Setting realistic restoration goals:

A guide for wetland restoration practitioners in South Africa

Damian Walters and Nancy Job

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in South Africa

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Authors: Damian Walters and Nancy Job
Editor: Emily Botts
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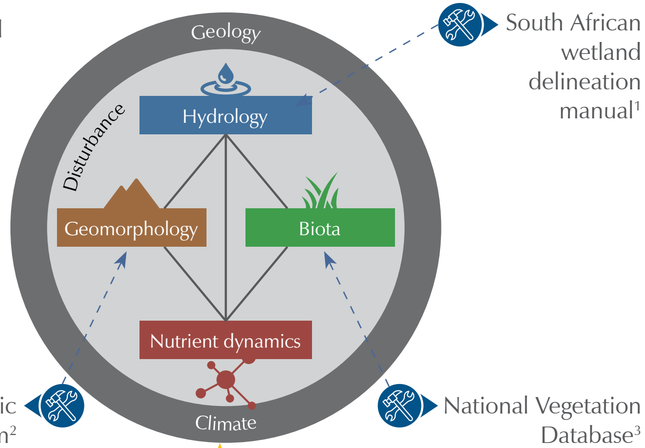
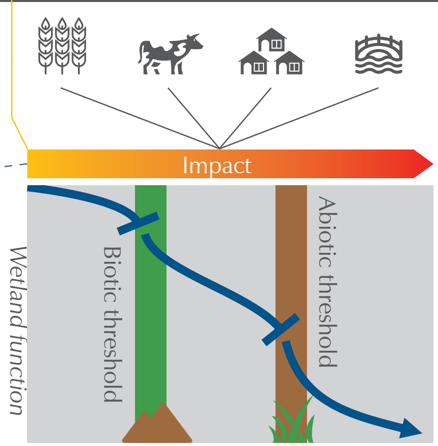
Understand how the wetland should function in natural condition, looking at the main wetland drivers:



2. Diagnose damage to the wetland

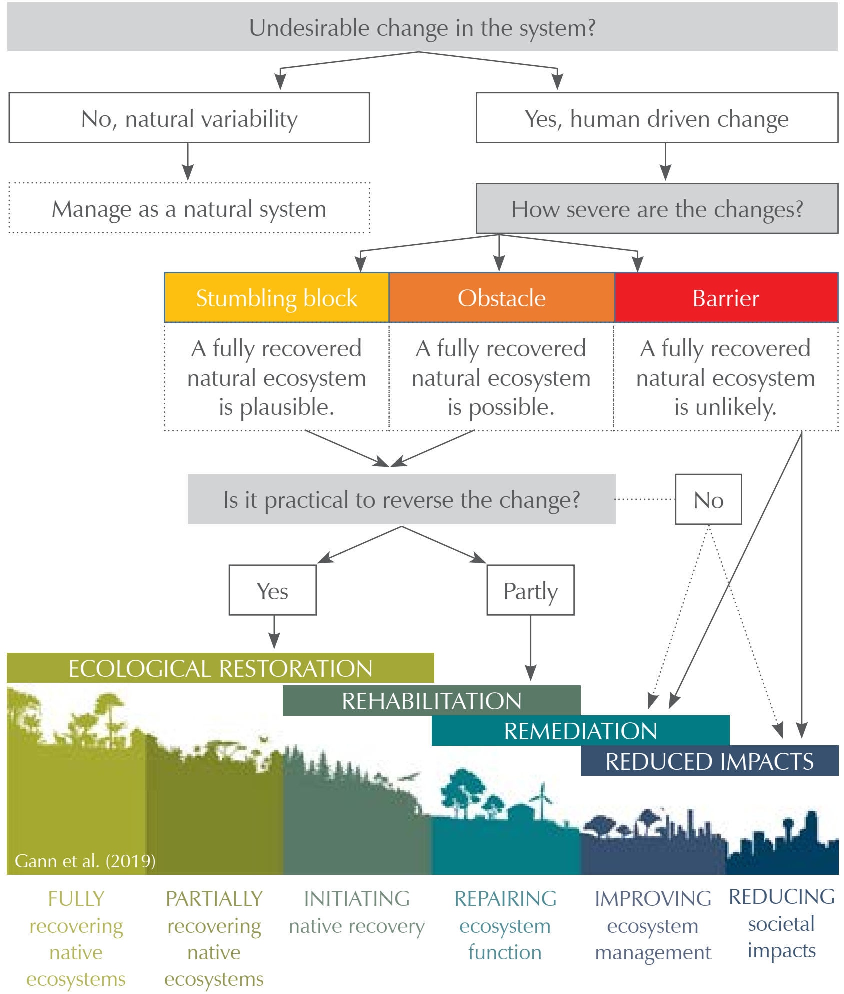
Assess how human activities have impacted the wetland, looking at how severely land-use changes have impacted natural functioning:



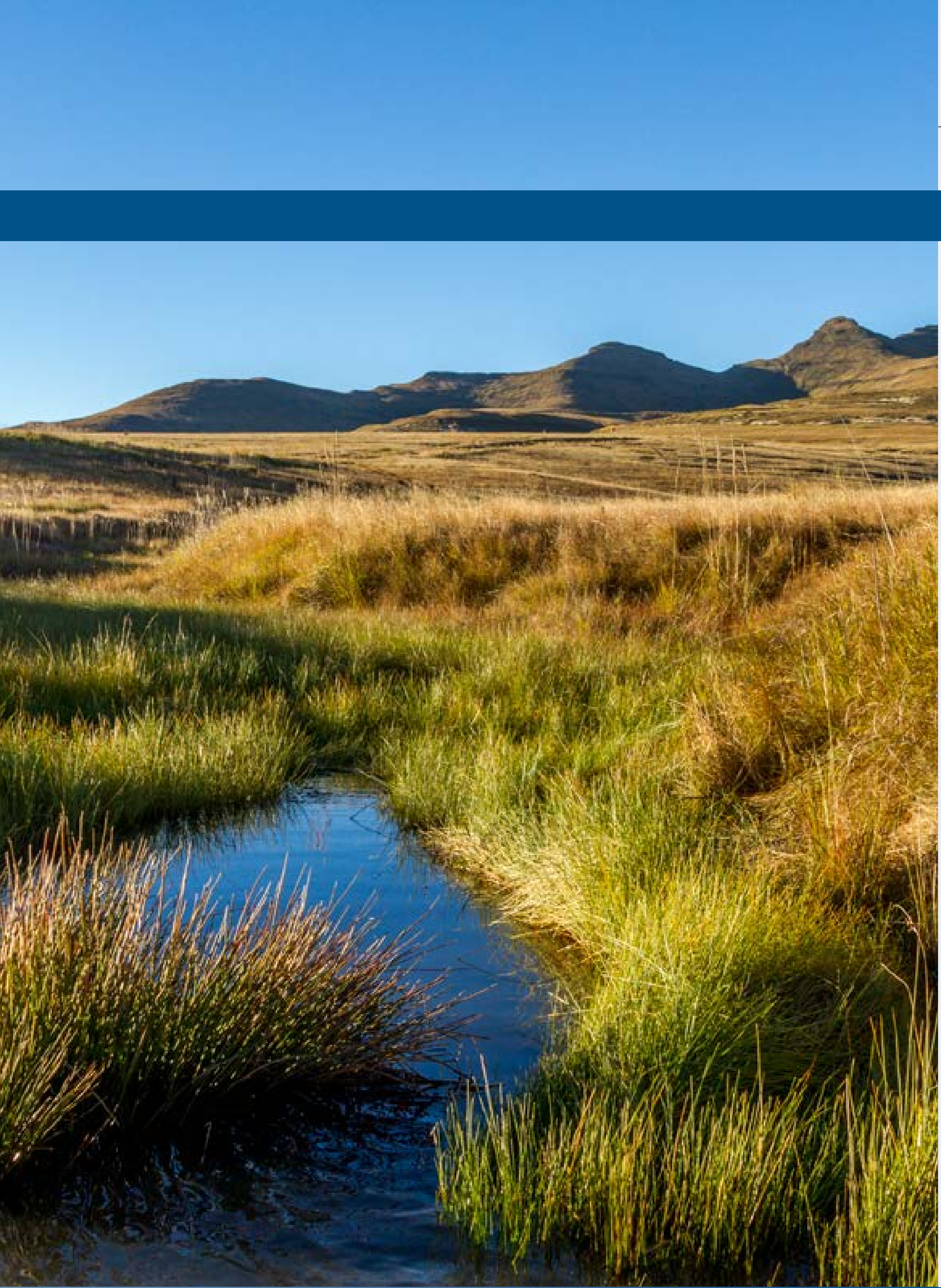
Consider whether the degree of impact has crossed biotic or abiotic thresholds:

3. Identify impediments to set realistic restoration goals

Apply the understanding of wetland functioning and impacts to identify what impediments there are to restoring the wetland and set realistic goals accordingly:



[1] DWAF (2005)
[2] Grenfell et al. (2019)
[3] Sieben et al. (2014)
[4] MacFarlane et al. (2020)



Introduction

Wetland restoration in South Africa

Wetlands are important features within the South African landscape due to their ability to provide many ecosystem services, particularly those related to water quantity and quality[39]. In South Africa only 15% of wetlands are in a near-natural ecological condition, while 67% are heavily to critically modified[67]. The Working for Wetlands programme, in partnership with the Expanded Public Works Programme, was initiated in 2004 to address impacts on wetland ecosystems and the subsequent loss of ecosystem services. Since 2004, over R800 million has been spent to rehabilitate more than 1 000 wetlands through the programme[78]. Much work to restore wetlands across the country has also taken place with private funds, often as a condition of environmental authorisations.

A key challenge of any wetland restoration project or programme is ensuring that efforts are as effective as possible. Effective restoration is strongly influenced by the ability to (1) diagnose ecosystem damage, and then (2) set realistic restoration goals[31].

What is restoration?

Ecological restoration is an increasingly important tool to mitigate human impacts on the world's ecosystems[21,31,30]. Ecological restoration is defined as "the process of assisting the recovery of an ecosystem that has been damaged, degraded or destroyed, towards an appropriate reference state"[21].

Ideally, the goal of restoration is substantial recovery relative to an appropriate reference state for a given ecosystem, with the important caveat that full recovery may not always be viable, especially where human activities have substantially altered natural processes[21]. Where full ecosystem recovery is not viable, the objective should be the highest level of recovery possible. Consequently, it is important to determine the restorative potential of a site.

Ecosystems exist in several different states, from natural through to degraded (**Figure 1**). States of degradation vary in their potential for repair, with some being easily restored and others requiring considerable effort to improve their state[38]. The more degraded an ecosystem is, and the more its ecosystem processes have been modified, the more difficult and expensive the restoration will be[31]. In diagnosing the ecosystem damage it is necessary to establish the current state of the system and the underlying factors that have led to that state.

Ecological restoration, therefore, is located along a restorative continuum that extends from simply reducing impacts in the most modified environments, through remediation, rehabilitation and finally to ecological restoration that aims to fully recover native ecosystems (**Figure 1**). The majority of wetland restoration activity in South Africa is focussed within the area of rehabilitation and ecological restoration on the restorative continuum.

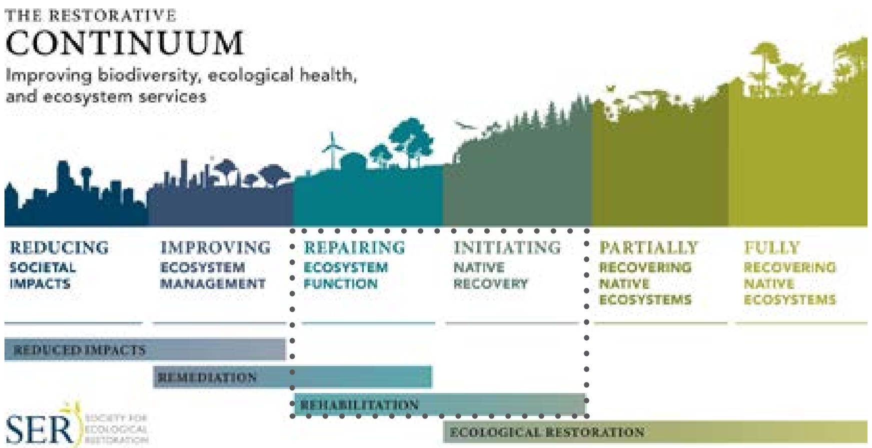


Figure 1. The majority of wetland restoration projects in South Africa are contained within the "rehabilitation" range of the restorative continuum (Gann et al. 2019)[21].

Purpose of this document

Some of the most common issues that undermine effective wetland restoration are a weak conceptual understanding of how the wetland ecosystem functions, as well as a failure to consider possible impediments that may influence restoration success.

When assessing a wetland ecosystem to plan for restoration, it is useful to clearly identify any impediments to the proposed restoration. Understanding the impediments will help to know what is required to restore the ecosystem and what the most appropriate restorative level may be. If a system has too many impediments, it may be prohibitively expensive or difficult to restore the ecosystem, and a less degraded system may be a better candidate.

The purpose of this document is to provide a framework to help restoration planners identify impediments to restoring wetlands. The framework is intended to compliment WET-Health (version 2.0)[45], with emphasis on assessing restoration potential. In the sections that follow, we provide an overview of the steps in the framework from (1) understanding the wetland and its natural functioning, (2) diagnosing damage to the wetland ecosystem and (3) identifying types of impediments and what they mean for restoration. We then provide a worked example to demonstrate how to apply the framework.

While the focus of this framework is on alluvial wetlands (wetlands structured by fluvial processes such as floodplains, valley-bottom, fans, blocked valleys and plains[25]) the approach is broadly applicable to other wetland types found in South Africa.

A framework for identifying impediments to wetland restoration

There are three main steps that a restoration planner must take to set realistic restoration objectives[31]:

Step 1. Understand the natural dynamics of the ecosystem before it was degraded.
Step 2. Diagnose damage to the wetland.
Step 3. Identify impediments to restoration and assess restoration potential.

This three-step framework (**Figure 2**) provides guidance for constructing a conceptual model of wetland dynamics, investigating the presence of impediments to restoration and finally setting realistic restoration objectives. The goal setting process should consider the damage diagnoses, and the possible restorative interventions that are available within the context of ongoing environmental change.

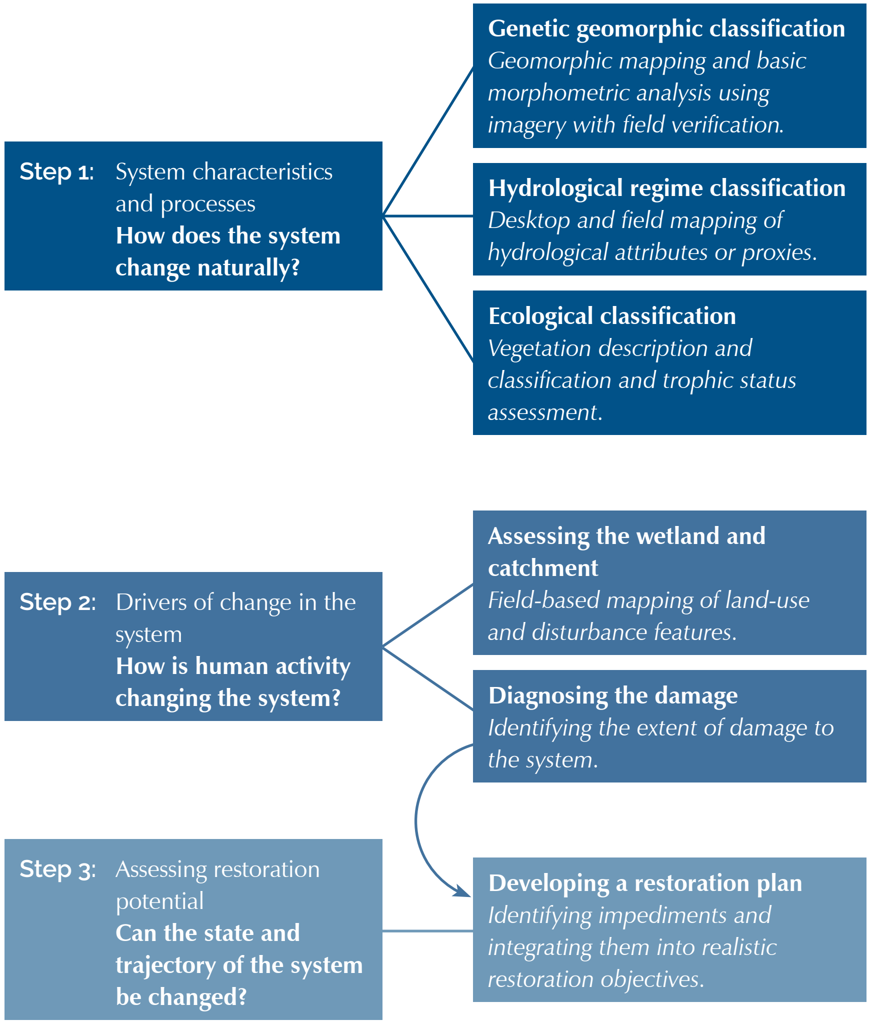


Figure 2. Framework for setting realistic wetland restoration goals.

Step 1: Describe wetland characteristics and processes

The purpose of this step is to build an understanding of the natural functioning of the wetland from a geomorphological, hydrological and ecological perspective. It is important to understand the natural variability of the system, so that it can be differentiated from human-induced degradation[5]. The following section presents these as concisely as possible. However, it is left to the practitioner to pursue each topic more fully through the references provided throughout this guide.

Drivers of wetland functionality

Conceptually, the drivers of wetland ecology can be viewed as four interacting components: hydrology, geomorphology, vegetation and nutrient dynamics (**Figure 3**).

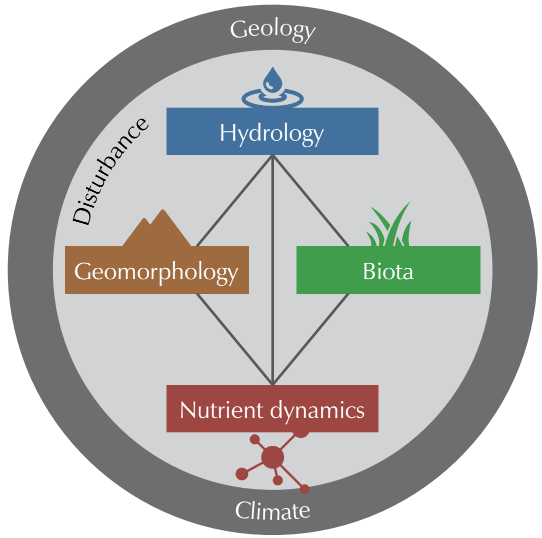


Figure 3. Interrelationships between the hydrological, geomorphological and vegetation components of wetland ecosystems (adapted from Macfarlane et al. 2009)[45].

Hydrology: Wetland ecosystems are ultimately formed by hydrological factors, specifically anoxia of the soil caused by flooding[48,37]. The period of soil saturation and the presence of inundation, its depth and duration are important in shaping wetland plant communities[36,48]. Due to the pre-eminent effect of hydrology, changes to hydrology are likely to interact with the other drivers. Changes to wetland internal hydrology are inextricably linked to changes in hydrology of the wetland catchment. Climate, geology and geomorphology interact to create an environment for prolonged, shallow saturation that allows for the establishment of plants that are characteristic of wetland ecosystems[16,46].

Geomorphology: The physical template of the wetland, provided by geology and climate, is external to the system, which means that it is not affected by feedback mechanisms that occur within the system. However, other drivers have internal interactions. Within the wetland, geomorphology and hydrology interact with each other through sediment that is carried by water moving through the wetland. The flow of water is controlled by the within-wetland relief, which is created by processes of deposition and erosion. Wetlands exist around an equilibrium between this process of sediment supply and discharge[16,26]. A change in either sediment or water supply can result in slope re-adjustment through erosion or deposition. Geomorphic processes such as erosion and deposition can in turn shape hydrology and vegetation communities. The vegetation has an important connection with geomorphology by assisting deposition of sediment[9,29,64].

Fertility: Nutrient dynamics are strongly influenced by wetland hydrology and geomorphology[62]. The fertility of a wetland, specifically the availability of nitrogen and phosphorous, influences the composition and structure of the vegetation[1,52]. An increase in nitrogen and phosphorous can result in shifts to vegetation composition and structure[1,52]. This is of particular concern in wetlands on nutrient poor substrates. These substrates in South Africa are those derived from coastal sands, quartzite (sandstones) and peat systems[57].

Disturbance: Grazing[20] and fire[40,44] are two important disturbances that play a role in shaping vegetation communities. Within South Africa, much

of wetland habitat is in fire prone ecosystems, where the occurrence or persistence of trees is limited by fire[4]. Fire exclusion can lead to a shift in vegetation from herbaceous to woody. Through selective biomass removal, grazing can influence grass dominated vegetation[6]. Long-term grazing, particularly selective grazing, favours species more tolerant of grazing[60,51]. South African wetlands are dominated by grasses (Poaceae)[58]. Drier grass dominated wetlands recover less well from cultivation compared to wetter sedge and grass dominated wetlands[56,74]. Hydrology, fertility and natural disturbances affect competition and thus successional processes by favouring some species over others[43,11]. Disturbance may act as a counter force to competition. Fire that limits succession towards forest establishment is a good example[3].

Competition: Competition can be affected by changes in the potential species pool whereby a newly introduced plant (alien) becomes invasive if it has higher intrinsic growth rates than the native species[72]. Invasive plants can change the character, condition, form or function of an ecosystem[54]. The invasion may be facilitated by disturbance or changes to environmental conditions such as soil fertility.

Significant changes to any of the four components or to the natural disturbance regime can lead to a change in the character of a wetland and thus to its functioning and the ecosystem services it provides.

Constructing a conceptual model

A wetland with similar landscape position, geology, climate and vegetation type to the wetland that is to be restored, but that has fewer or no impacts, can serve as a space-for-time substitution or reference wetland. Considering the reference wetland, a conceptual model should be built using a simple constructivist approach, by describing the wetland's geomorphology, hydrological regime and vegetation as it would have occurred under natural reference conditions. A weak conceptual understanding of the restoration wetland is arguably one of the most common reasons for an ineffective restoration outcome.

Geomorphic classification: As geomorphic processes and landforms are critical in forming wetland ecosystems, it is important to consider the geomorphology of the system[49,5]. The **genetic geomorphic classification system** developed for South African wetlands[25] can be used to classify the wetland and develop an understanding of the dynamic processes of sediment transport through the wetland. The classification system divides alluvial wetlands into five types: floodplain, alluvial valley-bottom, alluvial blocked valley-bottom, alluvial plain and alluvial fan. Each of these types is described in terms of its landscape position, its shape and geomorphic features. Using a combination of these, it is possible to classify the basic character of the wetland using imagery (aerial or satellite photography) or maps (orthophoto or topographic maps) with field verification. Because the classification is physically based and determined by processes of sediment deposition and erosion, it provides a description of the origin and evolution of the wetland from a geomorphological perspective.

Hydrological regime classification: Hydrology is the most important factor in wetland ecosystem formation. Hydrology includes the degree of soil anoxia, the period of soil saturation, and the presence, depth and duration of inundation. All of these are important in shaping wetland plant communities[36,48]. Describing the hydrological regime of the wetland is a field-based activity. While inundation (i.e. above ground flooding) may be a seasonal or temporary phenomenon in a wetland, prevailing soil saturation (i.e. below ground water table) can be inferred from soil features[41,70]. The **South African wetland delineation manual**[15] describes soil parameters to assign soils to permanent, seasonal and temporary waterlogged soils or zones. The manual uses vegetation as a proxy along with soils, for the purposes of zonation. A list of obligate and facultative wetland plant species is provided.

Ecological classification: The description and classification of wetland vegetation is a field-based activity. The wetland vegetation can be classified using the **National Wetland Vegetation Database**[58] which provides descriptions of vegetation communities at a national scale and indicator species for those communities. Invasive alien plant species should be identified and the distribution within the wetland (or potential to invade the wetland and catchment) must be mapped. The trophic (fertility) status of the wetland must be established. The trophic status of a waterbody is determined by nutrient concentration and productivity[22]. The simplest way to achieve a historic view is by using the dominant geology in the catchment[13]. Oligotrophic systems (with lower nutrient status) are usually found within geologies such as sandstone, granite and coastal sands. Systems derived from sedimentary, igneous and metamorphic geologies have higher nutrients. However, the degree of weathering of the catchment soils and climate also play an important role.

Step 2: Diagnose damage to the wetland

The next step of the framework is to assess the type and extent of human-induced change in the wetland and its catchment. The candidate wetland should be assessed for abiotic and biotic changes compared to the reference system. In writing and presenting a diagnosis, the investigator should structure the report in a way that presents the findings with supporting evidence, ensuring the conclusion flows logically from the evidence presented. This allows for a diagnosis to be presented in a transparent way.

Assessing land-use in the wetland and catchment

The purpose of this step is to describe and map any human-related activities within the wetland and its catchment. Catchment processes such as sediment, water and nutrient delivery are critical to wetland formation[50], so changes to the catchment can also be important to determine restorative potential. This is a predominantly field-based activity, but can be augmented by desktop mapping using imagery (aerial or satellite photography) or maps (orthophoto or topographic maps). Land cover such as alien plant infestations should also be mapped, as these can have an impact on the wetland. The description must be detailed enough for the investigator to make inferences about the potential impacts the identified activities have on the wetland. Where possible, the historic patterns of human impacts on the wetland should be considered by using historical records such as old aerial or satellite imagery, maps, photographs and written or oral narratives, to create a record of impacts on the wetland over time. The importance of understanding historic impacts on the wetland cannot be overstated, as the legacy effects of an activity such as cultivation can persist long after the activity itself has ceased[76].

Diagnosing damage to wetland drivers

There are a limited number of drivers that determine how wetlands assemble[37] (see *Drivers of wetland functionality*). It is important to assess changes to these drivers to evaluate the restorative potential of wetlands. In most circumstances, a number of factors would have been altered through human activity. The more developed a catchment is, the more likely it is that changes to drivers have occurred. It is necessary to consider how significant the change is – how much damage has been done to the structure and functioning of the wetland ecosystem.

An important part of this framework is separating natural change or variability from change that can be attributed to human activity. Attributing change to human or natural causes is challenging in dynamic systems. **Table 1** provides some possible direct and indirect indicators that can be used in the diagnosis.

In South Africa the predominant wetland assessment method is **WET-Health** (Version 2.0)[45]. The method assesses the ecological condition of freshwater wetlands based on deviation from a benchmark for a particular wetland type[53]. It uses a hydrogeomorphic classification system as the basis and relies on the occurrence of stressors (impacts) and response indicators to formulate an impact score. The method is invaluable for identifying impacts on wetlands and can be usefully used in restoration planning. However, it does not explicitly consider the reversibility of the impacts that have been identified or provide guidance for restoration planning. **Table 1** offers references to six additional supporting methods, and explanatory prompts on abiotic and biotic drivers, to deepen practitioner understanding of wetland ecology and to complement WET-Health. This will support a holistic assessment of impacts to the drivers of natural wetland ecosystem functioning and an effective restoration outcome.

Table 1. Changes to drivers of wetland ecosystems that constitute potential threshold breaches in southern African wetlands. See appendix for more detail.

Driver	Changes to	Cause	Effect	Potential indicators	References
Hydrology	Catchment hydrology (pattern and volume of water supplied to the wetland from its catchment)	• Change in catchment land use • Conversion of natural vegetation • Afforestation with exotic trees • Overgrazing by livestock • Urbanisation • Discharge from sanitation infrastructure • Exclusion of fire • Change in the base level of the wetlands • Inter-basin transfers • Upstream abstraction • Upstream impoundments • Alien invasive trees	• Change in wetland hydroperiod • Increase in water flow • Change in vegetation cover • Invasion by non-wetland plant species including invasive alien plants • Drop in groundwater table • Gullying within the wetland • Change in geomorphic processes (erosion and sedimentation) • Shift in plant community to terrestrial, invasive or woody species	A change in species composition relative to similar wetlands. The reduction of water inflows leads to more terrestrial species[23,27], while an increase in water favours species adapted to inundation[69,80]. Wetland Index Value[7] Hillslope types for South Africa[68]	24, 18, 2, 26, 46, 44
	Wetland hydrology (pattern of water distribution and retention within the wetland)	• Abstraction in the wetland • Impoundments in the wetland • Road crossings • Drainage canals • Dredging • Land use changes, especially cultivation	• Reduced flooding within wetland • Changes to surface flow of water • Channel modification • Change in geomorphic processes (erosion and sedimentation)		16, 18, 10

Table 1. Changes to drivers of wetland ecosystems that constitute potential threshold breaches in southern African wetlands. See appendix for more detail (continued).

Driver	Changes to	Cause	Effect	Potential indicators	References
Geomorphology	Sediment supply to the wetland from the catchment Pattern of deposition and erosion of sediment within the wetland	• Increase in water from the catchment • Change in the pattern of delivery of water to the wetland • Stream channel straightening • Morphology alteration • Base levels alteration • Disruption to downstream movement of sediment • Drainage canals • Culverts • Dams • Dredging	• Change in extent and rate of geomorphic process • Gully erosion • Channel modification • Increase incision of channels • Interruption in sediment transfer • Increase export of sediment • Reduce overbank flooding • Avulsion and channel abandonment • Shift in plant community towards terrestrial species	System wide erosion/ deposition, sudden channel avulsion or general increase in the morphodynamic process rate in the wetland. Land-Use characterisation for Nutrient and Sediment Risk Assessment[66]	65, 46, 17, 16, 18
Fertility	Supply of nitrogen and phosphorous	• Agriculture • Urbanisation	• Changes in wetland vegetation community composition and structure	Changes in wetland vegetation community composition and structure. Land-Use characterisation for Nutrient and Sediment Risk Assessment[66]. Vegetation-based Indicators of Wetland Nutrient enrichment[66].	

Table 1. Changes to drivers of wetland ecosystems that constitute potential threshold breaches in southern African wetlands. See appendix for more detail (continued).

Driver	Changes to	Cause	Effect	Potential indicators	References
Disturbance	Frequency and intensity of soil disturbance	• Land use change within the wetland • Cultivation • Afforestation • Mechanical disturbance of soils • Removal of native vegetation	• Floristically different habitats • Change in vegetation to species adapted to disturbance	Presence of increaser II species[61]. High incidence of weedy species[47]. Presence of decreaser species[61]. Change in woody species in the wetland. The reduction in tree cover in forested wetlands such as swamp forests. Floristic Quality Assessment Index[47] and the Ecological Benchmark Method[61].	76, 10
	Frequency and intensity of fire	• Increased frequency of fire • Exclusion of fire	• Woody plant recruitment • Loss of wetland communities		44
	Frequency and intensity of grazing	• Grazing in the wetland	• Changes in wetland vegetation community composition and structure		
Competition	Potential species pool	• Introduction of invasive alien species	• Reduce channel efficiency • Increase channel deposition and overbank flooding • Shift in plant communities to invasive species	Invasion of plant communities by exotic species.	65

Thresholds of change in wetlands

Thresholds, in ecology, refer to a point where even a small change in biophysical or environmental conditions can lead to a shift in an ecosystem to a different ecological state[19,34]. Once a threshold has been crossed, an ecosystem may not always easily return to its pre-threshold state[38].

Figure 4 illustrates the effects of thresholds on ecosystem functionality and state. The permanency of a shift in state can vary depending on thresholds crossed[38]. Degradation that does not cross a threshold (e.g. State 1 and 2 in **Figure 4**) can be reversed through minor manipulations like management[31]. Conversely, thresholds form 'barriers' which inhibit the movement of a system from a degraded state to a less degraded state (e.g. State 4 to 5 in **Figure 4**). Impacts that cause a threshold breach will need more manipulations to restore.

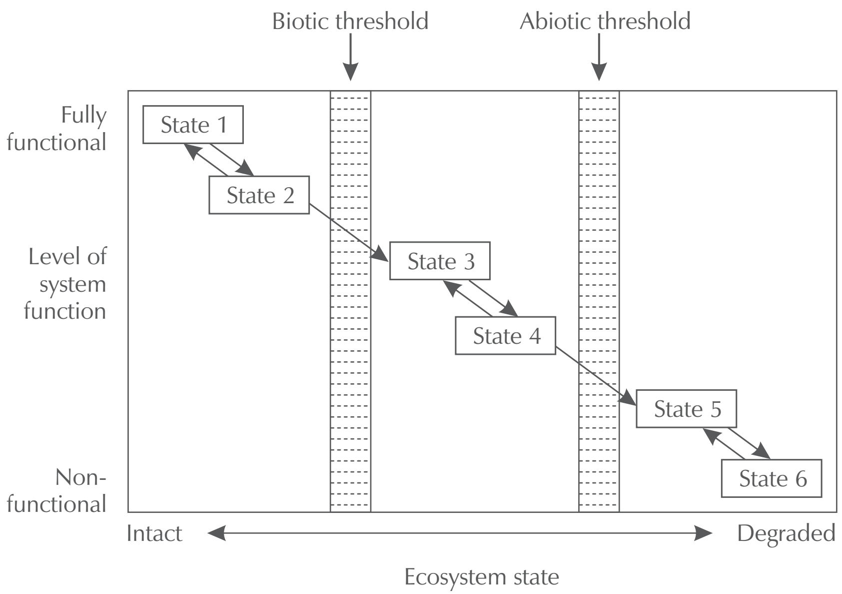


Figure 4. A summary of the state transition approach to ecosystem degradation, thresholds and restoration (adapted from Hobbs 2007)[31].

Thresholds can be biotic or abiotic (**Figure 4**). An example of a biotic threshold could be a wetland vegetation community. Some wetland plant communities are more resilient to disturbance and able to recover to a natural composition, while others recover very slowly or not at all[77,76,79]. If a biotic threshold is crossed (e.g. from State 2 to 3 in **Figure 4**) a vegetation management manipulation might involve the active removal of undesirable species and the introduction of desirable species.

An abiotic threshold, for example, could be geomorphic, where an impact causes a shift from aggradation to degradation within the wetland and a change in its hydrogeomorphic character[63]. A change in hydrogeomorphic character could affect the wetland's natural functions. For example, a shift from an un-channelled to a channelled wetland would change the water retention in the wetland and its ability to attenuate floodwater. If an abiotic threshold is crossed (e.g. State 4 and 5 in Figure 4), a physical manipulation may be required, like the deactivation of erosion or the manipulation of an altered hydrology.

For this framework, a degradation threshold refers to a point beyond which human impacts change an ecosystem into a degraded state, with a loss of composition, structure and functionality. Irreversible changes to the drivers of wetland ecosystems would result in irreversible changes in the wetland. Conceptually, each driver could be associated with a threshold, a point or 'barrier' beyond which the magnitude of change would make unassisted recovery in the wetland

Example 1: Disturbance change in an herbaceous wetland[44]

Consider a depression wetland with herbaceous vegetation. The exclusion of fire in this wetland is associated with fire management by commercial forestry to prevent economic loss of timber. It has resulted in reduced fire within a naturally fire prone ecosystem. The result is recruitment of woody plant species and loss of the herbaceous vegetation community. The surrounding land-use and change in the natural disturbance regime have resulted in a biotic state change from herbaceous to woody.

Example 2:
Change in catchment hydrology in a valley-bottom wetland[26]

There has been land-use change since the 1960s within the catchment of a valley-bottom wetland, with a change to cultivated fields. This has resulted in increased run-off delivered to the wetland from the catchment. An increase in the extent and rate of erosion has caused extensive gullying within the valley-bottom wetland.

unlikely. Thresholds are difficult to predict with any precision, but data from ecosystems in different states of degradation can help to predict the response of ecosystems to similar events[59]. **Table 1** provides some examples of human-induced threshold breaches described within a southern African context.

Step 3: Identify impediments and assess restoration potential

From the foundation of understanding the natural system, and then identifying human impacts to the wetland, it is then possible to identify impediments to restoration. The assessment of restoration potential can then be used to set realistic restoration objectives.

Impediments to restoration

Impediments to restoration refer to a process or feature of a wetland and its catchment that could limit the wetland's potential for restoration. To explain this we make use of an analogy.

> *Think of wetland restoration as a journey that has a starting point and an end point with some travelling linking the two. The starting point is the current state of the wetland and the destination is its state once the wetland has been restored. Like any journey, restoration requires some planning before setting off. Impediments to restoration are factors that have the potential to thwart the journey to our desired restorative outcome. We need to consider if the destination (goal) we have in mind is attainable and ensure that we choose the best possible route. Restoration is no different.*

Table 2 provides a typology for impediments. The presence of *barriers* should rule out attempts to fully recover native ecosystems, while *obstacles* signal potentially high levels of effort and cost associated with restoration. *Stumbling blocks* flag smaller but still important impediments that need to be addressed to achieve the goal. The drivers and thresholds noted in **Table 1** and its related references are a guide to determine what types of impediments constitute barriers, obstacles and stumbling blocks. A threshold breach is typically a barrier or in some cases an obstacle, depending on circumstances, and each breach would have to be evaluated individually to determine what type of impediment it is.

Table 2. Typology of impediments to restoration.

Types of impediments	Definition	Implication for objective setting
Barrier	A factor that makes achieving a fully recovered native ecosystem unlikely or impossible.	The presence of one or more barriers at a candidate wetland removes a fully recovered native ecosystem as a potential goal.
Obstacle	A factor that makes achieving a fully recovered native ecosystem possible but difficult or expensive.	The cost of restoration may be high, particularly if there is more than one obstacle present. Other candidate wetlands may offer better opportunities.
Stumbling block	A factor that makes achieving a fully recovered native ecosystem plausible but requires careful attention.	Restoration and other restorative options are possible.

Assessing human impacts

Wetlands are socio-ecological systems[35] which are linked systems of people and nature[73]. Ultimately, the state of a wetland has much to do with human-wetland interactions and how people choose to use and manage wetlands. It stands to reason that determining the restoration potential of a wetland must consider the role humans play in the management and persistence of the wetland.

Assessing restoration potential

For a restoration plan to be realistic, it must be achievable. Restoration initiatives are likely to be limited in their budgets and other resources, and there may be limits to what can be repaired from a restorative perspective.

Determining restoration potential begins with the question: “Is there undesirable change in the wetland?” (**Figure 5**). If the answer is yes, the investigator must ascertain if the change is due to natural variability or driven by human activity. If the system is undergoing natural change, then there is no reason to restore the wetland and it should be managed as a natural system.

Should the change be attributed largely to human activity, then the question of reversibility becomes central. Reversibility would depend on whether the wetland has passed a degradation threshold and has transitioned into a new stable state, and whether this state can be reversed (‘obstacle’ or ‘stumbling block’) or not (‘barrier’). State reversal depends on being able to stop or weaken the causes of degradation. Degraded systems can be highly resilient, but in an undesirable way. Such ‘undesirable resilience’[59] states are also referred to as lock-ins or socio-ecological traps[14].

Novel or emergent ecosystems: If achieving a fully recovered native ecosystem is unlikely or impossible, it may be necessary to simply manage the ecosystem as a novel ecosystem. A novel ecosystem is an ecosystem that differs in composition or function from present and past systems because of environmental alteration through climate and land use change[32]. Even if it is impossible to return an ecosystem to its natural state, it does not mean that it cannot still perform useful functions if managed correctly, such as urban green space in a city. For a novel ecosystem, the emphasis falls on how the ecosystem can best be managed.

If one cannot remove the cause of degradation then the degradation would be irreversible. An example of this is a wetland catchment which features extensive agricultural and urban development. Resulting changes to catchment hydrology and sediment delivery have caused erosion, leading to a development of a gully through what was historically a discontinuously channelled system[25]. While it may be possible to plug the gully, it would be very difficult, if not impossible to reinstate the natural geomorphic processes in the wetland, leaving the plugged gully vulnerable to ongoing degradation and the need for ongoing, potentially costly, maintenance. Even in instances where degradation thresholds may have not been breached, there may be limits posed to ecological restoration (**Figure 1**) by current land-use or future planned land-use.

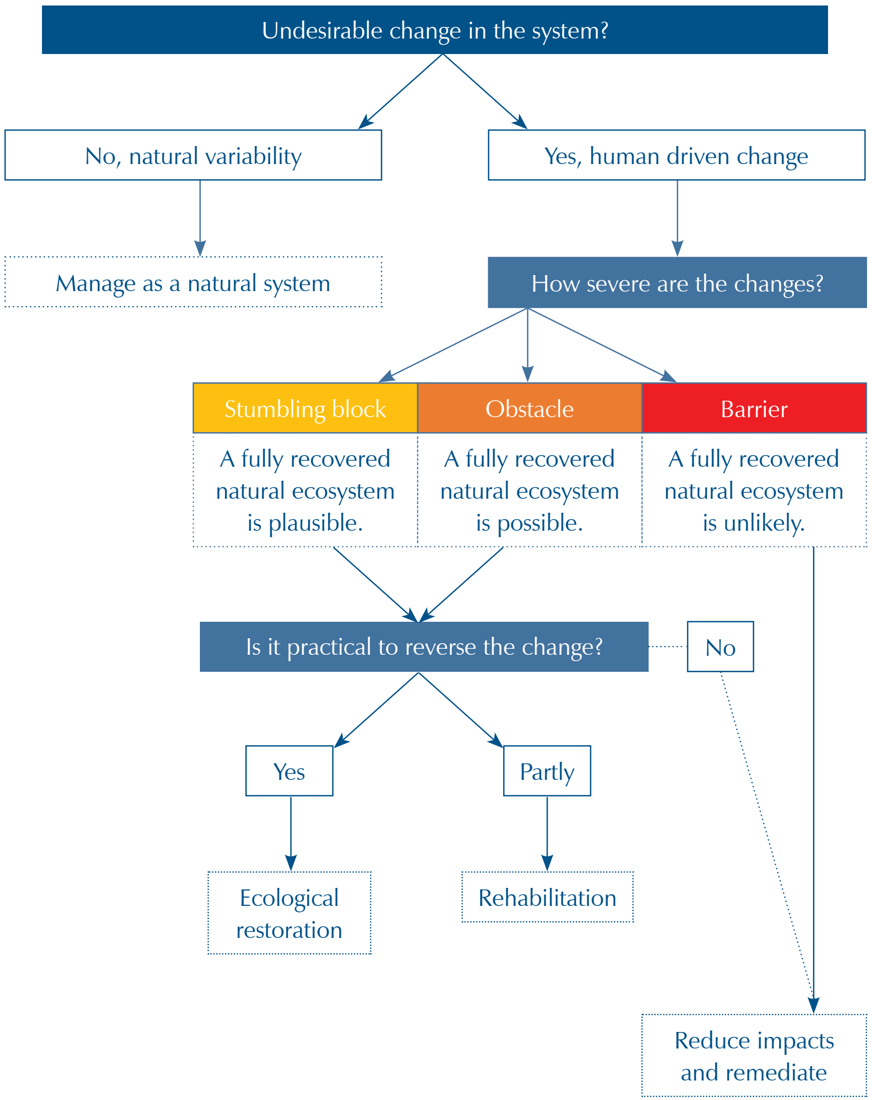


Figure 5. A decision tree for wetland restoration and management (adapted from Hobbs et al. 2014)[33].

Considering how restoration can be monitored

Realistic objectives, which are set based on a good understanding of the wetland and the potential for restoration, are a sound basis for later monitoring and evaluation. There are many benefits to monitoring progress throughout the implementation of a restoration project and beyond. Monitoring helps to identify unexpected challenges and manage these adaptively. It is also a way to purposely learn and improve understanding about the assumptions that are used in restoration planning. More directly, monitoring provides the answer to whether the restoration project has performed as expected. It is how restoration outcomes are ultimately measured, reported and shared with others.

Using the process described above of understanding the wetland conceptual model (Step 1), diagnosing the damage to the wetland drivers (Step 2) and identifying impediments (Step 3) helps to determine suitable indicators for restoration monitoring. An indicator is a measure of the changes or impact from an intervention. Indicators are more useful if they are specific, relevant to the context, easily measured and sensitive to the changes that are expected. Monitoring sites need to be located in the right areas to detect changes. In wetland restoration, indicators may include the percentage of the wetland flooded, cover of invasive alien plants or change in the composition of indigenous plants, among many others. The information gathered during thorough wetland restoration planning can help to develop a highly relevant monitoring plan. **Wet-RehabEvaluate**[75] provides a framework to guide monitoring and evaluation of wetland restoration.

A case study of assessing restoration potential

This section provides an example of how the framework can be applied in practice. A conceptual model of the wetland was developed and the candidate wetland was assessed using WET-Health[45] to understand its ecological condition.

Background

The candidate wetland is found in a highly developed catchment that includes both urban areas and commercial forestry interspersed with grassland (**Figure 6**). The wetland (25ha) is part of a larger complex consisting of hillslope seepage wetland and valley-bottom wetlands. Approximately 41% of the wetland catchment is planted to timber (*Eucalyptus* sp.), 9% woody invasive alien plants, with 40% consisting of secondary grassland and 10% assigned to infrastructure (roads and homesteads). The afforestation has resulted in a decrease in water supplied to the wetland from the catchment (**Table 3**). The wetland was drained in two areas in the past, which affects approximately 27% of the wetland area **Figure 6**). These drains have been very effective in reducing the distribution and retention of water in the wetland. In addition, there are three small dams within the wetland, as well as an area invaded by alien woody species. There are two road crossings over the wetland, the lower one is located on the lowest dam wall. The extent of secondary vegetation (70%) within the wetland suggests that the wetland may have been cultivated or planted to timber in the past. The wetland is currently frequently grazed. Currently the wetland is in a poor ecological condition (D – largely modified) with significant impacts to its hydrology and vegetation composition, and to a lesser degree, its geomorphology.

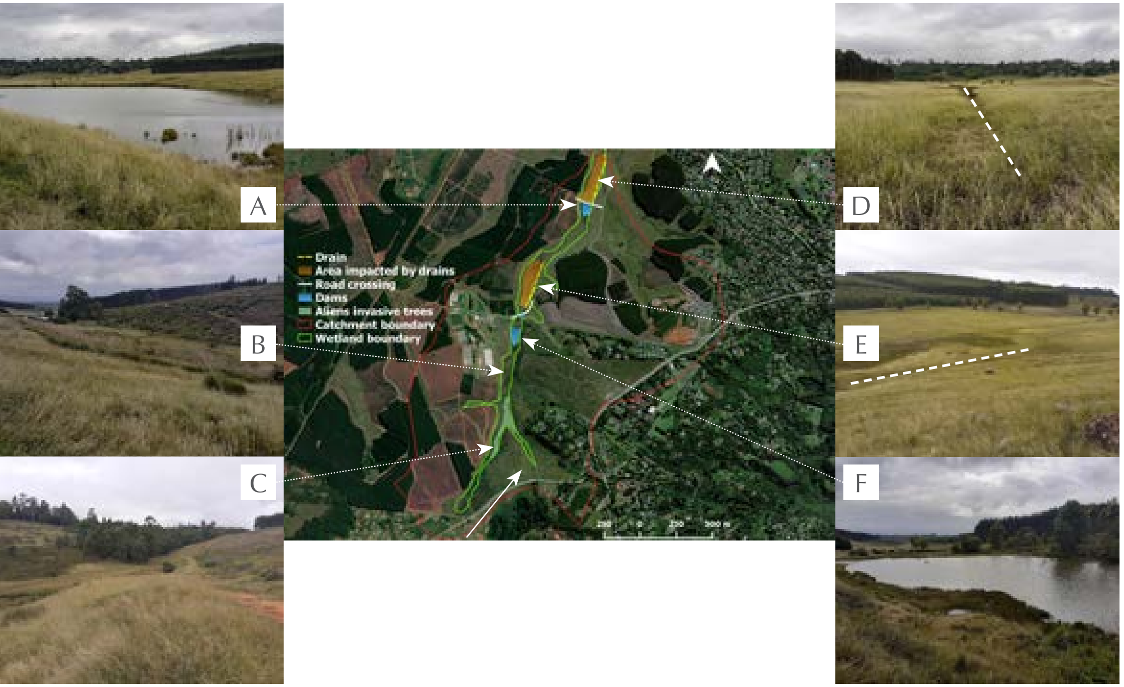


Figure 6. Overview of the candidate wetland and associated impacts. A, lower dam where the wall is also a road crossing; B, the area between the top dam and the alien trees; C, alien invasive trees in the wetland; D, the drain impacting the lowest part of the wetland; E, the drain impacting the middle of the wetland; F, dam in the top of the wetland.

Step 1: Conceptual model of system characteristics and behaviour

The conceptual model of the wetland was developed from assessment of a similar wetland located nearby, with similar landscape position and on the same geology.

The wetland would have been nested within a grassland-dominated catchment, with very limited bush or forest habitat where fire was excluded. The soils in the catchment are well-drained, deep red and yellow-red apedal soils. From a hydrological perspective these soils are known as recharge soils[68].

Recharge soils show no signs of vertical saturation and are free draining (vertically to bedrock). These soils are important for the provision of baseflow[68].

Typically these valley-bottom wetlands are unchannelled. Instead of a clearly defined channel, the wetlands feature a preferential flow zone, a low point in the wetland that can carry flows. The flow zone is generally narrow and shallow (width <1500mm and depth <500mm), trapezoidal in cross section and well-vegetated by *Carex* sp. and *Phragmites australis*. The wetlands may feature a very short section of channel at their toe that is in contact with bedrock, usually on dolerite intrusions that form localised base-level controls. As the wetlands are located on Pietermaritzburg Formation of the Ecca Group, the underlying geology is typically shales and siltstones, intruded by dolerite. These geologies give rise to fine clayey sediments in the wetland. The long-term origin and evolution of such unchannelled valley-bottom wetlands would feature periods of erosion and channel formation driven by sediment deposition and localised overstepping[25]. However, it is surmised that the morphodynamic process rates of these wetlands is very slow (1000s to 10 000s of years) due to very low sediment supply rates[25].

The soil hydromorphy and vegetation patterns in these wetlands indicate that they are mostly seasonally saturated with some flooding during the wettest part of the year. The preferential flow zones can be permanently or near permanently saturated, and often flooded during the wetland season.

Naturally the wetland would have been dominated by hydrophytic herbaceous vegetation. Typically the grasses *Arundinella nepalensis*, *Hemarthria altissima, Leersia hexandra* and the sedge *Carex sp* would have dominated the seasonal and permanently saturated area of the wetland, with grasses and geophytes typical of drier areas in the temporally saturated zones on the edges of the wetland. As these wetlands are in fire prone ecosystems, it is likely that they would have been exposed to frequently re-occurring fires in the same way as the adjacent grasslands would. Woody-stemmed plants are not commonly found in these wetlands. Grazing in the wetland would have been common.

Step 2: Diagnosing the damage to wetland drivers

There are a number of important drivers of change effecting the candidate wetland (**Table 3**).

1. The wetland's hydrology has been impacted by the introduction of trees into a catchment that would have been grassland. Exotic *Eucalyptus* species planted at high densities can significantly reduce the delivery of water from the catchment to the watercourse[42,55]. Using simple look-up tables that integrate the effect of species, climate and soil type on streamflow reduction[28], a reduction of 30% is indicated. Most of this reduction is during the growing season.

2. The wetland has been cultivated in the past. Approximately 70% of the wetland is classified as secondary vegetation. Seasonal or temporary grassy wetlands do not recover well after abandonment[10,76].

3. Invasive alien grasses dominate the vegetation cover, particularly in areas that were historically cultivated and are still impacted by the drainage system in the wetland.

4. The surface morphology of the wetland has been altered. An estimated 34% of the wetland has been affected by the excavation of highly efficient drainage ditches. The drains function as conduits for water and sediment, and have altered the affected areas of wetland from un-channelled to channelled wetland. Consequently, more than 30% of the wetland is now not subjected to surface flows.

5. Future land use in the wetland catchment is shifting from commercial forestry towards urbanisation.

Table 3. A summary of the WET-Health (2020) derived ecological condition of the candidate wetland.

Wetland Present Ecological State				
	Score	**Class**	**Drivers of degradation**	
Hydrology	6.5	**E**	**External hydrology**	Approximately 41% of the wetland complex catchment is afforested. The forestry areas have been well delineated and forestry is excluded from watercourses.
			Internal hydrology	21% of the wetland has been drained in the past by large drains that very effectively capture surface flows. Three dams in the wetland alter the distribution and retention pattern of water within 6% of the wetland. Approximately 10% of the wetland has been invaded by alien vegetation.
Geomorphology	1.0	**B**	Both drains in the wetland have eroded to bedrock but appear to have reached equilibrium and do not export sediment. The movement of sediment along the wetland has been altered due the sediment effect trapping of the dams in the wetland.	
Vegetation	4.5	**D**	Approximately 70% of the wetland vegetation appears to be secondary (historically cultivated) and has not recovered to what would be considered as benchmark (or an acceptable variation thereof). 13% of the wetland area is untransformed, 6% deeply flooded by dams, and about 1% altered by infrastructure (roads and dam walls). A significant portion of the vegetation is made up of exotic grassland species that are adapted to wetland conditions, namely *Paspalum urvillei* and *P dilitatum*.	
Integrated PES	4.4 (D) Largely modified. A large change in ecosystem process and loss of habitat and biota has occurred.			

Step 3: Identifying impediments and assessing restoration potential

Human activity has caused a number of significant changes to the wetland drivers and thus the structure and functioning of the wetland ecosystem itself. These changes have implications for setting restoration objectives (**Table 3**).

While the stream flow reduction effect of the commercial afforestation may eventually change, it will be replaced by the effects of urbanisation. This would result in less infiltration, increased run off, less baseflows and larger stormflow events[12]. It may also temporarily bring increased sediment yields during the construction phase of the urban development[8].

The drainage system within the wetland may be difficult to entirely eradicate within the system as much of the sediment from the excavation has been lost from the wetland (possibly trapped within the lower dams). The drains could be reconfigured to make them far less efficient by increasing their wetted perimeters or possibly using grade control structures such as concrete weirs. Reducing the efficiency of the drains would increase the retention time of water in the wetland and at least partially restore the wetlands patterns of water retention and distribution.

Research elsewhere has shown that displacing the invasive *Paspalum* grasses may be impossible even if the wetland hydrology is restored.

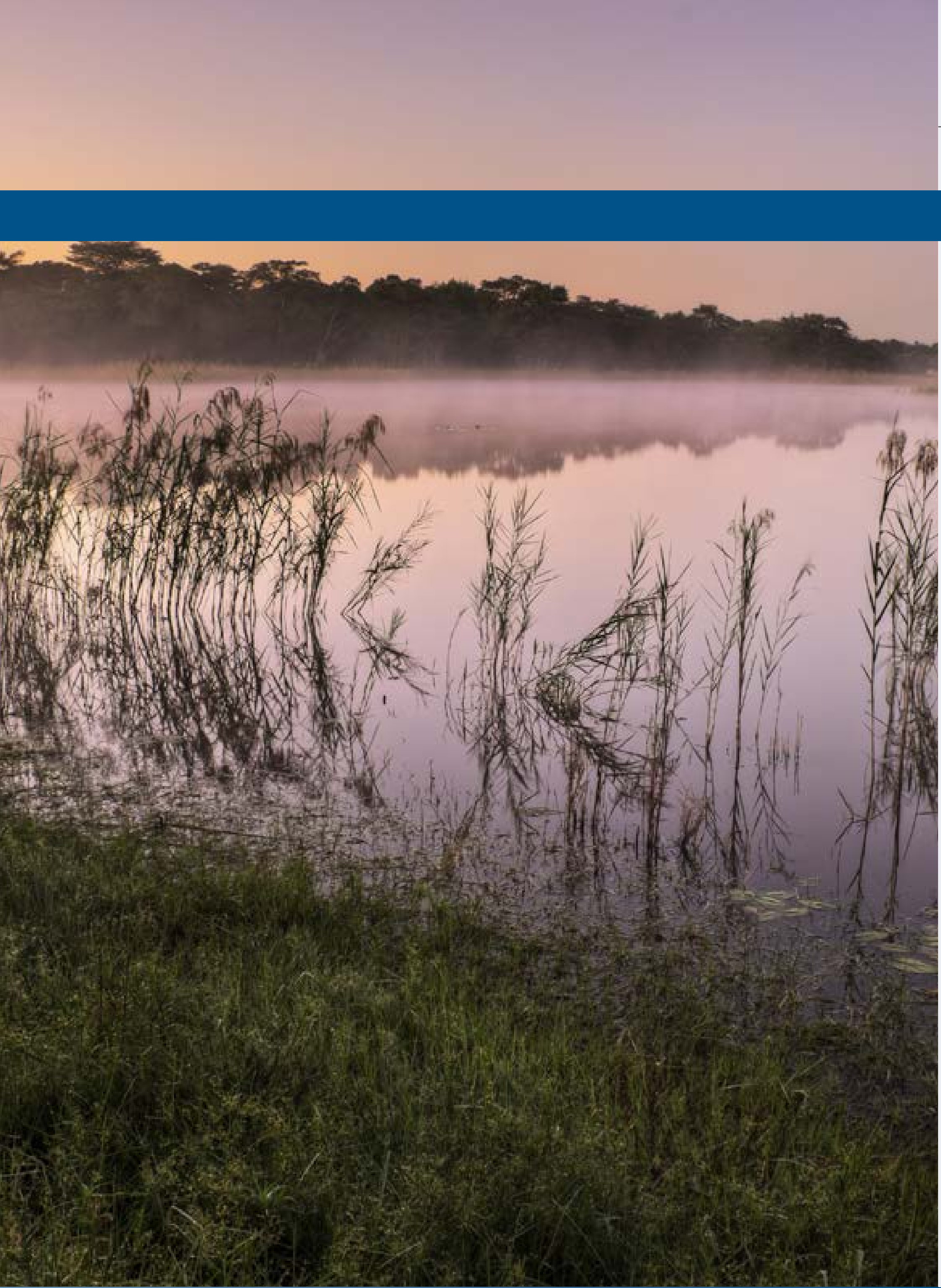
In summary, it is highly unlikely that the wetland is a suitable candidate for full ecological restoration (see **Figure 1**), with several barrier impediments (**Table 4**). Given that the wetland catchment is probably going to become urbanised, a good argument can be made that the demand for water quality functionality will increase. The aesthetic value of the wetland as open space may also increase. Given the foreseen future changes in the wetland catchment, the wetland would be an excellent candidate for rehabilitation with a purposeful focus on ecosystem functioning. The wetland could be rehabilitated to improve its ability to enhance water quality and its aesthetic value, while also possibly providing habitat for a few generalist wetland species.

Table 4. Impediments to wetland restoration and the implication for restoration planning.

Factor	Specific factor	Consideration	Impediment	Objective setting
Hydrology	**Flow reduction:** The afforestation in the wetland catchment (41%) reduces flows by ±30%, mostly in the wet season.	The wetland is drier than it would have been historically. The drying of the wetland has an impact on the wetland vegetation by reducing inundation and flooding.	Barrier	The wetland hydrology will be compromised as long as the catchment is altered. The reduced flows may be a permanent barrier to more representative wetland revegetation.
	Disruption of internal hydrology: Affects ± 27% of the wetland	Area in the wetland that would have received flows from upstream are now reliant on rainfall and lateral inputs (which are reduced).	Obstacle	If the drains remain effective the impact would persist.
Geomorphology	**Change in wetland morphology:** ± 34% of the length of the wetland is affected by a self-scouring (equilibrium) artificial channel.	Artificial drains have converted the wetland to a distinctly channelled system. The sediment from the drains has been exported and there is no evidence of significant deposition in the wetland. Dams and roads have altered the topography of 1% of the wetland.	Obstacle	The drains would have to be removed either by shaping, infilling or blocking to shift the wetland back into its historic geomorphic state.

Table 4. Impediments to wetland restoration and the implication for restoration planning (continued).

Factor	Specific factor	Consideration	Impediment	Objective setting
Geomorphology	**Increase in sediment inputs:** Timber plantations lose more sediment than grassland.	Change in flow patterns also affect the distribution of sediment within the wetland.	Obstacle	Uncertain
Disturbance	**Disturbance of vegetation:** ± 70% of the wetland has been cultivated.	Benchmark wetlands are dominated by *Arundinella npalensis, Hemarthria altissima* and *Carex sp*.	Obstacle	Unlike drier wetlands, seasonal/ permanent *Carex* marsh has good recovery potential.
Competition	**Presence of invasive alien species:** Giant paspalum *(Paspalum urvillei)*, Common paspalum *(Paspalum dilatatum)*, *Eucalyptus sp*.	These two grass species are highly competitive and have become the dominant species in terms of cover. The gum trees use more water than indigenous wetland plants and displace indigenous species.	Obstacle	Without changes to the wetland hydrology the invading species would persist. Even if the hydrology was restored, the invasive grasses would probably persist in the drier areas of the wetland.
Other	**Socio-ecological setting:** The wetland is in a rapidly urbanising landscape.	It is likely the land use in the wetland catchment will change within a decade. The area has been rezoned as residential and the landowner is selling parcels of land.	Barrier	It is likely that forestry will be replaced by urban developments.



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Appendix

Table 5: Examples of potential threshold breaches in South African wetlands.

Driver	Proximal cause	Wetland description	Cause	Effect	Indirect indicator	Response indicator	Reference
Hydrology	Change in catchment hydrology	A hillslope seepage wetland with a clastic sediment substrate and herbaceous vegetation.	Afforestation of the wetland catchment, replacing native grassland with exotic *Eucalyptus grandis* trees. The trees have a higher water demand compared to the native grassland and have reduced the total availability of water supplied to the wetland from the catchment.	A change in the wetland hydroperiod and the invasion of wetland plant communities by non-wetland plant species including alien invasive plants *Rubus cuneifolius*.	Catchment land use change.	A shift in the wetland plant community from wetland plants to species typical of terrestrial habitats including alien invasive species.	24
Hydrology	Change in catchment hydrology	Depression wetland with a peat substrate and herbaceous vegetation.	Afforestation of the wetland catchment, replacing native grassland with exotic *Eucalyptus sp.* and *Pinus sp.* trees. The trees have a higher water demand compared to the native grassland and have reduced the total availability of water supplied to the wetland from the catchment.	A change in the wetland hydroperiod including an elevational drop in the within-wetland groundwater table.	Catchment land use change.	An increased incidence of peat fires and an absence of recent peat accretion. The loss of or change in vegetation cover within the wetland.	18
Hydrology	Change in catchment hydrology	Mostly herbaceous covered valley-bottom wetlands.	Two hundred years of overgrazing by livestock affected the vegetation composition and structure in wetlands and their catchments resulting increased run-off and erosion.	Extensive synchronous gullying within valley-bottom wetlands that appears to have no recent (Holocene) analogue.	Catchment land use change.	An increase in extent and rate of geomorphic process (erosion).	2

Table 5: Examples of potential threshold breaches in South African wetlands (continued).

Driver	Proximal cause	Wetland description	Cause	Effect	Indirect indicator	Response indicator	Reference
Hydrology	Change in catchment hydrology	Valley-bottom wetlands.	Land-use change since the 1960s has led to the conversion of natural Fynbos vegetation to cultivated pastures and field crops resulting in increased run-off delivered to the wetland from the catchment and erosion.	Extensive synchronous gullying within valley-bottom wetlands that appears to have no recent (Holocene) analogue.	Catchment land use change.	An increase in extent and geomorphic process rate (erosion).	26
	Change in sediment dynamics within the wetland supply		Poorly designed road crossings have disrupted the downstream movement of sediment while in addition acting as locations for gully initiation by altering the base level of the wetlands at culverts.			A shift in the wetland plant community from wetland plants to species typical of terrestrial habitats including alien invasive species.	
Geomorphology	Change in wetland river channel morphology	A meandering river floodplain wetland.	A section of the river in the wetland was straightened and deepened in the 1930s.	An increase in geomorphic process rate resulting in a channel avulsion ~2-5ky earlier than would be expected and a reduction in overbank flooding in parts of the wetland.	Evidence of channel modification, straightening and dredging.	An increase in extent and rate geomorphic process (channel avulsion).	65
Competition	Introduction of an alien invasive species		The introduction of willow trees (*Salix spp.)* into the wetland, and specifically along the banks of the river has reduced channel cross-sectional area and created stable channel-spanning log-jams, both of which have reduced channel efficiency and increased within channel deposition and overbank flooding.			Presence of woody invasive alien species in an otherwise herbaceous wetland.	

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Table 5: Examples of potential threshold breaches in South African wetlands (continued).

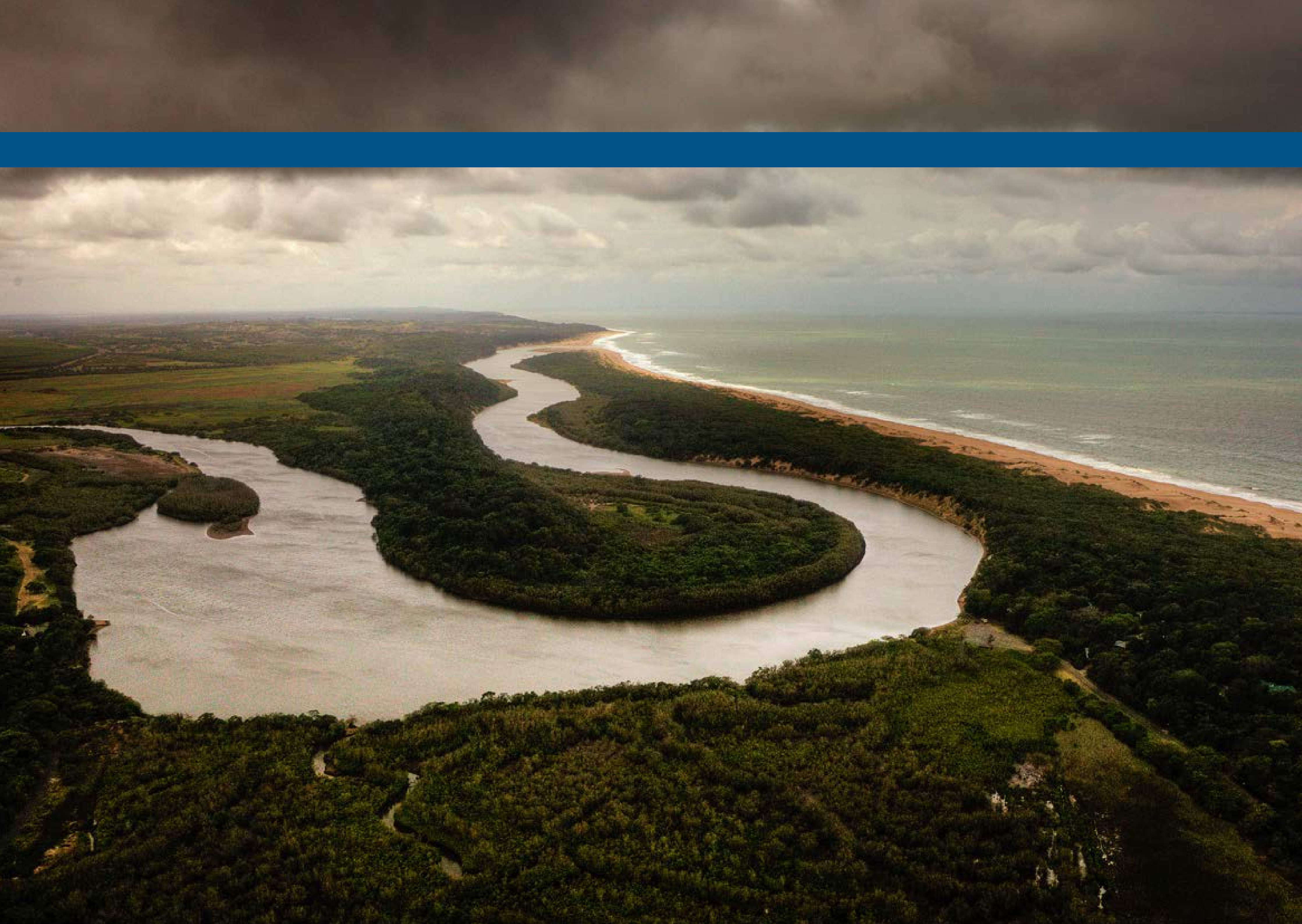
Driver	Proximal cause	Wetland description	Cause	Effect	Indirect indicator	Response indicator	Reference
Hydrology	Change in catchment hydrology	A discontinuously channelled valley-bottom wetland with peat and clastic sediments characterised by *Phragmites australis* reed beds.	The conversion of the wetland catchment from grassland to urbanisation have increased peak discharges, in addition, total volume of discharge has increased due to sewerage treatment work discharge into the wetland.	Significant ongoing gully erosion with the wetland. The gullies provide a far more efficient conduit for water and sediment than previously existed in the wetland.	Catchment land use change.	An increase in water flow within the wetland beyond that would have occurred naturally.	46
Geomorphology	Change to wetland river channel/surface morphology		Sections of the wetland were canalised in the 1930. The canals were designed to capture water in the wetland and lead it into a gravity irrigation scheme.		Evidence of channel modification, straightening and dredging.	An increase in extent and rate of geomorphic process (incision) and the export of sediment out of the system.	
Geomorphology	Change to wetland river channel morphology	A meandering river floodplain wetland.	A poorly designed road crossings altered the wetland base level at a culvert creating channel incision in the wetland.	The channel incision in the wetland caused a channel avulsion while the dam has starved the wetland below of sediments. The combination of the impacts have fundamentally changed the geomorphic character of the wetland.	Evidence of channel modification and dam located within the floodplain.	Channel avulsion on in-channel erosion coupled to the abandonment of the historic channel.	16
			A dam constructed in the upper reaches of the wetland has interrupted sediment transfer in the wetland and reduced overbank flooding.				

Table 5: Examples of potential threshold breaches in South African wetlands (continued).

Driver	Proximal cause	Wetland description	Cause	Effect	Indirect indicator	Response indicator	Reference
Geomorphology	Change to wetland river channel morphology	Meandering river floodplain within the Okavango Delta.	The distal Boro River floodplain was dredged in the early 1970s in order to increase surface outflows to meet human needs.	The dredging increased the efficiency of the of the river channel resulting in reduced over-bank flooding facilitating significant encroachment of terrestrial species into the floodplain.	Evidence of channel modification; straightening and dredging.	Encroachment of terrestrial plant species in areas that were historically wetland.	17
				The dredging initiated a nick point within the channel that has migrated upstream at a rate of 500m per year into undredged upstream regions of the river with similar impacts to that associated with the dredged system.		Ongoing within channel erosion and the persistence of large clearly defined channel where none previously existed.	
Geomorphology	Change to wetland river channel morphology	Meandering river floodplain wetland.	A minor irrigation canal excavated in the Mukze floodplain resulted in a large avulsion of the Mkuze River.	The avulsion created a surface flow connection to a larger drainage canal that was ineffective prior to the avulsion. The combination the two factors created a new highly efficient route for the river that has disconnected the river from the floodplain in all but large floods.	Excavation of canals.	Avulsion and channel abandonment.	17
Hydrology	Change in internal hydrology of the wetland						

Table 5: Examples of potential threshold breaches in South African wetlands (continued).

Driver	Proximal cause	Wetland description	Cause	Effect	Indirect indicator	Response indicator	Reference
Disturbance	Disturbance of the wetland soil and removal of native vegetation	Meandering river floodplain wetlands typified by drier, grassy habitats.	A series of wetlands were historically cultivated and subsequently abandoned. The period of cultivation for each wetland is not known but is assumed to have been for several decades.	Cultivated floodplain habitats were compositionally (floristically) different to the uncultivated habitats and showed no sign of recovery after abandonment.	Land use change within wetlands.	Wetland vegetation communities dominated by grass and sedge species that are adapted to disturbance.	76
Hydrology	Change in internal hydrology of the wetland	Wetland fan.	The wetland was drained to allow for crop production and then extensively cultivated. The wetland surface hydrology was rehabilitated in 2006 and the cultivated fields abandoned.	The drainage system disrupted surface flow patterns and reduced flooding within the wetland.	Land use change within a wetland or historical signs thereof.	Drainage canals with the wetland.	10
Disturbance	Disturbance of the wetland soil and removal of native vegetation			The floodplain habitats were compositionally (floristically) different to uncultivated habitats, included a dominant alien grass (*Paspalum dilatatum*) and showed no sign of recovery after abandonment.		Wetland vegetation communities dominated by grass and sedge species that are adapted to disturbance and show no sign of recovery despite rehabilitation of the wetland hydrology.	
Hydrology	Change in catchment hydrology	Depression wetland with a peat or clastic substrate and herbaceous vegetation.	The exclusion of fire from herbaceous wetlands within a fire prone ecosystem. The fire exclusion is associated with commercial afforestation fire management.	Woody plant recruitment within herbaceous wetland with the concomitant loss of herbaceous wetland communities.	Land use change in the wetland's catchment	Recruitment of woody plant species in wetlands otherwise dominated by herbaceous vegetation community maintained by fire.	44
Natural disturbance	Change in natural disturbance regime						



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