack of a control in the Killarney system in an attempt to identify the conditions if rehabilitation had not been undertaken.

Transect	Pre-rehabilitation (2005)	Post-rehabilitation (2011)
1	1) *Pennisetum thunbergii* [F+ 10] 2) *Carex acutiformis* [O 10] 3) *Eragrostis planiculmis* [O 5]	1) *C. acutiformis* 2) *Eleocharis dregeana* [O 10] 3) *P. thunbergii*
2	1) *E. planiculmis* 2) *P. thunbergii* 3) *Helichrysum aureonitens* [F+ 10]	1) *E. dregeana* 2) *P.thunbergii* 3) *E. planiculmis*
3	1) *Themeda triandra* [NW 10] 2) *H. aureonitens* 3) *E. planiculmis*	1) *E. dregeana* 2) *H.aureonitens* 3) *E.planiculmis*
4	-	1) *H.aureonitens* 2) *E.planiculmis* 3) *Andropogon appendiculatus* [F+ 10]

[FW] Facultative wetland; [F-] Facultative negative; [F+] Facultative positive; [O] Obligate wetland; [NW] Not wetland

[0] Alien invasive plants; [1] Ruderal or weedy plants; [5] occasionally ruderal or weedy plants; [10] Plant species intolerant of disturbance

Table 4.6. Dominant plant species identified for each of the treatments pre- and post- rehabilitation within Kruisfontein wetland. Given that the area ultimately affected by high, moderate and low flows was less extensive than anticipated, pre-rehabilitation (2005) plots are absent in this zone, but it appears to have very closely resembled the "Transformed control" area in 2005 and is likely to have shared the same dominant species.

Treatments	Pre-rehabilitation (2005)	Post-rehabilitation (2012)
Transformed control (transformed area unaffected by rehabilitation)	1) *Paspalum dilatatum* $^{F+\ 0}$ 2) *Cynodon dactylon* $^{F-\ 1}$ 3) *Eragrostis plana* $^{FW\ 5}$	1) *P. dilatatum* 2) *C. dactylon* 3) *E. plana*
WfWet rehabilitation high, moderate and low flows	-	1) *Paspalum distichum* $^{O\ 5}$ 2) *P.dilatatum* 3) *Schoenoplectus paludicola* $^{O\ 10}$
WfWet rehabilitation - high flows only	1) *Bidens pilosa* $^{NW\ 0}$ 2) *P. dilatatum* 3) *C. dactylon*	1) *P. dilatatum* 2) *Cyperus esculentus* $^{FW\ 1}$ 3) *Verbena bonariensis* $^{F-\ 0}$
Untransformed	1) *Carex acutiformis* $^{O\ 10}$ 2) *Hyparrhenia dregeana* $^{F-\ 5}$ 3) *P. distichum*	1) *P. dilatatum* 2) *H. dregeana* 3) *C. acutiformis*
Farmer's rehabilitation	1) *P. dilatatum* 2) *Juncus effusus* $^{O\ 5}$ 3) *C. dactylon*	1) *P. dilatatum* 2) *J. effusus* 3) *C. dactylon*

^{FW} Facultative wetland; $^{F-}$ Facultative negative; $^{F+}$ Facultative positive; ^{O} Obligate wetland; ^{NW} Not wetland
^{0} Alien invasive plants; ^{1} Ruderal or weedy plants; ^{5} occasionally ruderal or weedy plants; ^{10} Plant species intolerant of disturbance

The vegetation response within Kruisfontein wetland contrasted with Killarney wetland and provided additional opportunities to identify trends in vegetation recovery, as the baseline and follow-up surveys included 1) an area that has been subject to improved hydrology since 2004 when the landowner implemented wetland rehabilitation independently; 2) a ridge-and-furrowed area that serves as a control as it was unaffected by both the farmer's and WfWet's rehabilitation activities; and 3) a small area of intact vegetation not subject to ridge-and-furrow cultivation, although it had been subject to some less intensive human impacts such as livestock grazing. Nonetheless, it was the closest to an area of near-natural vegetation, and provided an indication of some of the native plant species to expect with recovery, notably *Carex acutiformis, Arundinella nepalensis*, and *E. dregeana*, see the full list in Appendix 1.

4.2.3.1 Wetland index value

WIVs, indicating the degree to which functional wetland vegetation is present, recorded in the Killarney wetland in 2005 (Table 4.7) support the original observation by Cowden et al. (2009) of a gradient from drier conditions upstream (Transect 3) to wetter conditions downstream (Transect 1). The recorded WIVs also decreased from 2005 to 2011 (Table 4.7), as the vegetation in Killarney wetland comprised more obligate or facultative positive wetland plant species, i.e. indicating wetter conditions. However, the WIVs for each of the plots within the two wetlands over time, showed that significant differences (P<0.05) existed only within the Kruisfontein wetland.

Table 4.7. WIVs recorded, pre- and post-rehabilitation, represented as the mean ± standard deviation for each transect in the Killarney wetland. No significant differences (P >0.05) were recorded pre- and post-rehabilitation

	Pre-rehabilitation (2005)	**Post-rehabilitation (2012)**
Transect 1	1.751 ± 0.878	1.661 ± 0.726
Transect 2	1.917 ± 0.942	1.755 ± 0.842
Transect 3	2.740 ± 1.113	1.625 ± 0.587
Transect 4	-**	2.195 ± 0.526

[*] Recorded WIVs ranged from 1 (obligate) to 5 (non-wetland) depending on the prevalence of the plant species within each indicator class in the particular plot.

[**] The sample plots within Transect 4 were only sampled in 2011 and not in 2005 prior to the wetland rehabilitation.

Comparison of "treatments", pre- and post-rehabilitation, within the Kruisfontein wetland showed no significant differences (P>0.05) in WIVs (Table 4.8). The comparison of the 2005 control with the other treatments from 2005 showed no significant differences. However, comparison of the 2012 control with other treatments from 2012 revealed that the area influenced by the high, moderate and low flows is significantly different to the control, suggesting a change in vegetation composition since the implementation of the WfWet rehabilitation (Table 4.9).

Table 4.8. Comparison, for Kruisfontein wetland, of the mean ± standard deviation WIV values recorded within sample plots for each of the 'treatments', pre- and post-rehabilitation. Significant differences (P < 0.05) within the rows are shown by different letters*

	Pre-rehabilitation (2005)	Post-rehabilitation (2012)
WfWet rehabilitation high, moderate and low flows	- **	1.335 ± 0.369 -
WfWet rehabilitation high flows only	3.941 ± 1.169 a	2.495 ± 0.367 a
Transformed control (transformed area unaffected by rehabilitation)	2.735 ± 0.574 a	2.850 ± 0.463 a
Untransformed	2.185 ± 1.404 a	2.701 ± 1.213 a
Farmer's rehabilitation	2.173 ± 0.718 a	2.405 ± 0.625 a

*Recorded WIV values ranged from 1 (obligate) to 5 (non-wetland) depending on the prevalence of the plant species within each indicator class in the particular plot.

** The sample plots grouped as 'WfWet rehabilitation high, moderate and low flows' were only sampled in 2012 and not in 2005 prior to the wetland rehabilitation.

Table 4.9. Comparison, for Kruisfontein wetland, of the mean ± standard deviation WIV values recorded within sample plots for each of the 'treatments' and compared with the control from the same year. Significant differences (P < 0.05) within columns are shown by different letters

	Pre-rehabilitation (2005)	Post-rehabilitation (2012)
Transformed control (transformed area unaffected by rehabilitation)	2.735 ± 0.574 a	2.850 ± 0.463 a
WfWet rehabilitation high, moderate and low flows	-*	1.335 ± 0.369 b
WfWet rehabilitation high flows only	3.941 ± 1.169 a	2.495 ± 0.367 a
Untransformed	2.735 ± 0.574 a	2.701 ± 1.213 a
Farmer's rehabilitation	2.185 ± 1.404 a	2.405 ± 0.625 a

*The sample plots grouped as 'WfWet rehabilitation high, moderate and low flows' were only sampled in 2012 and not in 2005 prior to the wetland rehabilitation.

In interpreting WIV, it is useful to consider the thresholds recommended by Wentworth and Johnson (1986) and applied by Carter et al. (1988):

- WIV <2.5 is designated as wetland;
- WIV 2.5 to 3.5 is designated as transitional;
- WIV >3.5 is designated as non-wetland.

Based on the aforementioned thresholds and the data represented in Table 4.7, Table 4.8 and Table 4.9, the WIV values recorded for Killarney wetland would generally be considered as 'wetland', in contrast to the WIV values recorded for Kruisfontein, which suggest the majority of the system is 'transitional', with a mix of wetland and non-wetland plant species.

4.2.3.2 Floristic quality assessment index

The FQAIs, indicating the degree to which the vegetation present reflects the natural reference condition for each of the plots within the wetlands, showed significant differences ($P<0.05$) between transects and "treatments" within the Killarney and Kruisfontein wetlands, respectively. Comparisons over time showed only significant differences for Transect 1 within the Killarney wetland, although the vegetation composition has generally altered towards non-opportunistic plant species, with the recorded FQAIs increasing for Transects 1, 2 and 3 (Table 4.10). In the case of Kruisfontein, the comparisons of FQAIs show that in 2005 there was no significant difference between "treatments" and the control. However, post-rehabilitation in 2012, those areas influenced by the high, moderate and low flows and the untransformed area, are significantly different to the control, suggesting a change in vegetation composition (Table 4.11). The strongly-competitive pioneer species, *P. dilatatum*, has retained its dominance within the system, except for the area influenced by high, moderate and low flows associated with the WfWet rehabilitation. Despite *J. effusus* having been present in the area affected by the farmer's rehabilitation in 2005, it has been unable to displace the abovementioned pioneer species even after nine years of improved hydrological conditions. In addition, there is a distinct lack of native species, such as *C. acutiformis*, which are less tolerant of disturbance. In contrast to the Killarney wetland, where it is anticipated that given enough time, the pioneer species will give way to more native vegetation, the vegetation within the Kruisfontein wetland appears to be stable in a severely transformed state.

Table 4.10. Comparison of the mean ± standard deviation FQAI values recorded within sample plots for each of the 'treatments' pre- and post-rehabilitation. Significant differences (P < 0.05) within the rows are shown by different letters *

Killarney Wetland	Pre-rehabilitation (2005)	Post-rehabilitation (2011)
Transect 1	81.064 ± 11.069 a	93.643 ± 6.068 b
Transect 2	75.701 ± 11.858 a	87.575 ± 9.574 a
Transect 3	85.188 ± 7.596 a	87.447 ± 5.458 a
Transect 4	No comparison possible **	
Kruisfontein Wetland	**Pre-rehabilitation (2005)**	**Post-rehabilitation (2011)**
WfWet rehabilitation high, moderate and low flows	No comparison possible ***	
WfWet rehabilitation high flows only	19.820 ± 12.182 a	13.608 ± 9.576 a
Transformed control	16.963 ± 14.518 a	22.229 ± 8.487 a
Untransformed	46.383 ± 35.799 a	45.413 ± 17.795 a
Farmer's rehabilitation	30.502 ± 10.474 a	22.384 ± 14.766 a

*Recorded FQAI values range from 0 (dominated by alien plant species) to 100 (dominated by indigenous plant species intolerant of disturbance)

** The sample plots within Transect 4 were only sampled in 2011 and not in 2005 prior to the wetland rehabilitation.

*** The sample plots grouped as 'WfWet rehabilitation high, moderate and low flows' were only sampled in 2012 and not in 2005 prior to the wetland rehabilitation.

Table 4.11. Comparison, for Kruisfontein wetland, of the mean ± standard deviation FQAI values recorded within sample plots for each of the 'treatments' and compared with the control from the same year. Significant differences (P < 0.05) within the columns are shown by different letters

	Pre-rehabilitation (2005)	Post-rehabilitation (2012)
Transformed control (transformed area unaffected by rehabilitation)	16.963 ± 14.518 a	22.229 ± 8.487 a
WfWet rehabilitation high, moderate and low flows	-	53.556 ± 24.084 b
WfWet rehabilitation high flows only	19.820 ± 12.182 a	13.608 ± 9.576 a
Untransformed	46.383 ± 35.799 a	45.413 ± 17.795 b
Farmer's rehabilitation	30.502 ± 10.474 a	22.384 ± 14.766 a

*The sample plots grouped as 'WfWet rehabilitation high, moderate and low flows' were only sampled in 2012 and not in 2005 prior to the wetland rehabilitation.

4.3 Discussion

The improvement in ecosystem integrity of the Killarney and Kruisfontein wetlands was less than the improvements in hectare equivalents predicted originally in the rehabilitation plans. This suggests that the rehabilitated wetlands have not followed the trajectory of change anticipated during the planning process. Within the Killarney wetland, the hydrology and geomorphology have recovered as anticipated, with the lower than expected gain in hectare equivalents being mostly attributed to the response of the vegetation component. However, it is anticipated that vegetation conditions may improve further if the desired state within the wetland is maintained. In a review of multiple wetland rehabilitation sites, Moreno-Mateos et al. (2012) noted that hydrological features appeared to recover immediately after the rehabilitation activities, but vegetation was the slowest to recover, with convergence with reference conditions taking on average thirty years. Within the Kruisfontein wetland, however, both hydrology and vegetation have not responded as anticipated. The hydrological response within the wetland was inhibited by the ineffectiveness of the spreader canal and the concentration of flows along the western edge of the wetland. The limited vegetation response in the Kruisfontein wetland is linked to a smaller area being flooded than expected and the dominance of disturbance-tolerant plant species, as shown by the FQAI results.

The improvements in the wetlands' effectiveness to supply ecosystem services, were strongly linked to the improvement in regulatory services (e.g. assimilating nutrients). The increased effectiveness relating to regulatory services was directly attributable to the redistribution of flows over larger areas of the wetlands. In addition to the change in effectiveness recorded for the two wetlands, Kotze et al. (2007) suggest that generally, the larger the wetland, the greater its provision of benefits and services. In terms of improvements linked to the rehabilitation, it is therefore important to also consider the increase in area of functional wetland within the landscape when assessing improved functioning. Another consideration is that the importance of wetland size varies between specific ecosystem services, for example, for water quality enhancement the size is considered to be "usually to always very important" (Kotze et al. 2007 p.31). The effect of spatial extent of intact wetland within a catchment on the assimilation of nutrients has been well demonstrated by Tiner (2005) and Turpie et al. (2010). The increase in regulatory services relating to water quality within the Kruisfontein wetland is particularly important if one considers that the area receives effluent from the dairy, which may deliver significant pollutants when discharged to streams (Bolan et al. 2009). With the increase in effective wetland size and the increased effectiveness in terms of ecosystem services associated with water quality enhancement, the rehabilitation therefore more than likely assists in buffering the Mooi River from nutrients originating from the nearby dairy.

Although subtle (i.e. non-significant differences), the results of the vegetation surveys for Killarney wetland generally followed expectations, where WIV values along the transects indicate that obligate wetland species (e.g. *E. dregeana)* have increased in abundance. It is suggested that non-significant differences were related to obligate wetland species replacing facultative positive wetland species (e.g. *P. thunbergii*), rather than facultative wetland species as was the case in the moderate and low flow area in Kruisfontein wetland. In addition, *C. acutiformis*, the species characteristic of the intact portions of the wetland, increased in abundance while the abundance of disturbance tolerant species decreased, shown by the significant differences in FQAI values observed over time for Transect 1. The response of the vegetation within the Killarney wetland therefore appears to be following the wetness gradient described by Cowden et al. (2009), where the historically wetter areas downstream are responding more quickly to the rehabilitation than the drier upstream areas. In contrast to Kruisfontein, it is anticipated that the changes in floristic quality have been facilitated by the presence of nearby intact areas of wetland habitat providing propagules, and the fact that the historical disturbance of the system was linked to desiccation associated with channel incision rather than long-term, intensive agricultural production. It is anticipated that the wetland vegetation will continue to recover, with vegetation recovery following rehabilitation often being recorded as slow (Galatowitsch and van der Valk 1996, Moreno-Mateos et al. 2012).

A significant result obtained for the Kruisfontein wetland was that after seven years of rehabilitation, the area is largely dominated by pioneer or ruderal species. This was reinforced by the lack of significant differences being recorded for the FQAI values over time. The presence of alternate stable states or regimes within natural systems is described by Walker et al. (2006), where socio-ecological systems are described as having multiple thresholds and theoretically being able to exist in a number of stable regimes. Walker et al. (2006) also highlight that once certain thresholds are crossed, the ecosystem may be limited in terms of the number of stable regimes it is then able to attain, even with rehabilitation. The current regime within the Kruisfontein wetland can be considered to be an alternative stable regime that would need a threshold to be crossed in order to promote a 'desired' regime. The findings at Kruisfontein wetland contradict the assertion, generally adopted by wetland rehabilitation practitioners in South Africa, that if the hydrology of the wetland is re-instated then this will be followed by the natural re-establishment of the native wetland vegetation.

The intensity and duration of human disturbance (i.e. ridge-and-furrow agriculture) preceding the rehabilitation is likely to have depleted the natural seed bank and any vegetative material which may have persisted within the Kruisfontein wetland. The duration of the disturbance is likely to have had a critical impact on the wetland vegetation, since the area was modified for cultivation prior to 1940. Weinhold and van der Valk (1989) found that propagules of sedge meadow species persisted for less than 20 years in the seed bank and as such, the re-establishment of native vegetation in areas cultivated for longer than 20 years is dependent on the dispersal of propagules from remote intact areas. At Kruisfontein, nearby intact wetland areas are very limited, and as highlighted by Seabloom and van der Valk (2003) and O'Connell et al. (2013) increased isolation of the wetland as a result of cumulative loss of wetlands in the landscape, inhibits colonisation by dispersal-limited indigenous species. The dominance of a competitive alien species (*P. dilatatum*), specifically adapted to wetter conditions, further added to the difficulty for a diversity of native species to become established in the site, just as Galatowitsch and van der Valk (1996) note that the competitive grass *Phalaris arundinacea* makes it more difficult for native sedge meadow species to become established should their propagules reach restored wetlands. Galatowitsch et al. (1999) highlights the profound impact that alien invasive plant species may have on the indigenous flora of wetlands. Although localized sections of the Kruisfontein wetland have attained permanent wetness, i.e. a high level of wetness and extended saturation periods, much of the area is still dominated by seasonal and temporary wetness zones. The rehabilitation measures therefore failed to create sufficient areas within the wetland with levels of wetness and saturation periodicity sufficiently wet to exclude pioneer, generalist and/or alien invasive plant species, as documented by previous research (Seabloom and van der Valk 2003, Walters et al. 2006, Walters et al. 2011).

Active planting of indigenous vegetation has been demonstrated to play an important role in re-establishing native vegetation, particularly in the less wet areas of a wetland, and is widely practiced in wetland rehabilitation projects across the US (Galatowitsch and van der Valk 1996, Gutrich et al. 2009). For example, *Carex* sp. sedges, which commonly occur on the edge of temperate freshwater wetlands in the US, do not readily re-establish and it is unlikely that they will reappear without deliberate reintroduction (Budelsky and Galatowitsch 2000). Active planting is usually not included in wetland rehabilitation projects in South Africa because it is assumed that indigenous vegetation will eventually establish naturally. However, this may frequently not be the case.

CHAPTER 5 - CONCLUSIONS AND RECOMMENDATIONS

This chapter will begin by firstly drawing on key findings from Chapter 3 relating to structural outputs and their costs in order to address the question of whether the rehabilitation was worthwhile at the two sites and Chapter 4 relating to ecological outcomes of rehabilitation. Key trends in the findings of the research undertaken in the Killarney and Kruisfontein wetlands will then be identified and lessons will be extracted which can be applied in future wetland rehabilitation efforts. This will be undertaken separately, firstly for structural outputs and secondly for ecological outcomes.

5.1 Was the rehabilitation worthwhile?

The costs of the rehabilitation undertaken at the Killarney and Kruisfontein wetlands were recorded by Cowden et al. (2009) and Kotze and Ellery (2009), respectively. The cost-effectiveness of the wetland rehabilitation at both sites (i.e. the costs of the rehabilitation in relation to the hectare equivalents of intact wetland that was gained as a result of the rehabilitation of the systems) were compared to the thresholds outlined in WET-RehabPlan (Table 2.3). An assessment of the cost-effectiveness for the rehabilitation undertaken at both wetlands is included in Table 5.1. Due to a lack of comparable data across multiple sites, an assessment of the cost-effectiveness of the wetland rehabilitation is limited to comparisons of the cost-effectiveness of the Killarney and Kruisfontein wetlands relative to each other. The cost-effectiveness would be considered ***Moderate*** and ***Intermediate*** to **High** for the Killarney and Kruisfontein wetlands, respectively (Table 5.1).

Table 5.1. Summary of the main benefits and costs of the Killarney and Kruisfontein wetland rehabilitation, with cost-effectiveness determined based on threshold values presented in Table 2.3.

	Killarney wetland	Kruisfontein wetland
Predicted Ha equiv. gained (Kotze and Ellery 2009)	8.0	5.0
Ha equiv. gained	6.8	3.3
Effectiveness of ecosystem services enhanced more than 50%.	Toxicant removal Carbon storage Water supply	Flood attenuation Sediment trapping
Costs of wetland rehabilitation (Cowden et al. 2009; Kotze and Ellery 2009)	R 1 785 300	R 429 212
Cost per hectare equivalent	R 262 544	R 130 064
Cost-effectiveness	Moderate	Intermediate to high
Objectives achieved	Yes	Partially

The review of the cost-effectiveness of the wetland rehabilitation highlighted that the rehabilitation undertaken at both the Killarney and Kruisfontein wetlands was considered ***Intermediate*** to ***High***. As suggested in Section 2.2.3, the cost-effectiveness of the wetland rehabilitation needs to be considered in context, with the following needing to be considered:

- Rehabilitation activities that focus on reinstating wetland condition tend to be more expensive than activities that are designed to prevent further degradation within a specified wetland, as highlighted by Cowden and Kotze (2009) and in this study, the cost-effectiveness of the Killarney wetland rehabilitation is relatively low, due to the intensive attempt to reinstate benchmark conditions.
- Streever (1997) reports that the size (i.e area) of the rehabilitated wetland influences project costs, with larger projects generally being less expensive than smaller projects, although it is acknowledged that the relationship may be influenced by other factors such as difficult/costly rehabilitation being limited to smaller systems.
- The nature and scale of the problem directly influences the costs. For example, despite the rehabilitation of the Manalana wetland in Mpumalanga Province focussing on

halting of erosion, the scale of the problems requiring stabilisation led to the relatively low cost-effectiveness of the project (Kotze and Ellery 2009). Black and Turpie (2016) also highlight the differences in rehabilitation costs between different activities, such as the clearing of alien invasive vegetation and structural interventions (e.g. concrete weirs). It should be noted that while some latitude exists for selecting between different rehabilitation activities to improve cost-effectiveness, certain problems in a wetland will require particular interventions. For example, while certain erosion problems in a wetland can be addressed through the exclusion of livestock, many erosion problems require particular structural interventions.

- Kimball et al. (2015) noted the influence of environmental variables on cost-effectiveness, such that costs increase where variables (e.g. steep slopes, north / south facing slopes, rainfall etc.) negatively influence vegetation establishment. Furthermore, Kimball et al. (2015) highlight that the target or reference condition that is aspired to influences cost-effectiveness, especially when fixed funds are available as the intensity required to achieve the reference condition reduces the extent of habitat restored. The rehabilitation at Killarney wetland attempted to attain a benchmark condition as close to natural as possible, contributing towards the relatively low cost-effectiveness.
- With the rehabilitation of priority wetlands such as Ramsar sites or wetlands that form part of larger protected areas and thus contribute towards the maintenance of regional biodiversity, it is generally more acceptable to spend funds on rehabilitation activities than on non-priority sites (Cowden and Kotze 2009). When comparing the Killarney and Kruisfontein wetlands rehabilitation cost-effectiveness, Killarney wetlands occurrence within a Ramsar site needs to be taken into consideration.
- The nature of the funding and the implementing agent also needs to be considered, as rehabilitation undertaken on behalf of WfWet is bound by limitations imposed by the EPWP, which includes defined labour components for the planned rehabilitation. Zentner et al. (2003) highlight that public sector rehabilitation costs are approximately 15-20 percent more than commercial or private contractor-based projects. However,

volunteer-based rehabilitation is generally less costly due to volunteer and in-kind donations of labour as reported by Streever (1997).

- The inherent risk associated with the wetland rehabilitation strategy influences the costs of the rehabilitation. For example rehabilitation planned within a high energy environment requires greater measures to protect against high energy flows than rehabilitation planned in a low energy environment.

For both systems, the rehabilitation required relatively large-scale interventions to address the identified problems. As such, the rehabilitation was focussed on reinstating wetland integrity to a degree that is difficult to achieve, increasing the costs associated with the rehabilitation. In addition, the ridge-and-furrow within the Kruisfontein wetland requires numerous interventions to block the furrows within the system, which cumulatively serve to reduce cost-effectiveness. The rehabilitation in the Killarney wetland occurs within a Ramsar site, i.e. a wetland of international importance, and as such the cost-effectiveness may be considered less important than if it was not viewed as such an important wetland, given South Africa's commitment in terms of the Ramsar Convention. In both instances, the wetland rehabilitation was funded by the State, in which case cost-effectiveness is less important that if the work was done by individual landowners (Zentner at al. 2003). A priority for the South African State is creation of jobs, such that the ecological outcomes can be achieved to a high degree as long as it means that people are employed.

In order to evaluate whether the wetland rehabilitation undertaken was worthwhile, both the outcomes and outputs of the project need to be considered, specifically the ecological response needs to be assessed taking into consideration the cost-effectiveness of the wetland rehabilitation. Based on a review of Table 5.1, it is evident that the improvement in ecosystem integrity, based on hectare equivalents, of the Killarney and Kruisfontein wetlands was less than the improvements originally predicted (Kotze and Ellery 2009). This is largely a result of the vegetation response in both systems being less than anticipated. For the Killarney wetland this appears to be more a result of a lag in response than an 'inadequate' response. In contrast, the

Kruisfontein wetland hardly responded to the rehabilitation interventions. Unfortunately, without further intervention the objectives of the wetland rehabilitation at Kruisfontein are not likely to be achieved.

In terms of comparing the cost per hectare equivalent values, Kruisfontein wetland is approximately half as costly as Killarney wetland (Table 5.1). However, considering the context of the rehabilitation as described above, the Killarney wetland may be viewed as more worthwhile than the Kruisfontein wetland, rehabilitating high value wetland habitat in a formally protected nature reserve, while the Kruisfontein wetland occurs on privately-owned land with limited protected status. The high value of the Killarney wetland is further supported by its inclusion into a Ramsar site, Ntsikeni Vlei) which is recognised internationally, while the Kruisfontein wetland is not recognised as a wetland of particular significance, even at a regional scale. In addition, the fact that that the wetland rehabilitation in the Killarney wetland has achieved its objectives, with the gain in hectare equivalents anticipated to improve over time as the vegetation continues to respond, may further contribute towards the view that the Killarney wetland rehabilitation was more worthwhile than the Kruisfontein wetland rehabilitation at this point in time. This is despite the Kruisfontein wetland rehabilitation being twice as cost-effective as the Killarney wetland rehabilitation.

Kotze and Ellery (2009) recommend that while the cost-effectiveness of wetland rehabilitation projects using the thresholds supplied in WET-RehabPlan (Table 2.3) appears useful in evaluating wetland rehabilitation projects, it should be applied to several sites. This process would allow the development of norms and standards, and possibly refinement of the classes, for future wetland rehabilitation evaluation. Based on the observations of the ecological response of the Killarney and Kruisfontein wetlands, it is strongly recommended that these recommendations be the focus of future research in this regard.

5.2 Assessment of structural outputs in terms of integrity, survival and cost-effectiveness.

The assessment of structural outputs has served to highlight a number of lessons that should be documented, shared and adopted within the South African wetland rehabilitation field of practice. In addition, the results and findings have allowed recommendations to improve the wetland rehabilitation field of practice.

5.2.1 Factors underpinning rehabilitation output successes and failures in the case study sites

The review of the structural outputs using WET-RehabEvaluate served to highlight shortfalls within the guideline document. Of particular importance is the technical nature of the criteria used to assess structural integrity. It was noted that without experience, it was considered unlikely that an environmental specialist other than an engineer would be able to accurately reflect issues identified with the structures. Furthermore, it was noted that problems identified with the structures were not necessarily encompassed by the criteria provided by WET-RehabEvaluate, such as consideration of the workmanship. While guidance is included to enable the specialist to assess the interventions, the document lacked guidance in terms of identifying and accounting for unanticipated consequences of the wetland rehabilitation interventions. This is clearly illustrated by the erosion recorded as a result of diverted flows in both wetlands. While the integrity of the structures is important, the guidelines do not consider whether the intervention is achieving its specific objective (e.g. raising water levels) thereby contributing towards the overall project objectives, or if adaptive management should be considered for a particular intervention and/or the overall rehabilitation strategy.

In terms of reviewing the rehabilitation strategy, based on cost-effectiveness and efficacy relating to meeting the stated objectives, the thresholds provided in WET-RehabPlan (Table 2.3) appear to be too broad. This was particularly evident for the Kruisfontein wetland where the cost-effectiveness was the same as reported by Kotze and Ellery (2009) despite the gained hectare equivalents recorded during this study being almost half of that expected (Table 5.1).

The review of the structural integrity of the various interventions in the Killarney and Kruisfontein wetlands (Appendix 2), served to highlight that with the adoption of an appropriate design rationale (Refer to Figure 3.1), failure of structural interventions was limited. However, the tunnelling recorded at one of the concrete interventions in the Killarney wetland does serve to highlight an important component of the design and construction phases, i.e. evaluating site conditions (e.g. foundation of the structure), which was historically limited due to time and budgetary constraints.

As described in Chapter 3, the identified issues with the structural interventions largely related to issues during the construction and implementation phase. This finding suggests that for 'technical' interventions, such as spreader canals, additional information may be required in the available guideline documents in order to better inform and guide implementation. Furthermore, engineering support during the construction phase is required to assist the implementer with interpreting the designs in the wetland rehabilitation plans and with the practical implementation thereof. This is especially important in those instances where inexperienced implementing agents may be in operation.

With regards to the achievement of the project objectives for both wetlands, the need for corrective action was noted for a number of the interventions (Appendix 2). The details of the corrective action are recorded in the following section of recommendations. However, unanticipated consequences of the wetland rehabilitation were also recorded (Refer to Chapter 3) with the initiation of erosion recorded in both wetlands. The need to consider this aspect is not clearly defined in the guideline documents, but potentially requires consideration and should be included in the guidelines.

5.2.2 Recommendations

Recommendations are made in terms of amendments to the respective Wetland Management Series guideline documents, including corrective action and adaptive management measures to assist in achieving the rehabilitation strategy at each site.

5.2.2.1 Amendments to the respective Wetland Management Series documents

Within the Wetland Management Series, WET-RehabEvaluate and WET-RehabMethods considered the outputs of the wetland rehabilitation process in detail, and as such, improvements associated with these documents have been recommended from the findings of this aspect of the research.

It is recommended that WET-RehabEvaluate include additional criteria to assess structural integrity, such as a consideration of workmanship during the implementation and construction of structural outputs. Despite the understanding that wetland rehabilitation monitoring and evaluation should be undertaken as a multi-disciplinary process and include an appropriately experienced engineer, it is considered important that the terminology and criteria described in WET-RehabEvaluate for monitoring structural outputs be further explained, possibly including examples to guide the monitoring of structural integrity. As highlighted by the erosion that has originated from the breaching of the spreader canal in Killarney wetland, the document should provide guidance in terms of identifying and accounting for unanticipated consequences of the wetland rehabilitation interventions. Of particular importance in the monitoring of structural outputs, is considering if the structural intervention is achieving its specific objective (e.g. redirect surface flows) and thus contributing towards the overall project objectives. As such, further research should be undertaken and further guidance should be provided in terms of incorporating adaptive management into the wetland rehabilitation project, especially if corrective actions are required as a result of monitoring project outputs. It should be noted that corrective action should include the option to amend the original rehabilitation strategy and/or incorporate additional interventions to optimise system response. Furthermore, the reviewing of the rehabilitation strategy, in term of cost-effectiveness and efficacy in terms of meeting the stated objectives, should be incorporated more fully into the guideline document, thereby assisting in the refinement of rehabilitation planning and increased efficiencies, especially where funding is limited.

A number of the issues noted during the monitoring of the structural outputs originated from inconsistencies and/or challenges in the implementation of the project. With the lessons learnt from the WfWet programme over the last seven years, improvements to the general approach to implementation of wetland rehabilitation have taken place, for instance the inclusion of signing off structural interventions, thereby ensuring the interventions are achieving their objectives. These amendments should be incorporated into the approach advocated by WET-RehabMethods. Due to advancement of the wetland rehabilitation field of practice in South Africa, a general review of all the approaches and/or techniques may be warranted at this point in time.

The review of structural integrity (Mr T Pike 2011, pers. comm., April 2011), highlighted the following recommendations in terms of the application of spreader canals and earthen berms.

The issues noted where the objectives of the structural interventions were partially or entirely not being met, related primarily to the ineffectiveness of the implemented spreader canals. While WET-RehabMethods includes clear guidelines for the adoption, design and construction of spreader canals (Russell 2009, p.175), their implementation appears to be problematic and the guideline document should be updated to incorporate additional mechanisms to ensure their successful implementation such that:

- Spreader canals should be set out as per the specifications outlined by Russell (2009);
- Spreader canals should be subject to input from the design engineer during the implementation phase;
- Spreader canals should preferably be constructed with a hardened downstream edge (e.g. concrete or brickwork) to prevent the development of a preferred discharge point from forming; and

- The relative elevation of the receiving wetland should be taken into account in the planning of spreader canals to ensure that diffuse flows are achieved, for instance where the spreader canal decants into an area of the wetland where local slopes is steeper than 1%, energy dissipating structures need to be incorporated into the design.

If earthen plugs are to be utilised, it is recommended that a high density of small structures (<0.5m freeboard) should be utilised to spread the flows throughout the wetland, with an understanding of the increased risk of overtopping of the structures. This approach would increase the hydraulic connectivity between furrows, attempting to reduce the dominance of terrestrial species on the ridges, but would need to be carefully designed to also maintain hydraulic connectivity along the furrows. This could be achieved through the use of base flow pipes through the earthen berms at key points in the wetland. The initially diverted flows also need to be managed either by means of a spreader canal that decants flows into the heads of each of the furrows, or reinforcing (e.g. concrete geocell-covering) those upstream berms within the direct flow path of the initially diverted flows. Based on these observations, it is recommended that future research into rehabilitation methods test the effectiveness of reversing the original earthworks by excavating the ridges and utilising the material as backfill for the furrows, effectively reinstating the natural topography of the wetland that would have existed prior to the disturbance taking place. Depending on the scale of the ridge-and-furrow modifications, this may only be possible using machinery and may not be applicable for rehabilitation within the EPWP.

The assessment of the earthen plugs and spreader canals also served to highlight that the reliance on these interventions to re-distribute flows in a wetland rehabilitation strategy should be supported by a good understanding of the topographic elevations of the site. Water flows within the Kruisfontein wetland followed the shortest route through the wetland resulting in some areas of the rehabilitation being bypassed due to limited connectivity along the length of the furrows. It is therefore recommended that rehabilitation of ridge-and-furrow drainage networks, incorporate a clear understanding of the topographic elevations of the wetland to ensure that diverted surface flows are able to move laterally such that earthen plugs should only be utilised in cases where the topography of the wetland is extremely gently sloping (<1% slope).

5.2.2.2 Remedial and adaptive management measures to be implemented at the case study sites.

With regards to the long-term implementation of the wetland rehabilitation strategy and the achievement of the project objectives for both the Killarney and Kruisfontein systems, corrective action is required with the following remedial and additional measures recommended.

Within the Killarney wetland, an earthen berm is recommended towards the end of the spreader canal, blocking flows that are currently exiting the canal, thereby reinstating flows along the length of the spreader canals overflow edge. Two of the concrete weirs require remedial actions, with the extension of the right hand shoulder wall and the construction of a concrete cut-off wall on the upstream side of the spillway. This would address the identified erosion and tunnelling at each of the interventions. An additional concrete weir may need to be considered between two of the interventions, but this would require further monitoring of water level in this area.

Within the Kruisfontein wetland, minor amendments and/or modifications to the concrete weir, specifically raising of the spillway, would greatly improve the degree to which the project objectives are being achieved. The functioning of the downstream spreader canal should be re-instated, with the repair of the breach in the structure to allow water to be spread across a wider portion of the wetland. It should be noted that the poor recovery of the vegetation within the Kruisfontein wetland had implications for the provisioning services supplied by the wetland. Specifically, some of the labourers on the farm used the wetland-dependent rush *Juncus punctorius* for weaving, and it was anticipated that this species would increase in abundance through rehabilitation. Despite the prevalence of *Juncus effusus*, planting of *J. punctorius* is recommended in order to actively promote its increased abundance, as *J. effusus* has been shown to be of very low value for craft production (Kotze and Traynor 2012). Thus there would be an increase in the value of the Kruisfontein wetland as a source of natural resources.

As identified in Chapter 3, unanticipated consequences of the wetland rehabilitation included the initiation of erosion in both wetlands. Within the Killarney wetland, the erosion has developed as a result of the concentrated flows from the spreader canal entering a secondary channel (Plate 3.5). With the implementation of the abovementioned corrective actions, no interventions would be envisaged to directly address the erosion. However, the erosion identified within the Kruisfontein wetland will require an intervention to stabilise the erosion (Plate 3.7) and enable flows to safely discharge into the Mooi River. This additional intervention could be constructed when the abovementioned corrective measures are implemented in the Kruisfontein wetland.

5.3 Assessment of ecological outcomes in terms of integrity, ecosystem services and vegetation composition.

The assessment of ecological outcomes has served to highlight a number of lessons that should be documented, shared and adopted. In addition, the results and findings have allowed recommendations to improve the wetland rehabilitation field of practice, including a number of recommendations relating to the publications within the Wetland Management Series.

5.3.1 Factors underpinning rehabilitation outcome successes and failures in the case study sites

The assessment of the Killarney and Kruisfontein wetlands in this study identified that the rehabilitation undertaken has not followed the anticipated trajectory of change predicted by Cowden et al. (2009) and Kotze (2009), although this has served to highlight a number of lessons. An important feature of the success of rehabilitation interventions at Killarney relates to the rehabilitation practitioners having made judgements about the design of interventions based on local conditions. The use of water, through back-flooding from downstream structures across the channel, was critical to the deactivation of the channel, especially given the lack of sediment movement within the system. Should the rehabilitation have relied on infrequent structures across the channel and the accumulation of sediment to deactivate the channel, it is unlikely that the response to the rehabilitation would have been successful.

The improvements in the levels of ecosystem service delivery in both the Killarney and the Kruisfontein wetlands were strongly linked to regulatory services such as trapping or assimilating nutrients. This is attributed to the rehabilitation strategies at both sites redistributing flows over larger areas of wetland. While the actual change in effectiveness recorded for the two wetlands may not be seen as large, with the exception of flood attenuation and sediment trapping at Kruisfontein, Kotze et al. (2007) suggest that generally, the larger the wetland, the greater its provision of benefits and services. Therefore, it is important to consider the increase in area of functional wetland when evaluating functioning. Unfortunately, the effect of wetland size on delivery of ecosystem services is not adequately reflected by the WET-EcoServices framework. The argument here is that this issue should be addressed in future revisions of the WET-EcoServices documentation. Another consideration is that the importance of wetland size varies between specific ecosystem services. For example, size is considered to be very significant for water quality enhancement, but this is not the case for cultural significance or education and research (Kotze et al. 2007).

Within the Killarney wetland, the hydrology and geomorphology of the system, in terms of ecosystem integrity, has recovered as anticipated but lower than expected gains in hectare equivalents overall was attributed to the response of the vegetation to the rehabilitation. With the reinstatement of the system hydrology, however, it is anticipated that the vegetation component will continue to improve over time. As discussed in Section 4.4, vegetation response is recognised as being slower to respond than other aspects of ecosystems and long term monitoring is required to show ecological response and needs to be considered when defining project objectives and expectations of the period of system response.

Within the Kruisfontein wetland, both hydrology and vegetation have not responded in accordance with the anticipated outcomes of the rehabilitation. The ineffectiveness of the spreader canal and the preferred flow path along the western edge of the earthen berms has partially restricted the hydrological response within the wetland to approximately half of the anticipated area. The limited vegetation response in the Kruisfontein wetland is likely linked to the limited area with improved hydrology, with disturbance-tolerant plant species continuing to dominate the wetland as described in Section 4.4.

5.3.2 Thresholds and alternate stable states in the Kruisfontein wetland

The assessment of ecosystem integrity and analyses of vegetation data using WIV and FQAI has served to highlight that the Kruisfontein wetland after seven years following rehabilitation is considered to be 'locked' into an alternate stable state in which disturbance-tolerant plant species are dominant. Notably, the strongly-competitive pioneer species, *Paspalum dilatatum*, has retained its dominance within the system, except for the area that is flooded during moderate and low flows, where a significant difference in WIV was recorded. In addition to the dominance of *P. dilatatum*, there is a distinct lack of native species such as *Carex acutiformis,* which are less tolerant of disturbance. This was reinforced by the lack of significant differences being recorded for the FQAI scores over time. In order to achieve the objectives of the rehabilitation, a threshold would need to be crossed, whereby *P. dilatatum* is removed or displaced from the system. The need to cross a threshold to promote a desired state was described by Ellery and McCarthy (1998) to promote the reestablishment of vegetation within the transformed Boro River system. Although it should be noted that Walker et al. (2006) also highlight that once certain thresholds are crossed, the ecosystem may be limited in terms of the number of stable regimes it is then able to attain, even with rehabilitation.

Rehabilitated wetland conditions dominated by strongly-competitive pioneer species are 'echoed' in the observations of ecosystem integrity of Zoar Vlei by Walters et al. (2011), where the majority (>80%) of the wetland was historically cultivated and drained, and was subsequently rehabilitated by Mondi Limited in 1999. The vegetation community of Zoar Vlei is described as "incomplete and may be locked into a new stable state by grazing pressure, the presence of a dominant alien grass species (*Paspalum urvillei*) and reduced water inflows" (Walters et al. 2011, p.131). Furthermore, the best recovery in the Zoar Vlei linked to the rehabilitation efforts was also recorded in the areas of the wetland that received the greatest quantity of water during periods of low flow.

In order to understand the threshold in Kruisfontein wetland, the following factors were identified as contributing towards the identified threshold:

- The intensity of disturbance was high as a result of major disturbance through ridge-and-furrow agricultural practices. The impact of the duration of the disturbance was also high in that the area was developed for cultivation prior to 1940. The intensity and duration of human disturbance preceding the rehabilitation, acting to deplete the natural seed bank (as discussed in Section 4.4) and any vegetative material which may persist on site, needs to be reversed as highlighted by Zedler (2000). Therefore, re-establishment of native vegetation in cultivated areas is dependent on the dispersal of propagules from outside areas, or active revegetation measures.
- The dominance of a competitive alien invasive species within the wetland immediately following the completion of the rehabilitation interventions needs to be reversed to allow a diversity of native species to become established on the site. As described in Section 4.4, competitive grass species will limit the establishment of other sedge meadow species, which is especially evident for alien invasive plant species (Galatowitsch et al. 1999).
- Further to the abovementioned constraints imposed by invasive alien plant species, Green and Galatowitsch (2002) highlight that nutrient levels can further contribute towards the suppression of indigenous plant communities. This is an important consideration for historically cultivated lands, specifically the Kruisfontein wetland, which receives the nutrient-enriched runoff from dairy operations.
- The level of wetness that is attained in the rehabilitated wetland should promote prolonged flooding to a shallow depth. The level of wetness then acts to exclude pioneer, generalist and/or alien invasive plant species more effectively than a lower level of wetness (Seabloom and van der Valk 2003; Walters et al. 2006; Walters et al. 2011). Although localized sections of the Kruisfontein wetland have attained near-permanent

wetness, much of the area is still dominated by seasonal and temporary inundation, which is considered insufficiently wet to exclude the competitive alien invasive species.

- Moreno-Mateos et al. (2012) reported that large wetlands (>100ha) recovered biological structure, including vegetation, sooner after rehabilitation than smaller wetlands, mostly as a result of smaller wetlands not being able to provide sufficient resources and/or connectivity for biota to recover. Systems with proximity to intact areas of wetland, with indigenous vegetation nearby, would also be better placed for re-colonisation by dispersal-limited indigenous species (Findlay and Houlahan 1997). In the case of Kruisfontein wetland, the system is relatively small and nearby intact wetland areas are very limited in extent.

These findings contradict the generally accepted premise that if the hydrology is re-instated, the natural re-establishment of native wetland vegetation will follow. This study has highlighted the need to alter the general approach of merely reinstating hydrology for those wetland systems exposed to long-term transformation and/or subject to encroachment by invasive plant species. In those instances the approach should be to either force a desired response in vegetation using permanently wet conditions (which will often not be practically feasible across the entire area being rehabilitated) or actively introduce desired plant species.

5.3.3 Strengths and weaknesses of current methods and those introduced in this study

As highlighted by WET-RehabEvaluate, success of wetland rehabilitation projects should be based on success standards derived from the objectives. The success standards adopted for wetland rehabilitation should include more than one measure (i.e. hectare equivalents). Although simple and effective, hectare equivalents may provide the impression that wetland rehabilitation has been unsuccessful where an alternate stable state has been attained, rather than the desired benchmark or reference condition. For example, if the primary objective of a rehabilitation project was to reinstate regulatory services within a wetland, it would be incorrect to judge the rehabilitation unsuccessful if the wetland has lower than anticipated vegetation integrity because it has remained dominated by invasive indigenous plant species rather than a diverse mix of native species. The use of hectare equivalents therefore results in understating the benefits of wetland rehabilitation at those sites where activities have improved the provision of ecosystem services but not the integrity of the systems.

The use of the WIV and FQAI indices was useful, and assisted in interpreting the response of the wetlands to the rehabilitation. Of particular importance was the ability, based on the indices, to address the queries relating to: 1) to what extent has there been a shift from vegetation indicating terrestrial conditions to vegetation indicating hydric (wetland) conditions?; and 2) to what extent has there been a shift from vegetation strongly dominated by pioneer / ruderal species to native vegetation? Based on the vegetation surveys, the results obtained for the wetlands illustrated the contribution of WIV in measuring response, for example in Killarney wetland where despite recording non-significant differences along the transects, obligate wetland species were shown to have increased in abundance, i.e. obligate wetland species replaced facultative positive wetland species, highlighting the importance of reflecting the trends in response, rather than solely determining a statistically significant difference. The contribution of FQAI in measuring response was illustrated in the Killarney system where *Carex acutiformis*, the wetland plants characteristic of the intact portions of the wetland increased in abundance while the abundance of disturbance tolerant species decreased, shown by the significant differences observed over time for Transect 1.

The assessment of the long-term response of the two wetlands to rehabilitation is seen as contributing positively towards the wetland rehabilitation field of practice in South Africa. The study has assisted in documenting lessons learnt, thereby informing future rehabilitation planning. In addition, the study has introduced two indices to objectively and defensibly utilise vegetation to reflect changes in long-term wetness, and as far as is known to the author, this is the first time that these indices have been applied in South Africa. Based on their application in the study it appears that these indices have particular value for measuring wetland ecosystem response to rehabilitation, and providing additional tools to those prescribed by Cowden and

Kotze (2009). Furthermore, the indices are likely to have much broader application, e.g. for wetland delineation and the assessment of current impacts on wetlands.

5.3.4 Recommendations

Recommendations are made in terms of specific amendments to the respective Wetland Management Series guideline documents and to the wetland rehabilitation field of practice in general.

5.3.4.1 Amendments to the respective Wetland Management Series documents

The application of a number of the Wetland Management Series guidelines and assessment frameworks, i.e. WET-Health, WET-RehabPlan etc., during the course of this research provided opportunities for identifying aspects of the series that could be improved upon with regard to their use in wetland rehabilitation monitoring. The following recommendations are made in terms of the Wetland Management Series.

Within WET-RehabPlan, the criteria for determining the cost-effectiveness of the wetland rehabilitation strategy based on costs per hectare equivalent needs to be further researched and refined to be more sensitive to changes, possibly by including more classes in terms of ZAR per hectare as described in Table 2.3. These refinements would contribute towards avoiding situations similar to that recorded for the Kruisfontein wetland, where the hectare equivalents achieved were approximately half of that anticipated during the rehabilitation planning process, but within the same ZAR per hectare class. WET-RehabPlan also needs to highlight that factors encompassed in the site's context, which are likely to have a potentially important influence over cost-effectiveness, need to be considered when interpreting the ZAR per hectare class into which a site falls as per the generic preliminary guidelines (Table 2.3). These factors, as identified during this study include the nature of the rehabilitation activities, the type and size of the problem being addressed, rehabilitation of priority and/or high value wetlands, limitations imposed by funders, and risks that need to be addressed by the rehabilitation strategy.

With regards to the assessment of the ecosystem integrity and functioning, WET-Health and WET-EcoServices should be updated a follows. The WET-EcoServices assessment framework should be updated to account for both the size of the wetland and the amount of functional wetland area within the wetland itself. A means of weighting ecosystem services depending on specific thresholds linked to the extent of the wetland restored should be investigated. In addition a better understanding of the interactions between system integrity and functioning should be investigated to provide a means of reporting on changes in ecosystem service delivery that can be directly linked to changes in integrity. If possible the WET-EcoServices framework should be refined based on specified requirements to inform the valuation of wetland rehabilitation based on resource economics. This would require detailed research into the return on investment and/or valuation of wetland rehabilitation. WET-Health should be refined to include recommendations for detailed mapping of disturbance units as an output of the assessment of hydrology, geomorphology and vegetation for each wetland rehabilitated, similar to the approach adopted by MacFarlane et al. (2012). This would provide a spatial coverage that could be compared pre- and post-rehabilitation, providing both detailed inputs into the WET-Health assessment framework and a visual indication of changes in the wetlands.

Due to the nature of the research conducted in this study, focussing on measuring the response of the two wetlands to rehabilitation, a number of recommendations are made for the amendment of WET-RehabEvaluate based on the assessment of the ecological outcomes.

Firstly, WET-RehabEvaluate should place greater emphasis on the collection of a detailed measure of the effect of wetland rehabilitation on the delivery of ecosystem services. At least, a detailed WET-EcoServices assessment needs to be undertaken rather than recording the degree of predicated changes, as currently adopted in the planning process. However, this research has shown that simply comparing WET-EcoServices assessment scores pre- and post-rehabilitation is a very coarse approach and can obscure important effects. Therefore, WET-RehabEvaluate needs to provide more explicit guidance in accounting for ecosystem service delivery, including both the supply and the demand for the services. More detailed data collection at this point would improve the inputs into the process of valuing the gains in ecosystem services linked to wetland rehabilitation.

Secondly, WET-RehabEvaluate should be refined to further promote the collection of detailed monitoring data, particularly vegetation, which proved to be exceptionally useful in highlighting trends in system response over time. This will assist in more accurately representing the benefits of wetland rehabilitation, avoiding the situation where the sole use of hectare equivalents would understate the benefits of wetland rehabilitation at those sites where ecosystem services have been improved but not necessarily the integrity of the system. Standardisation of data collection techniques for vegetation, in accordance with the guidelines provided by Sieben (2011) to address issues relating to different operators being involved in data collection, and also to assist in making comparisons between different wetlands. In addition to standardising data collection, the guidelines should promote consistency in data collection, despite the inherent diversity of wetland rehabilitation techniques linked to variability within and between wetlands and the objectives of different rehabilitation projects. This would need to be achieved by providing principles and guidelines to assist practitioners in identifying the key 'treatment areas' in a system that is effectively a 'rehabilitation experiment'.

Thirdly, WIV and FQAI should be included as key tools in WET-RehabEvaluate to assist in analysing and interpreting vegetation data collected as part of Level 3 monitoring. The potential value of FQAI in detecting impacts, such as wetland rehabilitation, on an individual wetland over time are highlighted by Lopez and Fennessy (2002). Further research relating to these indices would be required, given that these indices have only been applied at two wetlands in South Africa. In addition, regional wetland plant species lists would need to be compiled, with the indicator status and coefficients of conservatism recorded for each species as per Appendix 2. Regional species lists, as described by Miller and Wardrop (2006), are seen as appropriate in a South African context due to the differences recorded for some plant species across the different regions of South Africa. Furthermore, reference wetlands at a regional scale are required to calibrate the adopted indicator status and/or coefficients of conservatism for plant species, as well as to determine the standard for species occurring in reference wetlands as described by Andreas and Lichvar (1995).

Fourthly, an appropriate control area should be included within the wetland or within a comparable wetland area nearby which has been subject to similar impacts to the area being rehabilitated but would not be influenced by the proposed rehabilitation efforts. Wortley et al (2013) refer to an area that reflects the pre-rehabilitation state and is uninfluenced by the rehabilitation activities as a 'negative control'. A negative control is recommended and allows the monitoring programme to establish whether any changes which are measured in the rehabilitated area are as a result of the rehabilitation interventions themselves rather than as a result of some external influence, *e.g.* a sequence of above-average rainfall years. Including a negative control may not always be possible, especially if the rehabilitation strategy aims to influence the entire system. In this study, control site t-tests provided a useful means of establishing system response. Depending on the objectives of the rehabilitation, it is often useful to also include a reference area, which is comparable with the area being rehabilitated but has been subject to minimal human impact, and therefore represents a benchmark or reference condition for the area being rehabilitated. Such a "control" provides a useful point of reference in determining the level of recovery of the rehabilitated wetland. It is recognized, however, that both types of control may be extremely difficult to locate and would add significantly to monitoring costs, but would be justified given the insights which they are likely to yield.

5.3.4.2 Improvements to the wetland rehabilitation field of practice.

The Killarney and Kruisfontein wetlands provided generally applicable lessons relating to understanding the objectives of wetland rehabilitation. It is recommended that the following be considered during the planning of wetland rehabilitation and determining a rehabilitation strategy:

- If the objective of the wetland rehabilitation is to re-establish or secure the ecological condition of the wetland vegetation, then it is important to screen the site in terms of the readiness with which the indigenous vegetation is likely to recover based on an understanding of the factors that contributed towards the situation at the wetland. If the readiness for recovery is assessed as low then a high level of investment is likely to be required, and this needs to be assessed in relation to the objectives of the project and weighed up against the anticipated benefits of the project.

- If the primary objective of the rehabilitation is to reinstate the regulatory hydrological services supplied by the wetland, then understanding whether the wetland is dominated by an alien graminoid species such as *P. dilitatum* or a diverse mix of native graminoid species is probably of little consequence and therefore costly re-planting is unlikely to be justified.
- If the primary objective for the same site is biodiversity conservation through re-establishing or securing the ecological condition of the wetland vegetation, then planting is potentially justified. But if the project was still in its planning phase then it might be decided to seek an alternative site where the vegetation is likely to recover more readily than at a site already dominated by a competitive alien species such as P*. dilitatum*.
- If the objective of a rehabilitation plan is to offset the impacts of a proposed development, understanding of the thresholds within the system and the lag time that would be applicable for the natural response of the rehabilitated system would be critical. Without this understanding, the outcomes of the rehabilitation, especially in terms of timing of recovery, would often be overstated.

In terms of specific recommendations, should sites similar to the Kruisfontein and Zoar wetland systems be considered a priority for re-establishing native plant species, rehabilitation of such systems would need to be intensive, with the following key issues being considered:

- Where feasible, the wetland rehabilitation strategy should focus on reinstating permanent wetness zones, as based on the vegetation composition of the areas of permanent wetness (as within the Kruisfontein wetland). This would increase the relative proportion of permanently wet areas in the wetland would, which would clearly be to the strong disadvantage of species such as *P. dilitatum*. However, wetland rehabilitation practitioners need to be cautioned that if it was practically feasible to achieve permanently wet conditions across all of a rehabilitated wetland; it would be counterproductive in terms of re-establishing the indigenous vegetation. Based on information from pristine and near-natural wetlands (Kotze et al. 1994a, b and c) it is observed that usually at least 50% of the spatial extent of a wetland comprises temporarily to seasonally wet areas and the different zones have distinctly different assemblages of species (Kotze and O'Connor 2000). Therefore if a strong bias towards one particular zone in a rehabilitated wetland was created in the long-term, then such a wetland would be a poor representative example of the indigenous vegetation of the natural state.

- Should dominant pioneer species, such as *P. dilitatum* in the Kruisfontein wetland or *P. urvillei* in the Zoar wetland, be present within the wetland, rehabilitation efforts should be preceded by the herbicide treatment of these species. The need to address the constraint imposed by invasive alien plant species to the re-establishment of native vegetation in the less wet portions of wetlands is demonstrated by Galatowitsch et al. (1999) and Budelsky and Galatowitsch (2000).
- While it is recognized that planting is costly, the less wet areas of the wetland should be the focus of re-planting activities, Active planting of indigenous vegetation has been well demonstrated to play an important role in re-establishing native vegetation, particularly in the less wet areas of a wetland, and is widely practiced in wetland rehabilitation projects across the U.S. (Galatowitsch and van der Valk 1996). Active planting is usually not included in wetland rehabilitation / restoration projects in South Africa because it is assumed that indigenous vegetation will eventually establish naturally. However, this may frequently not be the case. For example, *Carex sp.* sedges, which commonly occur on the edge of temperate freshwater wetlands in the US do not readily re-establish, and it is unlikely that they will reappear without deliberate reintroduction (Budelsky and Galatowitsch 2000). Furthermore, Seabloom et al. (2003) suggest that without the introduction of seeds, the recruitment of annual forbs is constrained, irrespective of competitive interactions with invasive plants species. Should the provision of natural resources within the Kruisfontein wetland be seen as a priority, *J. punctorius* would need

to be planted into those areas receiving high, moderate and low flows, in order to actively promote its increased abundance. Obviously, the costs of the planting needs to be carefully considered against the objectives of the rehabilitation project.

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APPENDICES

Appendix 1. Plant species listed, with indicator status as defined by Van Ginkel et al. (2010) and pioneer / ruderal characteristics reflected as a 'Coefficient of Conservatism' (Miller and Wardrop 2006), for the Killarney and Kruisfontein wetlands. Alien invasive plants (0); Ruderal or weedy plants (1); Occasionally ruderal or weedy plants (5); and Plant species intolerant of disturbance (10).

(modified from Cowden et al. 2013).

Species	Indicator status	Coefficient of Conservatism
Grasses		
Agrostis eriantha var. eriantha	facultative positive	10
Agrostis lachnantha	facultative positive	5
Andropogon appendiculatus	facultative positive	10
Aristida junciformis	facultative	10
Arundinella nepalensis	facultative positive	10
Bromus catharticus	facultative negative	0
Cynodon dactylon	facultative negative	1
Digitaria eriantha	facultative negative	10
Digitaria setifolia	facultative negative	10
Echinochloa crus-galli	obligate	5
Eragrostis capensis	facultative negative	10
Eragrostis curvula	facultative negative	5
Eragrostis plana	facultative	5
Eragrostis planiculmis	obligate	5
Eragrostis racemosa	facultative negative	10
Festuca caprina	facultative positive	10
Fingerhuthia sesleriiformis	obligate	10
Harpochloa falx	facultative negative	10
Helictotrichon turgidulum	facultative positive	10
Hyparrhenia dregeana	facultative negative	5
Leersia hexandra	obligate	5
Lolium multiflorum	facultative negative	0
Loudetia densispica	non wetland	10
Microchloa caffra	non wetland	10
Monocymbium ceresiiforme	non wetland	10
Paspalum dilatatum	facultative positive	0
Paspalum distichum	obligate	5

Species	Indicator status	Coefficient of Conservatism
Paspalum urvillei	facultative positive	0
Pennisetum macrourum	obligate	10
Pennisetum sphacelatum	obligate	10
Pennisetum thunbergii	facultative positive	10
Phalaris arundinacea	obligate	0
Phalaris codinacea	obligate	0
Sacciolepis indica	non wetland	10
Setaria pallide-fusca	facultative negative	1
Sporobolus africanus	facultative	5
Themeda triandra	non wetland	10
Tristachya leucothrix	facultative	10
Sedges		
Ascolepis capensis	obligate	10
Bulbostylis schoenoides	obligate	10
Carex acutiformis	obligate	10
Carex austro-africanus	obligate	10
Carex cognata	obligate	10
Cyperus congestus	facultative positive	5
Cyperus denudatus	obligate	10
Cyperus esculentus	facultative	1
Cyperus rotundus	facultative	1
Eleocharis dregeana	obligate	10
Eleocharis limosa	obligate	10
Fuirena pubescens	obligate	10
Isolepis costata var. macra	obligate	10
Isolepis fluitans	obligate	10
Mariscus sp.	facultative	5
Pycreus macranthus	obligate	10
Pycreus mundii	obligate	10
Pycreus nitens	obligate	10
Pycreus unioloides	obligate	10
Schoenoplectus corymbosus	obligate	10
Schoenoplectus paludicola	obligate	10
Scleria welwitschii	obligate	10
Reeds and Rushes		
Juncus effusus	obligate	5
Juncus oxycarpus	obligate	10
Juncus punctorius	obligate	10
Phragmites australis	obligate	10

Species	Indicator status	Coefficient of Conservatism
Typha capensis	obligate	5
Forbs		
Acalypha punctata	facultative negative	10
Alternanthera pungens	facultative negative	0
Alternanthera sessilis	facultative positive	5
Atriplex cf. prostrata	facultative negative	1
Bidens bipinnata	non wetland	0
Bidens pilosa	non wetland	0
Cirsium vulgare	facultative	0
Cliffortia linearifolia	facultative negative	10
Cliffortia paucistaminea	non wetland	10
Commelina africana	facultative positive	10
Conyza cf. albida	facultative positive	1
Conyza pinnata	facultative positive	1
Cotula nigellifolia	facultative negative	1
Cyclospermum sp.	facultative positive	0
Daucus carota	non wetland	0
Epilobium capense	obligate	10
Fragaria vesca	facultative	0
Gladiolus sp	facultative	10
Gunnera perpensa	obligate	10
Helichrysum aureo-nitens	facultative positive	10
Helichrysum mundtii	obligate	10
Helichrysum pilosellum	facultative negative	10
Hibiscus trionum	facultative	1
Hirpicium armerioides	non wetland	10
Hypochaeris radicata	non wetland	0
Hypoxis rigidula var. rigidula	facultative negative	10
Kniphofia linearifolia	facultative positive	10
Ledebouria cooperi	facultative positive	10
Lepidium bonariense	non wetland	0
Lessertia sp.	facultative negative	1
Lobelia decipiens	facultative positive	10
Ludwigia palustris	facultative	10
Mentha aquatica	obligate	10
Modiola caroliniana	non wetland	0
Monopsis decipiens	facultative positive	10
Nasturtium officinale	obligate	0
Oenothera rosea	facultative negative	0

Species	Indicator status	Coefficient of Conservatism
Oenothera saligna	facultative	0
Oxalis smithiana	facultative negative	10
Persicaria cf. attenuatum	obligate	10
Persicaria hydropiper	obligate	0
Persicaria salicifolium	obligate	10
Persicaria serrulata	obligate	10
Physalis angulata	non wetland	0
Plantago lanceolata	facultative negative	0
Plantago major	facultative	0
Polygonum aviculare	obligate	10
Psammotropha mucronata subsp. mucronata	non wetland	10
Ranunculus multifidus	facultative positive	10
Rorippa cf. sylvistis	facultative	10
Rubus cuneifolius	facultative negative	0
Rumex acetosella subsp. Angiocarpus	facultative positive	1
Rumex crispus	facultative negative	0
Salvia repens	facultative negative	10
Schkuhria pinnata	non wetland	0
Scutellaria sp	facultative positive	5
Senecio inaequidens	non wetland	1
Senecio inornatus	facultative	1
Senecio isatideus	facultative negative	10
Sium repandum	obligate	10
Sonchus sp.	facultative	0
Stachys sp	facultative negative	10
Tagetes minuta	facultative negative	0
Trifolium repens	facultative	5
Tulbaghia leucantha	facultative negative	10
Verbena bonariensis	facultative negative	0
Veronica anagallis-aquatica	obligate	0
Aquatic Plants		
Lagarosiphon sp.	obligate	10
Shrubs and Trees		
Leucosidea sericea	facultative negative	10

Appendix 2. Observations of the vulnerability, appropriate corrective action, and an evaluation of effectiveness of the wetland rehabilitation interventions

(modified from Cowden et al. 2013)

Glossary of Terms (modified from Scott 1987 and Russell 2009)

Apron	An area laid down immediately downstream of a weir, protected by concrete or rock-filled gabions, to protect the foundation of the intervention from damage caused by water flowing over the spillway.
Berm	A mound or bank of earth used as a barrier to flows, often used to redirect flows out of channels.
Chute	A channel-type, sloping structure used to convey flows from a higher elevation to a lower one, often used to counteract the erosive energy of water falling over gully head erosion.
Foundation	The soil, rock or concrete upon which an intervention rests.
Freeboard	The height between normal water level and/or spillway level and the crest of an intervention
Heel	An extension of the base of an intervention on the upstream side of the intervention, often used to prevent undercutting.
Key wall	An extension of the spillway/overflow portion of a weir that extends into the stream/channel banks and prevents subsurface flows bypassing the structure at the soil-weir interface.
Shoulder wall	A wall connected at right angles to the spillway/overflow portion of a weir that retains the soil in the adjacent banks and protects these from splash action of flows over the spillway.
Spillway	A passageway underneath, around the side, or over the top of an intervention in order for water to flow downstream without damaging the intervention.
Spreader canal	An artificial canal excavated at a specified gradient to receive concentrated flows and redistribute these across a designated area when the water fills the canal and overtops its banks.
Toe	An extension of the base of an intervention on the downstream side of the intervention, often used to prevent undercutting.
Weir	A wall built across the full width of a stream/channel, with a horizontal crest over which water flows, to retard the flow of water through the stream/canal and/or raise the water level in the channel; An intervention placed in a stream/gully to lift the water level and/or trap sediment. It is usually built of concrete, rock masonry or rock-filled gabion baskets.

Table A2-1. Observations of the vulnerability, appropriate corrective action, and an evaluation of effectiveness of the Killarney wetland interventions

Int.	Type	Appropriateness of intervention[2]	Built to specifications?	Objectives met?	Structural Integrity	Recommended Corrective Action
T51HA	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed.	No corrective action required
T51HA	Spreader Canal	Not applicable.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Partially. Breaching of the canal, especially at its outlet, has led to flows being unequally distributed along its length, reducing its efficacy.	Due to the breaching of the end point of the spreader canal, base flows are being confined to the spreader canal and are not spilling over into the wetland as was intended. No evidence of risk to the spreader canal was observed, but flows are being directed to a channel on the right hand side of the wetland and this is resulting in the formation of headcut erosion at the outlet.	An earthen berm should be constructed towards the end of the spreader canal (i.e. block the spreader canal) to force flows into the wetland and deactivate the headcut erosion at the outlet.
T51HB	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs. It was confirmed that the level of the overflow wall has been lowered to	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed.	No corrective action required

[2] Appropriateness of the interventions was assessed based on criteria of Russell (2009), p. 34-35, Figure 4.1 and Figure 4.2. It should be noted that spreader canals are not subject to the decision tree as they are seen as an extension of the design of the berms and weirs and are used where necessary to redirect flows into the wetland.

Int.	Type	Appropriateness of intervention[2]	Built to specifications?	Objectives met?	Structural Integrity	Recommended Corrective Action
			account for deviations during implementation.			
T51HC	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs. The spillway is narrower than the channel however; this may have been an intended design specification to increase the occurrence of overbank topping.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed. Despite the narrow spillway, the site is well vegetated and there is no evidence of erosion of the upstream banks due to obstructions to flow by the key walls.	No corrective action required
T51HD	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed.	No corrective action required
T51HE	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs. It was confirmed that the level of the overflow wall has been lowered to account for deviations during implementation.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed.	No corrective action required

Int.	Type	Appropriateness of intervention[2]	Built to specifications?	Objectives met?	Structural Integrity	Recommended Corrective Action
T51HF	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs. It was confirmed that the level of the overflow wall has been lowered to account for deviations during implementation.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed.	No corrective action required
T51H0021	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed, although the left hand shoulder wall is directing water towards the right bank which is leading to erosion of the bank.	The right bank should be stabilised to prevent further erosion. Gabions or an extension of the right hand shoulder wall should be considered.
T51H0022	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed.	No corrective action required
T51H0023	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed. The poor appearance of the step below the spillway was considered to be a result of 'honeycombing', associated with poor compaction of the concrete, rather than corrosion.	No corrective action required

Int.	Type	Appropriateness of intervention[2]	Built to specifications?	Objectives met?	Structural Integrity	Recommended Corrective Action
T51H0024	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed. The overflow wall is close to being drowned by the backwater from the downstream intervention. This may be beneficial during low flows at which stage the water level in the channel will remain relatively high. The right hand key wall does not extend to the inside edge of the shoulder wall with the result that water is flowing along the top of the shoulder wall. The area behind the right shoulder wall is well vegetated and there is no evidence of erosion behind the wall as a result of scouring.	Monitor the area behind the right hand shoulder wall for scouring
T51H0025	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed. The poor appearance of the key walls and shoulder walls below the spillway was considered to be a result of 'honeycombing', associated with poor compaction of the concrete, rather than corrosion.	No corrective action required
T51H0026	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	No. Structure requires maintenance due to tunnelling (flow occurring beneath the structure). If not addressed there would be	Tunnelling has occurred at the weir and as a result, flows are passing under the structure and not over the spillway. The structure is not achieving is objective and is at risk of damage if the problem is not rectified. It appears that poor foundation conditions resulted in the tunnelling.	A cut-off wall should be constructed on the upstream side of the spillway to seal off the tunnelling. In addition, the pipe through the spillway should be sealed. Implementation was historically often carried out under time and budgetary

Int.	Type	Appropriateness of intervention[2]	Built to specifications?	Objectives met?	Structural Integrity	Recommended Corrective Action
				reduced frequency of overtopping and lowering of water table locally i.e. directly adjacent to the intervention.		constraints limiting opportunities for assessments (by the design engineer) of the foundation conditions following excavation.
T51H0027	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed. The banks and channel between T51H0026 and T51H0027 appear to be stable.	Investigate the option of constructing an additional weir between T51H0026 and T51H0027 to raise water levels in the channel if additional water is required from a wetland rehabilitation point of view.
T51H0028	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed. The key walls are relatively low (i.e. there is minimal freeboard) and the flows were going over the top of the key walls and left hand shoulder wall at the time of the inspection. No damage was observed due to the dense vegetation around to the structure.	Monitor the areas behind the shoulder walls to ensure that scouring does not take place. The key walls may need to be raised slightly if scouring does take place.
T51H0029	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed.	No corrective action required

Int.	Type	Appropriateness of intervention[2]	Built to specifications?	Objectives met?	Structural Integrity	Recommended Corrective Action
T51H0030	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. Interventions having the desired results.	No evidence of risk to the weirs structural integrity was observed.	No corrective action required
T51H0031	Earthen Berms	Yes. Non-perennial flows within a small (<0.5m deep) channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. Interventions having the desired results.	The earthen berms were stable and well vegetated. No erosion or damage to the berms was observed	No corrective action required
T51H0032	Concrete Weir	Yes. Perennial flows within a large-scale gully / channel that was not feasible to fill.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. Interventions having the desired results.	No evidence of risk to the weir's structural integrity was observed.	No corrective action required

Table A2-2. Observations of the vulnerability, appropriate corrective action, and an evaluation of effectiveness of the Kruisfontein wetland interventions

Int.	Type	Appropriateness of intervention[3]	Built to specifications?	Objectives met?	Structural Integrity	Recommended Corrective Action
V20E017	Concrete Weir	Yes. Diversions of flows from a perennial channel and deactivation of large headcut erosion.	No. As-built dimensions differ from the rehabilitation plan designs. Numerous discrepancies were identified between the design dimensions and the as-built dimensions. Specifically, the right hand wing wall is located approximately midway along the shoulder	Partially. Headcut erosion stabilised but high flows are not being frequently re-directed. The spillway of the intervention has been constructed lower than designed resulting in overbank topping occurring less frequently than planned. Volumes of water entering the upper reaches of the wetland were less than anticipated.	No evidence of risk to the weirs structural integrity was observed.	No corrective action required in terms of structural integrity, but minor amendments and/or modifications to the interventions can address the identified discrepancies in terms of meeting the objectives.

[3] Appropriateness of the interventions was assessed based on criteria of Russell (2009), P. 35- Figure 4.1 and Figure 4.2. It should be noted that spreader canals are not subject to the decision tree as they are seen as an extension of the design of the berms and weirs and are used where necessary to redirect flows into the wetland.

Int.	Type	Appropriateness of intervention[3]	Built to specifications?	Objectives met?	Structural Integrity	Recommended Corrective Action
			and not at the end of the shoulder as was specified in the design. Two buttresses along the wing wall (which were not specified in the design) were also implemented. Poor workmanship was noted with exposed steel reinforcing and poor contact between the buttress and the right hand wing wall (left) and poor quality			

Int.	Type	Appropriateness of intervention[3]	Built to specifications?	Objectives met?	Structural Integrity	Recommended Corrective Action
			concrete and exposed steel reinforcing in the left hand wing wall.			
V20E018	Concrete Weir	Not applicable	Not applicable	Not applicable	This intervention was not implemented as part of the wetland rehabilitation project.	Not applicable.
-	Concrete-covered Diversion Berm	Yes. Diversions of flows from a perennial channel.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Yes. The berm serves to redistribute flows into the adjacent wetland areas, with the armoured portion protecting the berm from elevated flows.	The diversion berm was structurally stable and there was no evidence of erosion along the structure. A slight incised channel (approximately 300mm deep) is located on the upstream side of the berm, however, this does not currently pose a risk to the intervention's structural integrity.	No corrective action required.
-	Spreader Canals	Not applicable.	No. As-built dimensions differ from the rehabilitation plan designs.	Partially. Breaching of the canal has led to flows exiting the canal via a preferred flow path and being unequally distributed along its length reducing its efficacy. Concentrated flows	The upstream spreader canal (receiving flows from the concrete weir) did not contain water at the time of the site inspection. The canal appeared stable and no corrective actions (in terms of securing its structural integrity) are therefore	The breach in the downstream spreader canal should be repaired and functioning of the spreader canal re-instated in order

Int.	Type	Appropriateness of intervention[3]	Built to specifications?	Objectives met?	Structural Integrity	Recommended Corrective Action
				along preferred flow paths rather than diffuse flows over a larger area of the wetland.	proposed for the spreader canal. The downstream spreader canal (receiving flows from the concrete-covered diversion berm) has breached close to the entry point of the water from the diversion berm. The breach in the canal has resulted in the development of a preferred flow path downstream of the intervention. The spreader canal is therefore not meeting its original objective of spreading flows across the wetland.	to allow for the spreading water across a wider portion of the wetland. Ideally, spreader canals should be designed with a hardened overflow edge and be set out with appropriate levels.
-	Earthen Plugs	Yes. Low volume flows within small (<0.5m deep) furrows.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Partially. The berms in the ridge-and-furrow only decant in one direction limiting the spread of flows. The local topography, sloping towards the Mooi River and the western channel in the wetland, has resulted in a preferred flow path along the	The earthen plugs were all structurally intact and showed no signs of damage and/or erosion.	No corrective action required in terms of structural integrity of the current interventions, however, detailed surveys of local elevation are required when

Int.	Type	Appropriateness of intervention[3]	Built to specifications?	Objectives met?	Structural Integrity	Recommended Corrective Action
				berms. Approximately one half of the anticipated area of the wetland has been influenced by the rehabilitation.		rehabilitating ridge-and-furrow to gain an understanding of the flows of the diverted water.