

ASSESSMENT OF THE LONG-TERM RESPONSE OF TWO WETLANDS TO WORKING FOR WETLANDS REHABILITATION

Report to the
Water Research Commission

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Executive Summary

The importance of wetlands with regards to supplying ecosystem goods and services has been described and highlighted in numerous studies. Wetlands in KwaZulu-Natal (KZN) have been subjected to high levels of modification and destruction, including the two sites identified for this research project, namely the Killarney and Kruisfontein wetlands. The recognition of benefits associated with wetland ecosystems and the need to reverse ecosystem degradation resulted in the initiation of the Working for Wetlands (WfWet) programme, aimed at protecting, rehabilitating and the sustainable use of South Africa's wetlands. To date, the monitoring and evaluation of rehabilitated wetlands within the WfWet programme has been severely limited due to budgetary constraints. The need to undertake such evaluations of wetland rehabilitation is considered critical to inform our understanding of system response and future rehabilitation efforts.

This Water Research Commission (WRC) project, investigated the long-term response of the two selected wetland systems to the rehabilitation that was undertaken by WfWet, based on the following objectives:

- 1) An assessment of the integrity and survival of the rehabilitation interventions;
- 2) A rapid assessment of the ecological integrity and ecosystem services supplied;
- 3) A more detailed investigation of the response of aspects of the system, specifically vegetation, to rehabilitation interventions; and
- 4) Documenting lessons learnt in terms of rehabilitation planning and the challenges of the long term monitoring of wetland rehabilitation efforts.

Generally, the socio-economic benefits of wetland rehabilitation associated with the WfWet programme would also need to be considered as outcomes, but was beyond the scope of this research project.

The study sites were of the Killarney wetland, which occupies a tributary valley of the Ntsikeni Vlei in southern KZN, and the Kruisfontein wetland, which occupies two coalesced tributaries of the Mooi River in the KZN Midlands east of the town of Mooi River. Both of the sites had undergone extensive modifications relating to historical land uses, but the overall level of modification at Killarney wetland was lower than that at Kruisfontein wetland. The Killarney wetland was characterised by the presence of a combination of "large and small-scale gullies (approximately 10 m wide by 3 m deep and 2 m wide and 0.5-1 m deep) respectively", but no historical cultivation. The Kruisfontein wetland was characterised by two cut-off drains excavated along the north-eastern and south-western boundaries of the wetland and ridge and furrow drainage and cultivation across the majority of the wetland, resulting in a draw-down effect across the wetland, and the loss of most of the native vegetation. Rehabilitation interventions were implemented in 2005 and 2006 for Kruisfontein and 2005, 2006 and 2007 for Killarney. The objectives of the rehabilitation for both wetlands were similar; primarily attempting to re-establish near-natural hydrological conditions and promote the re-establishment of native hydric plants.

In order to assess the response of the wetlands to the WfWet rehabilitation, pre-rehabilitation monitoring of the above-mentioned wetland systems was undertaken in 2005 during the Wetland Management Series research and post-rehabilitation in 2011 and 2012 for the Killarney and Kruisfontein

wetlands respectively. Primary data were collected from both desktop and infield analyses. To assist in the identification of plant species and to gain an understanding of surface water flows, the fieldwork component for each site was conducted during the rainfall season. Data were collected in accordance with the approaches of the original research, as per the monitoring approaches outlined in WET-RehabEvaluate (Cowden and Kotze, 2009). The monitoring included three levels of monitoring as described in WET-RehabEvaluate:

- Level 1 monitoring focused on the outputs of wetland rehabilitation, including the assessment of the structural integrity of the interventions, and identifying structural vulnerability;
- Level 2 monitoring with a rapid assessment of the outcomes of the rehabilitation, focused on the improvements in the functioning and integrity of the wetlands, with WET-EcoServices (Kotze *et al.*, 2007) and WET-Health (Macfarlane *et al.*, 2007) assessment frameworks being used respectively;
- Level 3 monitoring assessed the outcomes of the wetland rehabilitation, based on the stated objectives. Based on the rehabilitation objectives of the site to re-establish near-natural hydrological conditions and promote the re-establishment of native hydric plants, the species composition of vegetation was monitored using vegetation plots. To assist in the interpretation of the vegetation data, two indices were used to measure the response to rehabilitation:
 - Wetland Index Value (WIV) in order to address the question of whether the vegetation composition had shifted to a more hydric state; and
 - Floristic Quality Assessment Index (FQAI) in order to address the question of whether the vegetation composition had shifted away from domination by ruderal/pioneer species.

For Level 1 monitoring, the assessment of structural integrity confirmed that the earthen and concrete interventions, adopted for the rehabilitation of the Killarney and Kruisfontein wetlands, were used in appropriate settings as at both wetlands only minor issues relating to construction were identified. The assessment of the interventions, however, highlighted the importance of engineering supervision during the construction phase, including sign-off of the interventions according to the specified designs and objectives. Discrepancies in as-built dimensions in comparison to the designs reduced the efficacy of the interventions within the Kruisfontein wetland, particularly in terms of re-instating the distribution of high flows across the wetland.

For Level 2 monitoring, the assessment of the wetland systems' integrity and ability to supply ecosystem services within the landscape showed an improvement in both systems. Key characteristics linked to the systems' hydrological conditions, were considered to have improved as a result of the WfWet wetland rehabilitation. The improvements in the effectiveness of the wetlands to supply regulatory ecosystem services, within both the Killarney and Kruisfontein wetlands, were strongly linked to changes in the flows within the wetlands as a result of the rehabilitation. Specifically, the systems' abilities to trap and assimilate nutrients were improved by flows being spread over larger areas of wetland habitat. This was of particular importance in the Kruisfontein wetland, where the area receives effluent from the dairy on the farm. Increases in the effective size of the wetland and the increased effectiveness in terms of

services associated with water quality, linked to the rehabilitation, assists in buffering the Mooi River from effluent originating from the dairy. Based on the recorded impact scores and hectare equivalents (ha equiv.) or functional wetland area, the Killarney wetland improved from 30.7 ha equiv. to 37.5 ha equiv. while the Kruisfontein wetland improved from 8.2 to 11.5 ha equiv. The hectare equivalents gained per wetland, were less than originally anticipated in the rehabilitation planning and previous research projects. The costs per hectare equivalent to rehabilitate the wetlands were therefore greater than originally anticipated, especially for the Kruisfontein wetland. However, the cost effectiveness would still be considered *moderate* and *moderate to high* for the Killarney and Kruisfontein wetlands, respectively.

For Level 3 monitoring, several ‘treatment areas’ were identified in the Kruisfontein wetland, including WfWet rehabilitation high flows (areas receiving high flows as a result of the WfWet interventions), WfWet rehabilitation moderate and low flows (areas receiving moderate and low flows as a result of the WfWet interventions), Transformed control (a historically cultivated area that was unaffected by the farmers and WfWet rehabilitation activities), Untransformed (an area historically uncultivated within the landscape), and Farmer’s rehabilitation (areas with partially improved flow linked to rehabilitation undertaken by the landowner). As is evident from the aforementioned ‘treatment areas’ the Kruisfontein wetland included a control, which was lacking in the Killarney wetland, where transects were positioned across the wetland, but no specific area was unaffected by the wetland rehabilitation activities. The measurement of vegetation composition highlighted trends in vegetation response since the implementation of the WfWet rehabilitation. Within Killarney wetland, *Eleocharis dregeana*, and other obligate wetland species increased in abundance, reducing the dominance of facultative positive wetland species such as *Pennisetum thunbergii* in the central areas, and displacing *Themeda triandra*, a non-wetland species, as the most dominant species in the areas of high local elevation within and on the margin of the wetland. For Kruisfontein, obligate wetland species such as, *Paspalum distichum* and *Schoenoplectus paludicola*, increased in abundance in response to the moderate and low flows linked to WfWet rehabilitation when compared to the dominance of facultative and facultative positive wetland plant species within the area unaffected by the rehabilitation. Nonetheless, the alien grass *Paspalum dilatatum* remained strongly dominant over most of the wetland since rehabilitation.

Based on the Kruskal-Wallis test, WIVs derived for each of the plots within the two wetlands over time showed significant differences ($P < 0.05$) only existed within the Kruisfontein wetland. T-tests comparing ‘treatment areas’ within the Kruisfontein wetland over time showed no significant differences ($P > 0.05$) for the different areas of the wetland, but a Control t-test showed that no significant differences existed between the different ‘treatment areas’ and the control in 2005 prior to the WfWet rehabilitation. However, the area influenced by the low to moderate flows was significantly different to the control, suggesting a change in vegetation composition since the implementation of the WfWet rehabilitation. Overall the data recorded for Killarney showed a change from 2005 to 2011, with the recorded WIVs decreasing, *i.e.* indicating wetter conditions. A similar trend was shown for the Kruisfontein wetland, with the recorded WIVs generally decreasing from 2005 to 2012. Based on thresholds for WIV recommended by Wentworth and Johnson (1986) applied to the post-rehabilitation survey data, the

Killarney Wetland is considered to be wetland, but much of the Kruisfontein wetland is considered to be transitional between wetland and non-wetland vegetation.

The Kruskal-Wallis test of the FQAs derived for the two wetlands showed significant differences ($P < 0.05$) between transects and between 'treatment areas' within the Killarney and Kruisfontein wetlands respectively. T-tests comparing transects and 'treatment areas' within the wetlands over time showed only significant differences for Transect 1 within the Killarney wetland. The Control site t-test for Kruisfontein wetland showed significant differences existed between the areas influenced by the low to moderate flows and the untransformed area and the control, suggesting a change in vegetation composition since the implementation of the WfWet rehabilitation. General investigation of the data showed the vegetation composition within the Killarney wetland vegetation were altered towards non-opportunistic plant species with the recorded FQAs increasing for Transect 1, 2 and 3. Generally the FQAs recorded for Kruisfontein wetland were similar from 2005 to 2012, except for the area receiving low and moderate flows following the implementation of the rehabilitation, which has increased markedly.

The cross sectional profiles of the channels within the Killarney wetland were recorded and compared with the original measurements. The recorded values for 2005 and 2011 appear to be relatively similar, with minor changes in depths of the channel profile. This would suggest that the long-term sediment deposition within the channels has not necessarily increased as a result of the rehabilitation activities. The lack of sediment accumulation is attributed to the lack of sediment sources in the near-pristine catchment or erosion within the wetland upstream.

The results of the three levels of monitoring, undertaken for the Killarney and Kruisfontein wetlands identified a number of key trends to be considered in rehabilitation planning and served to document lessons to be applied in future planning.

The assessment of structural integrity for the interventions within the Killarney and Kruisfontein wetlands highlighted the following:

- Adoption of best practice in the formulation of a rehabilitation strategy and the appropriate adoption of intervention types in appropriate settings improves the long-term stability and survival of interventions.
- Concrete interventions may be associated with potentially higher costs initially, but the low long-term maintenance requirements were judged to outweigh these costs, especially when considering the remote nature of the Killarney wetland.
- The stability of the concrete-capped berm in Kruisfontein, suggests that the concept should be considered for future wetland rehabilitation projects as the berm appears to have durability similar to that of a concrete intervention, but has the advantage of being labour intensive, which is more suited to Expanded Public Works Programmes where person days are an important consideration.
- The success of spreader canals is strongly dependant on supervision and oversight by the project engineer during the implementation or construction phase, in order to ensure appropriate

gradients and redistribution of flows in the wetland and avoid flow concentration or breaching of the spreader canal.

- The approach to deactivating ridge and furrow drainage networks within wetland areas should be revised for future wetland rehabilitation planning. If earthen plugs are to be utilised, it is recommended that a high density of small-scale structures be utilised to spread the flows throughout the wetland. The most effective means of rehabilitating a ridge and furrow network would be to reverse the original earthworks by excavating the ridges and utilising the material as backfill for the furrows.
- Intervention monitoring in the long-term provides benefits associated with the early detection of maintenance requirements, the need for additional interventions, and to guide the intervention selection process for future planning.

The assessment of the ecosystem goods and services and ecological integrity of the wetlands before and after rehabilitation served to highlight the changes in functioning and integrity associated primarily with the WfWet rehabilitation. The improvements in the wetlands' levels of ecosystem service delivery were strongly linked to the improvements in regulatory services. 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 farm dairy. It should however be noted that the poor recovery of the vegetation within the Kruisfontein wetland, particularly the absence of *Juncus punctorius*, has reduced provisioning services as it is a species favoured for weaving. The assessment of the wetlands' integrity, especially with the derivation of hectare equivalents, provided a useful means to evaluate the response of the wetland systems. The improvement in ecosystem integrity of the Killarney and Kruisfontein wetlands was less than the anticipated improvements recorded by Kotze and Ellery (2009). This suggests that the rehabilitation of the wetlands has not followed the trajectory of change anticipated during the rehabilitation planning process. Within the Killarney wetland it is anticipated that vegetation conditions may improve further as the desired state/regime within the wetland is maintained. Within the Kruisfontein wetland, however, both hydrology and vegetation have not responded in accordance with the anticipated response. The hydrological response within the wetland was inhibited by the ineffectiveness of the spreader canal and the short-cutting of flows along the western edge of the earthen berms. The limited vegetation response in the Kruisfontein wetland is linked to there being reduced area with improved hydrology and the dominance of disturbance-tolerant plant species (as elaborated upon below).

The Level 3 monitoring results obtained for vegetation change in the Killarney wetland generally followed the expected trajectory of change, where obligate wetland species have increased in abundance and the vegetation composition moved away from disturbance tolerant species. The fact that the historical disturbance of the system was linked to desiccation associated with channel incision rather than long-term, intensive agricultural production, and the presence of nearby intact areas of wetland habitat, have served to facilitate the system's recovery. The vegetation response within the Kruisfontein wetland provided an unexpected result, with the area still largely dominated by pioneer/ruderal species after seven years of rehabilitation. *Paspalum dilatatum* has retained its dominance within the system, except for the area influenced by moderate and low flows associated with

the WfWet rehabilitation. In addition to the dominance of *P. dilatatum*, throughout the rehabilitated area of the wetland there is a distinct lack of native species, such as *Carex acutiformis*, which are less tolerant of disturbance.

The vegetation within the Kruisfontein wetland therefore appears to be stable in a severely transformed state such that a threshold of some kind needs to be crossed before the vegetation returns to its former state. Therefore, the assumption that if the hydrology of the wetland is re-instated then the re-establishment of the native wetland vegetation will follow does not seem to hold.

The results at Kruisfontein have served to identify that additional measures may need to be adopted in systems similar to this. A potential approach would be to increase the relative proportion of permanently wet areas in the wetland, but this must be weighed up against the natural extent of permanent wetness zones within the system, as a strong bias towards one particular zone in a rehabilitated wetland may result in the wetland being a poor representative example of the indigenous vegetation. Secondly, active planting of indigenous vegetation could serve to re-establish native vegetation, but it is recognized that planting is costly, and therefore these costs need to be weighed up against the objectives of the rehabilitation project.

The Killarney and Kruisfontein wetlands also provide valuable generally applicable lessons relating to understanding the objectives of the wetland rehabilitation:

- To re-establish/secure the ecological condition of wetland vegetation it is important to screen the site in terms of its readiness with respect to the establishment of indigenous vegetation.
- To reinstate the regulatory hydrological services supplied by the wetland, whether the wetland is dominated by *P. dilatatum* or a diverse mix of native species, is probably of little consequence and therefore costly re-planting is unlikely to be justified.
- Planting of wetland vegetation may be justified if biodiversity is an issue at a particular site.
- To offset the impacts of a proposed development, understanding both the thresholds that exist within a system and the lag time that would be applicable to the natural response of the rehabilitated system would be critical.

It is recommended that the following be revisited or included in the Wetland Management Series guidelines and assessment frameworks:

- The criteria for determining the cost effectiveness of the wetland rehabilitation strategy based on costs per hectare equivalent within WET-RehabPlan should be updated to be more sensitive to changes, so as to avoid situations similar to that recorded for the Kruisfontein wetland.
- 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, incorporating a means of weighting ecosystem services based on the extent of the wetland and an understanding of the interactions between system integrity and functioning.
- Investigate, by means of detailed research, the potential to update the WET-EcoServices framework to inform the valuation of wetland rehabilitation based on resource economics.

- Refine WET-Health to illustrate the value of the detailed mapping of disturbance units for hydrology, geomorphology and vegetation for each wetland rehabilitated, similar to the approach adopted by MacFarlane *et al.* (2012).
- Update the Level 1 monitoring to include additional criteria used to assess structural integrity, and incorporate guidance on reviewing the rehabilitation strategy adopted in terms of cost-effectiveness and efficacy in terms of meeting the stated objectives.
- Greater guidance in terms of the approaches and ‘experimental design’ of the wetland rehabilitation monitoring needs to be provided, and include the following:
 - Account for unanticipated system responses;
 - Include an appropriate control area within the wetland or within a comparable wetland area nearby which has been subject to similar impacts to the area being rehabilitated but which would not be influenced by the proposed rehabilitation efforts;
 - Depending on the objectives of the rehabilitation, it is often useful to also include an additional control 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;
 - Standardisation of data collection techniques for vegetation, in accordance with the current national guidelines; and
 - Promote consistency in data collection by providing principles and guidelines to assist practitioners in identifying the key ‘treatments areas’ in a system that is effectively a ‘rehabilitation experiment’.
- It is recommended that WfWet’s monitoring and evaluation framework include all levels of monitoring, but with Level 3 monitoring being adopted for large-scale or high value wetland rehabilitation projects to accommodate budgetary constraints.
- Greater emphasis needs to be placed on the collection of a detailed measure of the effect of wetland rehabilitation on the delivery of ecosystem services. More explicit guidance in accounting for ecosystem service delivery should be provided.
- Inclusion of WIV and FQAI as key tools in WET-RehabEvaluate to assist in analysing, quantifying and interpreting vegetation data collected as part of Level 3 monitoring. Further research relating to these indices would be required and regional wetland plant species lists would need to be compiled, with the indicator status and coefficients of conservatism recorded for each species.

The assessment of the long-term response of the two wetlands, Killarney and Kruisfontein, to WfWet rehabilitation is seen as contributing significantly towards the wetland rehabilitation field of practice as it allows one to reflect on challenges. This reflection assists in ‘closing the loop’ informing future rehabilitation planning, with recommendations documented for wetland rehabilitation implementation, planning, and monitoring and evaluation. In addition to documenting lessons learnt and refining wetland rehabilitation efforts in South Africa, this study introduces two indices to objectively and defensibly utilise vegetation to quantify changes in long-term wetness and habitat quality. This is the first time that these indices have been applied in South Africa, and based on their application in the

study it appears that these indices have particular value for measuring wetland ecosystem response to rehabilitation. In addition, the indices are likely to have much broader application, *e.g.* for wetland delineation and the assessment of current impacts on wetlands.

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Acronyms

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

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1 INTRODUCTION

Wetlands are important ecosystems within the landscape as they provide ecosystem services directly related to water quantity and quality (Kotze *et al.*, 2007). With South Africa being characterised by semi-arid conditions, the importance of wetlands cannot be overstated. Nel and Driver (2012) estimate that in excess of 65% of South Africa's wetlands are under threat, 48% of these are critically endangered. Kotze *et al.* (1995) estimate that approximately 50% of the wetlands in South Africa have been lost, which based on the definition of wetland loss by Kotze (2004), translates into these systems having been degraded beyond the point where they are able to maintain wetland properties and supply ecosystem services. Wetlands in KwaZulu-Natal (KZN), including the priority wetlands of KZN as described by Begg (1988), have been subjected to high levels of modification and destruction (Kotze *et al.*, 1995; Macfarlane *et al.*, 2012). The factors contributing towards the degradation of the 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, 2002). Ecosystem restoration is where the planned activities assist the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER, 2004). 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 and the subsequent loss of ecosystem services in South Africa, the Working for Wetlands (WfWet) programme was initiated in 2000. The WfWet programme is a combined initiative of the government Department of Environmental Affairs, Department of Tourism, Department of Agriculture Forestry and Fisheries, and Department of Water Affairs and is housed within the South African National Biodiversity Institute (SANBI). The approach adopted by the Working for Water programme, and similarly WfWet, has been compared with the concept relating to payments for ecosystem services, where voluntary payment, in this case government funding, is made for defined ecosystem services (Turpie *et al.*, 2008). WfWet, however, 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, 2005).

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 the planned rehabilitation. The intensive planning adopted by WfWet, to provide adequate details to project teams during implementation, also serves to reduce the funds available for monitoring and evaluation. Monitoring and evaluation within the WfWet programme to date 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 which is reported for each project implemented by WfWet. Despite spending in excess of 80 million Rands 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 and 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 result of conditions of authorization in terms of the original 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 and would need to be assessed to determine success or failure.

Rutherford *et al.* (2000) state that without the formal evaluation of project success, rehabilitation techniques would not be improved as there would be no understanding of the need for improvement. This highlights the importance of revisiting wetland rehabilitation projects, especially by those individuals undertaking wetland rehabilitation planning, to 'close the loop' by documenting lessons learnt (Figure 1-1). Reflecting on lessons learnt in past wetland rehabilitation projects would serve to document the efforts to date in terms of the 'learn by doing' approach that has generally been adopted by wetland rehabilitation efforts in South Africa. WET-RehabEvaluate (Cowden and Kotze, 2009) guidelines for monitoring wetland rehabilitation have been developed, including three levels (1-3), dealing with outputs, outcomes at a very coarse level, and outcomes at a more detailed level respectively. Monitoring of rehabilitation has been confined almost entirely to Level 1 (*i.e.* outputs) and to a limited extent, Level 2 assessments. Level 3 assessments have been absent, and a systematic evaluation of wetland rehabilitation in South Africa based on a standardised framework has yet to be undertaken. It was therefore considered critical that further research be undertaken to support and strengthen the implementation and science of wetland rehabilitation.

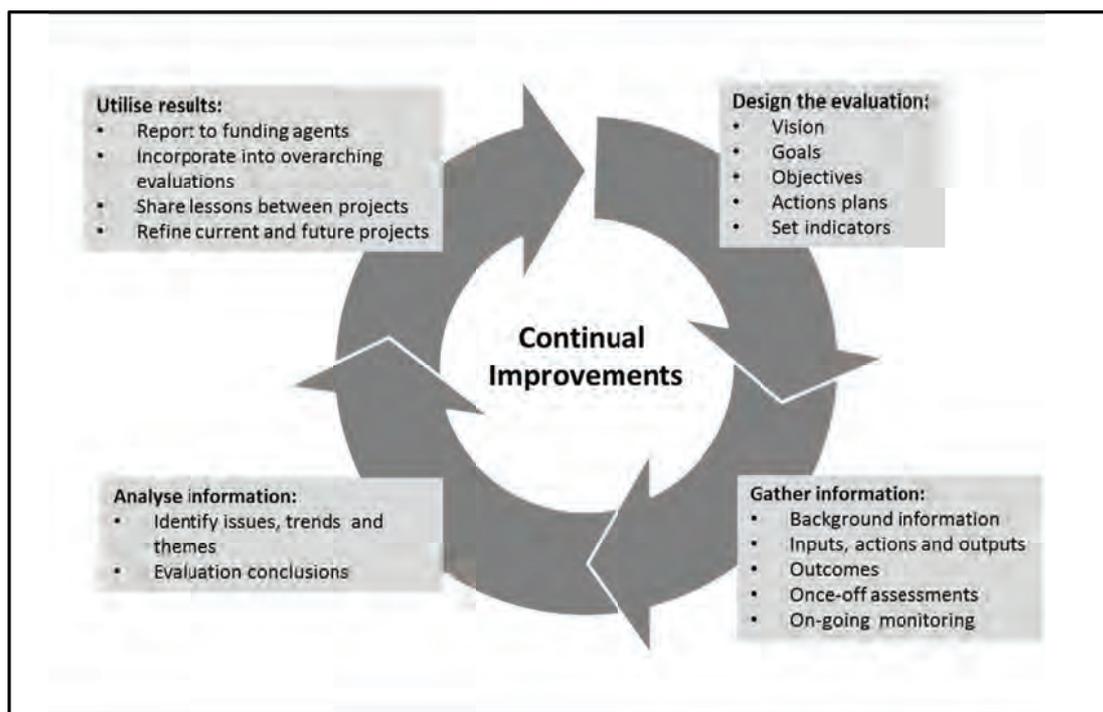


Figure 1-1. Evaluation process ultimately resulting in continual improvement of wetland rehabilitation projects
(adapted from Woodhill & Robins, 1998)

This Water Research Commission (WRC) research project aims to investigate the long-term response of selected wetland systems to the rehabilitation that was undertaken by WfWet, informing future rehabilitation planning within South Africa based on the following objectives:

- 1) An assessment of the integrity and survival of the adopted rehabilitation interventions within each wetland;
- 2) A rapid assessment of the ecological integrity and ecosystem services supplied for each of the wetlands;
- 3) A more detailed investigation of the response of aspects of the system, specifically vegetation, to rehabilitation interventions; and
- 4) Documenting lessons learnt in terms of rehabilitation planning and the challenges of the long term monitoring of wetland rehabilitation efforts.

It should be noted that while the socio-economic benefits of wetland rehabilitation, especially rehabilitation associated with the WfWet programme, may be significant, the measurement of these aspects of the rehabilitation undertaken at the selected wetlands were beyond the scope of this research project.

The monitoring and performance evaluation component of the Wetland Management Series (Dada *et al.*, 2007) research undertaken from 2002 to 2007 included the establishment of long-term sites for the monitoring and evaluation of wetland rehabilitation undertaken by WfWet. These included the Killarney wetland system, which is part of the wetland complex within the Ntsikeni Nature Reserve, and the Kruisfontein wetland, which drains into the Mooi River in the KwaZulu-Natal Midlands (Figure 1-2).

These two wetlands were selected as case studies for this research project as the pre-rehabilitation monitoring of these sites included all the levels of monitoring specified by Cowden & Kotze (2009), which provide good baselines from which to build long-term evaluations of wetland rehabilitation. The monitoring undertaken at the sites included the collection of baseline data of various indicators, including *inter alia*:

- Water depth;
- Vegetation;
- Ecosystem service delivery; and
- Ecosystem integrity (Kotze, 2009 and Cowden *et al.*, 2009).



Figure 1-2. Location of the study sites within KwaZulu-Natal

2 STUDY SITES

2.1 Killarney Wetland (Ntsikeni Nature Reserve)

The Killarney wetland is considered to be a channelled valley-bottom wetland and is one of the main tributaries of the main body of the Ntsikeni Vlei within the Ntsikeni Nature Reserve (NNR), proclaimed a Ramsar site (Ramsar Site No. 1904¹) on the 2nd February 2010 (Blackmore, 2010). Begg (1989) links the origin of the Ntsikeni Vlei to the presence of multiple dolerite dykes, specifically the dolerite sill that coincides with the Lubhukwini Waterfall. NNR is located approximately 20km north of the town of Franklin within the Umzimkhulu Local Municipality and is managed by Ezemvelo KZN Wildlife (EKZNW). The wetland drains into the upper reaches of the Lubhukwini River and falls within the T51H quaternary catchment, as defined by Midgley *et al.* (1994).

The NNR originally consisted of farmlands that were proclaimed as a nature reserve in 1978, by the then Transkei government, but was subject to illegal occupation by local communities for an extended period thereafter (Begg, 1989). At this point in time the area lacked a management plan, with alien invasive plant clearing and wetland rehabilitation activities being required. Linked to the historical land uses, the Killarney wetland was characterised by the presence of a combination of large and small-scale gullies. A combination of increased runoff, from poorly managed grassland areas, and a poorly planned road crossing had served to promulgate the identified gullies.

The Killarney wetland was therefore identified as a priority for wetland rehabilitation by WfWet in 2005, with the focus being to stabilise and/or deactivate the main gully within the system and to minimise its draining effect on the system. The intention of the rehabilitation efforts were also to promote more frequent flooding of the valley bottom, to promote the re-establishment of the hydric species associated with the seasonal and permanent wetness zones of the wetland. Prior to implementation of the proposed wetland rehabilitation activities in 2006 and 2007, a Water Research Commission research team, identified the site as an appropriate site for baseline and post-rehabilitation monitoring to inform the Wetland Management Series research. The baseline monitoring included the establishment of three transects² across the Killarney wetland (Figure 2-1), which formed the basis for the collection of data linked to vegetation composition, water levels within the soil profile, and gully cross sections. It is important to note that the rehabilitation implemented by WfWet comprised of multiple phases, and at the time of establishing the baseline monitoring for the Wetland Management Series research, only the initial phase of rehabilitation, *i.e.* in the upper reaches of the systems (Figure 2-1) had been planned. The baseline monitoring was therefore limited to the upper reaches of the extent of the system rehabilitated by WfWet. Following the implementation of the wetland rehabilitation activities, the site was revisited in 2011 and the rehabilitation efforts evaluated in terms of their success based on the above-mentioned baseline and assessments of ecological integrity and functioning.

¹ This refers to the Ramsar site reference number on the global register.

² Transect 4 was only collected in 2012, but is shown for reference purposes.

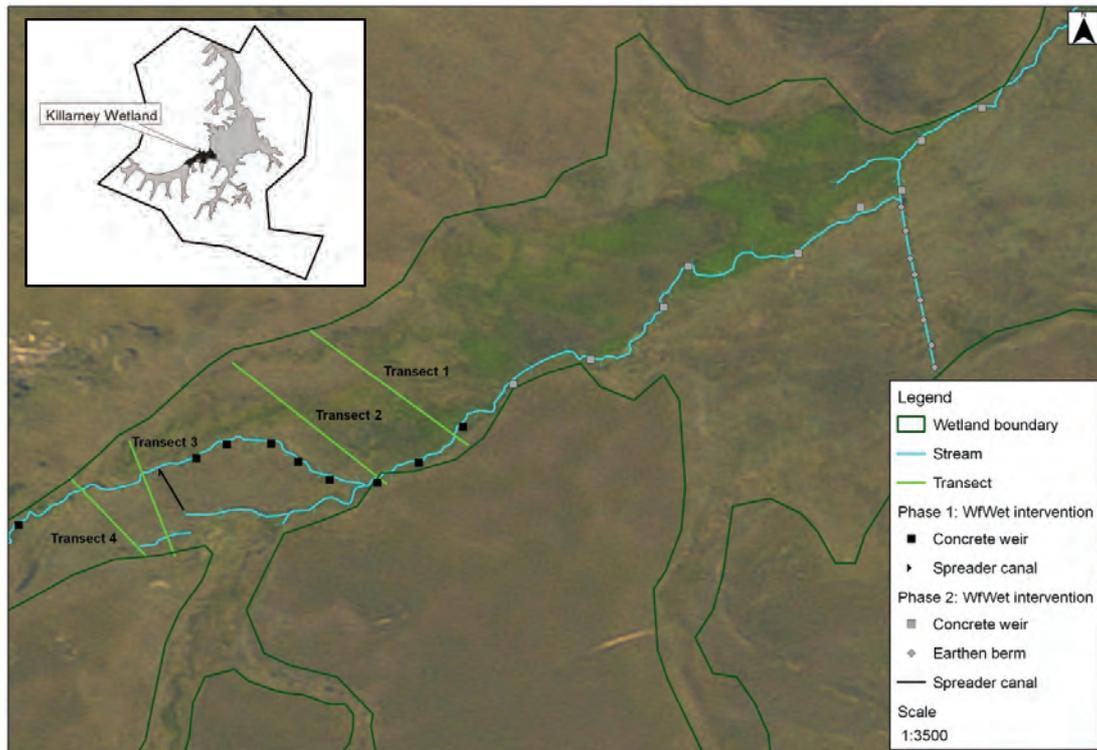


Figure 2-1. View of the Killarney wetland with the interventions and transects, with the inset showing the location of wetland within the Ntsikeni Nature Reserve.

2.2 Kruisfontein Wetland

The wetland includes valley-bottom and seepage wetland areas, draining into the Mooi River within the V20E quaternary catchment, as defined by Midgley *et al.* (1994). The Kruisfontein wetland is located at the confluence of two tributary streams with the Mooi River valley bottom. The wetland is located on privately-owned farmland, approximately 17km north-east of the town of Mooi River in the KZN midlands within the Mpofana Local Municipality.

The system was greatly modified by agricultural activities, including two cut-off drains excavated along the north-eastern and south-western boundaries of the wetland and ridge and furrow agriculture across the majority of the wetland. The ridge and furrow drainage network and the drainage channels along the outer edge of the wetland were used to create a draw-down effect across the wetland, making it suitable for cultivation purposes. Ownership of the farm changed approximately 10 years ago and the cultivation of the Kruisfontein wetland was ceased and the land owner attempted to rehabilitate the north-eastern portion of the system. 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 across the wetland 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.

Prior to implementation of the proposed wetland rehabilitation activities, a Water Research Commission research team identified the site as an appropriate site for baseline and post-rehabilitation monitoring to inform the Wetland Management Series research. The baseline monitoring included the establishment of two transects across the Kruisfontein wetland, which formed the basis for the collection of data linked to vegetation composition and distribution (Figure 2-2). Following the implementation of the wetland rehabilitation activities in 2006 and 2007, the site was revisited in 2012 and the rehabilitation efforts evaluated in terms of their success with reference to the above-mentioned baseline.

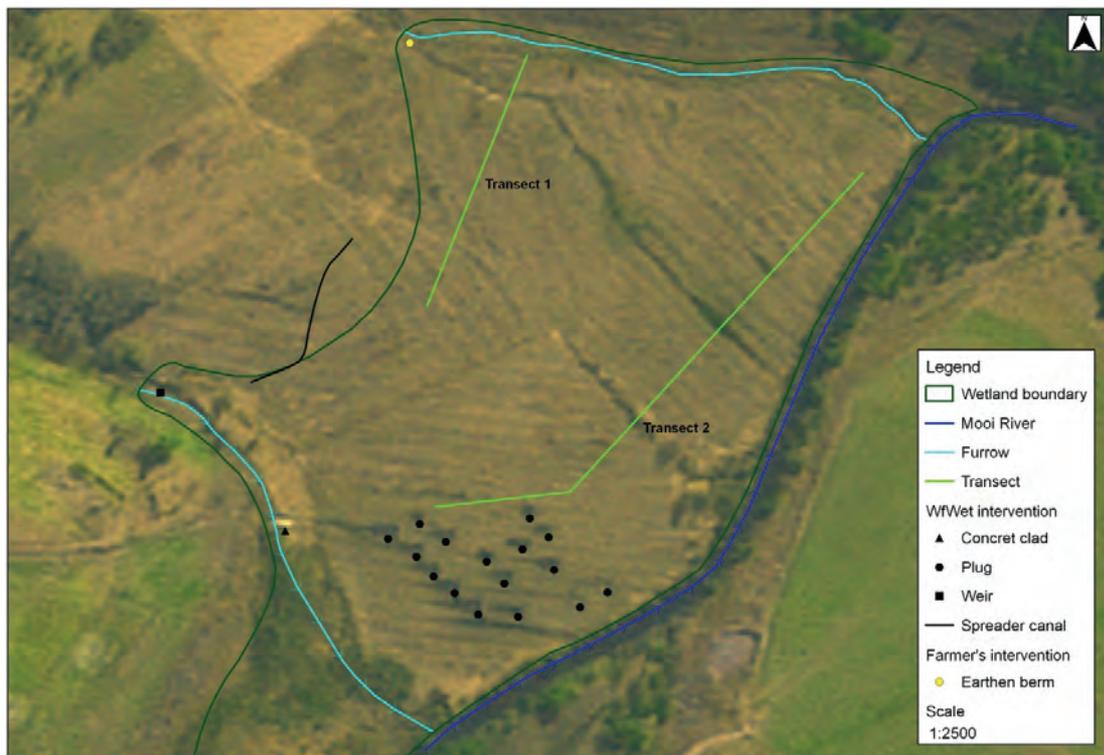


Figure 2-2. View of the Kruisfontein wetland with the interventions and transects

3 METHODOLOGY

The assessment of the response of the wetland systems to the WfWet rehabilitation was based on data derived from both desktop and infield analyses. The baseline studies undertaken as a component of the Wetland Management Series research were undertaken in April 2005 and January 2005, in the Killarney and Kruisfontein wetlands respectively. To assist in the identification of plant species and to gain an understanding of surface water flows, the fieldwork component 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. The site visit to Killarney included representatives from Ezemvelo KwaZulu-Natal Wildlife (EKZNW) and the South African Environmental Observation Network (SAEON), who assisted with the infield assessments and data collection.

The project team, comprising of a wetland ecologist and an environmental engineer, gathered data in accordance with the approaches of the original research, which was based on the monitoring approaches outlined in WET-RehabEvaluate (Cowden and Kotze, 2009). The details of the parameters measured onsite are described in Cowden *et al.* (2009) and Kotze (2009) and included different levels of monitoring:

- Level 1 – the outputs of the wetland rehabilitation in terms of physical interventions;
- Level 2 – the rapid assessments of the rehabilitation outcomes using appropriate assessment tools; and
- Level 3 – the comprehensive assessment of the wetland rehabilitation outcomes determined by the rehabilitation objectives.

3.1 Level 1 monitoring

Level 1 monitoring generally focuses on the outputs of wetland rehabilitation, which are generally limited to the implementation phase, where the wetland rehabilitation results in the construction of structural interventions. The long-term monitoring of the wetland rehabilitation outputs is therefore focussed on the assessment of the structural integrity of the interventions, with emphasis on identifying structural vulnerability. The rehabilitation of the Killarney and Kruisfontein wetlands included the construction of structural interventions to achieve the objectives of the rehabilitation planning. A number of different types of structural interventions, as described by Russell (2009), were used to rehabilitate the wetlands, namely:

- Rafted mass gravity concrete weirs;
- Earthen diversions, including a concrete-covered berm;
- Earthen plugs; and
- Spreader canals.

The structural interventions were assessed based on structural integrity and survival of specified flood levels as defined by Cowden and Kotze (2009), and the aftercare of interventions as specified by Russell (2009) as outlined in the following sections. Assessment of the various measures stipulated below

would assist in informing future rehabilitation planning with the selection and design of appropriate interventions within particular settings and in order to achieve specific 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 trees for the selection of appropriate rehabilitation measures to address gullies and/or drainage channels and headcuts in wetlands was applied for both sites. 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 was undertaken based on the specific criteria outlined in Table 3-1 and focussed on the long-term stability of the interventions and the likelihood of achieving the stated objectives. It should be noted that survey benchmarks were not utilised during the setting out of the interventions and therefore, there was no means of verifying that the spillway levels were according to the original plan. This assessment would serve to identify weaknesses or strengths of the selected interventions within the two wetlands.

Table 3-1. Criteria used for monitoring structural integrity of wetland rehabilitation interventions

(Modified from Cowden and Kotze, 2009).

<p>Concrete work:</p> <ul style="list-style-type: none"> • 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>i.e.</i> no signs of corrosion or segregation of the aggregate • Quality of workmanship 	<p>Earthen Structures (incl. berms and diversions):</p> <ul style="list-style-type: none"> • 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>i.e.</i> no slumping or excessive settling of the soil (> 10% of overall height) • Damage by livestock • Quality of workmanship
<p>Spreader Canals:</p> <ul style="list-style-type: none"> • Dimensions according to specifications • Authorised deviations from plan • Erosion of the lip of the canal <i>i.e.</i> concentrated outflow points • Free passage of water through the canals • Scouring within the canal • Quality of workmanship 	

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 a rainfall station 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 the Department of Water Affairs' nearby rainfall stations, and was used to determine whether daily rainfall in excess of that, required to generate a 1 in 20 year flood event, occurred during that period.

3.1.3 Rehabilitation intervention cost effectiveness

The rehabilitation strategies for both wetlands, including the specific interventions adopted, were reviewed in terms of cost effectiveness based on the professional opinion of the project team engineer, who differed from the original engineer involved in the rehabilitation planning. In this instance, cost effectiveness was not an analysis of economic benefit relative to the costs but rather an evaluation of the rehabilitation strategy³ and interventions in terms of providing insights for future rehabilitation planning in terms of reliable approaches to adopt with limited budget available, 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 Level 2 monitoring

The rapid assessment of the outcomes of the rehabilitation focused on the improvements in the functioning and integrity of the Killarney and Kruisfontein wetlands. The initial step to inform the assessments was to define the wetland habitats in terms of hydrogeomorphic type as outlined in Kotze *et al.* (2007). The Killarney and Kruisfontein wetlands were defined as channelled valley bottom wetlands, with the Kruisfontein system comprising the confluence of two valley-bottom systems, as they flow towards the Mooi River.

3.2.1 Assessment of the ecosystem services

The supply of ecosystem services was assessed using the WET-EcoServices (Kotze *et al.*, 2007) assessment framework, which assesses fifteen (15) ecosystem services that wetlands are capable of providing (Table 3-2).

³ Rehabilitation strategy refers to the overall approach adopted for the rehabilitation of an entire wetland, addressing the identified problems and achieving the stated objectives. Wetland rehabilitation linked to the WfWet programme often includes multiple rehabilitation plans for different financial years to implement the rehabilitation strategy.

Table 3-2. Ecosystem services supplied by wetlands

(Kotze *et al.*, 2007, p14)

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

The WET-EcoServices assessment technique focuses on assessing 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.

The above-mentioned ecosystem services, which include direct and indirect benefits to society and the surrounding landscape, 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)

The use of the WET-EcoServices assessment framework allowed for the pre-rehabilitation levels of ecosystem service delivery to be compared to the post-rehabilitation levels, specifically focusing on how the rehabilitation activities have improved the effectiveness of the wetlands to provide ecosystem services.

3.2.2 Assessment of the ecosystem integrity

The assessment of ecosystem integrity was undertaken using the assessment framework, WET-Health (Macfarlane *et al.*, 2007), which was developed for Southern African wetlands (Kotze, 2011; Kotze *et al.*, 2012). The WET-Health assessment framework is based on assessing the following components of the wetlands to determine the health of the systems:

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

The disturbance units within the wetlands were mapped using aerial imagery, pre- and post-rehabilitation, in a Geographic Information System (GIS). These disturbance units were then used to inform the assessment of the integrity of the biophysical components of the wetland hydrogeomorphic (HGM) unit for the pre- and post-rehabilitation scenario. Each of the above-mentioned components has a number of sub-categories which are considered during the assessment, and impacts are weighted using a scale of 0-10 (Kotze *et al.*, 2012; Macfarlane *et al.*, 2007) and used to derive the Present State Category for each component, reflecting the extent to which anthropogenic changes have impacted upon the wetland condition. These are represented as Present State Categories as outlined in WET-Health (Table 3-3).

Table 3-3. Impact scores and present state categories for describing the integrity of wetlands
(MacFarlane *et al.*, 2007)

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

The use of the WET-Health framework allowed for the pre-rehabilitation integrity of the wetlands to be determined and then compared to the post-rehabilitation scenario, seven (7) years after the commencement of wetland rehabilitation activities within the Killarney and Kruisfontein wetlands. The scores for each of the components hydrology, geomorphology and vegetation were integrated into a composite impact score, using the predetermined ratio of 3:2:2, respectively (MacFarlane *et al.*, 2007) for the three components. This composite impact score was used to derive a health score that then provided the basis for the calculation of hectare equivalents (also referred to as functional area), which can be described as the health of a wetland expressed as an area. The hectare equivalents calculation is a means of deriving a common unit of “currency” to measure the losses and gains, and how the ecosystem integrity has changed in response to the various interventions, based on the WET-Health results for the three biophysical drivers. The calculation for the hectare equivalents is as follows (Cowden and Kotze, 2009):

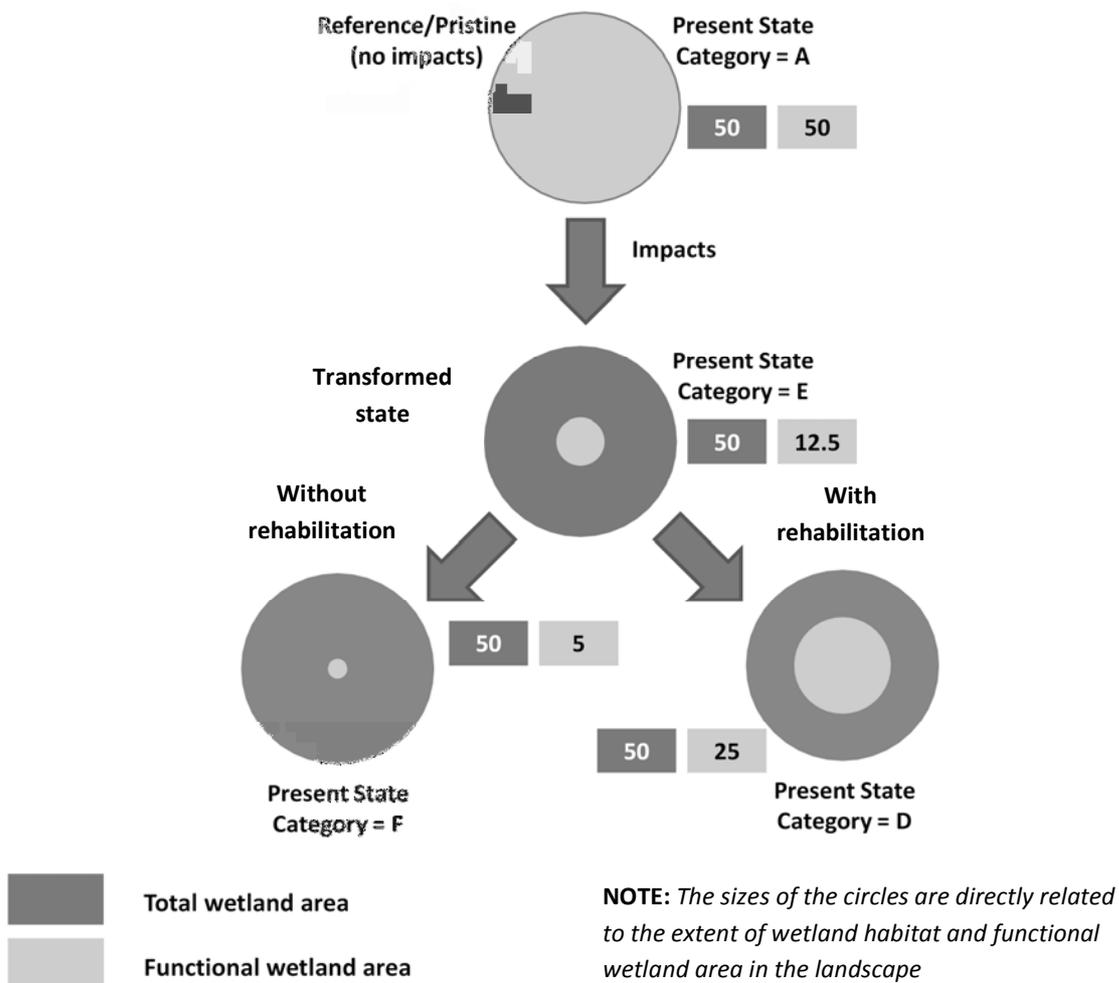
$$\text{Hectare Equivalents} = (10 - \text{Composite impact score})/10 \times (\text{Size of HGM Unit})$$

Cowden & Kotze (2009) make use of a simple example to explain the concept of hectare equivalents conceptually illustrated in **Box 3-1**.

Box 3-1. Example of the use of hectare equivalents to represent changes in wetland health.

The assessment of wetland health is based on comparisons to a reference state *i.e.* where the wetland's health is unmodified and the functional area of the wetland is equivalent to the full extent of the system. For example, if the health of a 50ha wetland is 100% (*Present State Category=A*) this equates to 50 hectare equivalents. For wetland rehabilitation to be considered, the pre-rehabilitation scenario for a particular system would reflect some form of historical degradation. If the aforementioned wetland was *seriously* degraded, the health would be reduced from the reference state to 25% (*reflecting a health score of 2.5*); a drop in hectare equivalents from 50 to 12.5 (50ha x 0.25) hectare equivalents would be recorded. The following would therefore be expected if the wetland in the above scenario was subject to the following two future options:

- a) Without rehabilitation, the system's health would be further reduced to 10% resulting in a drop in hectare equivalents to 5 hectare equivalents; and
- b) With rehabilitation, the system's health would be increased to 50% resulting in a gain in hectare equivalents to 25 hectare equivalents.



3.2.3 Cost effectiveness of the rehabilitation strategy

As for donor-funded programmes generally, WfWet require a means of justifying the programme expenditure in terms of return on investment. WET-RehabPlan (Kotze *et al.*, 2009) describes a standard for assessing the cost effectiveness of a rehabilitation project. This approach for assessing cost effectiveness is based on costs versus the hectare equivalents gained as a result of the rehabilitation specified by Kotze *et al.* (2009). The cost effectiveness of the wetland rehabilitation at both sites was assessed based on determining the costs of the rehabilitation against the hectare equivalents (as explained in Box 3.1) that have been gained with the rehabilitation of the systems. This approach was adopted by Kotze and Ellery (2009), to evaluate the outcomes of five WfWet rehabilitation sites during the Wetland Management Series research.

3.3 Level 3 monitoring

In order to comprehensively assess the outcomes of the wetland rehabilitation, it is important to understand the stated objectives. The objectives of the rehabilitation plans for both wetlands were similar; primarily attempting to re-establish near-natural hydrological conditions and promote the re-establishment of native hydric plants. Based on these objectives, detailed monitoring was originally undertaken, which included:

- Vegetation surveys (at Killarney and Kruisfontein wetlands);
- Water levels, measured using monitoring wells (at Killarney wetland); and
- Channel/gully cross-sectional profiles (at Killarney wetland).

It should be noted that due to the small-scale nature of this project, with limited budget, the field components of this study was limited to a single fieldtrip per wetland to collect post-rehabilitation data. As described, the fieldwork component was undertaken during the summer months to assist in the identification of plant species, thereby eliminating the feasibility of making comparison to the water levels originally recorded in the winter to spring months. In addition, the presence of a control (*i.e.* an area unaffected by rehabilitation) within the wetlands varied across the two sites. The Kruisfontein wetland included an area unaffected by the rehabilitation that was used as a control, but unfortunately Killarney did not include a control. In an attempt to identify trends between affected and unaffected areas of the Killarney wetland, an additional transect (Transect 4) upstream of the area most affected by the rehabilitation was recorded.

3.3.1 Vegetation surveys

The interpretations of the vegetation data were based on the use of indices, to simplify the analyses and in an attempt 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?

To a large extent, the rapid assessment techniques adopted for the Level 2 monitoring, WET-EcoServices and WET-Health, address these questions, but based on a subjective appraisal by the assessor. However, for a Level 3 assessment a more detailed assessment is required to report on project progress or success. This study makes use of two indices, using the vegetation survey data, to measure the wetlands' response to the rehabilitation activities:

- 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.

3.3.1.1 Wetland Index Value

The vegetation survey data were used to determine a Wetland Index Value (Wentworth and Johnston, 1986; Carter *et al.*, 1988) to show rehabilitation success. In particular, the use of the 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 a wetland indicator status. In this instance the wetland indicator status of the recorded vegetation was determined based on the classes as defined by Van Ginkel *et al.* (2010), as follows:

- Obligate;
- Facultative positive;
- Facultative;
- Facultative negative; and
- Non-wetland or terrestrial.

All plant species recorded during the vegetation surveys at both sites were assigned to one of the five above-mentioned classes (Refer to Appendix 2). Based on the approach defined by Carter *et al.* (1988) WIV calculations were undertaken as follows. Each of the abovementioned indicator classes were 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 were then summed and entered into the following equation, which makes use of a weighted average, to calculate the WIV score for the plot:

$$\text{WIV} = (1 \times \text{PA:O}/100) + (2 \times \text{PA:FP}/100) + (3 \times \text{PA:F}/100) + (4 \times \text{PA:FN}/100) + (5 \times \text{PA:NW}/100)$$

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.

Two hypothetical plots have been used to clearly illustrate the approach adopted in Table 3-4.

Table 3-4. Derivation of WIV for two hypothetical plots.

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

To determine the response of the wetland system to the rehabilitation activities, the wetlands were divided into different areas of response and the sample sites grouped accordingly, similar to the approach adopted by Campbell *et al.* (2002). The Kruskal-Wallis test, a non-parametric alternative to a one-way ANOVA (Ashcroft & Pereira, 2003), was used to determine if significant differences existed between the means for the different groups, as follows:

- Killarney wetland – data were grouped according to the transects (Figure 2-1), as it was anticipated that the response of the system to rehabilitation was likely to vary longitudinally down the length of the system; and
- Kruisfontein wetland – data were grouped according to the nature of the flows received by the areas (Section 2 and Figure 2-2), as it was anticipated that the response of the system to rehabilitation was likely to vary in accordance with the following different areas:
 - WfWet rehabilitation high flows – this refers to the area of the wetland affected by the flows redistributed from western channel by means of the concrete weir and the spreader canal;
 - WfWet rehabilitation moderate and low flows – this refers to the area of the wetland affected by the base flows diverted from the western channel by means of the concrete-capped earthen diversion berm;
 - Transformed Control – this refers to the central portion of the wetland unaffected by the WfWet and the farmer’s rehabilitation;
 - Untransformed – this refers to an area within the wetland that was not ridge and furrowed or cultivated historically, and was not affected by either the farmers or WfWet rehabilitation; and
 - Farmer’s rehabilitation – this refers to the area of the wetland affected by the flows diverted from the eastern channel by means of the farmer’s diversion.

In the event statistically significant differences ($P < 0.05$) were identified by the Kruskal-Wallis test, t-tests were undertaken to determine the wetlands responses to the WfWet rehabilitation. 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 unaffected by WfWet and the farmer's rehabilitation, control t-tests were used to compare the different groups 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 & Pereira, 2003).

Similar to Carter *et al.* (1988) the following thresholds recommended by Wentworth and Johnson (1986) were used in addition to the abovementioned analyses in interpreting WIV:

- 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 plots within the affected areas of the wetland would generally move from non-wetland towards wetland in the abovementioned WIV classes.

3.3.1.2 Floristic Quality Assessment Index

Similar to the approach adopted for WIV, the vegetation survey data were used to determine a Floristic Quality Assessment Index (FQAI) as defined by Miller and Wardrop (2006). FQAI provides an estimate of habitat quality and is 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 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 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)

All plant species recorded during the vegetation surveys at both sites were assigned to one of the five above-mentioned classes (Refer to Appendix 2). The recorded vegetation data at each plot were entered into the following equation to calculate the FQAI score for the plot:

$$\text{FQAI} = (C/10) \times (\sqrt{N}/\sqrt{S}) \times 100$$

Where:

C = Mean coefficient of conservatism (as determined by dividing the sum per plot by the native species richness)

N = Indigenous species richness

S = Total species richness

Two hypothetical plots have been used to clearly illustrate the approach adopted in Table 3-5.

Table 3-5. Derivation of FQAI for two hypothetical plots.

Species	Coefficient of conservatism	Plot 1	Plot 2
<i>Carex acutiformis</i>	10	10	-
<i>Eleocharis dregeana</i>	10	10	-
<i>Pennisetum thunbergii</i>	10	10	-
<i>Leersia hexandra</i>	5	5	
<i>Paspalum dilatatum</i>	0	-	0
<i>Hyparrhenia dregeana</i>	5	-	5
<i>Coryza sp.</i>	1	-	1
<i>Eragrostis plana</i>	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		87.5	31.75

Statistical analyses of the derived FQAI data was undertaken in the same manner as the approach adopted for the WIV scores.

3.3.2 Channel/gully cross-sections

Cross-sections of the channel and gullies within the Killarney wetland were surveyed with a dumpy level along the transects and compared to the original measurements recorded by Cowden *et al.* (2009). The surveying of cross-sectional profiles of the channels and gullies assisted in determining changes in channel morphology and trapping of sediment since the implementation of the rehabilitation activities.

4 RESULTS

4.1 Level 1 monitoring

Level 1 monitoring focuses on the outputs of the wetland rehabilitation, specifically the interventions, undertaken by WfWet. It should be noted that despite the lack of national guidelines, introduced with WET-RehabMethods, at the time of the rehabilitation planning, the rehabilitation interventions within both wetlands require very little maintenance and have generally achieved the objectives defined during the rehabilitation planning for each intervention.

4.1.1 Structural integrity

The application of the WET-RehabMethods decision tree confirmed that the earthen and concrete interventions, adopted for the rehabilitation of the Killarney and Kruisfontein wetlands, were used in the correct situations (Table 4-1 and Table 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.

The application of appropriate rationale, aligned with best practice outlined by the decision tree in Russell (2009), in the selection of structural interventions within the wetlands, would suggest that issues relating to structural integrity and survival of the interventions were likely to be limited within the Killarney and Kruisfontein wetlands. Based on infield observations, this is reinforced by the lack of issues of concern, in terms of structural integrity, as the assessment of the integrity of the different structural interventions at both wetlands identified minor issues relating to construction rather than 'catastrophic failure' of the interventions (Table 4-1 and Table 4-2). It appears that the adoption and implementation of available guidelines and best practices 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 (Table 4-1 and Table 4-2), but can be easily addressed with the implementation of maintenance.

Table 4-1. Evaluation of rehabilitation interventions implemented in the Killarney wetland

Intervention	Appropriateness of intervention ⁴	Built to specifications?	Objectives met?	Reasons for discrepancies	Implications of discrepancies	Additional notes
<u>Concrete Weirs:</u>	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. Except T51H0026 which requires maintenance due to tunnelling (flow occurring beneath the structure).	It appears that poor foundation conditions resulted in the tunnelling recorded for intervention T51H0026	If not addressed there would be reduced frequency of overtopping and lowering of water table locally <i>i.e.</i> directly adjacent to the intervention.	Implementation was historically often carried out under time and budgetary constraints limiting opportunities for assessments (by the design engineer) of the foundation conditions following excavation.
<u>Spreader Canal:</u>	Not applicable.	Yes. As-built dimensions aligned with rehabilitation plan designs.	Partially. Breaching of the outlet of the canal has reduced its efficacy.	Breaching of the canal, especially at its outlet, has led to flows being unequally distributed along its length, which may be attributed to the gradient of the canal being greater than planned.	Flows not being redistributed to the areas downstream of the canal. Potential erosion where concentrated flows exit the canal and enter the natural channel.	Spreader canals should be designed with a hardened overflow edge and be set out with appropriate levels.
<u>Earthen Berms:</u>	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.	Not applicable.	Not applicable.	Not applicable.

⁴ Appropriateness of the interventions was assessed based on criteria of Russell (2009), P. 35- Figure 4.1 and Figure 4.2.

Table 4-2. Evaluation of rehabilitation interventions implemented in the Kruisfontein wetland

Intervention	Appropriateness of intervention⁵	Built to specifications?	Objectives met?	Reasons for discrepancies	Implications of discrepancies	Additional notes
<u>Concrete Weirs:</u>	Yes. Diversion of flows from a perennial channel and deactivation of large headcut erosion.	No. As-built dimensions differ from the rehabilitation plan designs.	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.	Minor amendments to the interventions can address the identified discrepancies.
<u>Spreader Canal:</u>	Not applicable.	No. As-built dimensions differ from the rehabilitation plan designs.	Partially. Breaching of the canal has reduced its efficacy.	Breaching of the canal has led to flows exiting the canal via a preferred flow path and being unequally distributed along its length.	Concentrated flows along preferred flow paths rather than diffuse flows over a larger area of the wetland.	Spreader canals should be designed with a hardened overflow edge and be set out with appropriate levels.
<u>Earthen Berms:</u>	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 berms.	Approximately one half of the anticipated area of the wetland has been influenced by the rehabilitation.	Detailed surveys of local elevation are required when rehabilitating ridge and furrow to gain an understanding of the flows of the diverted water, which has been advocated and addressed in subsequent rehabilitation planning.

⁵ Appropriateness of the interventions was assessed based on criteria of Russell (2009), Figure 4.1 and Figure 4.2.

4.1.2 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 would be higher than if the converse were true.

Based on the rainfall recorded at nearby Department of Water Affairs (DWA) 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 levels 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 contributing to intervention success, with concrete weirs being planned with water from the downstream interventions back-flooding halfway up the interventions upstream (Figure 4-1). 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.



Figure 4-1. View of water back-flooding to the base of an intervention in Killarney wetland

4.1.3 Cost-effectiveness of rehabilitation interventions

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 engineers in increasing the effectiveness of selected interventions in various settings, especially given that WfWet has to undertake wetland rehabilitation in South Africa with limited budget and time constraints. The review of the interventions, in terms of cost-effectiveness, was supported by the assessment of the ecological responses of the systems and is shown in Table 4-3.

An overall assessment of the cost-effectiveness of the wetland rehabilitation cannot be quantified, due to a lack of comparable data across multiple sites, but it is possible to discuss the cost-effectiveness of the two sites relative to each other. In terms of meeting the stated objectives of reinstating the near-natural hydrological conditions, the interventions in the Killarney wetland are considered to have performed better than those in the Kruisfontein wetland. The primary reason for this is the discrepancies in the as-built dimensions of the interventions in the Kruisfontein wetland. However, it should be noted that with nominal additional costs it is anticipated that the rehabilitation could be improved.

Then, assuming that the interventions in both wetlands are achieving their objectives, could the same level of outcomes have been achieved with fewer or less costly interventions? Within both wetlands, there are points of view raised by the project team to consider:

- In the Killarney wetland, 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. This was raised based on the perception that the wetland appears to be less dependent on the flows originating from the channel, negating the need to encourage the water in the channel to frequently spread across the wetland in this area.
- In the Kruisfontein wetland, the earthen berms have worked well to trap water within the ridge and furrowed areas of the wetland, but one may question if a larger number of smaller interventions, especially towards the western channel may have increased the area affected by WfWet rehabilitation.

Table 4-3. Review of the cost-effectiveness of the strategy and interventions adopted for the wetland rehabilitation

	Rehabilitation strategy	Interventions
Killarney wetland	<p>1) The lack of sediment accumulation in the channel (Refer to Section 4.3.2), either due to a lack of sediment supply within the catchment or sediment being trapped by upstream interventions, supported the use of water to deactivate the channel rather than relying on sediment accumulation</p> <p>2) 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 subsequently the vegetation response (Refer to Sections 4.2 and 4.3) downstream of these interventions</p> <p>3) The increased frequency of overtopping, redistribution of flows, and high water levels maintained in the channel by interventions at frequent intervals along it, assisted in facilitating improved hydrological conditions (Refer to Section 4.3)</p>	<p>1) Based on the validation of the rehabilitation strategy, the use of fewer interventions would have detrimentally affected the outcomes and success of the rehabilitation, especially in the upper reaches of the Killarney wetland.</p> <p>2) It was noted during the assessment of the interventions that the freeboard incorporated into the design was minimal, limiting opportunities to reduce the heights of the key walls of the interventions used.</p> <p>3) 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 previous experience.</p>
Kruisfontein wetland	<p>1) It is anticipated that the issues identified in Table 4-1 contributed significantly to limited ecological response recorded for the wetland (Refer to Sections 4.2 and 4.3)</p> <p>2) 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</p>	<p>1) 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</p> <p>2) The size of the earthen plugs, with 1m freeboard, could have been substituted for a greater number small-scale (<0.5m freeboard) earthen plugs within the ridge and furrow for the equivalent available budget</p>

4.2 Level 2 monitoring

The improvement in the system's integrity and ability to supply ecosystem services within the landscape was assessed using the WET-EcoServices (Kotze *et al.*, 2007) and WET-Health (Macfarlane *et al.*, 2007) assessment frameworks. The use of both assessment frameworks was considered important as both the functioning and integrity of the wetlands was affected by the rehabilitation in varying degrees, which is explained in more detail in Section 5.

4.2.1 Assessment of the effect of rehabilitation on the delivery of ecosystem services

The improvement of the systems opportunities and ability to supply ecosystem services within the landscape was assessed using the WET-EcoServices (Kotze *et al.*, 2007) assessment framework. It is important to note that WET-EcoServices assesses both opportunities and effectiveness of the wetlands to supply ecosystem goods and services, and in order to determine the within-system changes, linked to the rehabilitation, change in effectiveness should be determined. Key characteristics linked to the systems' hydrological conditions and integrity, were considered to have improved as a result of the WfWet wetland rehabilitation as detailed in Figure 4-2 and Figure 4-3, and Table 4-4 and Table 4-5. The improvements in the effectiveness of the wetlands to supply ecosystem services, within both the Killarney and Kruisfontein wetlands, were strongly linked to changes in the flows within the wetlands as a result of the rehabilitation (Figure 4-2 and Figure 4-3). For example, the re-distribution of base flows linked to the spreader canals translated into increases in the effectiveness of the systems to assimilate phosphates, nitrates and toxicants, improved integrity and opportunities for water supply and carbon storage. 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 much more intensively used (for dairy production), as elaborated upon further in the Section 5. In terms of considering the value of the improvements in ecosystem services, based on a resource economics approach, serious limitations relating to the baseline data collected during the original research were identified (Refer to Appendix 3). The need to provide a valuation of wetland rehabilitation, linked to gains in ecosystem services, should therefore inform the collection of detailed baseline and follow-up data, rather than being included on a *post-hoc* basis.

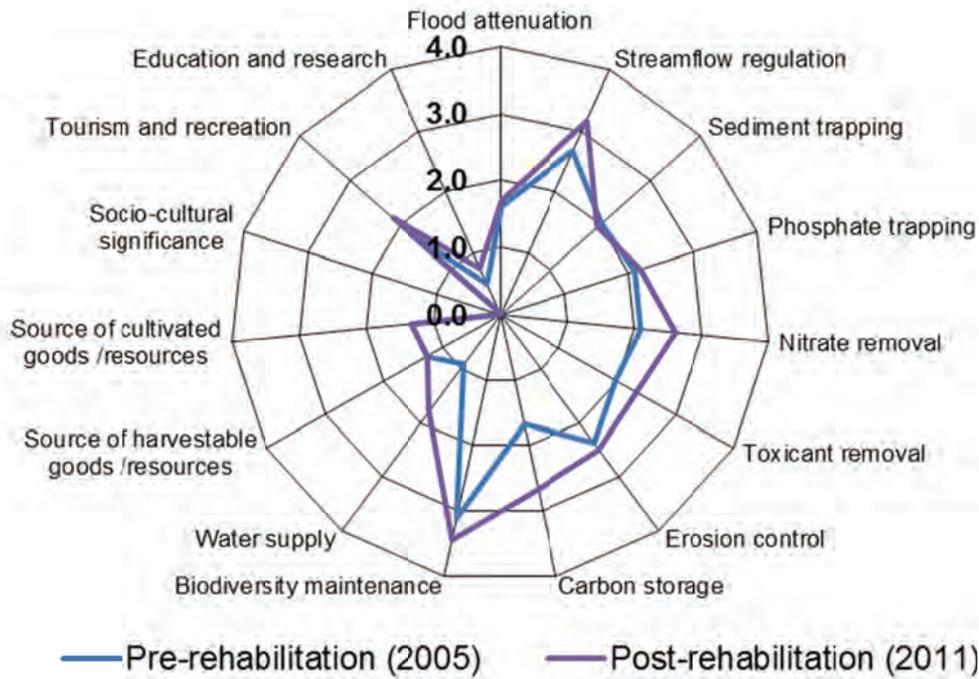


Figure 4-2. Levels of ecosystem service delivery pre- and post-rehabilitation in Killarney wetland

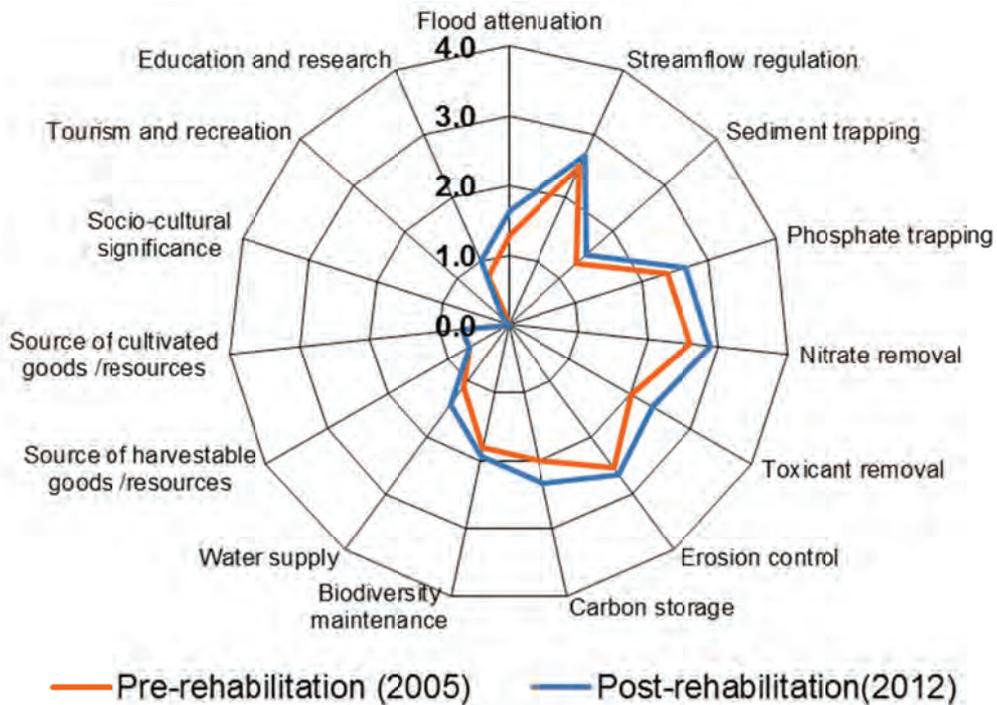


Figure 4-3. Levels of ecosystem service delivery pre- and post-rehabilitation in Kruisfontein wetland

Table 4-4. Summary of ecosystem services scores recorded pre- and post- rehabilitation at Killarney wetland

Ecosystem Services	2005		2011		% Change in effectiveness ⁶	Notes
	Score	Opportunity	Score	Opportunity		
Flood attenuation	1.6	1.7	1.4	1.8	25.0	The effectiveness of the wetland to attenuate floods was improved by the increase in surface roughness and 'sinuosity' of the stream channel linked to the redistribution of flows by the spreader canal and diversion pipe. Increased by the increased extent of the permanent wetness zone within the wetland.
<i>Score for effectiveness:</i>	1.4	1.8	1.8	1.6		
<i>Score for opportunity:</i>	1.8	1.6				
Stream flow regulation	2.7	3.2			18.8	
Sediment trapping	2.0	1.9			25.0	The increased effectiveness of the wetland to attenuate floods translated into an improved ability of the system to trap sediments.
<i>Score for effectiveness:</i>	0.7	0.9				
<i>Score for opportunity:</i>	3.3	3.0				
Phosphate trapping	2.1	2.2			25.0	The increased effectiveness of the wetland to trap sediments and the re-distribution of low flows, translated into an improved ability of the system to trap phosphates.
<i>Score for effectiveness:</i>	2.2	2.7				
<i>Score for opportunity:</i>	2.0	1.7				
Nitrate removal	2.1	2.6			45.5	The re-distribution of low flows and the representation of larger areas of permanent wetness zones within the wetland translated into increased system effectiveness in nitrate assimilation.
<i>Score for effectiveness:</i>	2.2	3.2				
<i>Score for opportunity:</i>	2.0	2.0				
Toxicant removal	2.0	2.3			53.3	The improved sediment trapping, re-distribution of low flows and the representation of larger areas of permanent wetness zones within the wetland translated into increased system effectiveness in toxicant assimilation.
<i>Score for effectiveness:</i>	1.9	3.0				
<i>Score for opportunity:</i>	2.0	1.7				
Erosion control	2.4	2.5			10.4	The effectiveness of the wetland to control erosion was increased by the increase in surface roughness and stabilisation of the identified erosion within the wetland.
<i>Score for effectiveness:</i>	3.0	3.3				
<i>Score for opportunity:</i>	1.8	1.7				
Carbon storage	1.7	2.7			60.0	The representation of larger areas of permanent wetness zones within the wetland translated
Biodiversity maintenance⁷	3.1	3.4			20.8	The improved hydrological conditions, with the deactivation of the channel, and improved vegetation composition increased the level of system integrity as reflected by the WET-Health assessment.
<i>Score for noteworthiness:</i>	3.3	3.3				
<i>Score for integrity:</i>	3.0	3.6				
Water supply	0.9	1.8			95.5	The improved stream flow regulation contributes towards improved water supply.
Source of harvestable goods /resources	1.3	1.3			0.0	Rehabilitation failed to promote the re-establishment of the favoured craft species <i>Juncus punctatorius</i>
Source of cultivated goods /resources	1.3	1.3			0.0	-
Socio-cultural significance	0.0	0.0			0.0	-
Tourism and recreation	1.9	2.1			15.4	Facilities and infrastructure in the reserve rather than the rehabilitation led to elevated scores.
Education and research	0.5	0.8			50.0	The on-going research at the Killarney wetland adds to its value.

⁶ Positive values represent an increase and negative values a decrease

⁷ The thresholds were removed and an average of noteworthiness and integrity was recorded, otherwise the benefit of the rehabilitation does not reflect in the final score.

Table 4-5. Summary of ecosystem services scores recorded pre- and post- rehabilitation at Kruisfontein wetland

Ecosystem Services	2005	2011	% Change in effectiveness ⁸	Notes
Flood attenuation	1.3	1.6		The effectiveness of the wetland to attenuate floods was improved by the increase in surface roughness, the presence of 'depressions' associated with the plugs, increased 'sinuosity' of the stream channel with the redistribution of flows, and increased overtopping of the stream.
<i>Score for effectiveness:</i>	0.6	1.3	125.0	
<i>Score for opportunity:</i>	2.0	2.0		
Stream flow regulation	2.5	2.7	6.7	Increased by the increased extent of the permanent wetness zone within the wetland.
Sediment trapping	1.3	1.5		The increased effectiveness of the wetland to attenuate floods translated into an improved ability of the system to trap sediments.
<i>Score for effectiveness:</i>	0.3	0.6	125.0	
<i>Score for opportunity:</i>	2.3	2.3		
Phosphate trapping	2.4	2.7		The increased effectiveness of the wetland to trap sediments and the re-distribution of low flows, translated into an improved ability of the system to trap phosphates.
<i>Score for effectiveness:</i>	2.1	2.7	28.4	
<i>Score for opportunity:</i>	2.7	2.7		
Nitrate removal	2.6	2.9		The re-distribution of low flows and the representation of larger areas of permanent wetness zones within the wetland translated into increased system effectiveness in nitrate assimilation.
<i>Score for effectiveness:</i>	2.2	2.8	27.3	
<i>Score for opportunity:</i>	3.0	3.0		
Toxicant removal	2.0	2.4		The improved sediment trapping, re-distribution of low flows and the representation of larger areas of permanent wetness zones within the wetland translated into increased system effectiveness in toxicant assimilation.
<i>Score for effectiveness:</i>	2.1	2.7	32.6	
<i>Score for opportunity:</i>	2.0	2.0		
Erosion control	2.5	2.7		The effectiveness of the wetland to control erosion was increased by the increase in surface roughness within the wetland.
<i>Score for effectiveness:</i>	3.3	3.5	7.7	
<i>Score for opportunity:</i>	1.8	1.8		
Carbon storage	2.0	2.3	16.7	The representation of larger areas of permanent wetness zones within the wetland translated into increased carbon storage.
Biodiversity maintenance⁹	1.8	1.9		The improved hydrological conditions, with the partial deactivation of the channels, increased the level of system integrity as reflected by the WET-Health assessment.
<i>Score for noteworthiness:</i>	2.0	2.0	15.4	
<i>Score for integrity:</i>	1.6	1.9		
Water supply	1.1	1.4	25.9	The improved stream flow regulation contributes towards improved water supply.
Source of harvestable goods /resources	0.7	0.7	0.0	Not available
Source of cultivated goods /resources	0.7	0.7	0.0	Not available
Socio-cultural significance	0.0	0.0	0.0	Not available
Tourism and recreation	0.0	0.1	0.0	Not available
Education and research	0.8	1.0	33.3	The on-going research at the Kruisfontein wetland adds to its value.

⁸ Positive values represent an increase and negative values a decrease

⁹ The thresholds were removed and an average of noteworthiness and integrity was recorded, otherwise the benefit of the rehabilitation does not reflect in the final score.

4.2.2 Assessment of the ecosystem integrity

In order to measure the improvements in ecological integrity of the Killarney and Kruisfontein wetlands, it is important to consider the levels of integrity for conditions pre- and post-rehabilitation. The assessment of the wetland habitat under pre-rehabilitation conditions identified extensive historical modifications, associated with agricultural activities within the wetlands. The impacts on the systems were linked to the following activities, *inter alia*:

- Incision of the natural channel;
- Artificial drainage channels (ridge and furrow agriculture); and
- Croplands.

In particular, the impacts on the Killarney system were limited to the desiccation of the upstream areas of the wetland linked to reduced frequency of overtopping of the channel and a draw-down effect directly adjacent to the channel. While historically being agricultural land, the wetland was not subjected to cultivation and removal of the natural vegetation. In contrast, the Kruisfontein wetland was subjected to extensive ridge and furrow, artificial drainage and cultivation. These disturbances included the alteration of both the vegetation and hydrological components to critical levels, with the total loss of indigenous vegetation cover and altered water flows and retention patterns within the system. The aforementioned activities have resulted in modifications to the systems' ecological integrity. Based on the WET-Health assessments of the level of transformation within the wetland and the derived overall impact scores (Table 4-6):

- Killarney wetland was determined to be a 'C' category (Table 4-7) *i.e.* "Moderately modified. A moderate change in ecosystem processes and loss of natural habitats has taken place but the natural habitat remains predominantly intact".
- Kruisfontein wetland was determined to be an 'E' category (Table 4-7) *i.e.* "The change in ecosystem processes and loss of natural habitat and biota is great but some remaining natural habitat features are still recognizable".

Table 4-6. The scores recorded for wetland systems integrity pre- and post-rehabilitation

	Killarney			Kruisfontein		
	Pre-rehabilitation	Post-rehabilitation	Post-rehabilitation (+10yrs)	Pre-rehabilitation	Post-rehabilitation	Post-rehabilitation (+10yrs)
Hydrology	3.0	1.0	1.0	9	7.5	7.5
Geomorphology	1.6	0.5	0.5	2.5	1.8	1.8
Vegetation	3.6	2.1	1.5	8.2	6.7	6.7
Overall impact score	2.8	1.2	1.0	6.9	5.6	5.6
Hectare equivalents*	30.7	37.5	41	8.2	11.5	11.5
Hectare equivalents reinstated**	6.8			3.3		

* 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)

Table 4-7. Impact scores and present state categories for describing the integrity of wetlands
(MacFarlane *et al.*, 2007)

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

It is evident from the assessments of ecological integrity that in comparison to the Killarney wetland, Kruisfontein wetland has been considerably impacted upon by land use activities, potentially affecting the system's response to rehabilitation.

The assessment of the wetland under the post-rehabilitation scenario showed that both wetlands have improved in terms of integrity by one impact class (Table 4-6):

- Killarney wetland was determined to be a 'B' category (Table 4-7) *i.e.* "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".
- Kruisfontein wetland was determined to be a 'D' category (Table 4-7) *i.e.* "Largely modified. A large change in ecosystem processes and loss of natural habitat and biota has occurred".

These improvements in ecosystem integrity were primarily linked to the improvements in the hydrological component of each of the wetlands (Table 4-6). The major changes recorded in the Killarney wetland were linked to reversing the impacts associated with the incised channel within the wetland, *i.e.* rewetting areas of the wetland that had become desiccated. Reversing the impacts of the channel on the wetland's hydrology also served to stabilise the identified erosion and promote wetland plant species, improving the geomorphology 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 component of the wetland, especially in those areas receiving moderate and low flows, but improvements in the vegetation component were largely limited due to inadequate recovery of the vegetation, with *P. dilatatum* remaining dominant within the system at the expense of native plant species. Within Kruisfontein wetland the geomorphology improved as a result of the stabilisation of active erosion identified during the rehabilitation planning process. The hypothetical post-rehabilitation scenario (+10yrs.) shown in Table 4-6 was included to illustrate the likely trajectory of change if the two wetlands were reassessed in excess of ten years after rehabilitation. It is evident that Kruisfontein wetland is considered to have reached a point where further recovery in terms wetland integrity is not anticipated, while Killarney wetland would recover beyond the levels of integrity originally envisaged by the original rehabilitation planning and research.

While the changes in ecological integrity depicted as changes in impact category, serve to illustrate the improvements in the wetlands' condition linked to the rehabilitation, the use of hectare equivalents (ha equiv.), as described in Section 3.2.2, provides an effective 'currency' for assessing the gains in wetland integrity. Based on the recorded impact scores, the Killarney wetland improved from 30.7 ha equiv. to 37.5 ha equiv. while the Kruisfontein wetland improved from 8.2 to 11.5 ha equiv. (Table 4-6, and Figure 4-4 and Figure 4-5).

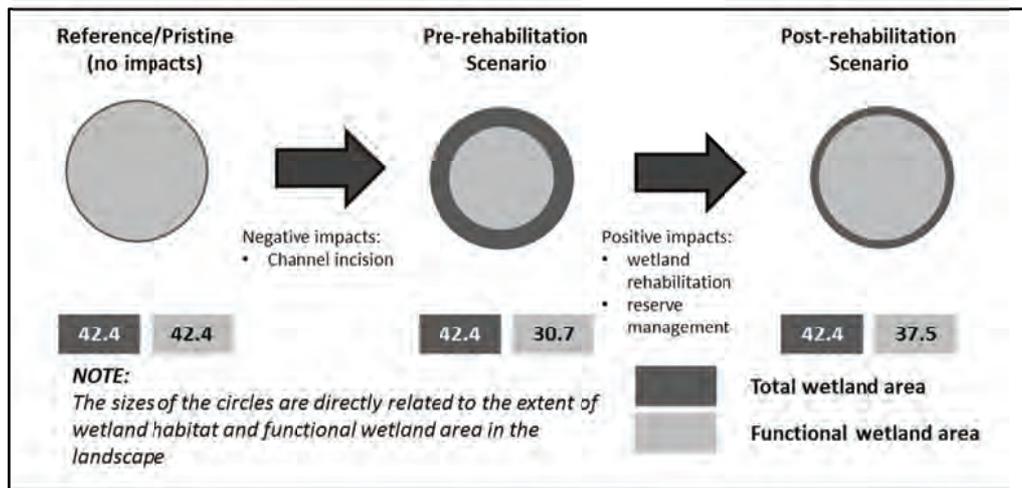


Figure 4-4. A graphic representation of the Killarney wetland, in terms of both spatial extent and functional area, from pre-rehabilitation conditions through to the rehabilitated conditions.

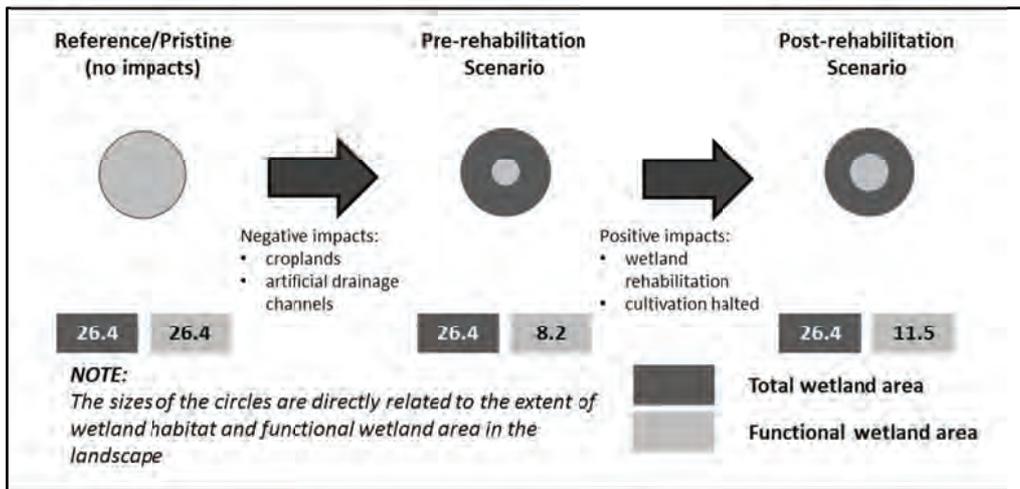


Figure 4-5. A graphic representation of the Kruisfontein wetland, in terms of both spatial extent and functional area, from pre-rehabilitation conditions through to the rehabilitated conditions.

4.2.3 Cost effectiveness of the rehabilitation strategy

Based on the approach outlined in WET-RehabPlan (Kotze *et al.*, 2009) the cost effectiveness of the rehabilitation projects was assessed. The costs of the rehabilitation undertaken at the Killarney and Kruisfontein wetlands were recorded by Cowden *et al.* (2009) and Kotze (2009), respectively. An assessment of the cost effectiveness for the rehabilitation undertaken at both wetlands is included in Table 4-8. It is evident from Table 4-8 that the hectare equivalents gained per wetland, based on the current research were less than originally anticipated in the rehabilitation planning and previous research. The costs per hectare equivalent to rehabilitate the wetlands were therefore greater than originally anticipated, especially for the Kruisfontein wetland. However, based on WET-RehabPlan, the cost effectiveness would still be considered *moderate* and *moderate* to *high* for the Killarney and Kruisfontein wetlands, respectively.

Table 4-8. Assessment of cost effectiveness of rehabilitation based on WET-RehabPlan

	Killarney wetland	Kruisfontein wetland
Costs of rehabilitation	R 1 623 000	R 390 193
Estimated gain in ha equiv.	8.0	6.0
Estimated cost effectiveness per ha equiv.	R 202 875 The cost effectiveness of the project is considered to be <i>moderate</i> , and justification would be required if improved ecosystem services were not moderate to high.	R 65 032 The cost effectiveness of the project is considered to be <i>moderate to high</i> .
Gain in ha equiv.	6.8	3.3
Recorded cost effectiveness (Rands/ha equiv.)	R 238 676 The cost effectiveness of the project is considered to be <i>moderate</i> , and justification would be required if improved ecosystem services were not moderate to high.	R 118 240 The cost effectiveness of the project is considered to be <i>moderate to high</i> .

4.3 Level 3 monitoring

Level 3 monitoring focuses on the outcomes of the wetland rehabilitation, and in this instance has proved to be very useful in defining the changes in the wetland systems since the implementation of the wetland rehabilitation.

4.3.1 Vegetation surveys

The vegetation composition recorded across the various transects using quadrats (Figure 4-6), highlighted trends in vegetation response since the implementation of the WfWet rehabilitation. The reporting on the vegetation response within each wetland has been summarised per transect (Killarney) and ‘treatment area’ (Kruisfontein). Recording the three most dominant plant species, in terms of proportional abundance, within each transect or ‘treatment area’ (Table 4-9 and Table 4-10), highlights the changes in dominance over time in response to the rehabilitation. Transects 1 and 2 at Killarney wetland, show *Eleocharis dregeana*, an obligate wetland species (Refer to Appendix 2), as increasing in dominance within the wetland, and together with other obligate wetland species, reducing the dominance of facultative positive wetland species such as *Pennisetum thunbergii*. *Eleocharis dregeana* also appears to have displaced *Themeda triandra*, a non-wetland species, as the most dominant species in Transect 3. For Kruisfontein, Table 4-10 clearly shows how obligate wetland species such as, *Paspalum distichum* and *Schoenoplectus paludicola*, have increased in abundance in response to the 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 how 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 4-10).

Table 4-9. Dominant plant species identified for each of the transects within Killarney wetland

Transect	Killarney	
	2005	2011
1	1) <i>Pennisetum thunbergii</i> 2) <i>Carex acutiformis</i> 3) <i>Eragrostis planiculmis</i>	1) <i>Carex acutiformis</i> 2) <i>Eleocharis dregeana</i> 3) <i>Pennisetum thunbergii</i>
2	1) <i>Eragrostis planiculmis</i> 2) <i>Pennisetum thunbergii</i> 3) <i>Helichrysum aureo-nitens</i>	1) <i>Eleocharis dregeana</i> 2) <i>Pennisetum thunbergii</i> 3) <i>Eragrostis planiculmis</i>
3	1) <i>Themeda triandra</i> 2) <i>Helichrysum aureo-nitens</i> 3) <i>Eragrostis planiculmis</i>	1) <i>Eleocharis dregeana</i> 2) <i>Helichrysum aureo-nitens</i> 3) <i>Eragrostis planiculmis</i>
4*	-	1) <i>Helichrysum aureo-nitens</i> 2) <i>Eragrostis planiculmis</i> 3) <i>Andropogon appendiculatus</i>

*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.

Table 4-10. Dominant plant species identified for each of the 'treatment areas' within Kruisfontein wetland

'Treatment areas'	Kruisfontein	
	2005	2012
Transformed Control (Unaffected by rehabilitation)	1) <i>Paspalum dilitatum</i> 2) <i>Cynodon dactylon</i> 3) <i>Eragrostis plana</i>	1) <i>Paspalum dilitatum</i> 2) <i>Cynodon dactylon</i> 3) <i>Eragrostis plana</i>
WfWet rehabilitation moderate and low flows*	-	1) <i>Paspalum distichum</i> 2) <i>Paspalum dilitatum</i> 3) <i>Schoenoplectus paludicola</i>
WfWet rehabilitation – high flows	1) <i>Bidens pilosa</i> 2) <i>Paspalum dilitatum</i> 3) <i>Cynodon dactylon</i>	1) <i>Paspalum dilitatum</i> 2) <i>Cyperus esculentus</i> 3) <i>Verbena bonariensis</i>
Untransformed	1) <i>Carex acutiformis</i> 2) <i>Hyparrhenia dregeana</i> 3) <i>Paspalum distichum</i>	1) <i>Paspalum dilitatum</i> 2) <i>Hyparrhenia dregeana</i> 3) <i>Carex acutiformis</i>
Farmer's rehabilitation	1) <i>Paspalum dilitatum</i> 2) <i>Juncus effuses</i> 3) <i>Cynodon dactylon</i>	1) <i>Paspalum dilitatum</i> 2) <i>Juncus effuses</i> 3) <i>Cynodon dactylon</i>

*Given that the area ultimately affected by moderate to low flows was less extensive than anticipated, pre-rehabilitation (2005) plots are absent in this zone. However, it appears to have very closely resembled the "Transformed control" area in 2005 and is likely to have shared the same dominant species with the "Transformed control" area.



Figure 4-6. The study team assessing the vegetation composition within Killarney wetland

4.3.1.1 Wetland Index Value (WIV)

Based on the Kruskal-Wallis test, grouping and analysis of the WIVs derived for each of the plots within the two wetlands over time showed significant differences ($P < 0.05$) only existed within the Kruisfontein wetland.

T-tests comparing 'treatment areas' within the Kruisfontein wetland over time showed no significant differences ($P > 0.05$) for the different areas of the wetland (Table 4-11). The t-test comparing other treatments with the control showed that no significant difference existed between the different 'treatment areas' and the control in 2005 prior to the WfWet rehabilitation, however, the area influenced by the low to moderate flows is significantly different to the control, suggesting a change in vegetation composition since the implementation of the WfWet rehabilitation (Table 4-12).

Table 4-11. Comparison of the mean \pm standard deviation WIV values recorded within sample plots grouped into ‘treatment areas’ for 2005 and 2012. Significant differences ($P < 0.05$) based on Kruskal-Wallis within the rows are shown by different letters.¹⁰

Kruisfontein Wetland	2005	2012
WfWet rehabilitation moderate and low flows	- ¹	1.335 \pm 0.369
WfWet rehabilitation high flows	3.941 \pm 1.169 a	2.495 \pm 0.367 a
Transformed Control	2.735 \pm 0.574 a	2.850 \pm 0.463 a
Untransformed	2.185 \pm 1.404 a	2.701 \pm 1.213 a
Farmer’s rehabilitation	2.173 \pm 0.718 a	2.405 \pm 0.625 a

¹The sample plots grouped as ‘WfWet rehabilitation moderate and low flows’ were only sampled in 2012 and not in 2005 prior to the wetland rehabilitation.

Table 4-12. Comparison of the mean \pm standard deviation WIV values recorded within sample plots grouped into ‘treatment areas’ per year and compared with the transformed control (Unaffected by WfWet rehabilitation). Significant differences ($P < 0.05$) based on Kruskal-Wallis to the control for each year is shown by different letters.

Kruisfontein Wetland	2005	2012
Transformed Control	2.735 \pm 0.574 a	2.850 \pm 0.463 a
WfWet rehabilitation moderate and low flows		1.335 \pm 0.369 b
WfWet rehabilitation high flows	3.941 \pm 1.169 a	2.495 \pm 0.367 a
Untransformed	2.735 \pm 0.574 a	2.701 \pm 1.213 a
Farmer’s rehabilitation	2.185 \pm 1.404 a	2.405 \pm 0.625 a

It is also useful to consider the trends in changes in vegetation composition based on box-and-whisker plots of the WIVs per group (Figure 4-7 and Figure 4-8). Within the Killarney wetland, it is clear that the WIVs recorded in 2005 support the original observation by Cowden *et al.* (2009) that a gradient from drier conditions upstream (Transect 3) to wetter conditions downstream (Transect 1) existed in this area of the wetland (Figure 4-7). Figure 4-7 also shows a change from 2005 to 2011, with the recorded WIVs decreasing, *i.e.* the vegetation in Killarney wetland comprising more obligate or facultative positive wetland plant species, *i.e.* indicating wetter conditions. A similar trend is shown for the Kruisfontein wetland (Figure 4-8), with the recorded WIVs generally decreasing from 2005 to 2012.

¹⁰ 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.

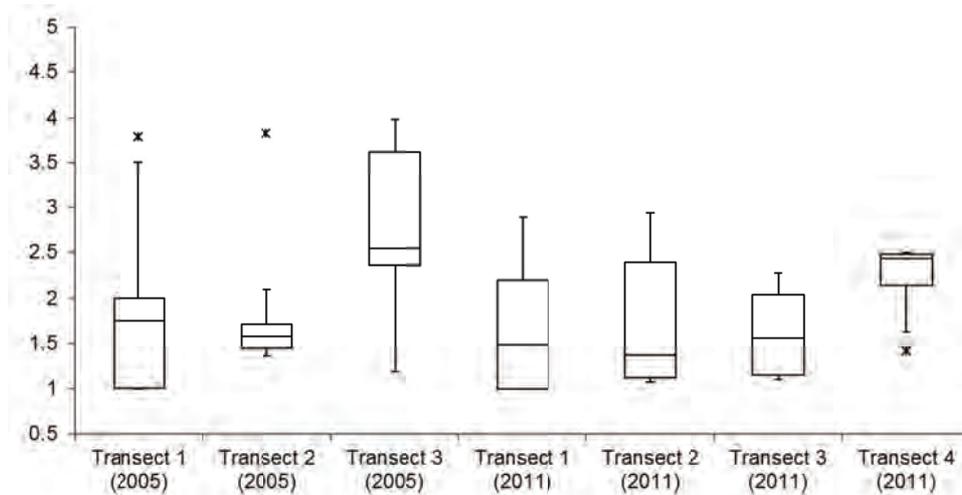


Figure 4-7. Box-and-whisker plot of the WIV values recorded for the different transects within the Killarney wetland for the respective years. *Central horizontal lines* indicate median WIV values, while the *boxes* show 25th and 75th percentiles respectively. *Whiskers* indicate maximum values, while maximum and/or minimum outliers are shown individually.

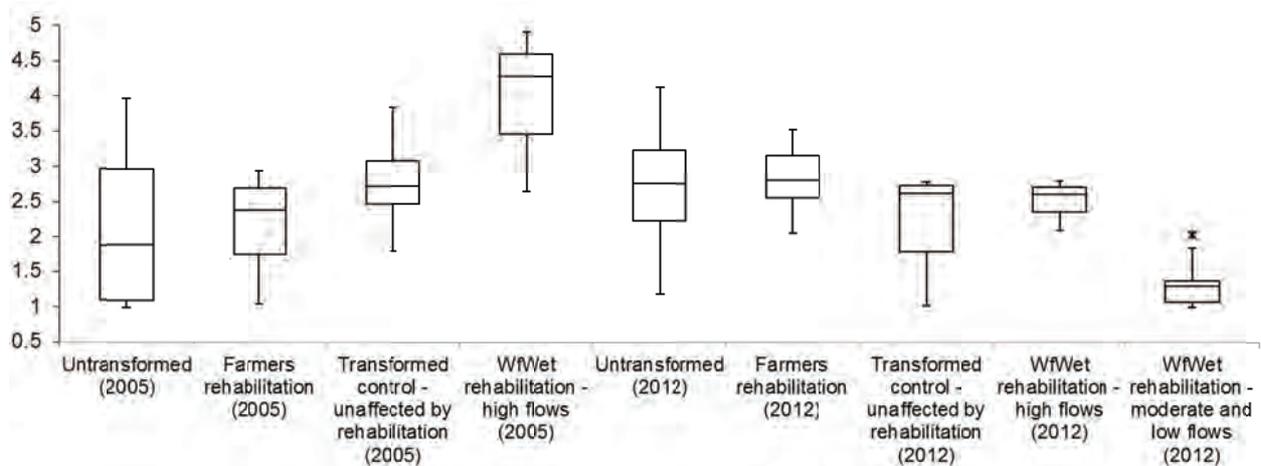


Figure 4-8. Box-and-whisker plot of the WIV values recorded for the different 'treatment areas' within the Kruisfontein wetland for the respective years. *Central horizontal lines* indicate median WIV values, while the *boxes* show 25th and 75th percentiles respectively. *Whiskers* indicate maximum values, while maximum and/or minimum outliers are shown individually.

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 the box-and-whisker plots (Figures 4-7 and 4-8), 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.

4.3.1.2 *Floristic Quality Assessment Index (FQAI)*

The Kruskal-Wallis test of the FQAI values derived for each of the plots within the two wetlands showed significant differences ($P < 0.05$) between transects and between ‘treatment areas’ within the Killarney and Kruisfontein wetlands respectively. T-tests comparing transects and ‘treatment areas’ within the wetlands over time showed only significant differences for Transect 1 within the Killarney wetland (Table 4-13). Similar to the analyses of WIV for Kruisfontein, the Control t-test shows that no significant difference existed between the different ‘treatment areas’ and the control in 2005 prior to the WfWet rehabilitation. However, the area influenced by the low to moderate flows and the untransformed area are significantly different to the control, suggesting a change in vegetation composition since the implementation of the WfWet rehabilitation in the Kruisfontein wetland (Table 4-14).

Table 4-13. Comparison of the mean \pm standard deviation FQAI values recorded within sample plots grouped into ‘treatment areas’ for 2005 and 2012. Significant differences ($P < 0.05$) within the rows are shown by different letters.¹¹

Killarney Wetland	2005	2011
Transect 1	81.064 \pm 11.069 a	93.643 \pm 6.068 b
Transect 2	75.701 \pm 11.858 a	87.575 \pm 9.574 a
Transect 3	85.188 \pm 7.596 a	87.447 \pm 5.458 a
Transect 4	No comparison possible ¹	
Kruisfontein Wetland	2005	2012
WfWet rehabilitation moderate and low flows	No comparison possible ²	
WfWet rehabilitation high flows	19.820 \pm 12.182 a	13.608 \pm 9.576 a
Transformed Control	16.963 \pm 14.518 a	22.229 \pm 8.487 a
Untransformed	46.383 \pm 35.799 a	45.413 \pm 17.795 a
Farmer’s rehabilitation	30.502 \pm 10.474 a	22.384 \pm 14.766 a

¹The sample plots within Transect K4 were only sampled in 2011 and not in 2005 prior to the wetland rehabilitation.

²The sample plots grouped as ‘WfWet rehabilitation moderate and low flows’ were only sampled in 2012 and not in 2005 prior to the wetland rehabilitation.

¹¹ Recorded FQAI values range from 0 (dominated by alien plant species) to 100 (dominated by indigenous plant species intolerant of disturbance)

Table 4-14. Comparison of the mean \pm standard deviation FQAI values recorded within sample plots grouped into 'treatment areas' per year and compared with the transformed control (Unaffected by WfWet rehabilitation). Significant differences ($P < 0.05$) to the control for each year are shown by different letters.

Kruisfontein Wetland	2005	2012
Transformed Control	16.963 \pm 14.518 a	22.229 \pm 8.487 a
WfWet rehabilitation moderate and low flows		53.556 \pm 24.084 b
WfWet rehabilitation high flows	19.820 \pm 12.182 a	13.608 \pm 9.576 a
Untransformed	46.383 \pm 35.799 a	45.413 \pm 17.795 b
Farmer's rehabilitation	30.502 \pm 10.474 a	22.384 \pm 14.766 a

Based on box-and-whisker plots of the FQAI values per transect (Figure 4-9), the vegetation composition within the Killarney wetland vegetation has altered towards non-opportunistic plant species with the recorded FQAI values increasing for Transect 1, 2 and 3. Generally the FQAI values recorded for Kruisfontein wetland are similar from 2005 to 2012, except for the area receiving low and moderate flows following the implementation of the rehabilitation, which has increased markedly (Figure 4-10).

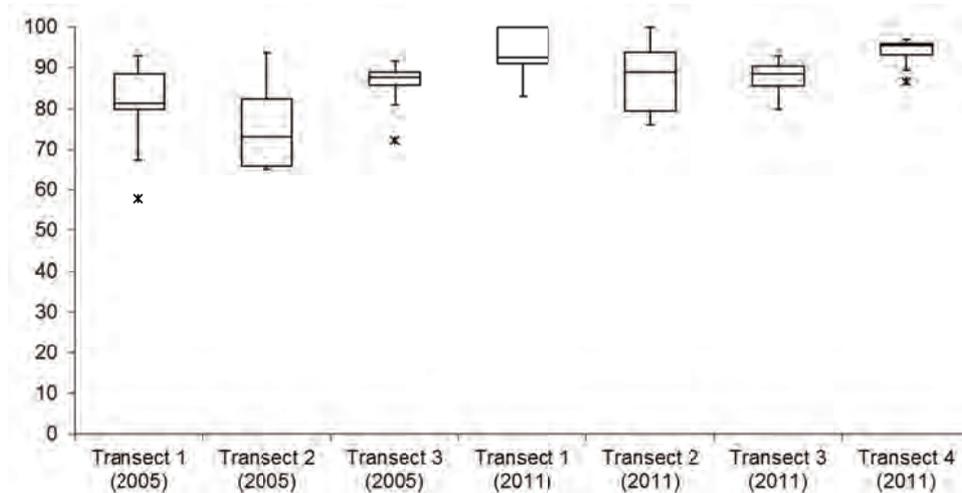


Figure 4-9. Box-and-whisker plot of the FQAI values recorded for the different transects within the Killarney wetland for the respective years. Central horizontal lines indicate median WIV values, while the boxes show 25th and 75th percentiles respectively. Whiskers indicate maximum values, while maximum and/or minimum outliers are shown individually.

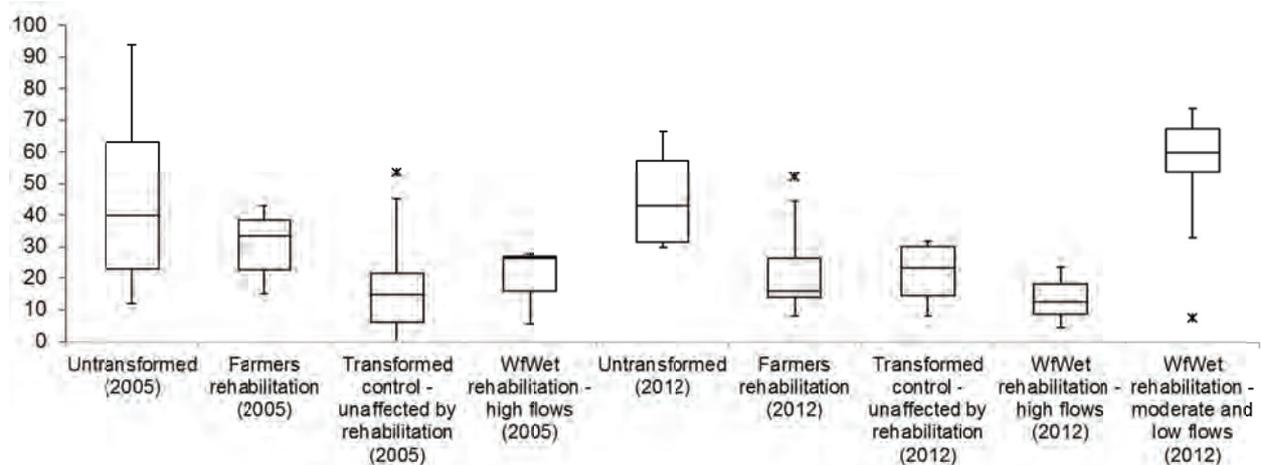


Figure 4-10. Box-and-whisker plot of the FQAI values recorded for the different ‘treatment areas’ within the Kruisfontein wetland for the respective years. *Central horizontal lines* indicate median WIV values, while the *boxes* show 25th and 75th percentiles respectively. *Whiskers* indicate maximum values, while maximum and/or minimum outliers are shown individually.

4.3.2 Channel/gully cross-sections

The cross sectional profiles of the channels within the Killarney wetland were recorded (Figure 4-11 and Figure 4-12) and compared with the original measurements. The recorded values for 2005 and 2011 appear to be relatively similar, with minor changes in depths of the profile, with increases and decreases in depth being recorded. This would suggest that the long-term sediment deposition within the channels has not necessarily increased as a result of the rehabilitation activities despite the interim findings described by Cowden *et al.* (2009). The lack of sediment accumulation is attributed either due to a lack of sediment supply within the catchment or sediment being trapped by upstream interventions.



Figure 4-11. Recording gully cross sections along the transects in Killarney wetland

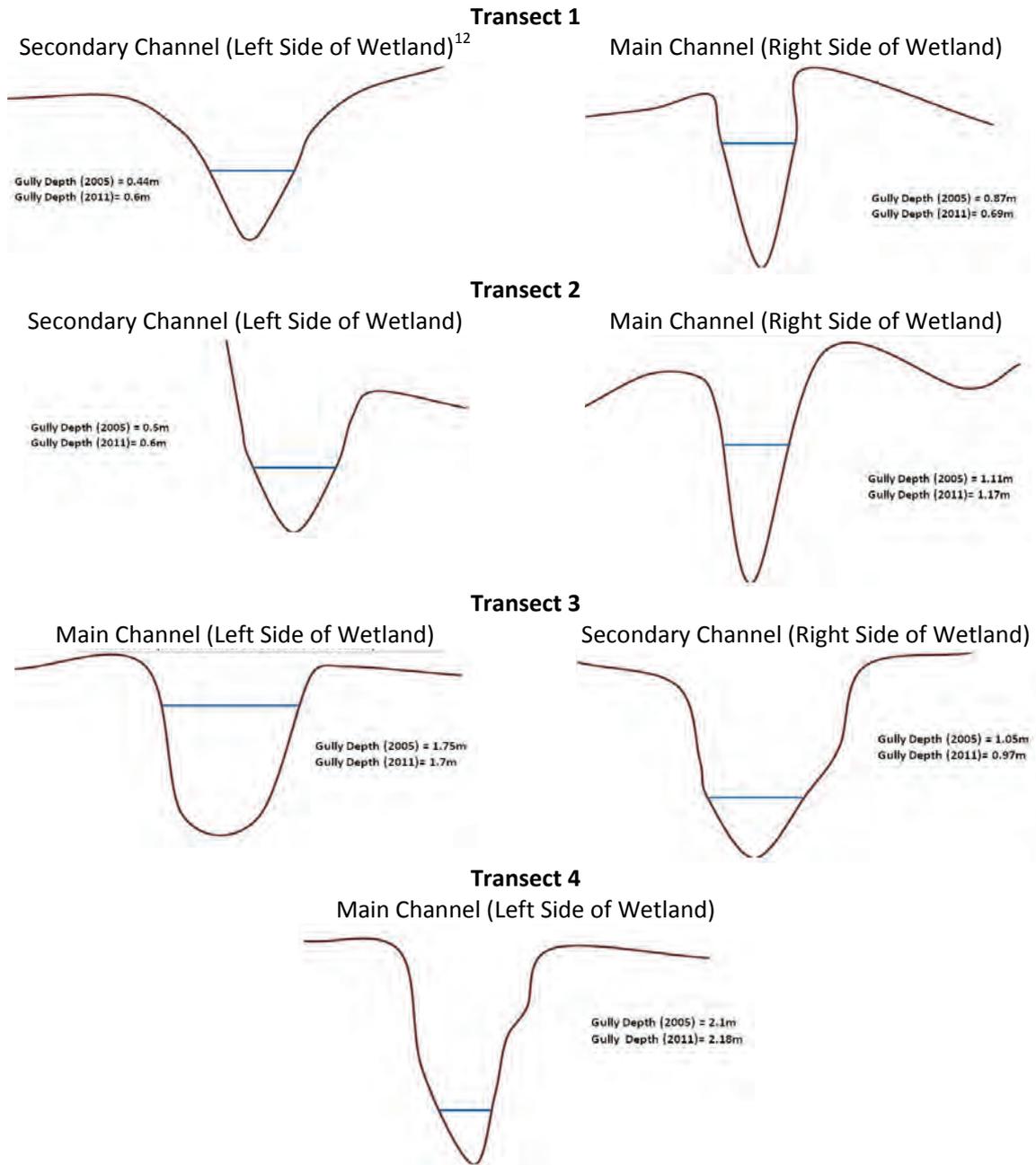


Figure 4-12. Gully cross sections along each of the transects in Killarney wetland with the recorded depths for 2005 and 2011

¹² As per the standard approach for directional references (taken facing downstream) used by Working for Wetlands.

5 DISCUSSION AND RECOMMENDATIONS

The results of the three levels of monitoring, undertaken for the Killarney and Kruisfontein wetlands, identified a number of key trends to be considered in rehabilitation planning and served to document lessons learnt and should be applied in future planning. For the ease of reporting the discussion and recommendations follow the levels of monitoring undertaken at the Killarney and Kruisfontein wetlands.

5.1 Level 1 monitoring

The assessment of the structural integrity of the rehabilitation interventions highlighted the importance of following best practice, such as the decision tree in Russell (2009), in the formulation of a rehabilitation strategy and the adoption of intervention types. With the appropriate interventions being implemented within the given settings, the long-term stability or survival of the rehabilitation interventions is improved. The adoption of appropriate interventions limited the recorded issues to individual occurrences within the wetland concerned and/or issues relating to construction. The identified discrepancies relating to the construction phase (Table 4-1 and Table 4-2) would be easily addressed by maintenance. In addition, it should be noted that the incorporation of additional procedures into WfWet's rehabilitation process, including the wetland rehabilitation planning, has reduced the likelihood of future rehabilitation projects recording similar discrepancies. These include defined procedures, including relevant documentation, to guide the process of wetland rehabilitation. In terms of the construction of interventions, significant inclusions in the process include an engineer being responsible for setting out the interventions and then signing off any variations and the final 'as-built' dimensions following completion of the rehabilitation.

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 for 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 stability of the berms being attributed to the low energy environment in which they were utilised. In particular, the concrete geocell-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 stability 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 solid concrete intervention, but has the advantage of being labour intensive (due to the earthen core), which is more suited to EPWP where person days 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. However, success of these interventions is strongly dependant on project engineer oversight during the implementation or construction phase. While the abovementioned improvements in WfWet's rehabilitation planning process may eliminate some of the recorded issues of concern relating to spreader canals, it is recommended that the following be incorporated into the design and implementation:

- Spreader canals should be set out as per the specifications outlined by Russell (2009):
 - The canal should be surveyed with a 1% gradient away from the intervention into the wetland for the initial 25-50m;
 - The remainder of the canal should be surveyed with a zero gradient, unless the total length exceeds 100m, in which case the canal should be surveyed to 0.1% gradient; and
 - The canal inflow should be formalised with a concrete sill or apron to fix the levels at the inflow.
- Spreader canals should be subject to input from the design engineer during the implementation phase;
- Spreader canals should 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 levels of the receiving wetland should also 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 would need to be incorporated into the design.

In addition to the stability 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 fact that high flows were encouraged to spread across the width of the wetland rather than only flow through each interventions spillway. This approach may be seen as a preferred means of deactivating a perennially flowing channel within a wetland, although the costs would need to be adequately motivated based on the anticipated cost effectiveness. Where deactivation of a channel was required but sediment yield in the catchment was low, this approach would also be seen as the preferred option as the water serves the purpose of deactivating the channel rather than sediment and vegetation.

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 dams within the wetland which has improved habitat diversity within the system to some extent, but they have not achieved the objective of reversing the effect of the ridge and furrow drainage network on the wetland as a whole. If earthen plugs are to be utilised, it is recommended that a high density of small structures (<0.5m freeboard) be utilised to spread the flows throughout the wetland. 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 rehabilitation strategy. The initially diverted flows would 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 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 *i.e.* plugs should only be utilised in cases where the topography of the wetland is extremely gently sloping (<1% slope).

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 the management of the wetland system, for example, 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, reducing 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.

5.2 Level 2 monitoring

The assessment of the ecosystem goods and services and ecological integrity of the wetlands before and after rehabilitation served to highlight clearly the changes in functioning and integrity associated primarily with the WfWet rehabilitation.

The improvements in the wetlands' levels of ecosystem service delivery were strongly linked to the regulatory services, for example, 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, which is not adequately reflected by the WET-EcoServices framework and should be addressed in future revisions of the documentation. In terms of the 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 water quality enhancement, supplied by the wetlands, the size is considered to be "usually to always very important" (Kotze *et al.*, 2007). 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 on the farm. Production of dairy cattle represents an important source of effluent by-products that is usually treated using a pond system (Bolan *et al.*, 2009), as is evident on the farm. Although this treatment should remove much of the biological oxygen demand and the suspended solids of the waste, it is not primarily designed to remove nutrients, which may represent 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, the rehabilitation is seen as assisting in buffering the Mooi River from nutrient levels originating from the nearby dairy.

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 use the wetland-dependent rush *Juncus punctorius* for weaving. In its pre-rehabilitation state, the extent of *J. punctorius* in the Kruisfontein wetland was very limited translating into low provisioning scores being recorded. Given that *J. punctorius* is specially 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 at all. In contrast, *Juncus effusus* was relatively abundant in some of the wetter rehabilitated portions of Kruisfontein, but as shown by Kotze and Traynor (2012) *J. effusus* is of very low value for craft production. Thus, planting of *J. punctorius* is recommended in order to actively promote its increased abundance, and therefore an increase in the value of the Kruisfontein wetland as a source of natural resources.

The assessment of the wetlands' integrity, especially with the derivation of hectare equivalents, provided a useful means to evaluate the response of the wetland systems. It was interesting to note that the improvement in ecosystem integrity of the Killarney and Kruisfontein wetlands was less than anticipated improvements recorded by Kotze and Ellery (2009). This suggests that the rehabilitation of the wetlands has not followed the trajectory of change anticipated during the rehabilitation planning process. Within the Killarney wetland the hydrology and geomorphology have recovered as would be anticipated, with the lower than expected gain in hectare equivalents being mostly attributed to the response of the vegetation component, but it is anticipated that vegetation conditions may improve further as the desired state within the wetland is maintained. This result was not entirely surprising as it is acknowledged that the vegetation in a wetland is often slow to recover following rehabilitation, thus requiring long term studies to best assess recovery (Galatowitsch and van der Valk 1996). Within the Kruisfontein wetland, however, both hydrology and vegetation have not responded in accordance with the anticipated response. The hydrological response within the wetland was inhibited by the ineffectiveness of the spreader canal and the short-cutting of flows along the western edge of the earthen berms, thereby only affecting approximately half of the anticipated area of wetland, as described by Kotze (2009). The limited vegetation response in the Kruisfontein wetland is linked to there being reduced area with improved hydrology and the dominance of disturbance tolerant plant species. This is more clearly shown by the assessment of FQAI in the Level 3 monitoring results.

In addition to the calculation of the hectare equivalents, it was interesting to note that the cost effectiveness would still be considered *moderate* and *moderate* to *high* for the Killarney and Kruisfontein wetlands, respectively. This suggests that the classes in WET-RehabPlan may be too broad, with cost effectiveness being considered the same despite the gained hectare equivalents being almost half the expected hectare equivalents for the Kruisfontein wetland. To use these standards to inform rehabilitation project success, additional classes may need to be included.

5.3 Level 3 monitoring

The Level 3 monitoring of the wetlands focussed on the response of the vegetation within both wetlands, and the use of the WIV and FQAI indices assisted in interpreting these responses. Based on the vegetation surveys, the results obtained for the Killarney wetland generally followed expectations, where despite recording non-significant differences in the WIV values along the transects, obligate wetland species (*e.g. Eleocharis dregeana*) have increased in abundance. It is anticipated that the lack of significant differences was linked to obligate wetland species replacing facultative positive wetland species (*e.g. Pennisetum thunbergii*), rather than facultative wetland species as was the case in the moderate and low flow area in the Kruisfontein wetland. In addition, *Carex acutiformis*, the wetland plants characteristic of the intact portions of the wetland increased in abundance while the abundance of disturbance tolerant species decreasing. This was clearly shown by the significant differences observed over time for Transect 1 when considering the FQAI values for the wetland. 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

quicker 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 the historical disturbance of the system was linked to desiccation associated with channel incision rather than long-term, intensive agricultural production.

The vegetation response within the Kruisfontein wetland was contrasted strikingly with the Killarney wetland and provided additional opportunities to identify trends in response and make comparisons, as the baseline and follow-up surveys included:

- An area that has been subject to improved hydrology since 2003 when the landowner implemented wetland rehabilitation independently. The area affected by the farmer's rehabilitation has had the longest time to recover in respect of the areas considered in this study, and therefore provides one of the best opportunities in the study to assess the recovery of vegetation;
- An area which would serve as a control as it was unaffected by both the farmer's and WfWet's rehabilitation activities; and
- A small area of intact vegetation not subject to ridge and furrow cultivation, although it had been subject to some less intensive human impacts, *e.g.* from 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 *Eleocharis dregeana*.

Based on the vegetation surveys, an unexpected and dramatic result obtained for the Kruisfontein wetland was that after seven years of rehabilitation, the area is still largely dominated by pioneer/ruderal species. This was reinforced by the lack of significant differences being recorded for the FQAI over time. Notably, the strongly-competitive pioneer species, *Paspalum dilatatum*, has retained its dominance within the system, except for the area influenced by moderate and low flows associated with the WfWet rehabilitation where a significant difference in WIV was recorded. Despite *Juncus effusus* having been present in the area affected by the farmer's rehabilitation in 2005, it has been unable to displace the above-mentioned pioneer species even after nine years of improved hydrological conditions. 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. In contrast to the Killarney wetland, where it is anticipated that given enough time, the pioneer species will give way to more of the native vegetation, the vegetation within the Kruisfontein wetland appears to be stable in a severely transformed state such that the threshold of some kind needs to be crossed before the vegetation returns to its former state. Furthermore, the health and ecosystem services of Zoar Vlei were recently assessed, with a number of the observations recorded by Walters *et al.* (2011), echoing the findings of the research at Kruisfontein wetland. The majority (>80%) of Zoar Vlei was historically cultivated and drained, and was subsequently rehabilitated by Mondi Limited in 1999 (Walters *et al.*, 2011). The vegetation communities' recovery 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)". The wettest areas of the wetland were also

described as showing the best recovery linked to the rehabilitation efforts. The presence of alternative stable states/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 regimes within both the Kruisfontein and Zoar Vlei wetlands are therefore alternative stable regimes that would need a threshold to be crossed in order to promote a 'desired' regime. The findings at Kruisfontein wetland and Zoar Vlei 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.

In order to transform the Kruisfontein wetland from a state where it is dominated by alien plant species to one where it is dominated by indigenous species, a threshold of some nature would need to be crossed. In order to understand the threshold in Kruisfontein wetland, an understanding of factors contributing towards this situation is required:

- The intensity and duration of human disturbance preceding the rehabilitation, which acts to deplete the natural seed bank and any vegetative material which may persist on site. In the case of Kruisfontein, the intensity of disturbance is high as a result of major disturbance through ridge and furrow practices. The impact of the duration of the disturbance is also high in that the area was developed 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. Therefore the natural re-establishment of native vegetation in areas cultivated for longer than 20 years are dependent on the dispersal of propagules from outside areas, and the rate and magnitude of dispersal will determine how quickly these species become established.
- The dominance of a competitive alien species (*P. dilatatum*) within the wetland immediately following the completion of the rehabilitation interventions. This species makes it more difficult for a diversity of native species to become established in the site, just as Galatowitsch and van der Valk (1996) note how the competitive grass *Phalaris arundinacea* makes it even more difficult for other sedge meadow species to become established should their propagules reach restored wetlands. Galatowitsch *et al.* (1999) highlights further the profound impact that alien invasive plant species may have on the indigenous flora of wetlands.
- The level of wetness that is attained in the rehabilitated wetland, with a high level of wetness generally acting 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 permanent wetness, *i.e.* a high level of wetness, much of the area is still dominated by seasonal and temporary wetness, which is considered insufficiently wet to exclude *P. dilatatum*.
- Proximity to intact areas of wetland, with indigenous vegetation nearby being much better placed to re-colonise a rehabilitated area than distant intact areas. In the case of Kruisfontein wetland, the nearby intact wetland areas are very limited in extent. As highlighted by Findlay and Houlahan (1997) and Seabloom and van der Valk (2003) increased isolation of the wetland

as a result of cumulative loss of wetlands in the landscape, inhibits colonisation by dispersal-limited indigenous species.

In the light of understanding the contributing factors, the next question to be addressed in order to inform wetland rehabilitation practice, is what can be done practically to assist the vegetation in recovering for those wetland systems subjected to similar conditions as the Kruisfontein wetland? It is anticipated that actions beyond simply rewetting portions of the wetland surface would be required to ensure that the alien plants are eliminated and indigenous species are encouraged to inhabit the created vacant niches:

- The dominance of *P. dilatatum* within the Kruisfontein wetland has served to trap the wetland within an alternate stable state, which differs from that envisaged during the rehabilitation planning process. In order to achieve the objectives of the rehabilitation, a threshold would need to be crossed, whereby the *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, where it was recommended that control structures were put in place to reduce flow velocity thereby allowing vegetation to colonise the system. Based on the vegetation composition of the areas of permanent wetness within the Kruisfontein wetland, increasing the relative proportion of permanently wet areas in the wetland would clearly be to the strong disadvantage of *P. dilatatum*. Based on the insights gained from the Kruisfontein wetland and Zoar Vlei, wetland rehabilitation planned on Mondi Limited property in the KZN midlands, has been planned as a pilot project to test this approach (GroundTruth, 2012). However, wetland rehabilitation practitioners must 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. 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.
- 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 United States of America (USA) (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 USA do not readily re-establish, and it is unlikely that they will reappear without deliberate reintroduction (Budelsky and Galatowitsch, 2000). The requirement for planting is likely to be greatest in those less wet areas of a wetland, and it is recommended that these be the focus for re-planting, which should be preceded by an herbicide treatment of the dominant pioneer species, such as *P. dilatatum* in the Kruisfontein wetland. It is recognized that planting is

costly, and therefore these costs need to be weighed up against the objectives of the rehabilitation project.

The Killarney and Kruisfontein wetlands also provide valuable generally applicable lessons relating to understanding the objectives of wetland rehabilitation and ensuring the rehabilitation strategy is aligned with these, as explained in the following examples:

- If the objective of the wetland rehabilitation is to re-establish/ 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 Kruisfontein 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 *i.e.* the return on investment would need to be assessed.
- If the primary objective of the rehabilitation is to reinstate the regulatory hydrological services supplied by the wetland then whether the wetland is dominated by *P. dilitatum* or a diverse mix of native 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/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 the *P. dilitatum*-dominated site.
- 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 would often be overstated.

5.4 Recommendations for improving components of the Wetland Management Series

The Wetland Management Series was developed to provide guidance in terms of various aspects of wetland management and rehabilitation. Due to the early stages of the wetland rehabilitation field of practice in South Africa, the series was published with the understanding that the various documents within the series would be revised to include experience from those individuals involved in wetland rehabilitation throughout the country. The application of a number of the Wetland Management Series guidelines and assessment frameworks during the course of this research provided opportunities for identifying aspects of the series that could be improved. It is therefore recommended that the following be revisited or included in 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 would need to be updated and refined to be more sensitive to changes, so as to avoid situations similar to that recorded for the

Kruisfontein wetland, where the hectare equivalents achieved were approximately half of that anticipated, but the WET-RehabPlan cost effectiveness rating remained same.

- 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 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 illustrate the value of the detailed mapping of disturbance units for 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.
- Update the Level 1 monitoring in WET-RehabEvaluate to include additional criteria used to assess structural integrity, and incorporate guidance on reviewing the rehabilitation strategy adopted in terms of cost-effectiveness and efficacy in terms of meeting the stated objectives.
- Greater guidance in WET-RehabEvaluate should be provided in terms of the approaches and 'experimental design' of the wetland rehabilitation monitoring needs to be provided, and include the following:
 - Account for unanticipated system responses, *e.g.* the vegetation survey of the Kruisfontein wetland in 2012 was expanded to include plots within the moderate and low flow areas as it was not anticipated that the response to the WfWet rehabilitation would be isolated to the western-most portion of the rehabilitated area.
 - Include an appropriate control area within the wetland or within a comparable wetland area nearby which has been subject to similar impacts to the area being rehabilitated but which would not be influenced by the proposed rehabilitation efforts. In this case Control site t-tests provided a useful means of establishing system response. This control 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 such a control may not always be possible, especially if the rehabilitation strategy aims to influence the entire system;
 - Depending on the objectives of the rehabilitation, it is often useful to also include an additional control 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;

- Standardisation of data collection techniques for vegetation, in accordance with the guidelines provided by Sieben (2011) to address the issues relating to different operators being involved in data collection and 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 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 'treatments areas' in a system that is effectively a 'rehabilitation experiment'.
- While WET-Health (Macfarlane *et al.*, 2007) has shown adequate sensitivity to identify some of the subtleties in the wetland systems' response, reliance solely on hectare equivalents derived from WET-Health for reporting on a rehabilitation project's success is not advised. WET-RehabEvaluate should be refined to further promote the collection of Level 3 monitoring data, particularly vegetation, which proved to be exceptionally useful in highlighting trends in system response over time. It is therefore recommended that WfWet's monitoring and evaluation framework include all levels of monitoring, with Level 3 monitoring being adopted for large-scale or high value wetland rehabilitation projects to accommodate budgetary constraints. 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 systems.
- 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.
- Inclusion of WIV and FQAI as key tools in WET-RehabEvaluate to assist in analysing and interpreting vegetation data collected as part of Level 3 monitoring. Further research relating to these indices would be required though, 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 are seen as appropriate due to the differences recorded for some plant species across the different regions of South Africa.

6 CONCLUSION

The assessment of the long-term response of the two wetlands, Killarney and Kruisfontein, to WfWet rehabilitation is seen as contributing significantly towards the wetland rehabilitation field of practice as it allows one to reflect on challenges. This reflection assists in documenting lessons learnt thereby informing future rehabilitation planning, with recommendations documented for wetland rehabilitation implementation, planning, and monitoring and evaluation. In addition to documenting lessons learnt and refining wetland rehabilitation efforts in South Africa, this study introduces two indices to objectively and defensibly utilise vegetation to reflect changes in long-term wetness. As far as is known to the authors, 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 provide additional tools to those prescribed by WET-RehabEvaluate. Furthermore, the indices are likely to have much broader application, *e.g.* for wetland delineation and the assessment of current impacts on wetlands.

Although the assessment of the two wetlands identified that the rehabilitation undertaken has not completely followed the anticipated trajectory of change outlined in WET-OutcomeEvaluate (Kotze and Ellery, 2009), the following should be noted:

- The vegetation in the Killarney wetland is still in the process of responding to the changes in hydrology, highlighting the time needed for a rehabilitated wetland to reach the anticipated levels of integrity.
- The Kruisfontein wetland is considered to be 'locked' into an alternate stable state dominated by disturbance-tolerant plant species, contradicting the generally accepted statement that if the hydrology is re-instated, the natural re-establishment of native wetland vegetation will follow. This has served to highlight the need to alter the general approach for those wetland systems exposed to long-term transformation and/or subject to encroachment by invasive plant species, where the approach would 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.
- As highlighted by WET-RehabEvaluate, success of wetland rehabilitation projects should be based on success standards derived from the objectives. The success standards adopted by WfWet should be more diverse, as reliance on hectare equivalents, although simple and effective, may provide the impression that wetland rehabilitation has been unsuccessful at a wetland rehabilitated to an alternate stable state, 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 hectare equivalent approach 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.

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8 APPENDICES

Appendix 1. Detailed assessments of structural integrity for the Killarney and Kruisfontein wetlands.

Killarney Wetland

A1.1 Wetland Rehabilitation Interventions

Wetland rehabilitation at the Killarney wetland involved the implementation of the following interventions:

- 17 concrete weirs in the main channel;
- A single spreader canal to divert water out of the main channel into the adjacent wetland; and
- A series of earthen plugs in a side drain.

The following photos show examples of the wetland rehabilitation interventions implemented at the Killarney wetland:



Figure A1-1: Concrete weirs in the main channel of the Killarney wetland



Figure A1-2: A spreader canal diverting a portion of the base flows out of the main channel

The various types of interventions are discussed in detail in the following sections:

A1.1.2 Concrete Weirs at the Killarney Wetland

The concrete weirs (**Figure A1-1**) were constructed across the main channel, with the spillway levels set very 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 draw down effect of the channel on the water table), as well as to encourage overbank topping 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 half way up the spillway of the next weir upstream (this is clearly shown in the photos in **Figure A1-1**). The high level of the spillways in relation 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 to the banks of the channel, as a result of the re-entry of the diverted flows into the main channel, was minimised.

The spacing of the weirs was therefore critical to the success of the rehabilitation 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 in the system as a whole. This was verified by the cross sections of the channel that were surveyed which showed minimal change to the channel profile from the cross sections that were surveyed a number of years prior to 2012.

The structural stability of the concrete weirs was investigated with only one of the seventeen weirs requiring maintenance (intervention T51H0026) where tunnelling had occurred (refer to Figure A1-3 below):



Figure A1-3: Photo showing weir T51H0026 where tunnelling has occurred allowing base flows to pass under the structure

A1.1.3 Spreader Canal

A single spreader canal was constructed across the upper portion of the Killarney wetland to divert a portion of the base flows out of the main channel from the upstream side of intervention T51H00A. The spreader canal allowed for a continual supply of water to be available for improving the hydrology within the wetland 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 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 nick points. The photos below show the nick points that are developing as a result of the concentrated flows from the spreader canal entering the secondary channel. Modifications to the spreader canal will be required to prevent further erosion from occurring, as well as to utilise the available water to enhance the hydrology of the wetland.



Figure A1-4: Photos showing the development of nick points where water from the spreader canal enters the secondary channel

A1.1.4 Earthen Diversion Berms

A series of earthen diversion berms were constructed across a 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 solutions for rehabilitating the drains in the low energy environment.

A1.2 Structural Integrity

The assessment of the structural integrity was undertaken based on the criteria described by Cowden and Kotze (2009) and focussed on the long-term stability of the interventions and the likelihood of achieving the stated objectives (**Table A1-1**). In comparison to the original assessments of the integrity of the interventions recorded by Cowden *et al.* (2009), there were issues identified that directly affect the likelihood of the interventions achieving the specified objectives. Specifically, water flows have tunnelled under intervention T51H0026 (**Figure A1-5**) and the intervention is not currently serving to maintain elevated water levels within the upstream portions of the channel.



Figure A1-5: View of intervention T51H0026, looking upstream, with no water flowing over the spillway

Table A1-1. Comments on the vulnerability of the interventions and appropriate corrective action

Intervention	Type	Comments on Structural Integrity	Recommended Corrected Action
T51HA	Concrete Weir	No evidence of risk to the weirs structural integrity was observed. The spreader canal is directing a portion of the base flows to a channel on the right hand side of the wetland and this is resulting in the formation of headcut erosion at the outlet. The base flows are being confined to the spreader canal and are not spilling over into the wetland as was intended.	An earthen berm should be constructed towards the end of the spreader canal (<i>i.e.</i> block the spreader canal) to force flows into the wetland and deactivate the headcut erosion at the outlet
T51HB	Concrete Weir	No evidence of risk to the weirs structural integrity was observed. It was confirmed that the level of the overflow wall has been lowered to account for deviations during implementation, rather than the corrosion of the concrete previously recorded in 2007.	No corrective action required
T51HC	Concrete Weir	No evidence of risk to the weirs structural integrity was observed. The spillway is narrower than the channel however; this may have been an intended design specification to increase the occurrence of overbank topping. 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	No evidence of risk to the weirs structural integrity was observed.	No corrective action required
T51HE	Concrete Weir	No evidence of risk to the weirs structural integrity was observed. It was confirmed that the level of the overflow wall has been lowered to account for deviations during implementation, rather than the corrosion of the concrete previously recorded in 2007.	No corrective action required
T51HF	Concrete Weir	No evidence of risk to the weirs structural integrity was observed. It was confirmed that the level of the overflow wall has been lowered to account for deviations during implementation, rather than the corrosion of the concrete previously recorded in 2007.	No corrective action required
T51H0021	Concrete Weir	No evidence of risk to the weirs structural integrity was observed. 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	No evidence of risk to the weirs structural integrity was observed.	Not applicable.
T51H0023	Concrete Weir	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 as previously recorded in 2007	Not applicable.

Table A1-1 (cont.). Comments on the vulnerability of the interventions and appropriate corrective action

Intervention	Type	Comments on Structural Integrity	Recommended Corrected Action
T51H0024	Concrete Weir	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	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 as previously recorded in 2007.	No corrective action required
T51H0026	Concrete Weir	Tunnelling has occurred to the weir and as a result, flows are passing under the structure and not over the spillway. The structure is not achieving its objective and is at risk of damage if the problem is not rectified.	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.
T51H0027	Concrete Weir	No evidence of risk to the weirs structural integrity was observed. The banks and channel between T51H0026 and T51H0027 appear to be stable (refer to comment from 2007).	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	No evidence of risk to the weirs structural integrity was observed. The key walls are relatively low (<i>i.e.</i> 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	No evidence of risk to the weirs structural integrity was observed.	No corrective action required
T51H0030	Concrete Weir	No evidence of risk to the weirs structural integrity was observed.	No corrective action required
T51H0031	Earthen Berms	The earthen berms were stable and well vegetated. No erosion or damage to the berms was observed	No corrective action required
T51H0032	Concrete Weir	No evidence of risk to the weirs structural integrity was observed.	No corrective action required

Kruisfontein Wetland

A1.3 Wetland Rehabilitation Interventions

Wetland rehabilitation at the Kruisfontein wetland involved the implementation of the following interventions:

- 1 concrete weir in the main channel;
- 1 concrete covered earthen diversion berm to divert a portion of the flows out of the main channel;
- 2 spreader canals; and
- a series of 16 earthen plugs within the furrows of the ridge and furrow drainage network.

The following photos show examples of the rehabilitation interventions utilised at the Kruisfontein wetland:



Figure A1-6: Concrete weir constructed across the main channel



Figure A1-7: A concrete covered earthen berm diverting flows out of the main channel



Figure A1-8: A series of earthen berms (red lines) used to deactivate the ridge and furrow drainage system

The various types of interventions are discussed in detail in the following sections:

A1.3.1 Concrete Weir

The concrete weir was implemented to divert flows from large storm events into the wetland. 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. In terms of the structural stability, 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 stability of the structure.

A1.3.2 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 stability of the structure can be attributed to the concrete covering that was strategically placed in the direct line of the receiving flows and can therefore be considered a successful intervention for wetland rehabilitation.

A1.3.3 Spreader Canals

A series of spreader canals were constructed at the wetland with the intention of diverting a portion of the base flows out of the main channel and into the adjacent wetland. None of the spreader canals were functioning as intended as flows were not being spread in a diffuse manner across the wetland. A single discharge point had developed along the spreader canals and this has resulted in the development of preferred flow paths within the wetland. The water in the preferred flow path from the lower spreader canal discharges into the Mooi River and this has led to the development of a headcut (refer to figure A1-9 below). An intervention will be required at the headcut to prevent the erosion from advancing into the wetland system.



Figure A1-9: Headcut erosion as a result of concentrated flows discharging over the bank of the Mooi River

A1.3.4 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. A preferred path has developed along the furrows and this has resulted in a hydrological response to a limited portion of the wetland. Further intervention to the ridge and furrow drainage network will be required if it is to be successfully deactivated.

A1.4 Structural Integrity

The assessment of the structural integrity was undertaken based on the criteria described by Cowden and Kotze (2009) and focussed on the long-term stability of the interventions and the likelihood of achieving the stated objectives. An assessment of the structural integrity of the wetland rehabilitation interventions had not previously been undertaken for this the site but was included based on the observations at Ntsikeni and perceived landowner dissatisfaction with the outcomes to-date.

A1.4.1 Intervention V20E017 (Concrete Weir)

The intervention consists of a mass gravity drop-inlet concrete weir (**Figure A1-10**). The intervention was inspected and numerous discrepancies were identified between the design dimensions and the as-built dimensions. The major discrepancies in the dimensions are as follows:

Item	Design Dimension (m)	As Built Dimension (m)
Spillway Width	7	10
Spillway Height	2	1.58
Depth of base flow notch	0.05	0.23
Top thickness of spillway	0.5	0.4
Height of shoulders	1	1.61
Height difference between top of apron slab and outside edge of geocells (left)	1.6	1.82
Length of right wingwall	Not specified	9.5



Figure A1-10: Concrete mass gravity weir – Intervention V20E017

In terms of the implementation of the design, the right hand wingwall is located approximately midway along the shoulder and not at the end of the shoulder as was specified in the design. Two buttresses along the wingwall (which were not specified in the design) were also implemented during the construction phase (**Figure A1-11**).



Figure A1-11: Showing location of right hand wing wall in relation to the specified location

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 (Figure A1-12):



Figure A1-12: Poor workmanship with exposed steel reinforcing and poor contact between the buttress and the right hand wing wall (Left) and poor quality concrete and exposed reinforcing steel in the left hand wing wall (Right).

A1.4.2 Intervention V20E018 (Concrete Buttress Weir)

This intervention was not implemented as part of the wetland rehabilitation project. It is unclear if it was deemed unnecessary or if the availability of funds during the 2005/2006 project cycle was a limiting factor.

A1.4.3 Diversion Berm

The diversion structure consists of an earthen diversion berm with a concrete geocell covering on the portion that is located within the receiving flows from the channel (**Figure A1-13**). The dimensions of the berm are as follows:

Item	Dimension (m)
Crest Length (geocell portion)	13
Crest Length (Earthen portion)	36
Base Width	5.7
Crest Width of geocell portion	Varies from 1.1m to 2.2m
Crest Width of earthen portion	Approximately 1m
Height	0.95
Length of earthen portion	36



Figure A1-13: Concrete geocell-covered diversion berm

The diversion berm is structurally stable and there is 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 actions are therefore proposed for the berm in terms of securing its structural integrity.

A1.4.4. Spreader Canals

Two spreader canals were identified onsite, one just downstream of the concrete weir (Intervention V20E017) and one just upstream of the geocell covered diversion berm. The upstream spreader canal (receiving flows from the concrete weir) 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 (in terms of securing its structural integrity) are therefore proposed for the spreader canal. The downstream spreader canal, receiving flows from the geocell-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 re-instated in order to allow for the spreading water across a wider portion of the wetland.

A1.4.5. Earthen Plugs

A total of 16 earthen plugs were identified on site (**Figure A1-14**). Measurements of the plugs were carried out during the site visit, the details of which are shown in the table below:

Plug Number	Average Crest Width (m)	Crest Length (m)	Average Height (m)	Average Base Width (m)	Volume (m ³)
1	1.0	14.0	0.85	3.0	29.7
2	1.2	13.0	0.75	5.0	42.6
3	1.2	14.5	0.80	4.0	39.8
4	1.0	14.5	0.90	4.0	38.5
5	1.0	13.5	0.75	4.0	35.6
6	1.0	13.5	0.70	4.0	35.5
7	1.0	14.0	0.80	4.0	37.0
8	1.0	13.0	0.95	4.0	34.9
9	1.0	14.0	0.90	4.0	37.3
10	1.0	14.0	0.75	4.0	36.9
11	1.0	12.0	0.95	4.0	32.4
12	1.0	13.0	0.75	4.0	34.4
13	1.0	14.0	0.75	3.5	33.2
14	1.0	13.0	0.85	4.0	34.6
15	1.2	14.0	0.95	5.0	46.3
16	1.0	14.0	0.80	4.0	37.0
Total Volume					585.6



Figure A1-14: A typical earthen plug within the Kruisfontein wetland

It should be noted that at the time of the site inspection (February 2012), all of the earthen plugs apart from Plug 15 and Plug 16, 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.

Appendix 2. Plant species list, with indicator status and weedy/ruderal characteristics

<i>Species</i>	<i>Indicator status</i>	<i>Coefficient of Conservatism</i> ¹³
<i>Acalypha punctata</i>	facultative negative	10
<i>Agrostis eriantha</i> var. <i>eriantha</i>	facultative positive	10
<i>Agrostis lachnantha</i>	facultative positive	5
<i>Alternanthera pungens</i>	facultative negative	0
<i>Alternanthera sessilis</i>	facultative positive	5
<i>Andropogon appendiculatus</i>	facultative positive	10
<i>Aristida junciformis</i>	facultative	10
<i>Arundinella nepalensis</i>	facultative positive	10
<i>Asclepis capensis</i>	obligate	10
<i>Atriplex</i> cf. <i>prostrata</i>	facultative negative	1
<i>Bidens bipinata</i>	non wetland	0
<i>Bidens pilosa</i>	non wetland	0
<i>Bromus catharticus</i> (<i>uniloides</i>)	facultative negative	0
<i>Bulbostylis schoenoides</i>	obligate	10
<i>Carex acutiformis</i>	obligate	10
<i>Carex austro-africanus</i>	obligate	10
<i>Carex cognata</i>	obligate	10
<i>Cirsium vulgare</i>	facultative	0
<i>Cliffortia linearifolia</i>	facultative negative	10
<i>Cliffortia paucistaminea</i>	non wetland	10
<i>Commelina africana</i>	facultative positive	10
<i>Conyza</i> cf. <i>albida</i>	facultative positive	1
<i>Conyza pinnata</i>	facultative positive	1
<i>Conyza</i> sp.	facultative positive	1
<i>Conyza weed</i>	facultative positive	1
<i>Cotula negelifolia</i> (<i>Matricaria</i>)	facultative negative	1
<i>Cyclosporum</i> sp.	facultative positive	0
<i>Cynodon dactylon</i>	facultative negative	1
<i>Cyperus congestus</i> (<i>Mariscus</i>)	facultative positive	5
<i>Cyperus denudatus</i>	obligate	10
<i>Cyperus esculentus</i>	facultative	1
<i>Cyperus rotundus</i>	facultative	1
<i>Cyperus</i> sp.	obligate	10
<i>Daucus carota</i>	non wetland	0
<i>Digitaria eriantha</i>	facultative negative	10

¹³ Alien invasive plants (0); Ruderal or weedy plants (1); Occasionally ruderal or weedy plants (5); and Plant species intolerant of disturbance (10)

<i>Species</i>	<i>Indicator status</i>	<i>Coefficient of Conservatism</i> ¹³
<i>Digitaria setifolia</i>	facultative negative	10
<i>Echinochloa crus-galli</i>	obligate	5
<i>Eleocharis dregeana</i>	obligate	10
<i>Eleocharis limosa</i>	obligate	10
<i>Epilobium capense</i>	obligate	10
<i>Eragrostis capensis</i>	facultative negative	10
<i>Eragrostis curvula</i>	facultative negative	5
<i>Eragrostis plana</i>	facultative	5
<i>Eragrostis planiculmis</i>	obligate	5
<i>Eragrostis racemosa</i>	facultative negative	10
<i>Festuca caprina</i>	facultative positive	10
<i>Fingerhuthia sesleriiformis</i>	obligate	10
<i>Fragaria vesca</i>	facultative	0
<i>Fuirena pubescens</i>	obligate	10
<i>Gladiolus sp</i>	facultative	10
<i>Gunnera perpensa</i>	obligate	10
<i>Harporchloa falx</i>	facultative negative	10
<i>Helichrysum aureo-nitens</i>	facultative positive	10
<i>Helichrysum mundtii</i>	obligate	10
<i>Helichrysum pilosellum</i>	facultative negative	10
<i>Helichrysum sp (spear leaf)</i>	facultative negative	10
<i>Helichrysum sp.</i>	facultative negative	10
<i>Helicotrichon turdigulam</i>	facultative positive	10
<i>Hibiscus trionum</i>	facultative	1
<i>Hirpicium ameroides</i>	non wetland	10
<i>Hyparrhenia dregeana</i>	facultative negative	5
<i>Hypochaeris radicata</i>	non wetland	0
<i>Hypoxis rigidula var. rigidula</i>	facultative negative	10
<i>Hypoxis sp</i>	facultative negative	10
<i>Hypoxis sp – lanceolate</i>	facultative negative	10
<i>Isolepis costata var. macra</i>	obligate	10
<i>Isolepis fluitans</i>	obligate	10
<i>Isolepis sp (prolifera)</i>	obligate	10
<i>Juncus effusus</i>	obligate	5
<i>Juncus oxycarpus</i>	obligate	10
<i>Juncus punctorius</i>	obligate	10
<i>Kniphofia linearifolia</i>	facultative positive	10
<i>Lagarosiphon sp.</i>	obligate	10
<i>Ledebouria cooperi</i>	facultative positive	10
<i>Leersia hexandra</i>	obligate	5

<i>Species</i>	<i>Indicator status</i>	<i>Coefficient of Conservatism</i> ¹³
<i>Lepidium bonariense</i>	non wetland	0
<i>Lessertia sp.</i>	facultative negative	1
<i>Leucosidea sericea</i>	facultative negative	10
<i>Lobelia decipiens</i>	facultative positive	10
<i>Lolium multiflorum</i>	facultative negative	0
<i>Loudetia densispica</i>	non wetland	10
<i>Ludwigia plastrus</i>	facultative	10
<i>Mariscus sp.</i>	facultative	5
<i>Mentha aquatica</i>	obligate	10
<i>Microchloa caffra</i>	non wetland	10
<i>Modiola caroliniana</i>	non wetland	0
<i>Monocymbium cerasiiforme</i>	non wetland	10
<i>Monopsis decipiens</i>	facultative positive	10
<i>Nasturtium officinale</i>	obligate	0
<i>Oenothera rosea</i>	facultative negative	0
<i>Oenothera saligna</i>	facultative	0
<i>Oxalis smithiana</i>	facultative negative	10
<i>Oxalis sp (latifolia)</i>	facultative negative	0
<i>Oxalis sp (semiloba)</i>	facultative negative	10
<i>Paspalum dilitatum</i>	facultative positive	0
<i>Paspalum distichum</i>	obligate	5
<i>Paspalum urvillei</i>	facultative positive	0
<i>Pennisetum macrourum</i>	obligate	10
<i>Pennisetum sphacelatum</i>	obligate	10
<i>Pennisetum thunbergii</i>	facultative positive	10
<i>Persicaria cf. altenuatum</i>	obligate	10
<i>Persicaria hydropiper</i>	obligate	0
<i>Persicaria salicifolium</i>	obligate	10
<i>Persicaria serrulata</i>	obligate	10
<i>Phalaris arundinacea</i>	obligate	0
<i>Philarus codinacea</i>	obligate	0
<i>Phragmites australis</i>	obligate	10
<i>Physalis angulata</i>	non wetland	0
<i>Plantago lanceolata</i>	facultative negative	0
<i>Plantago major</i>	facultative	0
<i>Polygonum aviculare</i>	obligate	10
<i>Psammotropha mucronata subsp. mucronata</i>	non wetland	10
<i>Pycreus macranthus</i>	obligate	10
<i>Pycreus mundii</i>	obligate	10
<i>Pycreus nitens</i>	obligate	10

<i>Species</i>	<i>Indicator status</i>	<i>Coefficient of Conservatism</i> ¹³
<i>Pycnus sp 1</i>	obligate	10
<i>Pycnus sp.</i>	obligate	10
<i>Pycnus unioloides</i>	obligate	10
<i>Ranunculus multifidus</i>	facultative positive	10
<i>Rorippa cf. sylvistis</i>	facultative	10
<i>Rubus cuneifolius</i>	facultative negative	0
<i>Rumex acetosella subsp. Angiocarpus</i>	facultative positive	1
<i>Rumex crispus</i>	facultative negative	0
<i>Rumex sp</i>	facultative	1
<i>Sacciolepis indica</i>	non wetland	10
<i>Salvia repens</i>	facultative negative	10
<i>Schkuhria pinnata</i>	non wetland	0
<i>Schoenoplectus corymbosus</i>	obligate	10
<i>Schoenoplectus paludicola</i>	obligate	10
<i>Scleria sp.</i>	obligate	10
<i>Scleria sp.</i>	obligate	10
<i>Scleria welwitschii</i>	obligate	10
<i>Scutellaria sp</i>	facultative positive	5
<i>Senecio inaequidens</i>	non wetland	1
<i>Senecio inornatus</i>	facultative	1
<i>Senecio isatideus</i>	facultative negative	10
<i>Senecio sp. (shiny leaf)</i>	facultative negative	10
<i>Senecio sp. 1</i>	facultative negative	10
<i>Setaria pallide-fusca</i>	facultative negative	1
<i>Sium repandrum</i>	obligate	10
<i>Soncus sp.</i>	facultative	0
<i>Sporobolus africanus</i>	facultative	5
<i>Sporobolus africanus</i>	facultative	5
<i>Stachys sp</i>	facultative negative	10
<i>Tagetes minuta</i>	facultative negative	0
<i>Themeda triandra</i>	non wetland	10
<i>Trifolium repens</i>	facultative	5
<i>Tristachya leucothrix</i>	facultative	10
<i>Tulbaghia leucantha</i>	facultative negative	10
<i>Typha capensis</i>	obligate	5
<i>Verbena bonariensis</i>	facultative negative	0
<i>Veronica anagalis-aquatica</i>	obligate	0

Appendix 3: A brief review of the required information for the valuation of wetland rehabilitation based on resource economics.

(Compiled by Michelle Brown¹⁴)

As is evident from the project, wetlands provide or have the potential to provide numerous ecosystem goods and services. Economic values are linked to these good and services, however, determining the value of natural capital and/or its rehabilitation is a challenging process. Rees *et al.* (2007) state that there is a lack of understanding of all the benefits that restoration provides, and many of these benefits are public goods with limited or no market value. Furthermore, the economic value of a particular ecosystem will depend on the value of the services it supplies as perceived by society *i.e.* the users (Turner *et al.*, 2000) and may differ between different types of users.

In South Africa, several projects have been undertaken to determine the economic value of various wetland systems or specific wetland services, including studies by:

- van Zyl *et al.* (2004) who estimated the costs and benefits of urban river and wetland rehabilitation projects in Cape Town; and
- Pollard *et al.* (2009) who considered the valuation of the livelihood benefits of structural rehabilitation interventions in the Manalana Wetland.

As part of the resource economics component of the Wetlands Health and Importance research programme (South Africa) several local case studies were reviewed (Turpie, 2010) including:

- A comparative study of the value of provisioning services of a rural wetland in Lesotho and a peri-urban wetland in Cape Town;
- Valuation of the water treatment function of wetlands: a comprehensive region-scale study of Western Cape wetlands; and
- The tourism value of Nylsvley floodplain.

The Wetlands Health and Importance research programme, also included the development of a protocol for the quantification and valuation of wetland ecosystem services (Turpie and Kleynhans, 2010). This protocol describes several steps to the process of valuation and provides a comprehensive discussion of:

- Determining the level of detail required for a valuation study (scope, extent of the valuation, accuracy required); and
- Selecting the valuation methods (estimation of direct use values only, at various levels of comprehensiveness).

A common theme of these studies is the challenge of estimating the total economic value of natural resources and the services they supply, and the focus rather, on quantifying or valuing only specific services. One reason for this is the lack of suitable indicators for measuring the delivery of goods and services provided by ecosystems (Balmford *et al.*, 2005; UNEP, 2009). Additionally, where such indicators are available, reliable data for their measurement is often not. Furthermore, in order to make

¹⁴ GroundTruth. PO Box 2005, Hilton, 3245. Email: michelle@groundtruth.co.za

value estimates of natural resources and the rehabilitation thereof, reliable data must be available for indicators of service supply.

In order to estimate the value of wetland rehabilitation, changes in service supply would need to be identified; the magnitude of the changes measured/quantified; and the value of the changes to society estimated. The economic value of wetland rehabilitation will depend on the value (to society) of the change in wetland service supply as a result of rehabilitation interventions. Both the change in service supply and the value of the change to society must be quantified in order to gain an economic understanding of the benefits of rehabilitation efforts. An assessment of the demand for wetland ecosystem services is required, as well as an assessment of the supply of ecosystem service and changes in this supply. An assessment of the value of the wetland rehabilitation at Kruisfontein and Killarney was not within the original scope of this project, but has been investigated to potentially inform future research in this field.

In terms of valuing the Kruisfontein and Killarney wetland rehabilitation, data availability is severely limited, particularly pre-rehabilitation. A WET-EcoServices assessment was performed pre- and post-rehabilitation for each of the wetlands, the results of which can be used to identify the probable service supply changes as a result of rehabilitation interventions (Kotze *et al.*, 2009). However, specific aspects such as water quality and flow were not measured pre- and post-rehabilitation.

The WET-EcoServices assessment undertaken for the Kruisfontein and Killarney wetland highlighted a significant change in the *effectiveness* for ten and five services (of the 15 assessed) respectively, as listed below:

Kruisfontein

- Flood attenuation
- Stream flow regulation
- Sediment trapping
- Phosphate trapping
- Nitrate removal
- Toxicant removal
- Erosion control
- Carbon storage
- Biodiversity maintenance
- Education and research

Killarney

- Stream flow regulation
- Carbon storage
- Biodiversity maintenance
- Tourism and recreation
- Education and research

Turpie and Kleynhans (2010) provide a detailed discussion on estimating the value of flow regulation and flood attenuation services making use of hydrological modelling to determine changes in service supply and replacement cost and damages avoided methods to derive the value of the change to society. Additionally, Turpie and Kleynhans (2010) provide direction in estimating the value of water quality amelioration services such as sediment, nutrient and toxicant trapping and erosion control using replacement costs and damage costs avoided approaches. Water quality monitoring is essential to

estimating the value of water quality amelioration services. Estimating the tourism and recreation value of wetlands is discussed by Turpie and Kleynhans (2010); approaches include using visitor statistics, tourism business interviews, enterprise models, travel cost methods, conjoint valuation and household surveys.

In order to value the benefits of the rehabilitation interventions for the Kruisfontein and Killarney wetlands, value estimates for the changes in the above ecosystem services would need to be made (depending on the demand for these services). However, based on Turpie and Kleynhans (2010), it is evident that the changes in service supply must be quantified at a level of detail greater than that recorded using the WET-EcoServices assessment framework to estimate the value of these changes. If the economic valuation of wetland rehabilitation is a desired outcome of a particular rehabilitation project, it is imperative that relevant and reliable data be collected before, during and after rehabilitation. The quantification of service supply changes was not an original objective of the initial research that formed the basis for this study, and as such there is little data available to accurately quantify the value of the service supply changes observed.