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ORIGINAL PAPER

Hierarchical spatial organization and prioritization of wetlands: a conceptual model for wetland rehabilitation in South Africa

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Abstract Wetland rehabilitation planning needs to take into account many different aspects of the wetland and its context. In South Africa, much emphasis is placed on the delivery of ecosystem services, poverty relief and skills development for those involved in labour-intensive rehabilitation measures. A framework is presented that facilitates decision-making with regards to wetland rehabilitation planning. This starts with prioritizing which wetlands need attention within a catchment. This is followed by decisions regarding which rehabilitation measures would be effective in improving certain ecosystem services based upon the aims of rehabilitation and the social context of the surrounding catchment. The functional unit that is most suitable to work with for rehabilitation is the Hydrogeomorphic (HGM) Unit, defined as a section of a wetland with more or less uniform hydrological and geomorphological characteristics. An individual wetland may comprise several HGM units, and a HGM Unit itself can be sub-divided into several smaller habitat or vegetation units. Different rehabilitation measures have been identified which are appropriate for the different scales in this spatial framework. Two case studies are presented as examples of how this spatial framework impacts upon the decisions made by the rehabilitation practitioner.

Keywords Wetland classification · Hydrogeomorphic (HGM) Units · Wetland planning · Restoration targets · Catchments

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Introduction

Wetlands are known to provide a wide range of ecosystem services (Mitsch and Gosselink 1993; Keddy 2004), including supporting (such as soil formation and biogeochemical cycling), provisioning (such as providing food and freshwater), regulating (such as climate regulation and flood attenuation) and cultural (such as education and tourism) services. Through loss and damage to wetland ecosystems many of these services have been lost (Millenium Ecosystem Assessment 2005).

One of the most important mandates of the South African government is to deal with poverty alleviation to reduce the inequalities of the past. Strategic national initiatives of the Expanded Public Works Programme target impoverished areas and employ people in these areas to obtain training and experience in rehabilitation work (Dada et al. 2007).

Because wetlands occupy landscape positions that are affected by activities taking place within catchments, human impacts to wetlands occur through activities both within and outside of wetlands. As such, human impacts to wetlands are often indirect and unintended, such as increasing solute loads (McCarthy et al. 2007). Alternatively, impacts on human well-being may be direct, such as the erosion of a wetland that threatens people's livelihoods by reducing their ability to produce crops (Pollard et al. 2009). Irrespective of their origin, impacts on wetlands reduce the ability of these ecosystems to provide a range of ecosystem services, in many cases with detrimental impacts on human well-being.

Given the impacts of human activities on wetland ecosystem structure and function, and therefore on human well-being, the conservation and rehabilitation of wetland ecosystems is well justified. This is particularly the case in semi-arid developing countries like South Africa, where people rely on wetlands most during critical periods when other livelihood options diminish (see Pollard et al. 2009). At present, there is an increased interest in understanding wetlands and their conservation in South Africa (Noble and Hemens 1978; Breen and Begg 1989), and increasing effort is made to documenting and valuing the goods and services that they provide to humans (Kotze et al. 2009a). The aims of rehabilitation activities often focus on specific ecosystem services such as enhancing water retention, ameliorating floods or conserving biodiversity (Daily 1997).

The goods and services provided by wetlands are generally correlated with the wetland type (Kotze et al. 2009a), which is in turn related to the pattern water flow into, through and out of the wetland. Thus, the assessment of both wetland health and ecosystem services is generally founded on division of individual wetlands into hydrogeomorphic (HGM) units. Landform and hydrological characteristics form the basis of the HGM classification system for wetlands, and these are generally acknowledged as the two fundamental features that determine the existence of all wetlands (Brinson 1993; Semuniuk and Semuniuk 1995; Ellery et al. 2009). A HGM unit is thus defined as a section of a wetland that has uniform hydrological and geomorphological characteristics. The HGM approach has been used extensively in South Africa and a simple system has been described by Macfarlane et al. (2009). Given this, and recent developments in the field of wetland classification in South Africa (Ewart-Smith et al. 2006; Ollis et al. 2009), it is important to critically assess classification as it applies to wetland rehabilitation in South Africa.

Wetland rehabilitation in accordance with the definition provided by Grenfell et al. (2007) in South Africa has been ongoing as a state-sponsored activity through the Working for Wetlands Programme for about a decade. Rehabilitation planning is hierarchical, and based largely on the outcomes of interventions with respect to the delivery of ecosystem services. Therefore, the planning approach requires a robust assessment of the natural functioning of the wetland being considered, and careful consideration of the likely reinstatement of ecosystem services following rehabilitation.

Before the planning of rehabilitation measures, a detailed analysis of the natural functioning of the wetland and the impacts that caused degradation needs to take place. Since impacts and rehabilitation targets can operate on a range of temporal and spatial scales, rehabilitation needs to consider wetlands and their functioning at the appropriate scale, particularly if rehabilitation is to do more than treat symptoms, and therefore be sustainable.

The identification of these spatial scales and the classification of the appropriate landscape units at each scale is an important aspect of wetland rehabilitation planning. We can conclude that the theory of hierarchical organization of ecosystems (O'Neill et al. 1986) has practical implications for wetland rehabilitation.

The aim of this paper is to present a planning framework for wetland rehabilitation that is mindful of scale through the hierarchical classification of wetlands, and which attempts to address underlying causes of degradation and not just the symptoms. The focus is on guidelines produced to support wetland rehabilitation in South Africa (Dada et al. 2007) bearing in mind that:

- Limited funds are available to support wetland rehabilitation,
- Wetland rehabilitation has a strong job creation and poverty alleviation component that forms part of an extended public works programme,
- Large numbers of poor people are dependent upon the goods and services provided by wetlands, and
- South Africa is a water scarce country with a semi-arid climate.

Classification of South Africa's wetlands

The subdivision of a wetland into hydrogeomorphic (HGM) units is an important step in the identification of ecological processes in the wetland. Information on the HGM units in a wetland provides clues to the sources of water, impacts that are most likely to occur, and ecological processes operating in the wetland. From the perspective of rehabilitation, meaningful classification can increase understanding of the hydrological and geomorphological processes that determine the origin and dynamics of wetlands, such that rehabilitation can more effectively treat causes of degradation and not just symptoms.

A hierarchical system of classification for South African wetlands has been proposed by Ewart-Smith et al. (2006) which was later improved by Ollis et al. (2009), both of which have HGM units as a key element. The classification is hierarchical, with six levels in the hierarchy in Ollis et al. (2009). For the purposes of this paper, only inland wetlands are considered. The term *discriminator* is used for any parameter that is required for distinguishing one (group of) wetland(s) from another on any of the levels of the hierarchy.

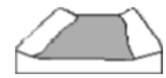
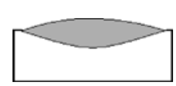
Classification of HGM units appears as Level 4 of the classification of Ollis et al. (2009) (Table 1). Observations on the perceived inputs, outputs and throughputs of a specific unit, assist in the identification of the HGM unit. The HGM unit classification in Table 1 contains some of the classes of Brinson (1993) but includes a greater variety of different classes. When applied, it is likely to result in somewhat finer distinctions being made than in the Brinson (1993) probably also leading to a greater degree of division of wetlands into separate assessment units. A further difference is that in South Africa there is a lack of reference wetlands (typically described in the US for different HGM types in different ecoregions, as explained by Johnson (2005)). Even though data are generally lacking to quantify the exact proportion of inputs to outputs from a wetland, it is possible to characterize wetlands in a coarse, qualitative manner sufficient to be able to allocate HGM units to the HGM classes given in Table 1.

It is recognized that due to its semi-arid climate and exceptionally high average elevation, most wetlands in South Africa are linked to the fluvial network (Tooth and McCarthy 2007; Ellery et al. 2009). Most rehabilitation of wetlands in South Africa takes place in wetlands where the outflow of water is to a stream or where a wetland dominated by diffuse flow is converted to a strongly channelized system through the excavation of artificial drains, or through gully erosion. Furthermore, an understanding of inputs can help identify the causes of wetland degradation. Wetlands that receive water in the form of diffuse surface inputs from a local catchment are likely to be affected by factors that affect runoff and groundwater recharge. Thus, afforestation or urban development in such catchments will have a substantial impact. Alternatively, those wetlands that receive their water supply via fluvial inputs will be most affected by factors affecting streamflow, such as the impoundment of streams or abstraction of water from the stream.

Throughflow of water in a wetland is informative when inferring ecosystem services that are provided by a wetland. The predominance of diffuse flow in a wetland is likely to enhance contact between the water column and the wetlands sediments, and therefore promote functions in which biogeochemical processes are important. Wetlands such as floodplains with considerable depression storage and a large surface area are important in flood attenuation and sediment trapping. Water management at the scale of a catchment can therefore influence the kinds of interventions that might be considered important in wetlands in individual catchments (Ellery et al. 2009).

At the levels below the HGM unit in the currently proposed wetland classification system of South Africa (Ollis et al. 2009), the habitat is described. The habitat defines the local conditions and constraints for plant growth at any location within the wetland. Thus, whereas a hydrogeomorphic unit is

Table 1 Proposed classification for wetland Hydrogeomorphic Units, modified from Ollis et al. (2009)

Functional (HGM) Unit (Level 4 in Ollis et al. 2009)	Predominant hydrological inputs	Pattern of through flow	Predominant hydrological outputs	Landscape setting	Schematic illustration
River margin and vegetated channel deposits	Fluvial	Channel	Fluvial	Gently sloping narrow valley	
Floodplain		Channel – diffuse in flood	Fluvial (and atmosphere)	Coastal Plain or very broad valley	
Valley-bottom without a channel	Surface flow – mainly fluvial	Diffuse		Gently sloping broad valley	
Valley-bottom with a channel		Diffuse and channel		Gently sloping broad valley	
Valleyhead seepage	Surface flow – mainly diffuse	Diffuse	Fluvial	Hanging valley at high altitude	
Hillslope seepage not feeding a stream	Groundwater	Diffuse	Groundwater	Hillslope	
Flat/Groundwater rest-level wetland		None (diffuse)		Coastal plain (mostly)	
Hillslope seepage feeding a stream		Diffuse	Fluvial	Hillslope	
Isolated spring		None (diffuse)	Atmosphere	Valley floor – but variable	
Dolomite cave		Underground caverns	Groundwater/ fluvial	Karst landscape	
Depression/Pan	Atmosphere + diffuse surface flow	None	Atmosphere	Closed basin	
Raised bog	Atmosphere	None (diffuse)	Groundwater	Rare in Southern hemisphere	
Geothermal spring	Geothermal	None (diffuse)	Atmosphere	Valley floor – but variable	

Shaded cells represent wetlands that are most commonly rehabilitated in South Africa

classified on the basis of the origin, dynamics and present functioning of the unit, the habitat type only deals with localized site characteristics and the conditions that prevail there, as a result of the landscape scale processes. The most important variable defining a habitat is the hydroperiod: the amount of time in a year that a certain patch in the wetland is inundated, but many other variables that define the habitat are given in Table 2. Kotze et al. (1996) give an example of how easily observed characters in the field assist in assessing the hydroperiod in a wetland.

Classification at this level is especially important when the rehabilitation aim is conservation of

Table 2 Proposed list of discriminators at the level of the habitat

Discriminator	Eventual classes
Hydroperiod	Temporary, Seasonal, Permanent, Shallow water, Deep water
Water velocity	Stagnant, low stream power, high stream power
Water fluctuation	Stable, low fluctuation, high fluctuation
Drought stress in dry period	No drought stress, temporary drought stress, seasonal drought stress
Seepage	Absent, subsurface flow, deep groundwater upwelling
Organic matter	Mineral soil, humic soil, melanic soil, fibrous peat, real peat
Salinity	Freshwater, brackish, saline, hypersaline
Burial	No burial, burial with sand, burial with clay
Disturbance	Pioneer, subclimax, climax
Fire history	Pioneer, subclimax, climax
Grazing pressure	No grazing, grazing, overgrazed
Substrate	Clay, loam, silt, sand, peat, rocks, bedrock
Nutrients	Oligotrophic, mesotrophic, eutrophic
Soil depth	Very shallow soil, shallow soil, deep soil
PH	Very acidic, acidic, neutral, alkaline
Redox potential	Strongly oxidized, oxidized, neutral, reduced, strongly reduced

The discriminators and their classes are chosen in such a way that they can relatively easily be assessed in the field

biodiversity. The different habitat units will indicate where rare species occur or are to be expected, and guide the aims of rehabilitation in terms of reinstating the conditions necessary for the improvement of habitat units to promote the recovery of the rare species. A wetland classification in general plays an important role in wetland conservation planning (Finlayson et al. 2002).

A spatial framework for wetland rehabilitation

Rehabilitation should prioritise and address problems to make interventions cost-effective (Allison 2007; Miller and Hobbs 2007). This requires that aims should be stated explicitly before rehabilitation commences (Zedler and Callaway 1999; Ehrenfeld 2000). Identification of the intention of rehabilitation forms the first step of rehabilitation planning, particularly as aims are best nested within a scale at least one level greater than that of the intended focal unit. Wetland rehabilitation should ideally fit into a vision that is devised on the level of the sub-catchment, catchment or even at a regional, provincial or national level. Broad-scale objectives for wetlands within large catchment areas may relate to those developed by Catchment Management Agencies and/or the South African Department Water Affairs (DWA), whilst at smaller spatial scales local objectives and constraints will play a stronger role (Rountree et al. 2009). During the planning process, the broad-scale (national or regional) objectives need to be reconciled with local (site-specific or sub-catchment) aims of rehabilitation. This is why a hierarchical approach to the planning is essential.

Rehabilitation planning should be in accordance with the broader aim for the tertiary catchment and address the causes of problems rather than the symptoms (Rutherfurd et al. 2000). Good planning and a clear statement of rehabilitation aims will also help in monitoring the outcomes of a rehabilitation project, since results can be measured against the objectives set in the rehabilitation plan (Rountree et al. 2009).

The spatial framework presented here can serve as a guideline for rehabilitation planning. Decisions need to be made based on assessments that affect the level in the hierarchical spatial framework appropriate for the objectives of rehabilitation. Identification of each part of the wetland at appropriate hierarchical level assists in decision-making for wetland restoration (Labadz et al. 2002). In the process of rehabilitation planning, the following six spatial scales are envisaged.

National or provincial prioritisation National or provincial policies are considered in identifying priority tertiary catchments (e.g. those that are water stressed and are experiencing reduced water security).

Quaternary catchment Within a tertiary catchment, smaller sub-catchments are identified on the basis of the broader priorities that arise from national or provincial policies and how these relate to the sub-catchment characteristics and rehabilitation opportunities. Additional local goals such as improving water quality for recreational fishing and ecotourism, may also come into play.

Wetland complex A wetland complex is a contiguous area within a quaternary catchment that displays wetland characteristics over its entire range. A wetland complex may consist of several contiguous hydrogeomorphic units, or the entire wetland consists.

HGM unit The HGM unit is the key element in the identification and typology of wetlands. In certain cases one or several HGM types might be affected by a change in land use. The allocation of a wetland to a certain HGM type is the key towards understanding what its natural functioning was and what degradation has taken place (Labadz et al. 2002).

Habitat type The habitat type is an area within a wetland where the same environmental conditions and constraints for plant growth apply. Habitat types can be described as discrete units, although it is recognized that in reality most units occur on a continuum.

Vegetation type In many cases, vegetation types coincide with habitat types within a single wetland, although some habitat types may encompass a mosaic of vegetation types.

Above the level of the hydrogeomorphic (HGM) unit, rehabilitation planning is often more specifically referred to as ‘prioritization’ (Rountree et al. 2009), whereas rehabilitation planning *sensu stricto* occurs at the level of the HGM unit or below (Kotze et al. 2009b). Three tiers are recognized in wetland monitoring and assessment programmes in the U.S., a Landscape Assessment (Tier I), a Rapid assessment (Tier II) and Intensive Site Assessment (Tier III) (Fennessy et al. 2007). The national to wetland complex scale falls within Tier I, the HGM unit within Tier II and habitat- and vegetation types generally fall within Tier III.

The planning exercise first follows through the hierarchical spatial scales to get to the wetland prioritized for rehabilitation (Fig. 1). At the broadest scale a GIS-based tool is available to apply at national or provincial scales to prioritise tertiary catchments in which to identify wetlands for rehabilitation (Rountree et al. 2009). This tool includes a range of biophysical and socio-economic criteria that may be considered important at this scale of prioritization, including: National Biodiversity Priority Areas, the distribution of Ramsar Sites, the distribution of water stressed catchments, spatial distributions of poverty levels (indicated through the Poverty Gap Index) and soil erodibility. Stakeholders that might be involved include national or provincial departments such as the Department of Water Affairs

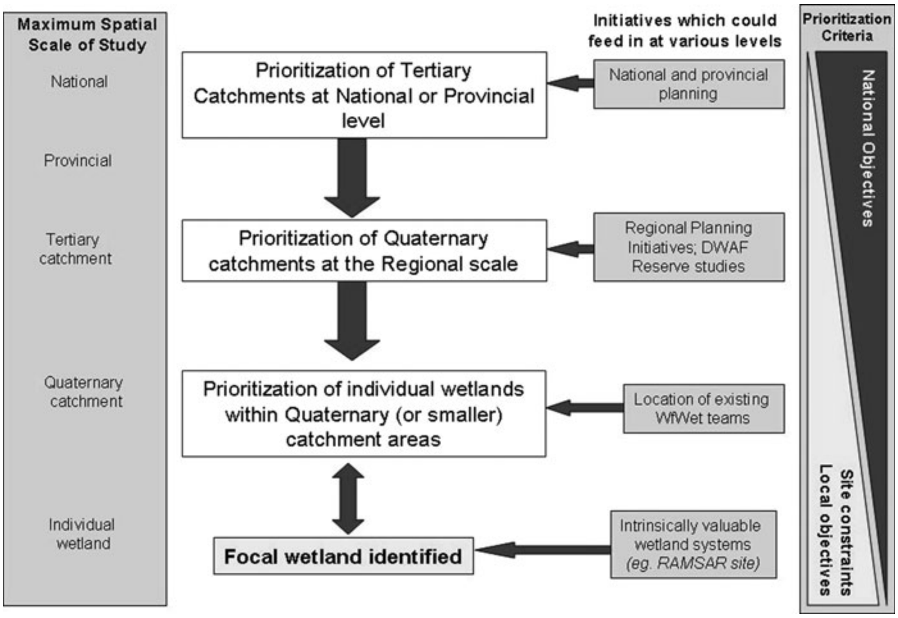


Fig. 1 The spatial scales of prioritization, from national down to individual sub-catchments to the focal (prioritized) wetland. *DWAF* Department of Water Affairs and Forestry, *WfWet* Working for Wetlands, an Expanded Public Works Programme aimed at building rehabilitation structures in many wetlands across the country (after Rountree et al. 2009)

and Forestry, the Department of Environmental Affairs and Tourism, the National Department of Agriculture and the Department of Public Works. In a country that faces severe water shortages in the near future, ecosystem services like water retention are of the highest importance (Davies and Day 1998; Postel and Richter 2003).

Once a tertiary catchment has been identified, the next step is to identify a quaternary catchment in which wetlands can be prioritized for rehabilitation. This should be done on the basis of the perceived benefits gained through improved delivery of ecosystem services by rehabilitating wetlands. It should be possible to find areas within the tertiary catchment that are likely to contribute to the achievement of catchment aims, by studying topographical and geological maps, aerial photographs and climatic data for the area. This step will yield a set of candidate wetlands for consideration for rehabilitation.

The candidate wetlands are then examined in more detail based on desktop study and field visits, in terms of the following: the extent to which the wetlands are damaged, the type of wetland and the likely impacts of rehabilitation on wetland health or provision of ecosystem services. Consideration of the rehabilitation aims and relevant ecosystem services are important when selecting the type of wetland to be rehabilitated, as can be seen from Table 3.

In order to gather the information required, it is important to undertake a field visit, supplementing the desk-top study with insights gained in the field. Final decisions about rehabilitation prioritisation need to be taken on the basis of the costs and benefits of rehabilitation, with cost-effective interventions having the highest priority. At this stage, it is often not possible to get an exact estimate of the price of intervention, but a quick assessment can be made, including planning, implementation, monitoring and maintenance costs.

A separate wetland health assessment is carried out for each HGM unit based upon the procedure of Macfarlane et al. (2009). This procedure scores the current integrity or health of the wetland hydrology, geomorphology and vegetation on a scale of 0 (no impact) to 10 (critical impact), giving the user insights into the causes of degradation, so that appropriate rehabilitation actions for each HGM unit can be devised. An assessment is also undertaken of predicted improvement in health following rehabilitation, and this is compared with the current condition.

Improvements in health are expressed on a spatial area basis, where a 10 ha wetland with a health score of 5 out of a possible score of 10, can be considered to be equivalent to 5 hectare equivalents of healthy wetland. Thus, if the wetland health can be improved to a health score of 8 out of a possible score of 10 through rehabilitation, an equivalent area of 3 hectares of healthy wetland can be considered to have been reinstated (Kotze et al. 2009b). The gains from wetland rehabilitation can then be expressed as gains in hectares of healthy wetland, which provides a "currency" for describing the ecosystem health benefits of wetland rehabilitation. It is nonetheless

Table 3 Possible criteria to prioritize wetlands within a catchment based on rehabilitation aims for a specific wetland

Ecosystem service featuring in rehabilitation aims	Possible priority wetlands
Habitat conservation	Wetlands with potential habitat for target species; wetlands within or at close proximity to nature reserves
Reducing soil loss	Wetlands in subcatchments that have steep slopes, erodible soil or a large proportion of hardened surfaces
Water quality	Wetland types which can improve water quality and are downstream of major sources of pollution
Maintenance of base flows/ Water retention	Wetlands downstream of large dams and preferably those that store large quantities of water (mostly permanent wetlands)
Flood retention	Wetlands upstream of major population centres and properties that are vulnerable to flooding
Livelihoods	Wetlands close to poverty nodes where communities harvest wetland species or are dependent on grazing or other goods and services
Cultural/Scenery	Wetlands close to National Roads or on major tourist routes, or those with high cultural values

recognized that some individual wetland-dependent species are likely to require a minimum threshold level of wetland health. If, for example, this threshold was a score of 7 then a 10 ha wetland with a health score of 5 (i.e. below the threshold) would certainly not be equivalent to 5 hectares of pristine wetland for that particular species.

Illustrating a spatial framework for planning wetland rehabilitation

Two case studies are presented: the first one focuses on priority setting on a large catchment scale to improve baseflows in a river, while the second one focuses on the conservation value of a specific habitat unit.

CASE STUDY 1: Hydrological functions in a water stressed catchment: the case of the Upper Berg River catchment in the Western Cape Province

A wetland prioritization exercise was carried out in the upper Berg River catchment in the Western Cape Province of South Africa, which illustrates the value of using a spatially explicit hierarchical approach for the pioritisation of wetlands for rehabilitation. The upper Berg River catchment is classified on a national scale by the Department of Water Affairs and Forestry as a priority catchment because of its importance for water supply for domestic and agricultural use. There are also good opportunities in the area for wetland rehabilitation since large pine plantations are being cleared from the catchment areas.

The study area consists of four Quaternary Catchments that are distributed from the upper catchment downstream along a declining rainfall gradient (Fig. 2). The catchments (and mean annual precipitation values) are G10A (1546 mm pa), G10B (1245 mm pa), G10C (994 mm pa) and G10D (640 mm pa). The first two catchments G10A (Franschhoek) and G10B (Wemmershoek) are largely montane, with the mountains consisting of Table Mountain Sandstone and the valleys underlain by granite and Malmesbury Shales. The upper catchment is vegetated by mountain fynbos. The town of Franschhoek is located in one of the valleys, which is centered in an important wine-producing region. The catchments G10C (Paarl) and G10D (Wellington) are located mostly in the lowlands on Malmesbury Shales between the granite inselbergs of the Paarl Mountain and Perdeberg. In the east these two catchments receive some runoff from the western slopes of the Wemmershoek and Klein Drakenstein Mountains. In the valleys directly next to the towns of Paarl and Wellington, wine-farming is common, whereas the gently undulating terrain towards the north is used for cultivation of crops and cattle farming.

The rehabilitation aims for the entire catchment deal particularly with the fact that a new dam is being built on the Berg River in the Assegaaiboschkloof, which is a narrow valley in the upper catchment. This will be a dam where water supply is going to be managed in a manner that is directly linked to water demand (Abe February, TCTA, pers. comm.). This means that the dam is mainly going to store water for the dry season (also the major growing season in the Western Cape), so that major flood events in winter will not be disrupted. The dam will start filling up to its full capacity at the beginning of the wet season so that baseflow will be maintained during the dry season even when abstractions are taking place. During winter there will be less regulation of flow as there is an abundant water supply at this time of the year.

Wetland rehabilitation and other catchments downstream will also play a major role in maintaining the baseflows of the Berg River. Wetlands with a strategic position that are not dependent on flood water from the main stem, but that will likely result in additional water retention and possible maintenance of baseflows, will have priority over wetlands that do not deliver such ecosystem services. Such strategic wetlands need to be looked for in tributaries that join the main stem of the river closely below the dam wall, and that receive a lot of rainfall or have a large catchment. Wetlands should have a low hydraulic conductivity, be permanent, and have a large storage capacity.

Table 4 offers an overview of health of selected wetlands that were assessed. Wetland degradation was caused by alien invasive plants in the catchment and the wetlands, timber plantations in the catchment, erosion gullies, roads, farm dams and artificial flow diversions in the wetlands. Prioritisation attempted to take the broader catchment issues into consideration, bearing in mind that the catchment has

Table 4 Wetland health assessments of selected Berg River wetlands

Wetland no.	Wetland health assessment	Wetland type	Catchment	Priority	Reason for prioritization
1	Hydrology impacted by 90%, due to location just below new dam. Geomorphology impacted by 40% due to lack of large floods caused by damming. Vegetation impacted by 75% due to predominance of pioneer plants	Floodplain	G10A	3	This wetland is located just downstream of the big dam in Assegaaiboskloof. It will have an important role in water retention downstream of the dam and securing base flows in the dry season, dependent on how much seepage is entering this wetland from neighbouring slopes, which needs to be investigated
3	Hydrology impacted by 70% and geomorphology impacted by 65% due to presence and draining effect of a major gully. Vegetation impacted by 70% due to terrestrial species encroachment resulting from drainage	Valley bottom with channel	G10B	1	This wetland is in a large catchment that feeds into the Berg River below the Wemmershoek Dam. Restoration of the wetland will ensure higher baseflows directly into the Berg River
4	Hydrology impacted by 30% due to timber plantations and upstream dam. Geomorphology impacted by 5%, due to lack of major floods caused by damming. Vegetation impacted by 35% due to timber plantations	Floodplain	G10C	(–)	This wetland is a floodplain and does not store large amounts of water
11	Hydrology impacted by 60% due to roads and farm dams. Vegetation impacted by 75%, due to terrestrial encroachment and presence of invasive grasses	Valley bottom with channel	G10D	8	This is a wetland that does not store large amounts of water
15	Hydrology impacted by 50% due to timber plantations and artificial diversion of flow. Vegetation impacted by 45%, due to seedlings of alien invasive species of *Acacia*	Valley bottom without channel	G10B	4	There is some erosion in the wetland due to the plantation and to the road going through, but the wetland is upstream from Wemmershoek Dam so any gains in water retention will be lost by evaporation from the dam
16	Hydrology impacted by 10% due to diversion of flow by ditch. Vegetation impacted by 10%, due to local terrestrial species encroachment	Valley bottom with channel	G10B	5	Similar situation as Wetland 15, but damage less extensive. Wetland upstream from Wemmershoek Dam so any gains in water retention will be lost through evaporation from the dam
17	No impacts	Floodplain	G10B	(–)	Only natural erosion occurring within this wetland

Table 4 continued

Wetland no.	Wetland health assessment	Wetland type	Catchment	Priority	Reason for prioritization
18	Hydrology impacted by 90% and vegetation impacted by 70% due to intense alien infestation	Valley bottom with channel	G10D	6	Some damage to the wetland had taken place, but the wetland had a low priority because of its place in the landscape, providing only small contributions to baseflow in the lowest reaches
21	Hydrology impacted by 70% and geomorphology impacted by 70% due to major erosion gully. Vegetation impacted by 100% due to alien invasion and manual vegetation removal	Valley bottom with channel	G10D	2	A gully was present that can continue to erode large parts of upstream intact wetland. This wetland feeds into the main stem of the Berg River and can help secure baseflows
22	Hydrology impacted by 30%, due to timber plantations. Vegetation impacted by 75%, due to predominance of pioneer species	Valley bottom without channel	G10A	7	Low priority, will probably recover by itself

Priority for rehabilitation is indicated as a number with the lowest numbers having the highest priority. (–) means that rehabilitation is not deemed necessary or possible. Cost of rehabilitation was not taken into account yet, which should happen in the next phase

been earmarked by the National Department of Water Affairs and Forestry because of its importance for water supply for domestic and agricultural use. Thus, rehabilitation aims should deal with water retention and maintenance of baseflows. The wetland types that supply water to downstream rivers or other wetlands should therefore have priority over wetlands which are more hydrologically isolated (such as pans).

The results from the overall survey indicated that a large number of wetlands with high priority are located in catchments G10A and G10B, because of the higher rainfall and larger wetlands. Thus retention of water is expected to be better, but they are also more likely to be more vulnerable to erosion since they are located on slopes in the foothills of the mountains. After the subsequent field visits prioritization focussed on assessing the health of individual wetlands before and after rehabilitation. The costs and benefits for every individual wetland rehabilitation activity were thus assessed and included in further decisions about prioritisation.

Opportunities and local support for wetland restoration are also important factors. With all other factors equal, wetland restoration on private land where farmers wish to maintain activities that damage wetlands (e.g. farm dams) should have a lower priority than wetlands where many parties can work together and where consensus exists over the rehabilitation strategies.

In this case study, wetland no. 3 was strategically the best wetland to restore (Fig. 2), because

– it is situated in a large high rainfall catchment;
– it is a large wetland and has the potential to retain a large amount of water;
– it has been badly damaged and opportunities exist for restoration because forestry companies have abandoned the catchment;
– the catchment in which this wetland is situated is downstream of the Wemmershoek Dam, so an improvement in its water retention and baseflow provision function will improve water supply to the sections of wetland and river downstream of the dam.

The difficulty however is that the gully in the wetland is very large and has incised through the entire wetland, so restoration will be an expensive exercise.

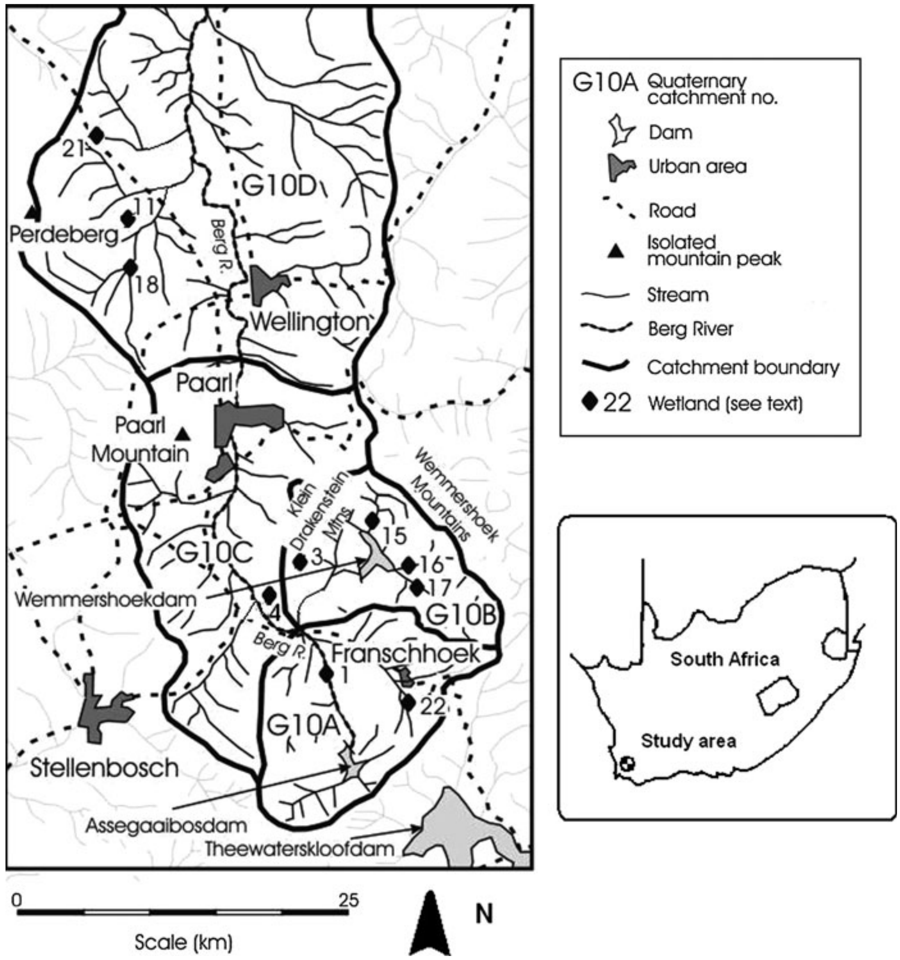


Fig. 2 Study area for the case study of the Upper Berg River Catchment

CASE STUDY 2: Biodiversity protection in a transformed landscape: selecting a habitat from available habitats in the southern Drakensberg Mountains of KwaZulu-Natal

Planning of wetland rehabilitation often does not take place down to the level of habitats because of a lack of detailed information about specific habitats occurring in a wetland and a shortage of time and specialist knowledge required for identifying and describing these habitats. When planning at an HGM scale, it is generally assumed that if the driving processes maintaining the HGM unit are secured or re-instated, then this will favour the integrity of the habitats associated with the natural condition of the HGM unit.

However, if biodiversity conservation is a priority, it may be necessary to plan and undertake rehabilitation down to a habitat scale. To illustrate this, a case study is presented of wetlands in the southern Drakensberg mountains near the town of Underberg (Walters et al. 2006). The wetlands are associated with the Pholela and Ngwangwane Rivers and are located in communal, private and government-owned land. The wetlands examined consist of floodplains with hillslope seepages extending from the outer margin of the floodplain up the adjacent slopes. The specific focus of this case study is on the floodplain HGM unit, which has been subject to the highest levels of cumulative impact and contains two main habitat types, hygrophilous grassland, found on the high-lying, temporarily saturated portions of the floodplain and *Cyperus fastigiatus* marsh, in the lower-lying, permanently saturated portions of the floodplain.

More than 85% of the hygrophilous grasslands were cultivated in the past and much of this had been abandoned over the last few decades, leaving extensive areas of secondary grassland that have established after abandonment of cultivation (Walters et al. 2006). Although not estimated accurately, a fairly limited extent of the low lying *C. fastigiatus*-dominated areas were artificially drained (probably less than 25% of these areas). Some of these drained areas were rehabilitated approximately 15 years ago by blocking the drains. An examination of the species composition of these areas showed them to very closely resemble the species composition of similar undrained areas, demonstrating recovery with respect to vegetation composition (Walters et al. 2006). This contrasts with the situation in slightly more elevated hygrophilous grassland in the same wetlands that were not as greatly altered hydrologically as the low-lying areas. Although the height and cover of the secondary hygrophilous grasslands in formerly drained areas is not markedly different to the virgin situation, their compositional integrity has been altered considerably (Walters et al. 2006). The richness of indigenous plant species (measured in 2 m radius quadrats) was found to be 36% less in secondary grassland compared with virgin grassland, demonstrating that only partial recovery had occurred (Walters et al. 2006). This is the case despite the fact that some of the hygrophilous grassland areas have not been cultivated for over three decades.

Therefore, if the objective of rehabilitation is to maintain the habitat integrity of the wetland as a whole, then a reasonable amount of each habitat in a high integrity state needs to be secured. This has already been comfortably achieved in the case of *C. fastigiatus* marsh, but falls very far short for hygrophilous grassland. Therefore, the focus of conservation and rehabilitation action should be on securing existing patches of high integrity hygrophilous grassland, and managing these appropriately.

Conclusions

The type of measures that should be taken during wetland rehabilitation depends on the scale at which a problem occurs. When setting up a rehabilitation plan for a wetland it is important to consider these scales and plan accordingly. A conceptual model of different units that occur at different scales in wetlands can be a powerful tool during rehabilitation planning. Different questions arise at different levels of the spatial framework, and the spatial framework provides a systematic way of dealing with these issues.

Every issue that arises in a specific context around rehabilitation needs to be seen from the corresponding level in the spatial framework, and different ecosystem services play out at different levels within the spatial framework. In general, one can say that concerns about hydrology are mostly dealt with at a high level in the spatial framework, whereas concerns about biodiversity play out at both the coarse- and fine scales in the spatial framework. Restoration of the original biodiversity can often be regarded as the most ‘ambitious’ form of restoration (Lockwood and Pimm 1999) and in the context of developing countries with high levels of poverty, restoration efforts often do not go to the level of detail (and the expenses) that is necessary for such interventions. Restoration efforts aimed at other ecological services, however, also contribute to a healthier ecosystem and to the well-being of people living around wetlands. This is why ecosystem services provide a valuable perspective towards wetland restoration and provides a wider angle on viewing ‘success’ in wetland rehabilitation. In a country like South Africa, every success has to be measured against the social background of the community in the catchment and government is most likely to fund projects aimed at poverty relief, job creation or sustaining natural resources for rural communities. The decision making tools provided by the Wetland Management Series provide an interesting perspective on wetland restoration accommodating both the detailed and expensive types of restoration aimed at the level of the plant community, as well as restoration aimed at broad-scale processes within the entire catchment such as water retention.

Overall, scale is an important aspect within a conceptual model of wetlands, and many recent papers dealing with wetland ecology are considering aspects of scale, whether it is about floodplains (Ward 1998), palustrine coastal wetlands (Rolon et al. 2008), or inland pans and valley bottom wetlands (Tooth and McCarthy 2007). Landscape attributes are also mentioned as an important aspect in restoration ecology (Aronson and Le Floc’h 1996; Mitsch and Wilson 1996) and the decision making framework as it was developed in South Africa (Dada et al. 2007) provides an example of how hierarchical scaling (O’Neill et al. 1986) can be integrated into a decision-making tool for wetland rehabilitation.

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