



water & forestry

Department: Water Affairs & Forestry **REPUBLIC OF SOUTH AFRICA** 



Free State River Health Programme

# **PREFACE**

The Free State Department of Tourism, Environmental and Economic Affairs, as with most other organizations, consists of numerous directorates and sub-directorates, each responsible for the execution of its specific line-functions. Some are responsible for law enforcement, while others are involved in EIA's, environmental education, research, conservancies and so on. These directorates and sub-directorates are collectively responsible for the conservation of the province's natural resources, including wetlands. As it is, wetland related questions are frequently directed to the Biodiversity Research sub-directorate for specialist input. This led to the idea of compiling a "one stop" departmental wetland reference manual from which most of the information usually requested can be obtained - this document is the result of that idea.

In addition to serving as a general wetland reference manual, it was also developed as a product of the Free State wetland policy which identifies five strategies and associated actions to promote wetland conservation in the Free State province. These include involving other government departments and private organisations and institutions in the wetland conservation effort, and also making wetland related information more accessible to a wider audience than is currently the case. It is often a lack of information and knowledge that prevents various organisations from being involved in the first place, and it is hoped that this document will to some extent address this deficiency.

I hope that this document will:

- Generate a wider interest in wetland conservation.
- Stimulate individuals and organisations to get involved in wetland conservation.
- Initiate various wetland conservation programmes and projects.

Over the past few years many people have contributed towards our current understanding and knowledge of wetlands in South Africa. This document consists mostly of the work of these people which has simply been collated. Credit for this document should therefore go to all these individuals, many of whom are referred to herein.

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In addition to general comments, Dr. P.A.L le Roux also contributed towards the contents of the section relating to wetland soils.

The compilation of such a document is a tedious and time consuming process. The process is such that a lot of work is done with very little to show until the final product is released. The patience and support received from my supervisors, Dr. D.B. Müller and Mr. P. de Villiers, is acknowledged and greatly appreciated.

A special word of thanks to the Department of Water Affairs and Forestry, and specifically to Me. G. Venter, for supporting this wetland initiative as part of their role of ensuring that wetlands are protected, used, developed, conserved, managed and controlled in ways that give effect to the National Water Act (Act 36 of 1998). Also, while I do take full responsibility for any errors that may still be present in the document, the effort of Mr. B.D. Colahan, who read and corrected the manuscript, is also acknowledged and appreciated.

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# 1. WHAT IS A WETLAND?

# Introduction

The word wetland usually conjures images of areas with tall reeds, open water and lush green vegetation. Although this image is true for the typical **floodplain** type wetland, this is just one of a variety of wetland types.

The term "wetland" is a generic term for all the different kinds of habitats where the land is wet for some period of time each year, but not necessarily <u>permanently</u> wet. Water which falls as rain or snow in the <u>catchment</u>, and which is not lost to the atmosphere through <u>evaporation</u> or <u>transpiration</u>, moves through the catchment to the sea. Wetlands are found where the landform (topography) or geology slows down or obstructs the movement of water through the catchment (e.g. where the landform is very flat), or where groundwater surfaces causing the surface soil layers in the area to be <u>temporarily</u>, <u>seasonally</u> or permanently wet. This provides an environment where particular plants (<u>hydrophytes</u>) that are adapted to wet conditions tend to grow in abundance. The plants in turn affect the soil and <u>hydrology</u> (e.g. by further slowing down the movement of water and by producing organic matter that may accumulate in the soil).

Many wetlands therefore occur in areas where surface water collects and/or where underground water (also referred to as **groundwater** or subsurface water) discharges to the surface (commonly referred to as seeps, springs or fountains), making the area wet for extended periods of time. Other wetlands occur along our coasts, such as estuaries and sometimes even coral reefs.

The term wetland therefore refers to aquatic systems that can be permanently **<u>saturated</u>**, as well as areas that occur at the other extreme, i.e. areas that are rarely saturated. Because wetlands occur between these extremes, they are often viewed as "transitional" **<u>ecosystems</u>** that share characteristics of both the wetland and non-wetland habitats.



**Figure 1:** Cross section through a valley bottom wetland, indicating how the soil wetness and vegetation <u>indicators</u> change as one moves along a gradient of decreasing wetness, from the permanent wet hydrological zone to the temporarily wet hydrological zone and eventually into non-wetland (Department of Water Affairs and Forestry, 2003 as adapted from Kotze, 1996).

It can therefore be concluded that a wetland is "wet land". However, not all land that is wet is necessarily a wetland, and not all land that is not wet is necessarily non-wetland. The real question is therefore: When is wet land a wetland?

For South Africa the definition of a wetland as defined by the <u>South African Water Act</u> is accepted and applied. The South African Water Act defines wetlands as:

"land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which in normal circumstances supports or would support vegetation typically adapted to life is saturated soil"

It is important to note from this definition that even drained wetlands of which the water table is no longer at, or near, the surface, or of which the land is no longer periodically covered with shallow water, are still considered to be wetlands.

The above definition, as do most other definitions of wetlands, contains three important concepts that define a piece of land as a wetland. These are:

- **Hydrology** This implies that the land is covered by water, or has saturated soil at some time when the soil is biologically active<sup>1</sup>. Saturated soil is that which contains sufficient water for long enough for reduction to occur.
- Saturated (reduced) soil This implies that the soil is <u>hydric</u>. Hydric soil means that the soil has been depleted of oxygen through the chemical process of <u>reduction</u>, which in turn results in the presence of <u>redoximorphic features</u>, e.g. features formed by the process of reduction, translocation and oxidation of Fe and Mn oxides.
- Hydrophytic vegetation This plant life is adapted to growing in saturated soils. Some plants have adapted to life in wetlands and are called <u>hydrophytes</u> (this means that they are "water loving", or rather, anoxia tolerant). These specialized plants have adapted to grow in the anaerobic conditions of hydric soils.

### A piece of land is therefore a wetland when the period of saturation is sufficient to allow for the development of hydric soils which in normal circumstances support, or would support, hydrophytic vegetation.

Wetlands are therefore land areas that exhibit at least one of the three essential characteristics, namely:

- wetland hydrology,
- hydric soils, or
- hydrophytic vegetation.

Application of these characteristics to identify wetlands is often troublesome. Wetland hydrology is the reason for the wetland being there in the first place. The difficulty with identifying wetlands by their hydrology is that the water it is not present all year round. Some wetlands or portions of wetlands may be wet all year round, but in most instances this is not the case. Most wetlands, or portions of them, are wet for only relatively short periods (please refer to the discussion on <u>hydrological zones</u>). The development of hydric soils and establishment of hydrophytic vegetation are the consequences of water being present for a sufficiently long period at some time when the soil is biologically active. Hydric soils and hydrophytic vegetation are therefore indirect indicators of wetland hydrology, indicating that at some stage the area is sufficiently wet for these characteristics to develop.

Application of the hydrophytic vegetation characteristic is also not without problems. When is a species considered to be hydrophytic? (Please refer to the discussion on <u>hydrophytes</u>). Some species are widely known to be hydrophytic, e.g. the common reed *Phragmites australis* and bulrush *Typha capensis*. However, many other species which are usually considered to be upland (non-wetland) species are actually also hydrophytes. Such species occur less frequently in wetland environments than those typically associated with wetlands. The definition of a hydrophytic species is therefore a complex one which involves the concept of the frequency with which such species are associated

<sup>&</sup>lt;sup>1</sup> Wetland definitions usually require saturated soil to be present during the "active growing season". Because of difficulty in defining when the "active growing season" is and is not, it was substituted by the phrase "when the soil is biologically active".

with wetlands, i.e. are they always, or only occasionally associated with wetlands. Subsequently no official list of hydrophytic vegetation for South Africa exists, which makes application of the hydrophytic vegetation criterion difficult. To complicate matters even further, vegetation is quick to react to changes in hydrology, so that the vegetation being measured is not always representative of the natural hydrological regime as it would be under normal circumstances (e.g. non-wetland species will dominate a drained wetland which under normal circumstances would have been dominated by hydrophytic vegetation).

It is because of the above-mentioned problems in applying the hydrological and hydrophytic vegetation criteria that much more emphasis is placed on identifying wetlands by applying the hydric soils criterion. Also, unlike the vegetation which changes with an altered hydrological regime, the morphological indicators of a hydric soil are relatively permanent. Hydric soils are therefore suitable to identify land which "in normal circumstances supports or would support vegetation typically adapted to life in saturated soil" as per the Water Act.

In practice, therefore, wetlands are usually identified by applying the hydric soils criterion, while the hydrological and hydrophytic vegetation criteria are mostly used to confirm the finding of the hydric soils criterion.

## Wetland soils

How does the soil become anaerobic (hydric)?

The spaces between the soil particles of non-wetland soils are under normal circumstances filled mostly with air (and some water). Plant roots and other microbes are biologically active within these spaces of the soil profile. Oxygen is used during this activity, but because the pores are connected to the atmosphere, the oxygen that is used by the organisms is readily replaced. In wetlands (<u>saturated</u> soils) the spaces between the soil particles are filled mostly with water (and some air) so that these spaces are not connected to the atmosphere. The biological activities use the oxygen initially present within the soil, but this is not replaced because it is sealed off from the atmosphere by the water (oxygen diffuses much more slowly through water than through air). The soil subsequently becomes depleted of oxygen, i.e. it becomes anaerobic, and this causes the soil to become reduced.

#### Requirements for redox reactions to occur

Four conditions are needed for a soil to support the process of redox reactions (Richardson and Vepraskas, 2001):

- The soil must contain organic tissue that can be oxidised or decomposed (source of electrons, e<sup>-</sup>).
- The soil must be saturated or inundated to exclude atmospheric oxygen (O<sub>2</sub>).
- An active microbial population that is oxidizing (decomposing) the organic tissue.
- The water should be stagnant or moving slowly.

What is reduction?

(Unless indicated otherwise, all text and images are from Vepraskas).

Reduction is the result of bacteria decomposing organic material. Saturation or inundation is required to keep the atmospheric oxygen out of the soil. In an aerobic soil that is moist but not saturated, bacteria consume and reduce  $O_2$  in air-filled soil pores during the decomposition of organic tissue. Anaerobic soils are saturated such that most pores will be filled with water. Bacteria in these soils consume the  $O_2$  dissolved in the soil water as they decompose the organic matter; when the dissolved  $O_2$  is gone, the soil water is said to be reduced. Exclusion of atmospheric oxygen is probably the most important factor determining whether or not reduction occurs in a saturated soil. As bacteria continue to decompose the organic matter, they also produce organic chemicals that can reduce nitrate, and also manganese and iron oxides, and eventually sulphur and carbon (Vepraskas, 1995). Moving water, either in the form of groundwater or flood water retards the onset of reduction, particularly Fe reduction. The moving water apparently carries oxygen through the soil - while the water is in motion, its oxygen is difficult to deplete (Richardson and Vepraskas, 2001).

A complete redox reaction consists of an oxidation and a reduction reaction called *half-reactions*. When we normally refer to reduction, i.e. "for an area to be considered a wetland the soil must have been reduced", we are actually referring to both the half-reactions of oxidation and reduction of the redox reaction, and not just to the half-reaction of reduction only (as they occur simultaneously under natural conditions). Redox reactions are more easily understood when the oxidation and reduction processes are considered separately. This is appropriate because oxidation and reduction and reduction processes each produce different effects on the soil (Richardson and Vepraskas, 2001). To better understand the redox reaction and its influences, the half-reactions will be considered under both aerobic and anaerobic conditions.

Redox reactions in aerobic soils Oxidation in aerobic soils

- The loss of one or more electrons from an atom is known as oxidation (Richardson and Vepraskas, 2001). Oxidation therefore produces electrons when two things are present, these being:
  - Organic matter; and
  - o Bacteria.



• Electrons are produced when the organic matter is eaten by the bacteria.



Reduction in aerobic soils

The gain of one or more electrons by an atom is known as reduction [because the addition of negatively charged electrons reduces the overall valence of the atom (i.e. in its oxidised state iron will be Fe<sup>3+</sup>, but once reduced it will have accepted an electron and it will have become Fe<sup>2+</sup>] (Richardson and Vepraskas, 2001). Reduction as a chemical process involves the reaction of the electrons (e<sup>-</sup>) with oxygen (O<sub>2</sub>) and hydrogen (H<sup>+</sup>) to produce water (H<sub>2</sub>O).



Redox reaction in aerobic soils

• The redox reaction is when both oxidation and reduction occur simultaneously, as they do under natural conditions.



• When O<sub>2</sub> is present within the soil, all the electrons produced by the organic matter is grabbed by the O<sub>2</sub> to produce water (H<sub>2</sub>O).

Redox reactions in anaerobic soils Oxidation in anaerobic soils

 In waterlogged soils O<sub>2</sub> does not enter the soil because it is sealed of by the column of water.

AND

- The organic matter continues to decompose in the waterlogged soils, i.e. it continues to be oxidized and give off electrons.
   BUT
- The electrons produced are grabbed by NO<sub>3</sub><sup>-</sup>, MnO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, SO<sub>4</sub><sup>2-</sup> and CO<sub>2</sub> instead of by O<sub>2</sub>.

Redox reaction in anaerobic soils

• Where O<sub>2</sub> is absent, NO<sub>3</sub>, MnO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, SO<sub>4</sub><sup>2-</sup> and CO<sub>2</sub> are reduced instead of O<sub>2</sub> (as is the case during the aerobic reduction half-reaction).



• Reduction during the anaerobic half-reaction involves the reaction of the electrons with  $NO_3^-$ ,  $MnO_2$ ,  $Fe_2O_3$ ,  $SO_4^{2-}$  and  $CO_2$  instead of  $O_2$  to produce water (H<sub>2</sub>O).

# $Fe_2O_3 + 4e^- + 6H^+ \longrightarrow 2Fe^{2+} + 3H_2O$

Iron oxide (Red solid) Reduced iron (Colorless in solution)

The elements within the soil that can be reduced are not reduced randomly, but are reduced in sequence, with  $O_2$  (oxygen) being reduced first, thereafter  $NO_3^-$  (nitrate), manganese oxides ( $Mn^{3+}$  and  $Mn^{4+}$ ) and then Fe<sup>3+</sup> oxides. The Fe oxide will not be

reduced until after the  $O_2$ ,  $NO_3^-$ , and Mn oxides that occur near the Fe oxides, have been reduced. After all the iron is reduced,  $SO_4^{2^-}$  (sulphates) and then  $CO_2$  (carbon dioxide) will be reduced. A soil is considered to be reduced only after the reduction of  $Fe^{3+}$  (resulting in  $Fe^{2+}$ ) has occurred rather than simply the depletion of oxygen, and for a piece of land to be considered a wetland,  $Fe^{3+}$  must have been reduced to  $Fe^{2+}$ (Vepraskas, 1995).

Chemical element	Oxidized form	Reduced form
Nitrogen	$NO_3^{-}$ (Nitrate)	N <sub>2</sub> O, N <sub>2</sub> , NH <sub>4</sub> <sup>+</sup>
Manganese	Mn <sup>4+</sup> (Manganic)	Mn <sup>2+</sup> (Manganous)
Iron	Fe <sup>3+</sup> (Ferric)	Fe <sup>2+</sup> (Ferrous)
Sulphur	SO <sub>4</sub> <sup>2-</sup> (Sulphate)	H <sub>2</sub> S (Sulphide)
Carbon	CO <sub>2</sub> (Carbon dioxide)	CH <sub>4</sub> (Methane)

**Table 1:** Oxidized and reduced forms of elements (Mitch and Gosselink, 2000).

Chemical element	Reduction	Reduction reaction (gain of electrons)
Oxygen	$O_2 \rightarrow H_2O$	$O_2 + 4e^- + 4H^+ \rightarrow 2H_2O$
Nitrogen	$NO_3^- \rightarrow N_2O, N_2, NH_4^+$	$2NO_3^{-} + 10e^{-} + 12H^+ \rightarrow N_{2+} 6H_2O$
Manganese	Mn <sup>4+</sup> → Mn <sup>2+</sup>	$MnO_2 + 2e^- + 4H^+ \rightarrow Mn^{2+} + 2H_2O$
Iron	$Fe^{3+} \rightarrow Fe^{2+}$	$Fe_2O_3 + 4e^- + 6H^+ \rightarrow 2Fe^{2+} + 3H_2O$
Sulphur	$SO_4^{2-} \rightarrow H_2S$	$SO_4^{2^-}$ + $8e^-$ + $9H^+ \rightarrow HS^-$ + $4H_2O$
Carbon	$CO_2 \rightarrow CH_4$	$CO_2 + 8e^{-} + 8H^{+} \rightarrow CH_4 + 2H_2O$

Table 2: Reduction reactions of elements (Mitch and Gosselink, 2000).

What is the significance of reduction?

In oxidized subsoil horizons, Fe oxide minerals give the horizons red, brown, yellow, or orange colours, depending on which Fe minerals are present. Manganese oxide minerals produce metallic black colours. The Fe and Mn oxides tend to coat the surfaces of <u>sand</u>, <u>silt</u>, and <u>clay</u> particles. Without the oxide "paint" on the surfaces, these soil particles are grey. The red, brown, yellow, and orange colours occur when Fe is in its oxidised state (Fe<sup>3+</sup>) and black colours also occur when Mn is in its oxidised state (Mn<sup>3+</sup> or Mn<sup>4+</sup>). Where these elements are reduced, several events happen (Vepraskas, 1995):

- Fe and Mn oxide minerals (Fe<sup>3+</sup> and Mn<sup>3+</sup> or Mn<sup>4+</sup> respectively) are reduced to become Fe<sup>2+</sup> and Mn<sup>2+</sup>. Fe<sup>2+</sup> and Mn<sup>2+</sup> are colourless and also soluble.
- Once soluble, the Fe<sup>2+</sup> and Mn<sup>2+</sup> ions diffuse within the soil horizon, move within the soil to other soil horizons or may be leached from the soil.
- With the Fe<sup>2+</sup> and Mn<sup>2+</sup> ions now being colourless and soluble, the natural grey colour of the soil particles is exposed so that the colour of the soil changes to grey.
- Where Fe<sup>2+</sup> and Mn<sup>2+</sup> are oxidized back to Fe<sup>3+</sup> and Mn<sup>3+</sup> or Mn<sup>4+</sup> respectively, they reappear as redox concentrations, mostly as mottles (Plate 3).

It follows that when Fe and Mn are in their reduced form, they have much less colouring effect on soil than when they are in their oxidised forms (because they are soluble they wash off from the soil particles and even if they do not, they are now mostly colourless). The grey soil colour is produced mainly by the natural colour of sand, silt, and clay

particles, although Fe<sup>2+</sup> may also have some colouring effect (Ponnamperuma, 1972 in Vepraskas, 1995).

Characteristic	Oxidised (Fe <sup>3+</sup> , Mn <sup>4+</sup> , Mn <sup>3+</sup> )	Reduced (Fe <sup>2+</sup> , Mn <sup>2+</sup> )
Soluble	No	Yes
Colourless	No	Yes

**Table 3:** The characteristics of Fe and Mn under oxidized and reduced conditions.



**Figure 2:** A schematic representation of the reduction of Fe<sup>3+</sup> and its visual effect on the soil particles which now appear grey due to the transparent and soluble properties of Fe<sup>2+</sup>.

It is easiest to grasp the concept and consequences of reduction by imagining the soil particles as a red Smartie (Figure 2). The dark chocolate inside being the natural grey colour of the soil (the soil particle), with the red sugar coating being the layer of red oxidised iron (Fe<sup>3+</sup>). When the Smartie is dropped into water and one assumes that the water is depleted of oxygen (anaerobic), then the red sugar coating is dissolved and subsequently removed so that the dark chocolate interior becomes visible. Similarly, when the soil is saturated for a long enough period for it to become anaerobic and subsequently reduced, the red layer of iron oxide (Fe<sup>3+</sup>) becomes soluble (Fe<sup>2+</sup>) so that it is removed from the surface of the soil particle and also becomes colourless, resulting in the grey soil particle becoming visible. The O<sub>2</sub> arrow in Figure 2 indicates that the Fe<sup>2+</sup> can once again become visible when oxidised (<u>Plate 5</u>).

### Hydric soil indicators

Redoximorphic features

For an area to be considered a wetland, redoximorphic features must be present within the upper 500 mm of the soil profile. Redoximorphic features are the result of the reduction, translocation and oxidation (precipitation) of Fe and Mn oxides and are recognized as (Vepraskas, 1995):

- A reduced matrix.
- Redox depletions.
- Redox concentrations.

The reduced matrix, the redox depletions and redox concentrations are considered to be <u>hydric soil</u> indicators, i.e. indicators that the soil has been reduced in the past.

Reduced matrix: The reduced matrix is characterised by an *in situ* low <u>chroma</u> because of the presence of Fe<sup>2+</sup> (or rather the absence of Fe<sup>3+</sup>) which is recognised by the relative "grey" colours of the soil matrix (Vepraskas, 1995). When exposed to air, the colour of the soil changes as the Fe<sup>2+</sup> is oxidised back to Fe<sup>3+</sup> (<u>Plate 1 & Plate 5</u>).

For a soil to qualify as having signs of wetness in the temporary, seasonal or permanent zones, the reduced matrix must have low chroma values. Contrary to the U.S. which specifies a chroma of 2 or less (Soil Survey Staff, 1999), the Soil Classification Working Group (1991) specifies for South African conditions that a reduced matrix (or redox depletion) is defined as a grey colour with chroma equal to or less than 4. When the chroma is  $\leq$ 4, then (Vepraskas):

- ◊ Soil particles have "no" Fe oxides on their surfaces, and
- ♦ The soil may be reduced for "significant" periods.

When chroma is >4, then (Vepraskas):

- ♦ Soil particles have some Fe oxides on their surfaces.
- ◊ The soil may be reduced for "short" periods, but
- ♦ May be saturated for significant periods.
- **Redox depletions:** Redox depletions are the "grey" (low chroma) bodies within the soil where Fe-Mn oxides have been stripped out, or where both Fe-Mn oxides and clay have been stripped. These are recognised by low chroma bodies (chroma as described for the reduced matrix) with high values (≥4). Two types of redox depletion are recognised, these being (Vepraskas, 1995):
  - Iron depletions: Iron depletions are similar in colour to a reduced matrix, but the area of reduction is limited to <u>ped</u> surfaces in structured soils (<u>Plate 2</u>) and grey mottles in structureless soils. The ped surface therefore typically has a low chroma (because of the absence of Fe<sup>3+</sup>), while the matrix of the ped has a higher chroma (more bright colours). The ped surface (grey) and ped matrix (bright coloured areas) therefore differ primarily in their iron content. When the soil matrix has colouring as described for the reduced matrix, it can be considered an *iron depleted matrix*. Other than for the reduced matrix, because the matrix has been depleted of Fe<sup>2+</sup>, its colour will not change when exposed to oxygen as there is no Fe<sup>2+</sup> to be oxidised back to Fe<sup>3+</sup>.
  - Clay depletions: Clay depletions in hydric soils occur where the silicate clay minerals are decomposed and the elementary chemical components are

removed by leaching. These areas therefore contain less iron, manganese and clay than the adjacent soil.

- **Redox concentrations:** Accumulation of iron and manganese oxides (also called mottles) and can occur as (Vepraskas, 1995):
  - <u>Fe-Mn concretions</u>: Firm, to extremely firm, irregularly shaped bodies with diffuse boundaries (<u>Plate 3</u>). Concretions with sharp boundaries are considered to be relict, while those with diffuse boundaries are still forming (Vepraskas).
  - Mottles: Mottles are soft bodies, mostly within the matrix, with variable shape and are recognized as blotches or spots of high chroma colours, e.g. red and yellow, of varying size (<u>Plate 3</u>).
  - Pore linings: Pore linings are zones of accumulation that may be either coatings on a pore surface, or impregnations of the matrix adjacent to the pore (Vepraskas, 1995). They are recognized as high chroma colours that follow the route of plants roots, and are also referred to as oxidised rhizospheres (Plate <u>4</u>).

Soils that contain <u>redoximorphic features</u> are also termed <u>gleyed</u> soils.

#### Alpha-alpha-dipyridyl

Soils that are saturated and reduced at the time of sampling may contain iron in the ferrous form (Fe<sup>2+</sup>). One way to test for reduced conditions is to use alpha-alpha-dipyridyl (also referred to as  $\alpha, \alpha'$ Dipyridyl or 2,2'Dipyridyl), a colourless chemical dye that turns pink in the presence of ferrous iron. To use in the field, the chemical is dropped or sprayed onto a freshly exposed soil sample and the colour change, if positive, will occur within a few seconds.



**Figure 3:** Alpha-Alpha-Dipyridyl turning pink after it has been dropped onto a reduced piece of soil containing ferrous iron (Fe<sup>2+</sup>).

However, it is important to note that in spite of its apparent value as an indicator of  $Fe^{2+}$ , certain situations may produce false negative or false positive readings, these being:

- Organic and sandy soils (Tiner, 1999) which are low in iron content may produce false negative readings.
- The presence of some iron species, e.g. hematite, which bond more strongly and require more energy to break than the Fe-O bond (Hunall & Szögi, 1996 in Tiner, 1999). The presence of such iron species will result in a false negative reading.
- A false positive reading may result where the soil being sampled was in close contact with steel spades, augers, probes or knives (Childs, 1981).
- A false positive reading may result if the soil was previously in contact with 10% hydrochloric acid, to test for carbonates (Childs, 1981).

In spite of the above-mentioned problems, the use of alpha-alpha-dipyridyl as an observed reduction test is recommended. The grey matrix colour and high organic content already indicate a reduced soil condition and conditions of false positive tests can be prevented. It should be noted that alpha-alpha-dipyridyl is useful only for indicating the presence of reduced soil matrix conditions **at that time**. It does not provide an indication of the degree of wetness (hydrological zones), that is, the frequency at which reduction occurs, or the duration of such events.

### Hydrological zones

As mentioned previously, because of the landscape in which wetlands usually occur, the hydrological regime is not constant throughout the entire wetland. Consider a typical floodplain wetland located within a valley bottom. Depressions could be present within this valley bottom wetland of which the soil surface is below the water table; they are therefore permanently saturated (wet even in the dry winter months). As one moves from these depressions towards the surrounding upland, the general trend will be to move along an incline from the valley bottom towards the foot slopes of the catchment. Flooding of the perimeter areas of the floodplain will therefore be dependent on the extent of flooding (volume of water per unit of time). During high runoff events, these areas will be flooded, and conversely, during low runoff events they will not be flooded. Consequently the period of flooding, which affects the development of reduced soil conditions, will also be shorter than for the lower lying areas. It can be concluded that within this wetland there exists a hydrological gradient ranging from permanent saturation at its deepest end, to periodic saturation at its shallowest end. At some point within this hydrological gradient the average period of saturation of the soil will be insufficient for this area to develop reduced soil conditions, and to therefore be classified as a wetland.

There are thus regions which range from those which remain permanently flooded and/or saturated for the entire year (permanently saturated) to those which are flooded and/or saturated for 5-11 months of the year (seasonally saturated), or saturated at or close to the soil surface for 1-5 months (temporarily saturated) in the year, but still long enough to develop reduced soil conditions. These areas of different duration of reduced soil conditions are referred to as hydrological zones. Depending on the hydrology, a wetland can possess all three hydrological zones (permanent, seasonal and temporary), any two of them, or only one (Figure 4).

The hydrological zones are recognised by the presence of <u>redoximorphic features</u> within the soil matrix, but are distinguished from one another by the relationships in which they occur. From <u>Figure 1</u> it can be seen that the redox concentrations (mottles: the red, yellow and black spots) are close to the soil surface in the seasonal and temporary wet

zones of the wetland, while they are much deeper in the soil profile in the non-wetland area. These mottles are absent or far fewer in the permanent wet area due to these areas being mostly void of oxygen (because of the relatively permanent presence of water) so that oxidation of the colourless  $Fe^{2+}$  to  $Fe^{3+}$  does not occur as readily as in the temporarily and seasonally wet soils. <u>Plate 4</u> is soil from a permanently wet hydrological zone where no oxidation of  $Fe^{2+}$  occurred due to the lack of oxygen. It is only the root canals that show signs of oxidation (redox concentrations: pore linings).



Figure 4: Vegetation differences indicating the different broad hydrological zones of a typical valley bottom wetland.

The significance of reduction and the resulting redox concentrations and redox depletions in defining a wetland is that it is only once the soil of a piece of land displays these <u>redoximorphic features</u> within the upper 500mm, that it is classified as being a wetland.

Wetlands are more about the lack of oxygen and subsequent reduction than about the abundance of water.

Soil characteristics (master and diagnostic horizons)

Soil forming processes are such that different horizons tend to develop within the material upon which it is operating (Soil Classification Working Group, 1991). Of importance is that specific horizons develop under specific soil-forming environments (Soil Classification Working Group, 1991). This implies that horizons which developed under reduced conditions, will display similar morphological features and characteristics which will be different from the morphological features and characteristics displayed by

horizons that developed under oxidized conditions. These horizons can be distinguished from one another and are referred to as master horizons (Figure 5). It is important to note that not all of the indicated horizons are necessarily present in all wetland soils.



Figure 5: Illustration of an idealized soil profile showing the different master horizons that are often (but not always) found in wetland (hydric) soils.

Master horizon:

- O An organic horizon which occurs on the surface of some wetland soils due to the accumulation of organic material under saturated conditions.
- A A mineral horizon which occurs on the surface or underneath an O horizon and which is comprised of mineral particles that are to a greater or lesser degree interspersed with organic material.
- E A bleached, sandy mineral horizon which occurs under an A horizon.
- B A mineral horizon occurring underneath the A or E horizon which is characterized by a bright colour, and an accumulation of clay or lime (carbonate).
- G A mineral horizon lying under an A or E horizon and with clear signs of redoximorphic features.
- C A mineral horizon occurring under the deepest B horizon, or which does not display any characteristics of the other master horizons.

Please also refer to the Soil Classification Working Group (1991) book for more detailed descriptions and definitions of the above-mentioned master horizons.

Soil Classification, a taxonomic system for South Africa, accommodates redoximorphic features in several diagnostic horizons (Soil Classification Working Group, 1991). The diagnostic criterion is a grey colour in the dry state. Diagnostic horizons that are characterized by redoximorphic features are:

- E horizon.
- G horizon.
- Soft or hard plinthic B horizons.
- Unspecified or unconsolidated material with signs of wetness in the C horizon.

The A, B and C master horizons are subdivided into diagnostic horizons. Diagnostic soil horizons have definitions developed to specifically include certain material and characteristics, while deliberately excluding others. The term "signs of wetness" is used as an equivalent for redoximorphic features. Figure 6 provides a schematic presentation of the master horizons and their diagnostic horizons that contain redoximorphic features (Soil Classification Working Group, 1991).



Figure 6: A schematic presentation of the master horizons and their diagnostic horizons that contain redoximorphic features (taken and adapted from the Soil Classification Working Group, 1991). Orthic A, melanic A and vertic A horizons may contain signs of wetness.

Diagnostic horizons with redoximorphic features

The presence/absence of diagnostic horizons and the sequence in which they occur determines the soil name (i.e., the soil form, e.g., a Katspruit, Kroonstad, Longlands, etc.) (Soil Classification Working Group, 1991). Diagnostic soil horizons have similar properties which reflect on similar soil-forming environments. All soil forms with e.g. a soft plinthic B horizon therefore developed under a <u>water regime</u> of periodic

saturation (a fluctuating water table). Soil forms with redoximorphic features therefore imply reduced conditions.

A reduced matrix is characteristic of the E and G horizons. The E horizon of the podzols is an exception as the grey colour of these E horizons is the result of podzolization and not reducing conditions. Redox depletions and concentrations may occur in all of the diagnostic horizons mentioned above but it dominates the morphology of soft and hard plinthic B horizons as mottles, and often also concretions (Soil Classification Working Group, 1991).

Soils with horizons or materials with redoximorphic features are common in the semiarid and wetter regions of South Africa. Soft plinthic B horizons fades out on the border between arid and semi-arid climates. E and hard plinthic B horizons are only reported under slightly wetter conditions. G horizons and materials with signs of wetness are also found in isolated localities, like pans, in arid areas (Le Roux, pers. comm.)<sup>2</sup>.

#### <u>E horizon</u>

E horizons are typically sandy (Le Roux *et al.*, 1999) and may be saturated for a month or longer in high rainfall areas (Van Huyssteen *et al.*, 2005). In the dry semiarid regions, which are the driest areas in which they occur in South Africa, they are probably only saturated for one month or longer during the two wettest years out of ten. Although the water of the E horizon drains away relatively quickly, the soil is sufficiently saturated during this period to become reduced (Le Roux, pers. comm.).

#### G horizon and material with signs of wetness

G horizons and material with signs of wetness usually have a relatively high clay content. On average G horizons may be saturated for 5 or more months of the year in high rainfall areas, and unspecified materials with signs of wetness for a week or more (Van Huyssteen *et al.*, 2005). In the semi-arid and arid regions of South Africa these horizons are probably only saturated during floods occurring once or twice in ten years. In spite of this relatively low frequency of saturation of the semi-arid and arid regions when compared to the G horizons of the wetter regions of South Africa, they remain reduced for long periods of time because the water is stagnant within the horizon and little if any drainage occurs (Le Roux, pers. comm.).

#### Soft and hard plinthic B horizons

Soft plinthic B horizons can be saturated with water for three to nine months of the year in high rainfall areas (Van Huysteen *et al.*, 2005). In the dry semi-arid regions they are probably saturated for not more than a week in the wet month of the year and for four to six weeks during the two wettest years out of ten. Hard plinthic B horizons probably require wetter soil water regimes to develop than those required for the soft plinthic B horizon (Le Roux, 1996).

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## Soil forms

For an area to qualify as wetland, the soil must be classified as belonging to at least one of the soil forms as proposed by the Department of Water Affairs and Forestry (2003), these being:

• The permanent wet zone will always have one or more of the following soil forms present (redoximorphic features incorporated at the form level):

**Table 4:** Soil forms always associated with wetlands.

Champagne	Katspruit	Willowbrook	Rensburg	
				_

• The seasonal and temporary wet zones will have one or more of the following soil forms (redoximorphic features incorporated at the form level) present:

**Table 5:** Soil forms sometimes associated with wetlands at the soil form level.

Estcourt	Vilafontes	Avalon	Bloemdal
Cartref	Kinkelbos	Glencoe	Witfontein
Fernwood	Westleigh	Pinedene	Sepane
Klapmuts	Dresden	Bainsvlei	Tukulu
•			Montagu
	Estcourt Cartref Fernwood Klapmuts	Estcourt Vilafontes Cartref Kinkelbos Fernwood Westleigh Klapmuts Dresden	Estcourt Vilafontes Avalon Cartref Kinkelbos Glencoe Fernwood Westleigh Pinedene Klapmuts Dresden Bainsvlei

• The seasonal and temporary wet zones will have one or more of the following soil forms (redoximorphic features incorporated at the family level) present:

**Table 6:** Soil forms sometimes associated with wetlands at the soil family level.

Inhoek	Tsitsikamma	Houwhoek	Molopo	Kimberley
Jonkersberg	Groenkop	Etosha	Addo	Brandvlei
Glenrosa	Dundee			

It is important to note that just as the permanent, seasonal and temporary hydrological zones are usually associated with a specific <u>terrain unit</u>, that the above-mentioned soil forms are also usually associated with these terrain units. In other words the Champagne and Katspruit soil forms (associated with areas of relatively long periods of saturation due to stagnant or slow moving water) are more likely to be found in the valley bottom terrain unit than the Kroonstad or Longlands soil forms (associated with areas of shorter periods of saturation and relative fast laterally flowing water). It follows then that certain of the soil forms are more closely associated with a specific hydrological zone, i.e. the soil form to be found in the permanent wet zone is more likely to be a Champagne or a Katspruit rather than an Avalon or a Pinedene.

The following exceptions and additional information should be noted:

 If a soil profile qualifies as Champagne, Rensburg, Willowbrook, or Katspruit form, it is not necessary that grey colours (depleted matrix) be present within the soil matrix for the soil to qualify as hydromorphic (Department of Water Affairs and Forestry, 2003). In soils of the Champagne and Rensburg forms grey colours often occur deeper than 500mm. The O horizon of the Champagne form is enough evidence of a reduced soil water regime (Le Roux, pers. comm.).

- Not all E horizons are indicators of wetness. E horizons may also develop through the process of podzolization. In such instances organic matter and sesquioxides are removed from the A horizon and deposited in the lower lying horizon, thereby leaving that portion of the A horizon as an E horizon (Van der Watt and Van Rooyen, 1995; Le Roux *et al.*, 1999).
- Melanic and vertic A horizons are dark coloured, base-rich soils typically having dark topsoil layers and low chroma (dark grey) matrix colours to considerable depths. The low chroma colours of these soils are not necessarily owing to prolonged saturation (Kotze, Klug, Hughes, & Breen, 1996).
- In some soils of the Fernwood form, subsoil saturation does not leave visible mottles because the sandy material is bleached by pre-weathering to the extent that it does not have any Fe on the surface of sand particles (Le Roux, pers. comm.).

Mottles qualifying as redoximorphic features appear in topsoils within a year where soils are saturated for intervals of 13 days or longer (Richardson and Vepraskas, 2001). It can therefore be assumed that wetlands can be successfully identified in manmade soils (Le Roux, 1996).

The above implies that for an area to be classified as being a wetland when using the soil criteria, it must contain at least one diagnostic horizon within the upper 500 mm of the soil profile that is characterized by <u>redoximorphic features</u>. If the redoximorphic features are deeper then 500mm, then the area is considered to be non-wetland (except in the case of above-mentioned exceptions), unless the area does support hydrophytic vegetation. It is important to note that it is not necessary to identify a diagnostic horizon or to classify the soil (assign it to a specific soil form, e.g. Katspruit, Kroonstad, etc.) to determine whether it is a wetland soil or not. The presence or absence of redoximorphic features within the upper 500mm of the soil profile alone is sufficient to identify the soil as being <u>hydric</u> (a wetland soil) or non-hydric (non-wetland soil). However, although a hydric soil will not necessarily contain all of the diagnostic horizons associated with redoximorphic features, all hydric soils will contain at least one (within the upper 500mm of the soil profile).



Figure 7: Example of a wetland soil (Katspruit soil form) showing a clear distinction between the different diagnostic horizons (separated by the vertical red lines). Note that the G horizon is separated into a G1- and a G2 horizon based on the difference in their morphology (their visual appearance).

### The wetland boundary

Being a transitional ecosystem, it is often difficult to identify the outer edge of a wetland, i.e. the outer edge of the <u>temporary zone</u>. The boundaries of wetlands, as well as the boundaries of the different hydrological zones, are therefore often transitional zones, rather than an exact line. Very often the delineation of a wetland boundary is at best an approximation of the transition zone between wetland and non-wetland. The outer edge of a wetland will therefore be the highest point on the gradient that meets at least one of the requirements of wetland hydrology, hydric soils or hydrophytic vegetation (Figure 8).



Figure 8: Illustration of the wetland boundary being the highest point on the gradient that meets at least one of the requirements of wetland hydrology, hydric soils or hydrophytic vegetation (taken and adapted from U.S. Army Corps of Engineers, 2004).

For more detailed information on wetland identification and <u>delineation</u> in South Africa, visit the following web site:

http://www-

dwaf.pwv.gov.za/docs/Water%20Resource%20Protection%20Policy/wetland%20ecosy stems/wet\_appW6\_version10.doc.

# 2. Wetland hydrology

'Wetland hydrology' generally refers to the hydrological characteristics responsible for the existence and ecology of the wetland, which includes the source of the water (precipitation, surface water inflow and ground water inflow), the way in which the water moves through the wetland (surface flow and subsurface flow) and also the way in which the water exits the wetland (evaporation, surface water outflow and ground water outflow).

## Water transfer mechanisms

Unless indicated to be otherwise, this section from Ramsar (COP9).

The ways in which water can move into or out of a wetland are called water transfer mechanisms. The first step in understanding wetland hydrology involves identifying which water transfer mechanisms are present in a wetland and which of these are the most important. Broadly speaking, the different water transfer mechanisms can be grouped as (Figure 9):

- Precipitation,
- Evapotranspiration,
- Surface water inflow and outflow, and
- Ground water inflow and outflow.



Figure 9: Groupings of water transfer mechanisms.

Different mechanisms of surface water and ground water flow exist. The diagrams of Figure 10 (Diagrams A to L) represent a list of possible water transfer mechanisms. These mechanisms do not necessarily dictate the distribution of water within a wetland or the rate of movement, but rather define the hydrological interface of the wetland with the surrounding environment. Any particular wetland will only be influenced by a subset of these mechanisms.



Key for Figures 10, 11 and 12.

- Permeability Geological strata vary considerably in their permeability, or the rate at which water can pass through them (also called hydraulic conductivity). Low permeability strata includes clay, whilst semi-permeable strata includes sand.
- Peizometer surface The piezometric head is the level that groundwater would reach if not impeded by a low permeability layer above the <u>aquifer</u> (the <u>aquiclude</u>, or aquitard), or depleted by, for example, evaporation or abstraction. In unconfined aquifers the piezometric head may be equal to the observed water table.



**P - precipitation**. Rain, sleet or snow falling directly onto the wetland and intercepted mist and condensation.

**E** - evapotranspiration. Water moving from the soil, open water or plant surfaces in the wetland to the atmosphere. It includes transpiration.

**R - runoff.** Water moving down-slope across the land surface, in streams or through shallow layers of the soil into the wetland.

**L** - **lateral inflow.** Water moving laterally through the soil from a ditch, river or lake into the wetland. The wetland water table level is lower than that in the issuing water body.

**D** - drainage. Water moving laterally over land or through the soil from the wetland to a ditch, river or lake. This may be natural or enhanced by artificial drains. The wetland water table level is higher than that in the receiving water body.



**OB** - over-bank flow. Water moving from a ditch, river or lake onto the wetland's surface. The water level in the issuing body is higher than the ground level of the wetland. This can be time dependant, e.g. only during high runoff events (floods).

**OF - out flow.** Water moving from a wetland down slope. This does not include water flowing back to a river after over-bank flooding when the river level has dropped (see drainage).

**PU - pumping.** Water moved between a wetland and a river, lake or ditch by a mechanical pump. Water may be pumped into or out of the wetland. This water transfer mechanism is of particular importance to depression type wetlands (pans) affected by mine discharge.

**S** - **spring.** Water issuing from an aquifer onto the surface of a wetland. Often this is associated with the location of an aquiclude beneath the aquifer.

**GD** - groundwater discharge. Water moving vertically upwards into a wetland from an underlying aquifer. The piezometric head/water level of the aquifer is higher than the water level in the wetland. There may or may not be a lower permeability layer between the wetland and the aquifer that could limit water flow.

**GR - groundwater recharge.** Water moving vertically downwards from a wetland to an underlying aquifer. The piezometric head/water level of the aquifer is lower than the water level in the wetland. There may or may not be a lower permeability layer between the wetland and the aquifer that could limit water flow.

**GS - groundwater seepage.** Water moving laterally into a wetland from an adjacent aquifer. There may or may not be a lower permeability layer between the wetland and the aquifer that could limit water flow.

Figure 10: Diagrams (A to L) illustrating a list of possible water transfer mechanisms together with their association to aquifers and less permeable strata (Ramsar, COP9).

## Wetland types (classification) and water transfer mechanisms

To aid in identifying the water transfer mechanisms of the different wetland types, a hydrological typology of wetlands has been developed by Acreman (2004) in Ramsar (COP9) based on landscape location. The hydrogeomorphic wetland classification system (HGM) is based on, amongst others, the topographical position of the wetland. It follows that the water transfer mechanisms of a wetland can be inferred from its HGM classification (see discussion on wetland functions and values). Figure 11 (A to C) provides schematic illustrations of the different water transfer mechanisms typically associated with wetlands of different landscape positions.

#### Figure 11A: Hillslope wetlands







#### Hillslope wetlands Surface water-fed: Wetland underlain by impermeable strata. Input dominated by precipitation, surface runoff and possible spring flow. Output by evaporation and surface outflow.

Hillslope wetlands Surface and groundwater-fed: Wetland separated from underlying aquifer by lower permeability layer. Input from groundwater seepage, precipitation and surface runoff. Groundwater input may be restricted by lower permeability layer. Output by evaporation and surface outflow.

Hillslope wetlands Groundwater-fed: Wetland in direct contact with underlying aquifer. Input dominated by groundwater seepage, supplemented by precipitation and surface runoff. Output by evaporation and surface outflow.

### Figure 11B: Depression wetlands



**Depression wetlands Surface water-fed:** Wetland underlain by impermeable strata. Input dominated by precipitation, surface runoff and possible spring flow. Output by evaporation only.



Depression wetlands Surface and groundwater-fed:

Wetland separated from underlying aquifer by lower permeability layer. Input from groundwater discharge, when groundwater table is high, precipitation, surface runoff and possibly spring flow. Groundwater input may be restricted by lower permeability layer. Output by evaporation and groundwater recharge when groundwater table low.



Depression wetlands

**Groundwater-fed:** Wetland in direct contact with underlying aquifer. Input dominated by groundwater discharge when groundwater table is high, supplemented by precipitation, surface runoff and spring flow. Output by evaporation and groundwater recharge when groundwater table low.

#### Figure 11C: Valley bottom wetlands



Valley bottom wetland Surface water-fed: Wetland underlain by impermeable strata. Input dominated by overbank flow and lateral flow, supplemented by precipitation and surface runoff. Output by drainage, surface outflow and evaporation. Inflows and outflows are controlled largely by water level in the river or lake.



GR

GD

Valley bottom wetland Surface and groundwater-fed:

Wetland separated from underlying aquifer by lower permeability layer. Input from over-bank flow and groundwater discharge, supplemented by runoff and precipitation. Groundwater flow may be restricted by intervening low permeability layer. Output by drainage, surface outflow, evaporation and groundwater recharge.

Valley bottom wetland Groundwater-fed: Wetland in direct contact with underlying aquifer. Input dominated by over-bank flow and groundwater discharge, when groundwater table is high, supplemented by runoff and precipitation. Output by groundwater recharge when water table is low, drainage, surface outflow and evaporation.

Figure 11: Linking landscape location and water transfer mechanisms (Ramsar, COP9).

The three landscape locations of wetlands (hillside, valley bottom and depression) presented here (there are actually seven landscape locations within the Ramsar definition of wetlands; hilltop, underground, flat lowland and coastal wetlands are not discussed here) can therefore be further subdivided on the basis of dominant water transfer mechanisms to produce the nine subtypes presented in Figure 11 (A to C). In particular, the subtypes are based on whether the likely dominant water transfer mechanism in each type is surface water or ground water, or a combination of the two. The three landscape locations and their associated hydrological subtypes are presented in Table 7.
Landscape location	Subtype based on water transfer mechanism				
Slope wetlands	Surface water-fed				
	Surface and groundwater-fed				
	Groundwater-fed				
Valley bottom wetlands	Surface water-fed				
	Surface and groundwater-fed				
	Groundwater-fed				
Depression wetlands	Surface water-fed				
	Surface and groundwater-fed				
	Groundwater-fed				

**Table 7:** The three landscape locations and their associated hydrological subtypes.

In practice it is not easy to identify the subtype as the contribution of groundwater to wetlands is difficult to determine. However, it is important to recognize the existence of the different water transfer mechanisms as they affect various aspects of the wetland ecology.

Figure 12 shows a cross-section of a hypothetical wetland where different water transfer mechanisms dominate in different zones (A to E) of the wetland. Hydrological inputs to zone A are dominated by spring flow (S) and outputs by pumping (PU), whereas in zone B over-bank flow from the river (OB) dominates. Zone C is an area of exchange with groundwater (GD, GR), whilst the hydrology of zone D is dominated by precipitation (P) and evaporation (E). In zone E inputs come from groundwater seepage (GS) and runoff from the adjacent slopes (R). It is important to note that the contribution of the different water transfer mechanisms may change over time (most notably from wet to dry seasons). The importance of the different water transfer mechanisms may also differ from one geographic region to another.



Figure 12: Cross-section of a hypothetical wetland where different water transfer mechanisms dominate in different zones (A to E) of the wetland (Ramsar, COP9).

# The water budget

The balance between the inputs and outputs of water in a wetland is called a water budget (or water balance). Quantification of the water budget of a wetland provides information on its hydrological functioning, including flood control and ground water recharge. When the water budget is used as the basis for a hydrological model, the impacts of various developments, such as the building of dams, can be predicted (Acreman, 2000).

Over the long term in a sustainable wetland system, water inputs equal outputs. Over shorter time intervals, however, wetlands may temporarily store and release water. Therefore, the water budget equation also has a storage term (U.S. Army Corps of Engineers, 2004).

The water balance of a wetland is based on comparing the total quantity of water transferred into a wetland with the total transferred out. By using the list of water transfer mechanisms, the water balance of a wetland can be summarized by a simple addition of inputs to, and outputs from, the wetland. The elements of Figure 12 can be expressed as the following equation:

$$V = (P + R + L + OB + PUi + S + GD + GS + TI) - (E + D + OF + PUo + GR + TO)$$

Water input to the wetland

Water output from the wetland

V = Storage

PUi = Pumped water into the wetland

PUo = Pumped water out of the wetland

# The wetland hydroperiod

The hydroperiod of a wetland is the result of its water balance, i.e. the changes in water inputs and outputs of the wetland (Cronk & Siobhan Fennessy, 2001). The term hydroperiod therefore describes the different variations in water input and output that form a wetland and eventually characterizes its ecology. The hydroperiod of a wetland may vary by (Davies):

- Season.
- Year (climatic patterns).
- Diurnal (daily) effects.
- Locational effects resulting in randomly timed flooding.

Such changes in the hydroperiod usually affect at least one of the following;

- The volume of water that enters/exits the wetland over a period of time.
- The timing of water inputs (does the water enter the wetland at the beginning of the rainy season, at the end of the rainy season or on a continual basis).
- The frequency at which water enters the wetland (does water enter the wetland once a year or more frequently).
- The duration of flooding (is the wetland saturated for, e.g., 2 weeks, 2 months or 12 months of the year).

Hydrology is one of the strongest determinants for the establishment and maintenance of wetland types and processes. The hydroperiod of a wetland significantly affects a number of wetland characteristics, including the vegetative composition and diversity, primary productivity, organic matter accumulation, nutrient cycling and nutrient inflows. Hydroperiod may be one of the wetland characteristics that is most sensitive to anthropogenic impacts. Wetland ecosystem response to changes in the hydroperiod may be manifested in major habitat changes (through shifts in vegetation community abundance, diversity, and invasive/opportunistic species occurrence), as well as altered flood storage capacity and altered chemical properties. The hydroperiod of a wetland therefore has great practical significance as we strive to maintain these important ecosystems (Massachusetts Coastal Zone Management March, 1998).

# 3. Wetland plants

# What is a hydrophyte?

According to Tiner (1999) a hydrophyte is defined as "an individual plant adapted for life in water or periodically flooded and/or saturated soils (<u>hydric soils</u>) and growing in wetlands and deepwater habitats; it may represent the entire population of a species or only a subset of individuals so adapted".

Important to note from this definition is the specific reference to "an individual plant" and which "may represent the entire population of a species or only a subset of individuals so adapted". This wording implies that not all individuals of a species need to occur within wetlands for that species to be considered a hydrophyte. In other words, if only a single individual of a species occurs within a wetland, then that species is considered to be a hydrophyte. Because wetlands are "transitional" ecosystems, it is common to find species typically considered to be non-wetland species within these transition zones (the temporary and seasonal hydrological zones). All species present within these transitional zones are hydrophytes. It follows that a species like red grass (*Themeda triandra*) is therefore also a hydrophyte.

To account for this phenomenon, wetland plants are divided into five categories (called wetland indicator status) based on their expected frequency of occurrence in wetlands. These groups are (Tiner 1999):

- **Obligate Wetland (OBL).** Almost always occurs in wetlands (estimated probability >99%) under natural conditions.
- **Facultative Wetland (FACW).** Usually occurs in wetlands (estimated probability 67% 99%), but occasionally found in uplands.
- **Facultative (FAC).** Equally likely to occur in wetlands (estimated probability 34% 66%), or uplands.
- **Facultative Upland (FACU).** Usually occur outside wetlands (estimated probability 67% 99%), but occasionally found in wetlands (estimated probability 1% 33%).
- **Obligate Upland (UPL).** Occur almost always (estimated probability >99%) outside wetlands under natural conditions.

In addition to the indicator status categories, positive (+) and negative (-) signs is also used for the facultative categories. The "+" sign indicates a frequency towards the wetter end of the category (more frequently found in wetlands) and the "-" sign indicates a frequency towards the drier end of the category (less frequently found in wetlands).

# Wetland plant communities

Wetland plant communities are defined according to the "association concept", which is a plant community type of a specific floristic composition resulting from certain environmental conditions and displaying relatively uniform physiognomy. One of the simplest wetland classification systems, based on a particular set of *plant* and animal associates that recur, recognizes the following types of wetlands (Keddy, 2002):

- Aquatic: a wetland community dominated by truly aquatic plants, growing in and covered by at least 25cm of water.
- Marsh: a frequently or continually inundated wetland characterized by emergent herbaceous vegetation adapted to saturated soil conditions. In European

terminology marshes have a mineral soil substrate and do not accumulate peat (Mitch and Gosselink, 2000). Marshes can be subdivided into:

- Deep marshes: Deep marsh plant communities have standing water depths of between 15cm and 1000cm, or more, during the growing season. Herbaceous <u>emergent</u>, <u>floating</u>, <u>floating-leaved</u>, and <u>submergent</u> vegetation compose this community, with a strong dominance of cattails, bulrush and reeds.
- **Shallow marshes:** Shallow marsh plant communities have soils that are saturated, to inundated, by standing water up to 15cm deep through most of the growing season. Herbaceous emergent vegetation, such as grasses and sedges, characterize this community.
- Mire: used mainly in Europe to include any peat-forming wetland (bog, or fen).
  - Bog: a peat-accumulating wetland that has no significant water inflows or outflows and supports acidophylic mosses, particularly *Sphagnum* (Mitch and Gosselink, 2000) (usually acidic; pH <7).</li>
  - **Fen:** a peat-accumulating wetland that receives some water from surrounding mineral soil and usually supports marsh-like vegetation (Mitch and Gosselink, 2000) (usually alkaline; pH >7).
- Swamp: a wetland dominated by trees and shrubs (Mitch and Gosselink, 2000).
- Wet meadow: a grassland with water logged soil near the surface but without standing water for most of the year (Mitch and Gosselink, 2000).

It is outside of the scope of this document to go into more details of wetland plant community dynamics, but it is important to mention that the type of plant communities that develop are the result of numerous environmental gradients (e.g. hydroperiod, soil type, soil chemistry, climate, etc.), of which the hydroperiod is probably the most important. Hydrological processes or characteristics that determine plant species establishment, and therefore distribution within a wetland, include: flow rates, water depth, internal flow rates and patterns, the timing and duration of flooding, and underground water exchange (Cronk & Siobhan Fennessy, 2001). The type of and distribution of plant communities within a wetland is therefore very dependant on the <u>hydroperiod</u> of the wetland.

The two hydroperiod characteristics most important for determining plant species distribution within wetlands are (Keddy, 2002):

- The duration of flooding.
- The depth of flooding.

The interaction between the duration of flooding and the depth of flooding, and the resulting wetland types are presented in Figure 13 (Keddy, 2002).



Figure 13: Four wetland types that develop in response to duration of flooding and depth of flooding (Keddy, 2002).

It is important to note that, because of variations in other physical, chemical and abiotic factors that affect the structure of the ecosystem, the species composition of a vegetation type (e.g. emergent) of different wetlands of a specific kind (e.g. marsh) can differ markedly (e.g. the emergent vegetation of one marsh type wetland may be dominated by *Eleocharis dregeana*, while that of another may be dominated by *Carex cognata*).

# When is a plant community hydrophytic?

Communities dominated by hydrophytes are referred to as hydrophytic plant communities. However, the practical application of this statement is more complicated than one would think. Plant communities of the drier hydrological zone (the temporary wet hydrological zone) will contain species of both the wetland (hydrophytes) and the non-wetland (nonhydrophytes) environments. The presence of scattered individuals of an upland plant species in a community dominated by hydrophytic species is not sufficient for concluding that the area is an upland community. Likewise, the presence of a few individuals of a hydrophytic species in a community dominated by upland species is not sufficient for concluding that the area has hydrophytic vegetation. It is therefore reasonable to ask when such plant communities are hydrophytic (a wetland plant community) and when are they not (a terrestrial plant community).

Two widely used methods that have been applied to determine the presence of hydrophytic vegetation are the *dominance ratio* and the *prevalence index* methods (Cronk & Siobhan Fennessy, 2001).

The dominance ratio method is calculated using the "50/20 rule" in which the dominant species in each stratum are defined as the species whose cumulative cover makes up >50% of the total cover of the stratum, plus any individual species that form at least 20% of the total cover in the stratum (Federal Interagency Committee for Wetland Delineation, 1989). A plant community is classified as being hydrophytic by this method if >50% of

dominant species across all strata have an indicator status of OBL, FACW, or FAC (excluding FAC-) (Cronk & Siobhan Fennessy, 2001).

The prevalence index method is a weighted average of the wetland indicator status of all plants present. In this method, each plant along a transect must be identified, and each plant is given a score (OBL = 1.0, FACW = 2.0, FAC = 3.0, FACU = 4.0, and UPL= 5.0). The scores are summed and the average is the score for that plot; plots that score <3.0 are considered to be wetland and those that score >3.0 are designated upland (Cronk & Siobhan Fennessy, 2001).

It is important to note that although the Federal Interagency Committee for Wetland Delineation (1989) presented these two approaches as alternative, but equivalent, methods, a study designed to test the similarity between the two methods found that the dominance ratio and the prevalence index methods cannot be considered equivalent, and should not be interpreted as such. Unfortunately, this study did not conclude which of these two methods is the most reliable (Cronk & Siobhan Fennessy, 2001). It was, however, recommended that for the prevalence index, scores of between 2.5 and 3.5 should be confirmed with soil and hydrology indicators, i.e. the hydrology and/or the soil must indicate typical wetland features for the associated plant community to be classified as being hydrophytic.

# Types of hydrophytes

It was previously mentioned that wetlands are "transitional" ecosystems that share characteristics of both the wetland and non-wetland habitats - the range of wetland habitats is therefore extremely diverse. Plants have developed into various life forms in response to this diversity of habitat types. Hydrophytes are consequently classified as follows (Cronk & Siobhan Fennessy, 2001):

- <u>Emergent plants</u> rooted in the soil with basal portions typically growing beneath the surface of the water, but whose leaves, stems (photosynthetic parts) and reproductive organs are aerial.
- <u>Submerged plants</u> with the possible exception of flowering, submerged plants typically spend their entire life cycle beneath the surface of the water.
- <u>Floating-leaved plants</u> the leaves of floating-leaved species float on the water's surface, while their roots are anchored in the substrate.
- <u>Floating plants</u> the leaves and stems of floating plants float on the water's surface.

# Growth conditions within wetlands

Contrary to common belief, the wetland environment is an extremely harsh environment for plants to grow in. The fluctuating water levels experienced in most wetlands are probably directly and indirectly the most severe environmental strains that wetland plants have to endure. The frequency and duration of flooding can vary greatly, even within the same wetland, so that the plants are subjected to a very unstable environment. Plants have three basic requirements: light, water and nutrients and they also need oxygen for respiration. Access to these resources is completely different during the alternating wet and dry periods in the life of a wetland (Grillas & Roché, 1997). Some of the unique and stressful growing conditions that occur to a greater or lesser extent in individual wetlands are (Cronk & Siobhan Fennessy, 2001):

• Anaerobic sediments

Because the soil oxygen is used up by biological activity, oxygen which is required for cellular respiration (to dispose of carbon dioxide, CO<sub>2</sub>), is not readily replaced and the plants roots find themselves within an anaerobic environment. Characteristics of a reduced soil are:

Reduced form of elements

◊ Nitrogen

Nitrogen is a vital nutrient for plant growth. In flooded soils the nitrate level can decline to zero within 3 days of flooding, thereby depriving the plants of this vital nutrient.

◊ Manganese

While plants require only a small amount of manganese, high levels of  $Mn^{2+}$  (the reduced form of  $Mn^{3+}$  and  $Mn^{4+}$ ) interfere with enzyme structure and nutrient consumption.

 $\diamond$  Iron

In its reduced form, iron is soluble and subsequently becomes more bioavailable (is more easily taken up by plants). This can result in to excessively high concentrations of iron for the plants. Plants exhibiting iron toxicity often have discoloured leaves, diminished photosynthetic activity and decreased root respiration, and the iron may also interfere with magnesium during chlorophyll formation. Also, if the iron is oxidised within the plants oxidised rhizosphere (the oxygenated area surrounding the plants roots where oxygen has 'leaked' from the roots into the surrounding reduced soil environment), an insoluble iron plaque ( $Fe^{3+}$ ) can form, coating the roots and blocking nutrient uptake.

♦ Sulphur

Sulphur is an essential micronutrient for plant growth, and is usually taken up in the form of sulphate  $(SO_4^{2^-})$ . When plants take up excessive concentrations of sulphide (its uptake is usually metabolically controlled), it inhibits enzymes involved in photosynthesis and reduces the capacity of the roots to respire aerobically. Sulphide may also limit the generation of energy through anaerobic metabolism.

◊ Carbon

At extremely low redox levels (soils that have been intensely reduced, i.e. permanently wet soils), carbon dioxide  $(CO_2)$  and organic carbon (methyl compounds) are reduced to methane  $(CH_4)$  in a microbial process known as methanogenesis. The availability of  $CO_2$  for photosynthesis may thus become problematic, especially for submerged plants which are not exposed to the atmosphere.

• Nutrient availability changes

Essential plant nutrients such as phosphorous, potassium, magnesium and calcium are not reduced, but the reduction of other elements can change their availability:

- $\diamond$  In reduced conditions, phosphate (PO\_4^3-) is more available to plants than in oxidised soils.
- ♦ This also applies to potassium, magnesium and calcium (the positively charged ions).

- O However, toxic cations such as copper, zinc and manganese also become more available.
- o Toxins become present

Some toxins are produced from anaerobic respiration and a potentially toxic accumulation of acetic and butyric acids may occur. Anaerobic metabolism could also result in the accumulation of ethanol. All these products produce a hostile environment for plant growth.

- Substrate conditions in saltwater wetlands (e.g. <u>pans</u>) Problems for wetland plants in <u>saline</u> (salt) soils are:
  - Under non-saline conditions water moves into the plant because the external water potential is greater than within the plant (water will move naturally from solutions with low salt concentrations to those with higher salt concentrations). The saline conditions that occur is some wetlands reverses the water potential so that water will now tend to move from the plant to the lower water potential outside of the plant. Plants in saline wetlands are therefore frequently under water stress.
  - There is a different ionic mix in saline wetlands than from that in freshwater wetlands, making the uptake of beneficial ions difficult. For example, Na<sup>+</sup> (harmful) and K<sup>+</sup> (beneficial) are chemically similar. Subsequently, where Na<sup>+</sup> occurs in high concentrations, the uptake of the beneficial K<sup>+</sup> is prevented.
  - The saline environment interferes with the uptake of carbon (required for photosynthesis). Plants obtain carbon from CO<sub>2</sub>, so that it is ultimately obtained from the atmosphere. Opening of the stomas to take up CO<sub>2</sub> also results in water loss;-since the plants are already in a water stressed environment because of the lower water potential outside of the plant as previously mentioned, the uptake of carbon is subsequently problematic.
  - The plants of saline wetlands are also often exposed to high concentrations of sulphides which are stressful and potentially toxic.
  - Some studies have shown plants in saline wetlands to be nitrogen-limited (i.e. there is insufficient nitrogen to supply demand).
- Substrate conditions in nutrient-poor wetlands (peat wetlands)
   Plants in nutrient-poor wetlands, e.g. peat wetlands, are usually limited by one or several nutrients, e.g. N (nitrogen), P (phosphorous) or K<sup>+</sup> (potassium).

Such wetlands also tend to be acidic (have a low pH) which precludes many plant species and which also affects the availability of certain plant nutrients.

- Growth conditions for submerged plants
  - Light availability

Light availability is probably the most important regulator of the distribution of submerged plants. The availability of light to these plants depends on numerous factors, e.g. the depth of water column, the turbidity of the water, etc. A large portion of the available light is also reflected away by the surface of the water column.

• Carbon dioxide availability

Like oxygen,  $CO_2$  diffuses approximately 10 000 time slower in water than through air. The availability of  $CO_2$  for photosynthesis is therefore problematic.

# 4. Adaptations of plants for growth conditions in wetlands

Wetlands are therefore extremely harsh environments to which few species have adapted (hence the relative low diversity of plant species when compared to upland plant communities). Obviously the degree of harshness decreases as one moves along the hydrological gradient from the wetter towards the drier end of the hydrological zones. In order for plants to survive in the harsh wetland environment, they have to employ special strategies. The most common strategies employed by wetland plants are the following (Cronk & Siobhan Fennessy, 2001):

# **Physiological Adaptations**

• Oxidized rhizosphere

As mentioned previously, plants can release  $O_2$  into the soil around their own roots. The released oxygen subsequently oxidizes unusable forms of nutrients so that these can be taken up by the roots (see <u>Plate 4</u>).

• Germination flexibility

Seedlings are often killed with extended flooding and some plants have developed the ability for their seeds to germinate under water. The ability of seeds to germinate while inundated has both advantages and disadvantages, depending on the conditions of inundation. Species whose seeds can germinate and grow under flooded conditions experience less competition; rice is one such species.

The ability of seeds to survive long periods of flooded conditions while buried in sediments in a dormant state is also helpful. Infrequent droughts would expose soil surfaces and surviving seeds would have the opportunity to germinate.

Frequent flooding can result in good seed dispersal if the seeds can float and avoid getting <u>waterlogged</u>. They can float until they lodge on a dry spot, possibly suitable for germination.

Some plants can delay flowering or seed production during floods, or accelerate flowering during dry periods.

• Accelerated stem growth

In certain plants, flooding stimulates the production of ethylene (hormone) which causes accelerated growth. This results in shoots growing more quickly above water level.

• C<sub>4</sub> photosynthesis

 $C_4$  photosynthesis is thought to provide an evolutionary advantage in environments where  $CO_2$  concentrations are low, and enables enhanced water-use efficiency. For some species the photosynthesis pathway followed is reversible - they can revert from the  $C_3$  pathway to the  $C_4$  pathway when exposed to air, and then back to the  $C_3$ pathway when submerged again.

Some plants can develop tissue for either C<sub>3</sub> or C<sub>4</sub> photosynthesis pathways

depending on their state of submergence.

• Alternate metabolic pathways

Under aerobic conditions, plant cells produce energy for maintenance and growth by breaking down carbohydrate molecules, such as glucose, into carbon dioxide and water and capturing the released energy in the form of <u>ATP</u>, producing 38 ATP per molecule of glucose. Anaerobic pathways permit metabolism to continue in the absence of oxygen, but at reduced energy efficiency and with the potential for build-up of toxic by-products, such as ethanol (Figure 14) (U.S. Army Corps of Engineers, 2004).



Figure 14: An illustration of alternative metabolic pathways as a physiological adaptation to anaerobic soil conditions (U.S. Army Corps of Engineers, 2004).

Lactate production under anaerobic conditions often occurs in plant roots subjected to flooding; however, this pathway cannot be sustained due to toxic effects. Production of non-toxic organic acids, such as malate, may help sustain root metabolism in the absence of oxygen. These compounds can be utilized further when oxygen again becomes available in the root zone, or they may be transported and used in the aerial portions of the plant (U.S. Army Corps of Engineers, 2004).

# **Morphological Adaptations**

• Aerenchyma

The primary plant strategy in response to flooding is the development of air spaces in the roots and stems which allow diffusion of oxygen from the aerial portions of the plant into the roots. Thus the roots don't have to depend on getting oxygen from the soil (which they require for respiration). "Regular" plants may have a porosity (percentage air space in roots and stems) of 2-7% of their volume, while a wetland plant may have up to 60% pore space by volume.

Water lilies offer an example of this: air moves into the internal gas spaces of young leaves floating on the water surface and is forced down through the aerenchyma of the stem to the roots by the slight pressure caused by the warming of the leaves. The older leaves lose their capacity to support pressure gradients so gas from the roots exits through these leaves.



Figure 15: Microscopic view of aerenchyma (taken from http://www.uri.edu/artsci/bio/plant\_anatomy/26.html).

Hollow stems

Some hydrophytes have hollow stems that may improve root aeration and the accumulation of  $CO_2$ .

• Shallow roots

Even in soils that are permanently flooded, a thin oxidised upper layer usually persists, made possible by benthic algal production of oxygen as well as gas

exchange with the atmosphere (Cronk & Siobhan Fennessy, 2001). Some species have developed a shallow rooting system to take advantage of this phenomenon.



Figure 16: Shallow roots as an adaptation to waterlogged conditions (U.S. Army Corps of Engineers, 2004).

# Dealing with salt (i.e. salt pans)

Interestingly, wetland plants in saline environments have the same problem that plants in arid climates have, that is, difficulty in getting and keeping water. Because of the salt levels, water tends to leave the plant via osmosis, or at least not enter the plant.

• Exclusion

Some plants survive the high saline environments by not taking up the salts. These plants can, for example, specifically exclude  $Na^+$  and  $CI^-$ , but still take up K<sup>+</sup> which is chemically similar to  $Na^+$ . Other plants might take up the excessive salts, but then store these in other parts of the plants to prevent them access to the more sensitive parts, e.g. the young shoots.

Secretion

Some plants that typically occur within high saline environments have developed salt glands that secrete the excess salts previously absorbed. Some develop the ability to specifically excrete  $Na^+$  while retaining  $K^+$ .

Shedding

Some plants get rid of the excess salts by shedding parts of the plants in which the salts have accumulated, usually the leaves.

## • Succulence

Succulence is an increase in the water content per unit area of leaf. This adaptation results in a dilution of the salt concentration within the plant.

# 5. Why are wetlands important?

# Wetland functions and values

Wetlands are important because of the **<u>functions</u>** and **<u>values</u>** that they provide which benefit mankind. These benefits can be either **direct** or **indirect benefits** (Table 8). Until very recently the benefits of wetlands to society were often not recognized, and many wetlands have been destroyed, or poorly managed.

Wetland benefits refer to: "those functions, products, attributes and services provided by the ecosystem that have values to humans in terms of worth, merit, quality or importance. These benefits may derive from outputs that can be consumed directly; indirect uses which arise from the functions or attributes occurring within the ecosystem; or possible future direct outputs or indirect uses" (Howe *et al.*, 1991 in Kotze *et al.*, 2005).

As mentioned, the HGM approach is a wetland assessment procedure from which certain wetland functions can be derived [based on position in the landscape (geomorphic setting), water source (hydrology), and the flow and fluctuation of the water once in the wetland (hydrodynamics)]. The functioning of a wetland is also affected by other factors, many of which result from the activities of people. These include "off-site" factors which take place in the surrounding catchment (e.g. a change in land cover from natural grassland to a gum tree plantation which would decrease the amount of water reaching the wetland) and "on-site" factors which take place at the wetland (e.g. fire, draining, damming, etc.). By classifying a wetland according to Table 9, some rating on the hydrological functions likely to be performed by that wetland based on the hydrogeomorphic type can be deducted. Table 10 lists a number of wetland attributes related to the different hydrological zones that enable them to perform the hydrological functions mentioned herein.

Wetland benefits (goods and services)	Indirect benefits		Water purification		
		Hydrological benefits	Sustained stream flow		
			Flood reduction		
			Ground water recharge/discharge		
			Erosion control		
		Biodiversity conservation – integrity & irreplaceability			
		Chemical cycling			
	Direct benefits	Water supply			
		Provision of harvestable resources			
		Socio-cultural significance			
		Tourism and recreation			
		Education an	d research		

Table 8: Direct and indirect wetland benefits (Kotze et al., 2005).

**Table 9:** Rating of the hydrological functions likely to be performed by a wetland given its particular hydrogeomorphic type (Kotze *et al.*, 2005).

WETLAND HYDRO- GEOMORPHIC TYPE	HYDROLOGICAL FUNCTIONS POTENTIALLY PERFORMED BY THE WETLAND								
	Flood attenuation		Stream flow augmentation		Erosion	Enhancement of water quality			
						Codimont	Phoe		
	Early wet	Late wet	Early wet	Late wet	control	trapping	phates	Nitrates	Toxicants <sup>1</sup>
	season	season	season	season					
1. Floodplain	++	+	0	0	++	++	++	+	+
2. Valley bottom – channelled	+	0	0	0	++	+	+	+	+
3. Valley bottom – unchanneled	+	+	+?	+?	++	++	+	+	++
4. Hillslope seepage feeding a stream channel	+	0	+	+	++	0	0	++	++
5. Hillslope seepage not feeding a stream	+	0	0	0	++	0	0	++	+
7. Pan/ Depression	+	+	0	0	0	0	0	+	+

Note: <sup>1</sup>Toxicants are taken to include heavy metals and biocides

0

Function unlikely to be performed to any significant extent

+ Function likely to be present at least to some degree

++ Function very likely to be present (and often performed to a high level)

The link between the hydrogeomorphic type and functioning is based on the attributes and characteristics of the hydrogeomorphic wetland type and how these relate to wetland functions. Functions normally associated with the different hydrogeomorphic wetland types are:

## Floodplains

Due to the nature of the vegetation and the topography they occupy, floodplains are considered important for flood attenuation. Flood attenuation is likely to be high early in the season until the floodplain soils are saturated (McCartney, 2000 in Kotze *et al.*, 2005; McCartney *et al.*, 1998 in Kotze *et al.*, 2005), and the oxbows and other depressions are filled. In the late season, the flood attenuation capacity is usually reduced, but is nevertheless still likely to be achieved to some extent, particularly in drier years (Kotze *et al.*, 2005).

Floodplains are generally unlikely to contribute significantly to stream flow augmentation. The generally clayey nature of floodplain soils retains water which is likely to be lost through evapotranspiration, thereby limiting their contribution to stream flow augmentation and groundwater recharge (Kotze *et al.*, 2005).

In general, once the flood overflows the river banks, the velocity of flow decreases laterally, permitting the deposition of particles within the floodplain landscape. Phosphorous and any toxicants bound to trapped sediments are therefore likely to be effectively retained on the floodplains, and this is a key mechanism through which wetlands trap phosphates (Boto and Patrick, 1979 in Kotze *et al.*, 2005; Hemond and Benoit, 1988 in Kotze *et al.*, 2005). Generally, the inundation period in floodplains is short, but in the oxbow depression portions of the floodplain inundation is more prolonged and some of the deposited phosphates may be released as a consequence of change in redox potential, given that phosphorus is held more tightly

Rating:

to soil particles under oxidized conditions than under reduced conditions (Cronk and Siobhan Fennessy, 2001; Keddy, 2002).

## Channelled valley bottom wetlands

From a functional point of view, they tend to contribute less towards flood attenuation and sediment trapping, but still perform these functions to a certain extent. Some nitrate and toxicant removal potential can be expected, particularly from the water being delivered from the adjacent hillsides.

# Non-channelled valley bottom wetlands

Nitrate and toxicant removal should be higher than in floodplains, because of the greater contact of the wetland with runoff waters, particularly if there is a significant groundwater contribution to the wetland. The shallow waters promote sunlight penetration, contributing to the photo-degradation of certain toxicants. However, phosphate retention levels tend to be lower than in floodplains because a proportion of phosphate may be re-mobilized under prolonged anaerobic conditions (Cronk and Siobhan Fennessy, 2001; Keddy, 2002). In addition, the nitrate removal potential would generally not be as high as in seepage slopes because sub-surface water movement through the wetland (where the greatest levels of nitrate removal generally take place, associated with high organic matter levels and low dissolved oxygen levels) occurs to a lesser degree owing to the generally finer, less permeable soils and lower gradients (Kotze *et al.*, 2005).

Stream flow augmentation may take place to some extent, but this is likely to depend strongly on factors such as transpirative loss from the vegetation and the nature of the soil, which would require field description to characterize (Kotze *et al.*, 2005).

Typical examples of this type include Wakkerstroom <u>vlei</u> in Mpumalanga, Mgeni vlei in KwaZulu-Natal and Bedford/Chatsworth wetland in the eastern Free State (Kotze *et al.*, 2005).

## Hillslope seepage wetlands feeding a stream

These systems are normally associated with groundwater discharges, although flows through them may be supplemented by surface water contributions. They can be expected to contribute to some surface flow attenuation early in the season, until the soils are saturated, after which their contribution to flood attenuation is likely to be limited (McCartney, 2000 in Kotze *et al.*, 2005; McCartney *et al.*, 1998 in Kotze *et al.*, 2005).

Evapotranspiration in the wetland may result in a considerable reduction in the total volume of water which would otherwise potentially reach the stream system (this would also apply to other wetland types). Nonetheless, the accumulation of organic matter and fine sediments in the wetland soils results in the wetland slowing down the sub-surface movement of water down the slope. This "plugging effect" increases the storage capacity of the slope above the wetland, and prolongs the contribution of water to the stream system during low flow periods. For some hillslope seepage wetlands this contribution may continue into the dry season, but for many others it is confined mainly to the wet season.

Seepage wetlands are widely considered to perform a number of water quality enhancement functions, for example, removing excess nutrients and inorganic pollutants produced by agriculture, industry and domestic waste (Rogers, Rogers and Buzer, 1985 in Kotze *et al.*, 2005; Green, 1995 in Kotze *et al.*, 2005; Ewel, 1997 in Kotze *et al.*, 2005; Postel and Carpenter, 1997 in Kotze *et al.*, 2005). Hillslope seepages generally would be expected to have a relatively high nitrogen removal potential. Nitrogen and specifically nitrate removal could be expected as the groundwater emerges through low redox potential zones within the wetland soils, with the wetland plants contributing to the necessary supply of organic carbon. Particularly effective removal of nitrates from diffuse sub-surface flow, as characterizes hillslope seepages, has been recorded (Muscutt *et al.*, 1993 in Kotze *et al.*, 2005).

Owing to their slope, hillslope seepages tend to perform limited sediment-trapping, provided that the vegetation remains intact.

#### Hillslope seepage wetlands not feeding a stream

The key between a seepage feeding and a seepage not feeding a stream is that the latter makes little direct contribution to augmentation as they are not directly connected to a stream channel feeding into the regional drainage network. Based on the assumption that hillslope seepages delivering water on a more prolonged basis will tend to develop a channel draining them, it can also be assumed that the hillslope seepages lacking a channel, tend to be saturated for less prolonged periods than seepages with a stream, making them less effective from a soil organic matter accumulation and toxicant assimilation perspective. It must be highlighted, however, that permanently saturated hillslope seepages may occur widely, and discharge water diffusely (i.e. they do not feed a channel).

#### Depressions (pans)

The opportunity for attenuating floods is limited by their position in the landscape, which is generally isolated from stream channels. However, they do capture runoff because of their inward draining nature, and thus they reduce the volume of surface water that would otherwise reach the stream system and contribute to storm flows. This inward draining nature, together with their generally impermeable underlying layer, also means, however, that they are unlikely to play a significant role in stream flow augmentation, although in the Highveld there appear to be some exceptions to this. In addition, pans are also not considered important locations for sediment trapping, with many pans, in fact, originating from the removal of sediment by wind, thus creating what are referred to as deflation basins (Goudie and Thomas, 1985 in Kotze *et al.*, 2005; Marshal and Harmse, 1992 in Kotze *et al.*, 2005).

Temporarily wet pans provide the opportunity for the precipitation of minerals including phosphate minerals because of the concentrating effects of evaporation. Nitrogen cycling is likely to be important with some losses due to de-nitrification, and volatilisation in the case of high pH. Water quality in pans is influenced by the pedology, geology, and local climate (Allan *et al.* 1995 in Kotze *et al.*, 2005). These factors in turn, also influence the response of these systems to nutrient inputs. In pans that dry out completely at some stage or another (non-perennial pans), some of the accumulated salts and nutrients (such as organic nitrogen, and various phosphate and sulphate salts) can be transported out of system by wind and be

deposited on the surrounding slopes. Those remaining may re-dissolve when water enters the system again as the pan fills after rainfall events (Kotze *et al.,* 2005).

# **Indirect Benefits**

Unless otherwise indicated, this section is from Kotze and Breen (1994).



Figure 17: A schematic presentation of the most important indirect benefits provided by wetlands (Kotze and Breen, 1994).

# Hydrological

An important characteristic of wetlands that allows them to perform most of their functions, is their ability to slow down the velocity of flowing water. Wetlands spread out and slow down water moving through the catchment because of: (1) the characteristically gentle slopes of wetlands, and (2) the resistance offered by the dense wetland vegetation. Also, many wetlands do not have well defined channels that would otherwise speed up the movement of water.



**Figure 18:** A schematic illustration of how wetlands spread out incoming fast-flowing water, thereby reducing its velocity (Kotze and Breen, 1994).

By slowing down the movement of water and detaining it for a while, wetlands act like sponges, reducing floods and also prolonging stream flow during low flow periods.

# Water purification

Wetlands are natural filters, helping to purify water by trapping pollutants [i.e. sediments, excess nutrients (especially nitrogen and phosphorus) heavy metals, disease-causing bacteria and viruses, and synthesized organic pollutants such as pesticides]. The water leaving a wetland is therefore often cleaner than the water which enters it. Wetlands are able to purify water effectively because:

- they slow down the flow of water (see flood reduction and stream flow regulation) causing sediment carried in the water to be deposited. This also results in the trapping of other pollutants (e.g. phosphorus) which are attached to soil particles;
- surface water is spread out over a wide area, facilitating exchanges between soil and water;
- there are many different chemical processes taking place in wetlands that remove pollutants from the water. For example, they provide a suitable place for denitrification because anaerobic and <u>aerobic</u> soil zones are found close together. Denitrification is important because it converts nitrates, which could potentially pollute the water, to atmospheric nitrogen, which is not a pollution hazard;
- some pollutants such as nitrates (NO<sub>3</sub>) are taken up by the rapidly growing wetland plants;
- the abundant organic matter in wetland soils provides suitable surfaces for trapping certain pollutants such as heavy metals; and
- wetland micro-organisms help decompose man-made organic pollutants, such as pesticides.

## Nitrogen removal

The principle flow of nitrogen within wetlands occurs among three components: the organic matter, the oxidised surface layer of the soil and the deeper anaerobic layers (Keddy, 2002). Even in soils that are permanently flooded, a thin oxidized upper layer usually persists, made possible by benthic algal production of oxygen, as well as gas

exchange with the atmosphere. Oxygen from root plants also contribute towards the existence of the oxidised surface layer of the soil (Cronk & Siobhan Fennessy, 2001).

#### Sources of nitrogen

Inputs of nitrogen into wetlands can be categorized as being point source or non-point source (http://www.chesapeakebay.net/nutr1.htm):

- Point source a source of pollution that can be attributed to a specific physical location; an identifiable, end of pipe "point". The vast majority of point source discharges for nutrients are from wastewater treatment plants (e.g. sewage plants), and from industries.
- Non point source a diffuse source of pollution that cannot be attributed to a clearly identifiable, specific physical location, or a defined discharge channel. This includes the nutrients that runoff the ground from any land-use, for example, croplands, feedlots, lawns, parking lots, streets, forests, etc. It also includes nutrients that enter through fixation. During nitrogen fixation, bacteria inside the root nodules of certain plants (legumes) reduce atmospheric nitrogen (N<sub>2</sub>) to ammonium (NH<sub>4</sub><sup>+</sup>) and nitrate (NO<sub>3</sub><sup>-</sup>). Atmospheric nitrogen is also transformed into a usable form by lightning. The great electrical energy of lightning is easily able to convert N<sub>2</sub> to NO<sub>3</sub><sup>-</sup>. Rates of fixation are however, generally relatively low.

Nitrogen enters wetlands in either an organic or inorganic form (Cronk & Siobhan Fennessy, 2001), with most coming organically (as plant litter falling into the wetland), and being stored in organic sediments (Keddy, 2002).

#### Transformation of nitrogen

Within a wetland, one of the principle steps controlling the rate of nitrogen cycling is the rate at which organic nitrogen is mineralised to ammonium  $(NH_4^+)$  (Keddy, 2002), which is an inorganic form of nitrogen. Other inorganic forms of nitrogen are nitrate  $(NO_3^-)$ , nitrite  $(NO_2^-)$ , and ammonia  $(NH_3)$  (Cronk & Siobhan Fennessy, 2001).

Once the organic nitrogen has been mineralised to ammonium  $(NH_4^+)$ , it is oxidized to nitrate  $(NO_3^-)$ . Both ammonium  $(NH_4^+)$  and nitrate  $(NO_3^-)$  can be taken up by plants and so removed from the system (Mitch and Gosselink, 2000). The depletion of  $NH_4^+$  in the upper oxidized layers sets up a concentration gradient, which causes upward diffusion of  $NH_4^+$  from the deeper anaerobic layers to the oxidized surface layer. Here the  $NH_4^+$  is again oxidized to nitrate  $(NO_3^-)$ . However, at the same time, nitrogen in the form of  $NO_3^-$  flows in the reverse direction, in other words, from the oxidized surface layer towards the deep anaerobic layers.

Once within the deeper anaerobic (reduced) soils, nitrate  $(NO_3^-)$  may be transformed in two different reduction processes, *denitrification* and *nitrate ammonification*. In the first, nitrate is reduced by anaerobic bacteria (called denitrifying bacteria) in a series of redox reactions to nitrite  $(NO_2^-)$ , then to nitrous oxide  $(N_2O)$  and ultimately to dinitrogen gas  $(N_2)$ . This process is called *denitrification* (Cronk & Siobhan Fennessy, 2001). N<sub>2</sub>O and N<sub>2</sub> are released into the atmosphere, with appreciable amounts also trapped within the aerenchyma of plants (Keddy, 2002). This process of denitrification is dependent on the presence of nitrate  $(NO_3^-)$ , which is itself produced by the oxidation of ammonia  $(NH_4^+)$  and nitrite  $(NO_2^-)$ ; therefore, when nitrate is limited, denitrification is also limited (Cronk & Siobhan Fennessy, 2001). In *nitrate ammonification*, a second type of nitrate-reducing bacteria (called nitrate ammonifying bacteria) reduces nitrate  $(NO_3^-)$  back to ammonium  $(NH_4^+)$ . Because of the concentration gradient caused by the oxidation of  $NH_4^+$  to  $NO_3^-$ , the  $NH_4^+$  diffuses upwards to be oxidized back to nitrate  $(NO_3^-)$ . In other words, the ammonium can then be *nitrified* (the oxidation of ammonia and ammonium to nitrate and nitrite) in the upper oxidized layer of the soil or water column (Cronk & Siobhan Fennessy, 2001). The nitrate can then diffuse downwards to the deeper anaerobic layers where it can be either denitrified (and released to the atmosphere as  $N_2$ ), or again be subjected to nitrate ammonification.



Figure 19: A simplified schematic presentation of some of the processes involved in the uptake and removal of nitrogen by wetlands (taken and adapted from http://www.marine.unc.edu/Paerllab/research/ogf/Pages/Experimental%2 0Design.htm).

It is important to note that denitrifying bacteria removes nitrogen from the soil while nitrate ammonifying bacteria conserves total nitrogen in the soil (which can then be removed from the soil through the processes of nitrification and then denitrification).

#### Phosphorus removal

The most notable difference between nitrogen and phosphorus, is that phosphorus occurs in a sedimentary cycle in contrast to nitrogen, which occurs in a gaseous cycle. This implies that instead of being altered by changes in redox potential, as is nitrogen, phosphorus adheres to sediments, and to other elements, such as iron.

At any one time a major proportion of the phosphorus in a wetland is tied up in organic litter and peat, and in inorganic sediments, with the former dominating peatlands and the latter dominating in mineral soil wetlands (Mitch and Gosselink, 2000).

#### Sources of phosphorus

Phosphorus occurs as soluble and insoluble complexes in both organic and inorganic forms in wetland soils. Inorganic forms include the orthophosphate ions  $PO_4^{3^-}$ ,  $HPO_4^{2^-}$  and  $H_2PO_4^{-}$ , the predominant form depending on the pH (Mitch and Gosselink, 2000). Potential sources of phosphorus are decaying vegetation, animal wastes, fertilizers, detergents, and sewage treatment plants.

#### Phosphorus removal

Inorganic forms of phosphorus may become chemically bound with suspended solids and sediment in a process called sorption. Phosphorus sorbs to oxides and hydroxides of iron (Fe<sup>3+</sup>) and aluminium, and to calcium carbonate. As these suspended solids settle, the sorbed phosphorus is removed from the water column. There is a finite supply of these minerals in the sediments, and inorganic phosphorus must come in direct contact with the sediments before it can be retained here. Once the sorption sites are saturated, the capacity of the soils to release phosphorus increases (Cronk & Siobhan Fennessy, 2001).

Under oxidized conditions phosphorus is held more tightly to soil particles than under reduced conditions. Under reduced conditions phosphorus is released due to the reduction of ferric ( $Fe^{3+}$ ) phosphate compounds to the more soluble ferrous ( $Fe^{2+}$ ) forms (i.e. when the iron is reduced to soluble  $Fe^{2+}$ , it no longer has the ability to hold on to the sorbed phosphorus, which is then released). If the soil is not vegetated, the released phosphorus diffuses back to surface waters. When plants are present, they assimilate (the conversion of nutritive materials into a living organism) the released phosphorus (or a portion of it), and so prevent its movement out of the sediments (Cronk & Siobhan Fennessy, 2001).

Although phosphorus is not directly altered by changes in redox potential, as are nitrogen, iron, manganese and sulphur, it is indirectly affected in soils and sediments by its association with several of these elements, especially iron, which is altered by the redox potential (i.e. which are reduced, and oxidized). Phosphorus is rendered relatively unavailable to plants and microorganisms by (Mitch and Gosselink, 2000):

- The sorption of insoluble phosphates with ferric iron (Fe<sup>3+</sup>), calcium, and aluminium under aerobic conditions.
- The adsorption of phosphate onto clay particles, organic peat, and ferric and aluminium hydroxides and oxides.
- The binding of phosphorous in organic matter as a result of its incorporation into the living biomass of bacteria, algae, and vascular macrophytes.

There are three general conclusions about the tendency of phosphorus to sorb with selected ions; these are (Mitch and Gosselink, 2000):

- Phosphorus is fixed as aluminium and iron phosphates in acid soils.
- Phosphorus is bound by calcium and magnesium in alkaline sols.
- Phosphorus is most bio-available at slightly acidic to neutral pH.



Figure 20: A simplified schematic presentation of some of the processes involved in the uptake and removal of phosphorus by wetlands (taken and adapted from

http://www.marine.unc.edu/Paerllab/research/ogf/Pages/Experimental%2 0Design.htm).

# Flood reduction

Because of the ability of wetlands to slow down the velocity of flowing water, as well to absorb some of the water within the system, the peaks of floods are often reduced. This implies that instead of all the water flowing down the river in one big flood event, some of the water is held back to be released later, so that the same volume of water flows down the river over a longer period of time. This decreases the peak of the flood, thereby preventing or attenuating potential flooding events.



Figure 21: A schematic presentation of how wetlands attenuate flood peaks, thereby reducing the risk of flooding.

# Ground water recharge and discharge

Wetlands may have an important influence on the recharge or discharge of groundwater. Groundwater recharge refers to the movement of surface water down through the soil into the zone in which permeable rocks and overlying soil are saturated. Groundwater discharge, in contrast, refers to the movement of groundwater out onto the soil surface. Although poorly understood, it appears that most wetlands are groundwater discharge or flow-through areas. Wetland areas where groundwater is discharging are often referred to as seepage wetlands because they are places where the water seeps slowly out onto the soil surface.



Figure 22: A schematic presentation of the processes of groundwater recharge and ground -water discharge (Kotze and Breen, 1994).

# Sustained stream flow

By acting as sponges, the water that is captured during the rainy season is slowly released during the dry season; this causes rivers and streams to have sustainable flows long after the rain has stopped.

# Erosion control by wetland vegetation

Wetland vegetation is generally good at controlling erosion by: (1) reducing wave and current energy; (2) binding and stabilizing the soil; and (3) recovering rapidly from flood damage.



Figure 23: A schematic presentation of how wetlands prevent excessive erosion during high runoff events (Kotze and Breen, 1994).

# **Biodiversity**

Wetlands are usually places where there is much plant growth because of the abundance of water and nutrients in the soil; the plants, in turn, provide food and shelter for animals. There are many different plants and animals that depend on wetlands, and without the habitat that wetlands provide, they would not be able to survive. Several of

these species, such as the white-winged flufftail (*Sarothura ayresi*) and wattled crane (*Bugeranus carunculatus*), are threatened. Three of South Africa's five critically endangered bird species are wetland dependant [these being the bittern (*Botaurus stellaris*), white-winged flufftail and wattled crane].

## Chemical cycling

In wetlands, the <u>decomposition</u> of organic matter is slowed down by the anaerobic conditions present in wetlands. This results in wetlands trapping carbon as soil organic matter, instead of releasing it into the atmosphere as carbon dioxide. Presently too much carbon dioxide is being released into the atmosphere when fossil fuels (i.e. coal and oil) are used to produce energy, resulting in the global climate being disrupted. Coal is, in fact, formed from plant material accumulated under wetland conditions in swamps that existed millions of years ago. Thus, instead of destroying wetlands and releasing carbon dioxide into the atmosphere, we should be conserving wetlands and thereby help reduce carbon dioxide levels in the atmosphere.

# **Direct Benefits**

Except where indicated, this section is from Kotze and Breen (1994).

# Livestock grazing

Wetlands, especially temporarily and seasonally waterlogged areas, may provide very valuable grazing-lands for domestic and wild grazers. This is particularly so in the early growing season, and during droughts, when grazing reserves are low in the surrounding veld (rangeland) while the wetlands continue to produce much grazing. Permanently wet **marsh** areas tend to have a lower grazing value because most mature marsh plants are unpalatable, and the excessive wetness may stop animals getting into the wetland. Utilization needs to be **sustainable** if the wetland is to maintain its value for grazing. As with dryland pastures, wetlands are only able to sustain a certain amount of grazing, and particular care is required in wetlands where the erosion hazard is high.

## Fibre for construction and handcraft production

Wetland plants have been used for thousands of years, providing valued material for products such as mats, baskets and paper (produced from papyrus, which is a sedge). There are several plant species which are suitable and are used extensively for making traditional handcrafts in South Africa, such as the <u>rush</u> *Juncus krausii* (*iNcema*, in Zulu), and the sedges *Cyperus latifolius* (*Ikhwane*) and *C. textilis* (*iMisis*). The common reed (*Phragmites australis*) is used for construction purposes. Some wetland plants are also collected for traditional medicines.



Figure 24: Cyperus latifidius and Juncus krausii are used for making handcrafts (Kotze and Breen, 1994).

Handcraft production from harvested wetland plants has many benefits as a development option in poor communities: it makes use of local traditional skills, has the potential for immediate cash returns and, by increasing the financial benefits to the local people, it increases the incentive not to destroy the wetland, thereby contributing to the conservation of natural habitats. However, harvesting needs to be sensitive to the functioning of the wetland.

## Valuable fisheries

Although the value of wetlands for fisheries varies greatly, floodplain wetlands (e.g. Pongola River Flats) and estuaries (e.g. Kosi Bay) are particularly valuable in the production of fish for human consumption. Many sea fishes in South Africa spend some of the early phases of their life cycle in estuaries, and some freshwater fishes, such as barbel, also use wetlands.

## Hunting waterfowl and other wildlife

Some wetlands are important places where waterfowl (including ducks and geese) and other wildlife, such as reedbuck, can be hunted. In the USA a great many people take part in the recreational hunting of waterfowl which depend on wetlands for breeding and food; in fact, duck hunters have helped to conserve many wetlands. The hunters recognize the importance of wetlands for ducks and are willing to pay to make sure that the wetlands remain in their natural, functioning condition.

#### Valuable land for cultivation

Wetland soils are potentially productive, but the anaerobic conditions associated with wetlands exclude most commonly grown crops, except for those specially adapted,

such as madumbes (*Colocasia esculenta*) and rice. Thus, wetlands are often drained so that plants not adapted to the waterlogged conditions can be grown. This has important environmental impacts, requiring that the cultivation of wetlands be well controlled.



Figure 25: A schematic illustration of sustainable and unsustainable cultivation within wetlands (Kotze and Breen, 1994).

Some wetlands are used for timber production, but because of the impact that trees have on wetland benefits, strict controls are required.

# A valuable source of water

Because water is stored in wetlands, they provide sites for the supply of water for domestic and livestock use, as well as for irrigation. The storage capacities of wetlands are sometimes increased through damming; however, this often has significant negative effects.

## Economically efficient wastewater treatment

The fact that wetlands have the ability to clean polluted water has been mentioned. Natural wetlands provide this service to society "free of charge", and are therefore sometimes purposefully used to treat polluted water, while many artificial wetlands area being created for wastewater treatment. When using a wetland to treat wastewater, several factors need to be considered to assess how effectively a wetland will purify the water:

- the pollutant, the wetland soil, flow patterns in the wetland, the size of the wetland, and the climate affecting the wetland, all of which determine the capacity of the wetland for purifying the wastewater. For example, more pollutants are likely to be trapped in a wetland where the flow is spread out across all of it, than in a one where a channel concentrates flow in only part of the wetland. If the pollutants are heavy metals then a wetland with soils rich in organic matter is likely to be more efficient at trapping heavy metals than one with soils poor in organic matter; and,
- the amount of pollutant relative to the capacity of the wetland. The capacity of the wetland is obviously limited, and if the amount of pollutant greatly exceeds this capacity, the wetland will not effectively purify the water. The impacts of pollutants on the wetland also need to be considered.



Figure 26: A schematic presentation of the limits of wetlands at performing the function of wastewater treatment (Kotze and Breen, 1994).

## Aesthetics and the appreciation of nature

Although wetlands which fringe estuaries, rivers and streams are adjacent to open water, most natural inland wetlands have fairly limited open water associated with them. They are thus generally not good sites for water sports. However, wetlands are good places to see birds - large numbers are often attracted to wetlands, with many of these birds being wetland specialists. Wetlands also add to the diversity and beauty of the landscape; they have a diverse range of colours and textures and some very attractive flowers, such as those of vlei lilies (*Crinum* spp.) and ground orchids.



Figure 27: A schematic presentation of the different textures and the variety of species (both plants and animals) that occur within wetlands and contribute towards their aesthetics (Kotze and Breen, 1994).

# 6. Wetland degradation and wetland loss

Whereas the previous section introduced the direct and indirect ways in which wetlands benefit society, this section should help you to understand how these benefits are affected by the activities of people. The manner in which we use wetlands and the scale on which we do so, determines the extent of our impact. Uses which provide good economic returns are not necessarily sustainable. Land-use activities (e.g. growing crops or damming water) often affect how a wetland functions, and what benefits it provides to society. In many cases, the effects are negative, such as when a wetland is disturbed in order to plant crops, the wetland's function of trapping sediment and holding the soil is reduced. This reduces the benefits that society receives from the wetland in purifying water and controlling erosion.

Impacts on wetlands result from both 'on-site' activities at the wetland site (e.g. drainage, disturbance through cultivation, infilling, and flooding by dams) and from 'off-site' activities in the wetland's surrounding catchment (e.g. afforestation, mining and crop production).

# On site impacts

Unless indicated otherwise, this section comes from Kotze and Breen (1994).

Below are four points to consider when assessing the general "on-site" impacts of landuses on wetlands (for more information, see references).

1. <u>Changes to the flow pattern</u> within the wetland through drainage channels, which cause flow to become more channelled and less diffuse, thereby <u>reducing the wetness of the area</u>.





2. Disturbances of the soil, making it more susceptible to erosion.



Figure 29: A schematic presentation of different levels of disturbance within a wetland (Kotze and Breen, 1994).

3. <u>Changes in the surface roughness and vegetation cover</u> (when these are reduced the ability of the wetland to slow down water flow, reduce erosion and purify water are reduced).



Figure 30: A schematic presentation of different levels of changes in the surface roughness and vegetation cover (Kotze and Breen, 1994).

4. <u>Replacement of the natural vegetation</u> by introduced plants, which generally reduces the value of the wetland for wetland dependent species.



Figure 31: A schematic presentation of different levels at which the natural vegetation has been replaced by introduced plants (Kotze and Breen, 1994).

These generally affect the wetland <u>hydroperiod</u>, i.e. the timing, frequency, duration and extent of flooding.

# Drainage and the production of crops and planted pastures

When wetlands are converted to cropland most of their indirect benefits are lost, especially if they are drained. Drained wetlands are less effective at regulating stream flow and purifying water, because the drainage channels speed up the movement of water through the wetland. Drainage increases the danger of erosion by concentrating water flow and thus increasing the erosive power of the water. Also, the hydrological changes resulting from drainage have negative effects on the soil (e.g. reduced soil organic matter and moisture levels and, sometimes, increased risk of underground fires, and increased acidity due to the oxidation of sulphides to produce sulphuric acid).

The soil is disturbed when crops are planted, and crops do not bind or cover the soils as well as the natural wetland vegetation. Thus, erosion is controlled less effectively, which may be a very serious problem in areas with high erosion hazards. Adding fertilizer and pesticides (which may leach into the river system) further reduces the effectiveness of the wetland in purifying water. The impact of cultivation can be reduced if practices characteristic of low input/traditional cultivation are followed.



**Figure 32:** A schematic illustration of madumbe (*Colocasia esculenta*) cultivation within a wetland (Kotze and Breen, 1994).

Traditional cultivation practices, which are more sensitive to the functioning of the wetland, include:

- planting crops (e.g. madumbes) which are tolerant of water logging, minimizing the need to drain;
- tillage and harvesting by hand, resulting in less soil compaction and potential disturbance than with mechanical tillage and harvesting;
- not using pesticides and artificial fertilizers, which reduces the impact on water quality; and,
- not planting extensive areas, leaving indigenous vegetation between cultivated patches.

In South Africa wetlands are protected by, amongst others, the Conservation of Agricultural Resources Act 43 of 1983 (<u>CARA</u>) (administered by the Directorate: Resource Conservation) that prevents land-users from cultivating or draining wetlands (also refer to the discussion on <u>Legislation applicable to wetlands</u>).

## Timber production

Timber plantations have a high impact on the water storage function of wetlands because a lot of water is lost by the trees through transpiration. Some trees (e.g. *Eucalyptus* spp.) use more water than other trees (e.g. poplars, which lose their leaves in winter). Trees also have a strong negative effect on the habitat value of wetlands. With increased shading beneath the trees, the vigour of indigenous plants which are not adapted to these conditions is reduced and they are often out-competed by alien invasive plants. In South Africa there is a law (Section 75 of the Forestry Act No 122 of 1986) which prevents the planting of wetlands with timber.

#### Grazing of undeveloped wetlands by domestic stock

Grazing may have both positive and negative effects on the indirect benefits of wetlands. In wetlands which have some areas grazed short and other areas left tall, the diversity of habitats is increased; however, those which are completely grazed, the diversity of habitats is decreased.

Heavy grazing may cause valuable grazing species to be replaced by less productive and/or palatable species. Some wetlands erode easily when disturbed by trampling and grazing. The most easily eroded are those wetlands with unstable soil and where water flowing diffusely across the wetland, concentrates into a channel. In these situations erosion can cause the channel to cut into the wetland and dry it out, destroying most of its functions and values. Thus, grazing pressure should not be too high, and cattle need to be kept away from these areas of flow concentration.



Figure 33: A schematic illustration of one of the possible effects resulting from over grazing a wetland (Kotze and Breen, 1994).

# Causes and effects of wetland erosion

As previously mentioned, wetlands are characteristically areas where the movement of surface water is slowed down and sediment is deposited. Sometimes, however, wetlands vulnerable to erosion, do erode and more sediment is removed than is deposited. The susceptibility of the wetland to erosion depends on several factors, including the erodibility (stability) of the soil, slope, and landform setting. Other factors, influenced by management, such as vegetation cover and disturbance of the soil (e.g. by cattle or farm machinery), also contribute to erosion. As a very general rule, soils from dry areas (i.e. <750mm of rainfall per year) tend to be less erodible than soils from wetter areas (>750mm rainfall). The particular type of rock from which the soil is formed also affects its erodibility. Landforms that are steep and landforms that have open drainage tend to erode more easily than those which are gently sloped and those which have inward drainage.

Erosion of a wetland may result in deep **<u>gullies</u>** which drain the water rapidly from the wetland, making it less wet; this often greatly reduces the values of the wetland.

## Mowing and harvesting of plants

Mowing and harvesting of plants by hand tends to have much less of a negative impact on the indirect benefits of wetlands than cultivation. Cutting plants has similar effects to grazing and generally increases habitat diversity, provided that extensive areas are not mown or cut at one time. Mowing and harvesting may also be harmful if done while wetland animals are still breeding. In the case of mowing, the machinery used for cutting may also disturb the wetland soil and increase the danger of erosion; this would not occur when plants are harvested by hand. Harvesting must be done on a sustainable basis if we are to continue to benefit from the wetland plants. If harvesting is beyond the resource's capacity for renewal, resource degradation will occur and the benefits derived by the users will be lost. Plants should not be harvested more than once a year, and the areas which are harvested should be rested for a whole year at least every third or fourth year.

#### Fishing and hunting

For hunting and fishing to be sustainable, the number of animals caught or hunted should obviously not exceed the capacity of the population to renew itself. If too many animals are caught or hunted there will not be enough left to reproduce, and to replace the ones that are removed. Consequently, the value of the wetland to continue providing these resources will be reduced.

#### Burning

Wetlands are burnt for many reasons: to improve the grazing value for livestock by removing old dead material and increase productivity; to improve the habitat value for wetland dependent species; to assist in alien plant control; and, to reduce the risk of run-away fires.

Wetland fires usually burn above-ground plant parts and most plants recover rapidly from this. Some fires also burn soil and plant parts below the ground, which usually destroys the plants. This generally detracts from the values of the wetland (e.g. by increasing the risk of erosion). However, by burning away the upper soil layers, open water areas may be created, which may enhance the diversity of the wetland.

While burning has short term impacts such as killing some animals which are not able to escape, it also has many positive effects (e.g. controlling alien plants and increasing the productivity of the indigenous plants, which may increase the breeding success of certain wetland dependent animals). Whether or not the overall effect will be positive or negative depends on many factors including: timing, frequency and extent of the fire, and the type of fire (determined by conditions at the time of the fire, such as humidity and air temperature). Late winter burning is least likely to impact on breeding animals, as very few species are likely to be breeding at this time, while early winter or summer burns are more likely to affect breeding animals.

It appears that in the high rainfall areas of South Africa, a fire every second year is unlikely to have a negative effect on known wetland dependent species. However, when a wetland area is burnt, it is important that un-burnt areas are present nearby where animals can seek cover while the burnt area is re-growing.



Figure 34: A comparison of a burnt wetland providing much less cover to wetland dependant species, compared to the un-burnt wetland (Kotze and Breen, 1994).

Back fires (burning against the wind) tend to have a greater impact on the growing points of plants than head fires (burning with the wind). Burning when humidity is high and air temperature low, generally has a lower impact than burning when humidity is low and air temperature high.

# Damming

Many wetlands in South Africa have been flooded by dams, as wetlands are often found in places which are ideal dam sites. Whilst dams achieve certain wetland functions (e.g. sediment trapping and water storage), they do not perform other functions well. The habitat required by specialized wetland dependent species is frequently lost when a wetland is dammed. The vegetation which develops around the shoreline is limited in many dams by sudden fluctuations in the water level and by the steep sides of the dam. When a series of dams occurs along a stream, the cumulative effect that the dams have in reducing the stream flow may be considerable, particularly where water is pumped out of the dams. The effects of dams are usually most noticeable in the early wet season, when they are at their lowest levels after the dry season and retain the early flows, thereby negatively impacting upon the timing of flooding.

## Purification of wastewater

We saw that wetlands are generally very effective at purifying polluted water. However, using a wetland to purify wastewater will affect the functioning of the wetland and may cause a loss of some of its other benefits, particularly if the pollutant loadings are close to, or greater than, the capacity of the wetland for purification. For example, under increased nutrient inputs the bulrush (*Typha capensis*), a very common wetland species that competes well under nutrient-rich conditions, may out-compete and eliminate less common wetland species - this would reduce the diversity of the wetland. Standards have been set by the Department of Water Affairs and Forestry for the discharge of wastewater into streams and these should not be exceeded.
# **Off site Impacts**

This section is from Kotze and Breen (1994), except where indicated.

Most of the water in a wetland originates from the catchment surrounding the wetland. Therefore wetlands are strongly influenced by activities in the surrounding catchment, even when they are distant from the wetland. When assessing the impacts of off-site land-uses on wetlands one needs to look at how the land-uses change the <u>hydroperiod</u> of the wetland and how this, in turn, affects the functioning and benefits of the wetland.

Probably the two most important land-uses affecting runoff quantity and timing from the wetland's surrounding catchment are damming/pumping of water (usually for irrigation), and afforestation. As a general rule, trees use more water than natural grassland. Gum trees use the most water (sometimes increasing water loss by more than twice that of natural grassland) followed by wattle and pine trees. Sugarcane also increases water loss. The extra water used by trees, sugarcane or any other crop that has a high transpiration rate means that this no longer reaches the wetland. Dams reduce runoff through evaporation from the dam surface, and also allow for large quantities of water to be abstracted and used for irrigation, which may greatly reduce runoff to the wetland.

There are several land-uses that may affect the quality of runoff, including:

- mining;
- intensive animal production;
- sewage works;
- industries;
- crop production;
- poorly managed grazing lands; and
- human settlements with inadequate sanitation.



Figure 35: A schematic illustration of the most common off-site impacts on wetlands (Kotze and Breen, 1994).

Runoff from mines typically has high pollutant levels. For example, iron sulphate-bearing rocks dug up to mine coal are exposed to oxygen and water, which produces sulphuric acid, and, under these acidic conditions metals such as manganese and zinc become more soluble and may reach toxic concentrations. Wastewaters from many industries also have high levels of a wide range of pollutants. Wastewaters from intensive animal production operations and sewage works typically have high levels of nutrients and disease-causing bacteria and viruses.

By law, water from point sources has to meet certain water quality standards set by the Department of Water Affairs and Forestry. However, in many cases, even though wastewaters receive some treatment before being allowed to continue down the catchment, the water quality standards are not met.

Well-managed veld used for grazing generally has a low level of impact on runoff. However, heavy grazing pressure may have a high impact, particularly if it leads to high levels of soil erosion. Also, heavy grazing pressure, causing decreased vegetation cover and increased soil compaction, decreases infiltration and groundwater recharge. This, in turn, increases floods and reduces dry season flows from the catchment. The disturbance involved in crop production and the reduced vegetation cover, especially when harvesting, increases soil loss, leading to increased sediment loads. It has been shown that even if lands are protected, and acceptable levels of soil loss are occurring, soil loss is still likely to be greater than that which would occur from well-managed natural veld. Thus, where lands are inadequately protected, the potential impact may be considerable.

Human settlements without adequate sanitation usually produce pollutants consisting of nutrients and disease-causing bacteria and viruses. These pollutants can either get washed into the wetland by surface run-off, or seep into the groundwater, which ultimately ends up in the wetland.

Let us look at the surrounding catchment of a wetland under different land-use scenarios and see to what extent the quality and quantity of runoff is likely to differ (refer to the diagrams illustrating Scenarios A, B and C).



Figure 36: A comparison of different levels of land-use within the catchment of a wetland, with low levels of land-use in the case of scenario A, and high levels of land-use in the case of scenario C (Kotze and Breen, 1994).

Scenario A has very little human activity and is likely to yield unaltered volumes of good quality water, which would benefit downstream users. In Scenario B, a large proportion of the catchment is afforested and there are several dams and some irrigation. Scenario B is likely to yield less water for downstream users, which may be of a slightly lower quality than in Scenario A. Scenario C has no afforestation and damming but has cultivation and

human settlements with poor sanitation situated close to the streams. It is therefore likely to have poorer water quality than Scenarios A and B, but yield more water than Scenario B. Imagine a combination of catchment B and C, where the quality and quantity of water would be lowered.

#### How do off-site impacts on runoff affect wetlands?

The effect of a change in the water quality of the runoff on the functioning and benefits of a wetland depends very much on the type and concentrations of the pollutant and the type of wetland. The deposition within the wetland of excess sediment from the wetland's catchment will alter the wetland landform, which may then affect the hydroperiod of the wetland. For example, if a wetland depression is filled with deposited sediment, it will retain less water than previously.

A reduction in the quantity of runoff obviously changes the hydrology of the wetland. If the runoff is greatly reduced, the wetland may become much drier. This would happen if the wetland was artificially drained, causing many of its benefits to society to be lost. A change in the timing of runoff would also alter the hydrology of the wetland, and is likely to cause some of the wetland benefits to be lost. The species found naturally in a wetland may be adapted to wetness at a particular time and they may not be able to survive if this is changed.

Besides reducing the amount of water reaching the wetland, trees planted close to the wetland may increase shading of the natural vegetation and allow the establishment of alien plants. Wetland dependent species, such as the wattled crane, which may use non-wetland grassland areas nearby for feeding, would also be negatively affected by trees planted close to the wetland.

# Conclusion

We have seen that functioning wetlands may have many benefits to society. Some of these benefits, particularly the indirect benefits, are not obvious and can be easily overlooked. This is partly why many of the wetlands in South Africa have been destroyed through development and degradation. Unless action is taken to positively influence the activities of people affecting wetlands, the results could be very serious. In a water-poor country such as South Africa, continued destruction of wetlands will result in:

- lower agricultural productivity;
- less potable water;
- less reliable water supplies;
- increased downstream flooding; and,
- increasingly threatened plant and animal resources.

From the discussion on wetland benefits and land-use impacts we have seen that the hydrology of a wetland is the most important factor determining its functioning. **Thus, as a general rule, the more one alters the hydrology of a wetland, the greater will be the effect on its functioning**. When people use wetlands or their catchments to obtain resources, the functioning and indirect benefits of the wetland are often affected negatively. However, some uses (e.g. sustainable harvesting of wetland plants) are much less destructive than others (e.g. draining and cultivating crops). Those uses which do not alter the hydrology and which do not affect the functioning of the wetland negatively, need to be promoted. By doing this, local people can benefit directly from

the wetland while, at the same time, the benefits received by society are not lost (i.e. more people benefit and the total value of the wetland is increased).

If you use a wetland directly or are giving advice, it is important to know how different land-use choices affect the functioning of the wetland and the benefits it provides to society.

# 7. Wetland Policy

The Free State department of Tourism, Environmental and Economic affairs has developed a wetland policy to guide the effort of provincial wetland conservation. According to this policy, the Department will strive to achieve the following goals (taken and adapted from the Canadian Federal Government Policy on Wetland Conservation):

- Achieve no net loss of wetland functioning.
- Enhance and <u>rehabilitate</u> wetlands in areas where the continuing loss or degradation of wetlands, or their functions, have occurred and/or reached critical levels.
- Recognise wetland functions in resource planning, management and economic decision-making with regard to all programmes, policies and activities.
- Secure wetlands of significance on a provincial, national and international scale.
- Recognise sound, sustainable management practices in sectors such as agriculture, that make a positive contribution to wetlands conservation while also achieving wise-use of wetland resources.
- Promote the sustainable utilisation of wetlands in a manner that enhances prospects for their sustained and productive use by future generations.

Implications of these goals are:

- Achieve no net loss of wetland functions or values.
  - To prohibit any activities that will detract from the ability of a wetland to perform, or deliver upon its inherent functions and values. In instances where such impacts cannot be avoided, the functions and values to be lost must be mitigated for through off-site mitigation. This goal also implies preventing further degradation of wetlands.
- Enhance and rehabilitate wetlands in areas where the continuing loss or degradation of wetlands, or their functions, have occurred and/or reached critical levels.

Priority catchments needs to be identified, and the extent of wetland loss within these need to be determined. Strategies to prevent further function loss through wetland loss and degradation needs to be sought and implemented.

• Recognise wetland functions in resource planning, management and economic decision-making with regard to all programmes, policies and activities.

Government and non-government organizations need to be made aware of the functions and values of wetlands, and how different land-uses and disturbances negatively impact upon these. Such departments need to be made aware of the constraints and the opportunities that wetlands could impose, and how these should be dealt with.

- Secure wetlands of significance on a provincial, national and international scale.
- An **inventory** of the wetland of the Free State needs to be compiled. The spatial information needs to be supplemented by the appropriate attribute data, to allow for the compilation of a list of wetlands of provincial importance. Such wetlands should be assigned the appropriate classification (e.g. **Ramsar** status), and measures to secure these wetlands need to be put into place.
- Recognise sound, sustainable management practices in sectors such as agriculture that make a positive contribution to wetland conservation, while also achieving wise-use of wetland resources.

Collaborate with relevant stakeholders to identify different land-uses and activities that are compatible with wetland conservation. Encourage and support the implementation of such practices.

• Promote the sustainable utilisation of wetlands in a manner that enhances prospects for their sustained and productive use by future generations.

Identify different land-uses and activities and determine how these impact upon wetland functions and values. Promote and improve on those that are sustainable, while investigating various methods and procedures to mitigate negative impacts.

The complete FS DTEEA Wetland Policy is obtainable from collinsn@dteea.fs.gov.za.

# 8. Legislation applicable to wetlands

Unless indicated otherwise, this section is from Kotze *et al.* (Wetland Rehabilitation Manual).

# Introduction

In the previous section a number of activities that may have an adverse impact on wetlands were identified and discussed. Most of these activities are related to poor practices in the agriculture, forestry and mining sectors. In most cases, these activities or practices are dealt with by means of sector-specific legislation. However, there are several provisions of South African environmental law and policy which have an over-arching (and cross-cutting) control over these activities. They are the Environmental Impact Assessment (EIA) regulations passed under the Environmental Conservation Act (ECA), aspects of NEMA and the General Policy passed under the ECA. These general controls over activities which may have a negative impact on wetlands will be considered before activity-specific laws are analyzed.

# General legislative controls over activities which may have a negative impact on wetlands

#### The EIA regulations

In terms of the ECA, the Minister of Environmental Affairs and Tourism is entitled to identify activities which he or she believes may have a substantial detrimental effect on the environment. No-one may carry out such an identified activity without the prior written permission of a competent authority. Permission may not be granted without compliance with (or exemption from) the EIA regulations. The EIA regulations commenced in three phases between 8 September 1997 and 1 April 1998. They apply to all identified activities physically undertaken after these dates.

The Minister has identified a list of activities concerning wetland degradation and rehabilitation, of which the most important are:

- The construction or upgrading of:
  - roads and associated structures outside the borders of town planning schemes;
  - canals and channels, including diversions of the normal flow of water in a river bed and impoundments;
  - o dams, levies, or weirs affecting the flow of the river; and,
  - schemes for the abstraction or utilisation of ground or surface water for bulk supply purposes.
- The intensive husbandry of, or importation of, any plant or animal that has been declared a weed or alien invasive species;

- The reclamation of land below the high-water mark of the sea, and in inland water including wetlands;
- Defined change(s) of land-use.

The precise meaning of these activities is open to individual interpretation. For example, some officials are of the view that agricultural operations in a wetland constitute reclamation of inland water, an identified activity, whereas others think it does not. Clearly, these identified activities encompass a number of human undertakings which are likely to have an adverse impact on wetlands.

The EIA regulations contain a number of procedural and substantive requirements, including an obligation to complete a scoping report which must include a brief project description, a description of how the environment may be affected, a description of environmental issues identified, and a description of all alternatives identified. An applicant is also required to ensure adequate public participation in the process. Where the impact is likely to be a particularly significant one, the applicant will be required to conduct a full environmental impact assessment.

Experience gained in the implementation of the ECA Regulations (R1182, R1183, R1184) has resulted in several deficiencies being highlighted. These deficiencies have been addressed through an approach of amendment to NEMA, revised Regulations and an adapted approach to EIA implementation. Regulations under Government Notice numbers R1182, R1183 and R1184 under ECA will be repealed and replaced by new Regulations published in terms of Section 24(5) of NEMA. These revised Regulations in terms of Section 24 of NEMA have not yet been promulgated.<sup>3</sup>

The purpose of these amendments is amongst others to streamline the EIA procedure. Within the new notices, a distinction is made between activities that require screening and those that require scoping and an EIA. Those that require screening are listing in schedule 2 of the notice while those that require scoping and an EIA are listed in schedule 3. However, the competent authority could request scoping and an EIA for activities listed in schedule 2. Wetland related activities that are listed, are:

Schedule 2:

- The construction of facilities or infrastructure, including associated structures or infrastructure, for any purpose in the one in ten year flood line of a river or stream, or within 32 metres from the bank of a river or stream where the floodline is unknown, excluding purposes associated with existing residential use, but including
  - o Canals
  - o Channels
  - o Bridges
  - Dams, and
  - o Weirs

<sup>&</sup>lt;sup>3</sup> Mr. D. Krynauw. Senior environmental officer. Free State Department of Tourism, Environmental and Economic Affairs. Tel: 051 4004814; Cell: 082 4352108.

• The dredging, excavation, infilling, removal, or moving of soil, san or rock exceeding 5 cubic metres from a river, tidal lagoon, tidal river, lake, dam or wetland.

Schedule 3:

• The extraction of peat.

In accordance with the provisions of section 24(2)(c) of the Act, an MEC may exclude above listed activities where the receiving environment is not sensitive to the undertaking of such activities.

### NEMA

Importantly, NEMA contains provisions regarding an obligation to conduct environmental impact assessments for proposed activities, even where they are not those identified by the Minister in terms of section 21 of the ECA. NEMA provides that where someone proposes to carry out an activity which, firstly, requires permission or authorization by law, and secondly, may significantly affect the environment, that proposed activity must be considered, investigated and assessed prior to implementation, and reported to the organ of state charged by law with giving the permission. The section makes it clear that the existing EIA regulations remain in force, but that, notwithstanding those, the minimum requirements for investigation and assessment, contained in section 24(7) of NEMA, must be complied with even where an activity is not scheduled under the EIA regulations. They include: an obligation to investigate the potential impacts, including cumulative effects of the activity and its alternatives, an investigation into the alternative of not implementing the activity, and reporting on gaps in knowledge and underlying assumptions. These requirements are, in some respects, considerably broader than those required by the EIA regulations.

An application under the EIA regulations will fall within the ambit of section 24, since it is an undertaking which requires permission and, by its very nature, may have a significant effect on the environment. It therefore follows that anyone wishing to conduct an identified activity which is potentially harmful to a wetland, must comply with the requirements of both the EIA regulations and with section 24(7) of NEMA.

This section of NEMA also has important implications for activities which are likely to affect wetlands negatively and which are currently not subject to the EIA regulations - one such example is mining. Importantly, insofar as wetland rehabilitation is concerned, any activities which meet the two-pronged test referred to above, must also be subject to the minimum requirements contained in section 24(7) of NEMA.

#### General policy under the ECA

This policy was passed in terms of section 2 of the ECA, but does not appear to have been enforced in any significant way until fairly recently. In relation to land-use it requires that, before embarking on any large-scale or high-impact development project, a planned analysis must be taken in which all interested and affected parties must be involved. The Cape Provincial Division enforced this requirement in the matter of *The Save Klein Hangklip Association v The Minister of Planning, Administration and Culture* 

*(Western Cape) and Others.* The failure by the second respondent to carry out a planned analysis (that is, an EIA) at the time when an application was made for the change of land-use rights, resulted in the court setting aside those land-use rights. This policy may be significant where wetlands have been degraded prior to the entry into force of the EIA regulations in 1997. However, the provisions of NEMA, which are retrospective in effect, have, for the most part, superseded the provisions of the policy.

# Activity specific controls

#### Poor agricultural practices

The Conservation of Agricultural Resources Act (CARA)

The main focus of the Conservation of Agricultural Resources Act (CARA) is upon agricultural resources, but it has indirect implications for wetlands, especially insofar as they play a positive role in agricultural activities. It is also one of the primary statutes through which agricultural activities which negatively affect wetlands may be regulated. Of particular importance are the recently promulgated regulations. The stated object of CARA is to provide for the conservation of the natural agricultural resources of the Republic by the: maintenance of the production potential of land; the combating and prevention of erosion; prevention of the weakening or destruction of the water sources; by the protection of the vegetation, and by combating weeds and invader plants. The resources which CARA is accordingly concerned with are land, water and the related aspects of the veld and vegetation.

Importantly, CARA does not apply to land (and by implication, wetlands) situated in urban areas. The term urban area is defined in section 1 of CARA and includes areas under the control of local authorities as well as public open spaces within local authority areas. Since the division of the entire Republic into municipal areas in December 2001, the entire Republic is (for the purposes of the Act) an urban area. Until such time that CARA is amended, a large proportion of the Act may therefore not have application in the Republic. However, the application of the provisions of the act relating to weeds and invader plants (including the regulations) is specifically extended to urban areas.

Notwithstanding its current non-application, the provisions of CARA should be taken into account as it is anticipated that the definition of urban area will be amended shortly. CARA regulates rehabilitation of wetlands insofar as that activity falls under the definition of conservation which, in relation to the natural agricultural resources, includes the protection, recovery and reclamation of those resources.

The Minister of Agriculture may prescribe control measures with which all land-users must comply. Section 6 includes the control measures which are relevant to wetland rehabilitation. They are:

- the irrigation of land;
- the prevention or control of waterlogging, or salinization of land;
- the utilisation and protection of vleis, marshes, water sponges, watercourses and water sources;

- the regulation of the flow pattern of run-off water;
- the utilisation and protection of vegetation;
- the control of weeds and invader plants;
- the protection of water sources against pollution on account of farming practices; and,
- any other matter which the Minister may deem necessary or expedient in order that the objects of CARA be achieved.

The Minister has published a number of control measures. These include those in accordance with section 6(2) concerning the utilization and protection of vleis, marshes, water sponges and watercourses; regulation of the flow pattern of water; restoration and reclamation of eroded land, and restoration and reclamation of disturbed or denuded land. With the Minister's co-operation, these may be employed to compel wetland rehabilitation, where this is appropriate.

Regulations amending the original regulations under the Act were promulgated on 30 March 2001. Regulations 15 and 16 of the original regulations, which dealt with weeds and invader plants, have been substituted with new regulations. The amending regulations apply to those plants identified as category 1 species (weeds) or categories 2 and 3 species (invader plants), and prescribe measures for the combating of each of these categories. Relevant to wetland rehabilitation and protection is the provision that land-users control plants which occur contrary to the provisions of the amending regulations, and that they must prevent and effectively restore or reclaim land on which excessive soil loss due to erosion occurs, or has occurred. Methods of control are set out and specified and include uprooting, felling, cutting or burning. As stated above, these Regulations specifically apply to urban areas, as well as rural areas.

#### Poor forestry practices

The Free State province has been fortunate in that limited forestry activities have taken place here. Forestry activities are governed by several pieces of national legislation, including the National Water Act, the National Forests Act and NEMA. Insofar as these laws regulate wetland rehabilitation, their important provisions are as follows:

#### National Water Act

The Act identifies the use of land for commercial afforestation as a "stream flow reduction activity". Stream flow reduction activities are included in the definition of water uses. Such a license would not be granted until a consideration of the use of water had been undertaken. Although the Act does not make this explicit, it would be reasonable to include an examination of the extent to which proposed forestry activities negatively impact on wetlands.

#### National Forests Act

Like much of the legislation which has been passed in South Africa recently, the National Forests Act rests on a principle-based approach to decision-making. Some

of the principles which underpin this Act, and which are relevant to wetlands, are the requirement that forests be developed and managed so as to:

- conserve biological diversity, ecosystems and habitats; and,
- sustain the potential yield of their economic, social and environmental benefits.

The Act also makes provision for licenses to be granted for activities conducted in State forests, including the construction of roads, buildings or structures, grazing or herding of animals, and cultivation of lands, all of which impact on wetlands situated in State forests.

State forests may also be managed by communities in terms of community forestry agreements. Such an agreement would include permitted activities within an area designated to be the subject of a community forestry agreement. If wetland rehabilitation were to take place in such an area, the co-operation of the community concerned would need to be secured.

#### The EIA regulations

The identified activities referred to previously include the intensive husbandry of, or importation of any plant or animal that has been declared a weed, or an invasive alien species. It will therefore be necessary for anyone intending to conduct the commercial forestry of any plant which has been declared an invasive alien species to comply with the EIA regulations, in addition to any other statutory obligations (like those under the new CARA regulations) he or she may have.

#### Poor mining practices

Mining is one of the human activities which has potentially the most significant adverse impacts on wetlands. This was highlighted in the case of *The Director: Mineral Development (Gauteng Region) and Another vs Save the Vaal Environment and Others*. Mining is regulated by the Minerals Act and regulations passed under it or its predecessor, the Mines and Works Act.

#### The Minerals Act

The Act requires that anyone intending to prospect or to mine, must first be in possession of the appropriate permit and an approved Environmental Management Plan (EMP). It is a requirement that the EMP be implemented as a part of the prospecting or mining process and simultaneously with such operations. It is further required that no sand may be extracted from the bank of any stream, river, dam or watercourse except with written permission. Furthermore, where damage has been caused to the bank of a stream, river, dam, pan or lake, that bank must be restored to the satisfaction of the inspector of mines at the expense of the owner or manager. Sand or slimes dumps may not be established on the bank of a river or stream, dam, pan or lake without the written permission of the inspector of mines.

#### NEMA

It is important to recognize that, in addition to obtaining a prospecting or mining license and an approved EMP, a person wishing to undertake mining activities will be obliged to comply with section 24 of NEMA. This is because a prospecting or mining license, or the approval of an EMP, falls within the ambit of an activity which requires authorization or permission by law, and mining may significantly affect the environment. Given that those tests are met, someone wishing to undertake mining activities must comply with the procedures laid down in section 24(7) of NEMA.

#### The spread of alien invasives

#### Introduction

This activity is governed by two primary legal controls: the first of these is the EIA regulations, (previously discussed); and the second is the recently promulgated regulations under CARA, which came into force on 30 March 2001.

#### The EIA regulations

As mentioned previously, the intensive husbandry of, or importation of any plant or animal that has been declared a weed or invasive alien species, is an activity identified in terms of section 21 of the ECA and it will therefore be necessary for anybody carrying out any such intensive husbandry to comply with the EIA regulations. If the growing of such plants does not fall within the ambit of intensive husbandry, perhaps because the plants are simply grown ornamentally or as a hobby, then the regulations will not apply.

#### The new CARA regulations

As discussed previously under The Conservation of Agricultural Resources Act, the new CARA regulations amend the existing regulations relating to weeds and invader plants. The effect of the regulations is to place a duty on land-users to control weeds and invader plants in certain identified areas, which would, in most cases, include wetlands. The introduction of this "duty to control" will have the effect of lessening the burden of the authorities charged with rehabilitating wetlands affected by alien invasives.

#### Urbanisation

#### The Physical Planning Acts

Aside from mining, urbanization is one of the most significant threats to wetlands. Land-use control laws in South Africa operate primarily through town planning or zoning schemes, promulgated under provincial ordinances and laws, and this will increasingly become the case since South Africa has established wall-to-wall local government. However, there are several pieces of national legislation which regulate land-use planning. They are the two physical Planning Acts, the Black Communities Development Act, and the Less Formal Townships Establishment Act.

The only national Act which is of direct relevance to wetland rehabilitation is the Development Facilitation Act.

#### The Development Facilitation Act

The Development Facilitation Act (DFA) sets the overall framework and administrative structures for planning throughout the country. It is intended to be a

framework law which allows provinces to pass provincial planning laws and regulations appropriate for specific circumstances.

The overall objective of the DFA is evident from its long title, namely to introduce extraordinary measures to facilitate and speed up the implementation of reconstruction and development programmes and projects in relation to land; and, in doing so, to lay down general principles governing land development throughout the Republic.

"Environment" is as defined in section 1 of the ECA, and "environmental evaluation" means an evaluation of the environmental impact of a proposed land development, conducted in accordance with the integrated environmental management guidelines (which are from time to time issued, or amended, by the Department of Environment Affairs and Tourism).

The DFA contains general principles for land development and conflict resolution. Principles relevant to the rehabilitation of wetlands are the following:

- Policy, administrative practice and laws should promote efficient and integrated land development in that they:
  - promote the integration of the social, economic, institutional and physical aspects of land development;
  - promote integrated land development in rural and urban areas in support of each other; and,
  - encourage environmentally sustainable land development practices and processes.
- Furthermore, the DFA requires that policy, administrative practice and laws should promote sustainable land development at the required scale in that they should:
  - promote land development which is within the fiscal, institutional and administrative means of the Republic;
  - promote the establishment of viable communities;
  - o promote sustained protection of the environment; and,
  - o meet the basic needs of all citizens in an affordable way.

Each proposed land development area should be judged on its own merits and no particular use of land, such as residential, commercial, conservational, industrial, community facility, mining, agricultural or public use, should in advance, or in general, be regarded as being less important or desirable than any other use of land.

#### The construction of roads

Introduction

Roads are often constructed through wetlands, thereby dividing them and changing their nature. In addition, the runoff from roads may create unexpected water movement or erosion some distance from the roads, thereby leading to unanticipated impacts on wetlands. These problems are regulated, at least partially, by three pieces of legislation:

The South African National Roads Agency Limited and National Roads Act The South African National Roads Agency Limited and National Roads Act does not specifically provide for the carrying out of environmental impact assessments by the National Roads Agency during the construction of maintenance of roads. The only power which it has which may positively affect wetlands, is the power to plant trees, shrubs or other plants, or to take any other steps for the convenience of road users, the appearance of the road, or to prevent soil erosion arising as a result of the construction of a national road.

#### The EIA regulations

As was mentioned previously, the construction of, among other things, roads and associated structures outside the borders of town planning schemes is an activity requiring compliance with the EIA regulations. Road-building must also be done in compliance with section 24(7) of NEMA, if it meets the two-pronged test in section 24(7).

#### The National Water Act

The construction of a road may well have the effect of diverting the flow of water of a watercourse, or of altering the characteristics of a watercourse, thereby constituting a water use for which a water-use license would be required.

#### South African provincial law

An analysis of provincial laws in South Africa which may have a bearing on wetland rehabilitation is excluded from the ambit of this report. However, provincial laws which may be relevant include the Town Planning or Land Use Planning Ordinances enacted by the four former provinces in South Africa before 1994. Some provinces have passed laws replacing those, which do or will regulate planning and development. Some provinces are in the process of enacting broader environment conservation laws, and all provinces are subject at least to the provisions of the Nature Conservation Ordinances of the former four provinces. KwaZulu-Natal also has a Prevention of Environmental Pollution Ordinance. Each of these might have a bearing on wetland degradation and rehabilitation.

#### Local legislation

It is worth bearing in mind that many municipalities (or their predecessors-in-law) will have passed local authority by-laws which may regulate activities which degrade wetlands. These are likely to be contained in water supply, or effluent discharge by-laws, both categories of which will, generally speaking, make it an offence to pollute water resources, which, by definition, would ordinarily include a wetland. In addition, nuisance by-laws may also have a bearing on wetland degradation in that they will prohibit their pollution. Finally, solid waste disposal by-laws may have similar provisions.

# 9. THE RAMSAR CONVENTION

The following information was taken from the Ramsar web page: <u>http://www.ramsar.org/</u>. The complete Ramsar Convention Manual, third edition, 2004, can be obtained from http://www.ramsar.org/lib\_manual2004e.htm.

# What is the Ramsar Convention on Wetlands?

The **Convention on Wetlands** is an inter-governmental treaty adopted on 2 February 1971 in the Iranian city of Ramsar, on the southern shore of the Caspian Sea. Thus, though nowadays the name of the Convention is usually written "Convention on Wetlands (Ramsar, Iran, 1971)", it has come to be known popularly as the "Ramsar Convention". Ramsar is the first of the modern global inter-governmental treaties on conservation and wise use of natural resources, but, compared with more recent ones, its provisions are relatively straightforward and general. Over the years, the Conference of the Contracting Parties (the main decision-making body of the Convention, composed of delegates from all the Member States) has further developed and interpreted the basic tenets of the treaty text, and succeeded in keeping the work of the Convention abreast of changing world perceptions, priorities, and trends in environmental thinking.

The official name of the treaty – *The Convention on Wetlands of International Importance especially as Waterfowl Habitat* – reflects its original emphasis on the conservation and wise use of wetlands primarily to provide habitat for waterbirds. Over the years, however, the Convention has broadened its scope to cover **all aspects** of wetland conservation and wise use, recognizing wetlands as ecosystems that are extremely important for biodiversity conservation in general, and for the well-being of human communities. For this reason, the increasingly common use of the short form of the treaty's title, the "Convention on Wetlands", is entirely appropriate.

The Convention came into force in 1975 and, as of September 2003, has 138 Contracting Parties. More than 1310 wetlands have been designated for inclusion in the List of Wetlands of International Importance, covering some 111 million hectares (1.11 million km<sup>2</sup>), more than the surface area of France, Germany, and Switzerland combined.

UNESCO serves as depositary for the Convention, but its administration has been entrusted to a secretariat known as the "Ramsar Bureau", which is housed in the headquarters of the IUCN – The World Conservation Union, in Gland, Switzerland, under the authority of the Conference of the Parties and the Standing Committee of the Convention.

# Why do countries join the Ramsar Convention?

Membership in the Ramsar Convention:

 entails an endorsement of the principles that the Convention represents, facilitating the development at national level of policies and actions, including legislation that helps nations to make the best possible use of their wetland resources in their quest for sustainable development;

- presents an opportunity for a country to make its voice heard in the principal intergovernmental forum on the conservation and wise use of wetlands;
- brings increased publicity and prestige for the wetlands designated for the "List of Wetlands of International Importance", and hence increased possibility of support for conservation and wise-use measures;
- brings access to the latest information and advice on application of the Convention's internationally-accepted standards, such as criteria for identifying wetlands of international importance, guidelines on application of the wise-use concept, and guidelines on management planning in wetlands;
- brings access to expert advice on national and site-related problems of wetland conservation and management through contacts with Ramsar Bureau personnel and consultants, and through application of the Ramsar Advisory Mission mechanism when appropriate; and,
- encourages international co-operation on wetland issues and brings the possibility of support for wetland projects, either through the Convention's own Small Grants Fund, or through the Convention's contacts with multilateral and bilateral external support agencies.

# What are the commitments of Parties joining the Ramsar Convention?

When countries join the Convention, they are enlisting in an international effort to ensure the conservation and wise use of wetlands. The treaty includes four main commitments that the Contracting Parties have agreed to by joining.

#### Listed sites

The first obligation under the Convention is to designate at least one wetland for inclusion in the **List of Wetlands of International Importance** (the "Ramsar List") and to promote its conservation, including, where appropriate, its wise use. Selection for the Ramsar List should be based on the wetland's significance in terms of ecology, botany, zoology, limnology, or hydrology. The Contracting Parties have adopted specific criteria and guidelines for identifying sites that qualify for inclusion in the List of Wetlands of International Importance.

#### Wise use

Under the Convention there is a general obligation for the Contracting Parties to include wetland conservation considerations in their national land-use planning. They have undertaken to formulate and implement this planning so as to promote, as far as possible, "the wise use of wetlands in their territory" (Article 3.1 of the treaty).

The Conference of the Contracting Parties has approved guidelines and additional guidance on how to achieve "wise use", which has been interpreted as being synonymous with "sustainable use".

# Reserves and training

Contracting Parties have also undertaken to establish nature reserves in wetlands, whether or not they are included in the Ramsar List, and they are also expected to promote training in the fields of wetland research, management and wardening.

#### International co-operation

Contracting Parties have also agreed to consult with other Contracting Parties about implementation of the Convention, especially in regard to transfrontier wetlands, shared water systems, and shared species.

Over the years, the Conference of the Contracting Parties has interpreted and elaborated upon these four major obligations included within the text of the treaty, and it has developed guidelines for assisting the Parties in their implementation. These guidelines are published in the Ramsar Handbook series.

It is important to note from the above that the responsibilities and commitments of the Contracting Parties are not limited to those of listed wetlands alone, but extend towards all wetlands within their territory.

#### Reporting

Contracting Parties report on progress in implementing their commitments under the Convention by submission of triennial National Reports to the Conference of the Contracting Parties. The National Reports become part of the public record.

# The Montreux Record

The Montreux Record is a register of wetland sites on the List of Wetlands of International Importance where changes in ecological character have occurred, are occurring, or are likely to occur as a result of technological developments, pollution or other human interference. It is maintained as part of the Ramsar List. The Conference of the Parties has adopted a working definition of "ecological character" and of "change in ecological character", as well as a *Wetland Risk Assessment Framework*.

The Montreux Record was established by Recommendation 4.8 of the Conference of the Contracting Parties (1990). Resolution 5.4 of the Conference (1993) determined that the Montreux Record should be employed to identify priority sites for positive national and international conservation attention. As they expressed it in Resolution VIII.8 (2002), the Parties believe that "the voluntary inclusion of a particular site on the Montreux Record is a useful tool available to Contracting Parties in circumstances where:

- a) demonstrating national commitment to resolve the adverse changes would assist in their resolution;
- b) highlighting particularly serious cases would be beneficial at national and/or international level;
- c) positive national and international conservation attention would benefit the site; and/or
- d) inclusion on the Record would provide guidance in the allocation of resources available under financial mechanisms."

Resolution VI.1 (1996) established more precise procedures for the utilization of the Montreux Record mechanism, with guidelines on the steps to be taken for including Ramsar Sites on the Record and removing sites from it. Sites may be added to and removed from the Record only with the approval of the Contracting Parties in which they lie. As of December 2003, 55 sites are present in the Montreux Record - 23 sites which had been listed on the Montreux Record have since been removed from it (though one of these has been listed once more).

At the request of the Contracting Party concerned, the Secretariat may send a technical mission, known as the "Ramsar Advisory Mission", to analyze the situation at one or more particular Montreux Record sites, provide advice on the measures to be taken, and assess the desirability of removing a site from the Montreux Record when measures have been implemented successfully.

# The Conference of the Contracting Parties

The implementation of the Ramsar Convention is a continuing partnership between the Contracting Parties, the Standing Committee, and the Convention Secretariat (the Ramsar Bureau), with the advice of the Scientific and Technical Review Panel (STRP) and the support of the International Organization Partners. Every three years, government representatives of the Contracting Parties meet as the Conference of the Contracting Parties (COP), the policy-making organ of the Convention which reviews the general trends in the implementation of the Convention as reflected in the National Reports and adopts decisions to improve the way in which the Convention works. The programme of each meeting of the Conference also includes a series of technical sessions which analyze issues of importance in the field of wetland conservation and wise use, including further interpretation and development of the key Convention concepts. Ramsar COPs have gained the reputation of being highly effective events, allowing an active involvement and participation of the non-governmental and academic community.

# The Standing Committee

The Standing Committee meets annually to: carry out interim activity between each COP on matters previously approved by the Conference; prepare documentation for consideration at the next COP; supervise implementation of policy by the Ramsar Bureau and execution of the Bureau's budget; and decide upon applications for project support from the Ramsar Small Grants Fund.

The Standing Committee consists of 13 Contracting Parties elected on a proportional basis from the six Ramsar regions – Africa, Asia, Europe, Neotropics, North America, and Oceania – as well as the host countries of the most recent meeting and the next meeting of the COP. The Contracting Parties which host the Ramsar Bureau, and Wetlands International, are invited to participate as Permanent Observers, and the "International Organization Partners" (see below) are invited to participate in an advisory capacity.

# The Secretariat

The **Ramsar Convention Bureau** is the permanent secretariat for the Convention and carries out the day-to-day coordination of the Convention's activities. The Bureau is

headed by a Secretary General, who supervises the work of a small number (currently 16) of technical, communications and administrative staff, four interns, and five outposted members of the MedWet Coordination Unit in Athens, Greece. Ramsar staff members work in several languages (notably the Convention's three official languages, English, French, and Spanish) and provide expertise in a range of disciplines. Consultants are recruited from time to time, as required.

### The Scientific and Technical Review Panel

The Scientific and Technical Review Panel (STRP) provides scientific and technical advice to the Conference of the Contracting Parties. The STRP is composed of 13 individual members with appropriate scientific and technical knowledge, selected from the six Ramsar regions, and representatives of the four International Organization Partners. Other relevant organizations also contribute to the work of the STRP, as observers.

# The International Organization Partners

The Conference of the Parties may confer the status of International Organization Partner to international organizations, both inter-governmental and non-governmental, that "contribute on a regular basis and to the best of their abilities to the further development of the policies and technical and scientific tools of the Convention and to their application". So far, four international non-government organizations which have been associated with the Convention since its inception have been recognized as IOPs. They are BirdLife International, IUCN – The World Conservation Union, Wetlands International, and the World Wide Fund for Nature (WWF).

**Table 10:** Attributes and characteristics of floodplain and valley bottom wetlands that enable them to perform certain functions.

Wetland type/hydrological class.	Attributes and characteristics.	Contribution of attributes and characteristics towards its ability to perform various hydrological functions.
Wetland type: Floodplain and Valley bottom (channelled and	Flat/wide	1) Their flat and wide nature assists in reducing the velocity of the flow, because of reduced gravitation and spreading of the concentrated channel flow over a wider area. This causes sediment to settle down, thereby purifying the water from sediment, but also of other pollutants adsorbed to the sediments, e.g. bacteria and viruses.
unenamerica		2) The flatness of the surface area promotes contact between water and sediments because of the shallow nature of the water column, leading to high levels of sediment/soil-water exchanges. The shallow nature also promotes exposure of bacteria and viruses to solar radiation, which assists in the elimination of these from wetland waters (Seidel, 1970; Rogers, 1983 in Kotze <i>et al.</i> , 1994).
		<ol> <li>The shallow oxygenated surface water promotes the occurrence of aerobic/anaerobic processes by maximising the aerobic/anaerobic interface where denitrification can occur (Hemond and Benoit, 1988; Hammer, 1992 in Kotze <i>et al.</i>, 1994).</li> </ol>
		4) The flat and wide nature of palustrine floodplain-type wetlands is responsible for the greater retention time of these systems relative to the river or channel flow. One of the most important mechanisms for bacterial removal by wetlands is simply detention while natural die-back occurs. Pathogenic micro-organisms found in sewage effluent generally cannot survive for long periods of time outside the host organisms (Hemond and Benoit, 1988 in Kotze <i>et al.</i> , 1994).
		Summary: The physical nature of the palustrine floodplain-type wetland promotes all hydrological functions associated with palustrine floodplain-type wetlands due to the effect that it has on reducing the velocity, which enhances the efficiency of these functions.
Permanent wet	Aerobic/anaerobic conditions	<ol> <li>Promotes high soil organic matter contents (accumulates primarily as a result of anaerobic conditions) which favours the retention of elements such as heavy metals.</li> </ol>
		<ol> <li>Denitrification, caused by anaerobic bacteria, is the primary mechanism for nitrogen removal from wetland waters (Sather and Smith, 1984 in Kotze <i>et al.</i>, 1994).</li> </ol>

Relationshir	hetween the ecologic	al zones within wet	lands and their a	ability to perform	certain hydrological functions
relationship		ai 201163 within wet	ianus anu then a	αριπιχ το ρεποπη	

Wetland type/hydrological class.	Attributes and characteristics.	Contribution of attributes and characteristics towards its ability to perform various hydrological functions.
		3) Certain metals, such as cadmium and zinc, are more strongly bound to humic material under anaerobic conditions than under aerobic ones. In contrast, other metals, such as iron (precipitated as ferric oxide under aerobic conditions) may be released back into wetland waters as ferrous iron with the onset of anaerobic conditions (Hemond and Benoit, 1988 in Kotze <i>et al.</i> , 1994).
		4) Another important mechanism by which metals may be removed is through precipitation as oxides, hydroxides, carbonates, phosphates and sulphides. Most transition metals are precipitated as sulphides. This occurs under anaerobic conditions and thus, provided wetlands contain appreciable sulphide ions, the conditions generally prevailing in wetlands tend to promote the precipitation of transition metals. This process is usually more important in saltwater than freshwater because of the generally higher sulphate concentration in saltwater (Hemond and Benoit, 1988 in Kotze <i>et al.</i> , 1994).
		5) Several workers (Parr and Smith, 1976; Sleat and Robinson, 1983; Suflita <i>et al.</i> , 1983; Gambrell <i>et al.</i> , 1984; Gambrell and Patrick, 1988 in Kotze <i>et al.</i> , 1994) have shown that many organic compounds, such as halomethanes, are degraded far more rapidly under anaerobic than aerobic conditions. Thus, wetlands, which characteristically have anaerobic soils, may play a vital role in the degradation of these compounds.
		6) BOD (Biological Oxygen Demand) of water is a measure of the oxygen required for the degradation of organic matter. Wetlands decrease the BOD of introduced waters through the decomposition of organic matter during aerobic bacterial respiration (Hemond and Benoit, 1988 in Kotze <i>et al.</i> , 1994).
	Organic content	1) Wetlands tend to have a high organic content in the upper soil horizons which increases the porosity and water-holding capacity of these layers, as well as the overall depth of the soil profile (Begg, 1986; Mitsch and Gosselink, 1986 in Kotze <i>et al.</i> , 1994). These factors may be important in contributing to a wetland's water-holding ability (Angus, 1987 in Kotze <i>et al.</i> , 1994).
	Soils	1) Most metals are adsorbed more efficiently by organic soils than by mineral ones (Vestergaard, 1979 in Kotze <i>et al.</i> , 1994). Since wetland sediments are usually rich in organic matter, they are likely to be better suited for sorption of metals than non-wetland soils with less organic matter. Some metal cations also appear to form organically bound complexes with soil organic matter; in such cases, sorption is essentially non-reversible provided the soil is not disturbed (Wieder and Lang, 1986 in

Wetland type/hydrological class.	Attributes and characteristics.	Contribution of attributes and characteristics towards its ability to perform various hydrological functions.
		Kotze <i>et al.</i> , 1994).
	Vegetation: Typically dense and tall with high frictional value	1) The permanent wet areas are usually characterised by vegetation which offer high resistance to stream flow, even under large flooding conditions as this vegetation is typically tall, e.g. <i>Phragmites</i> reeds and <i>Typha</i> sp. (bullrushes). Therefore, closely associated with the aerobic/anaerobic conditions, is its ability to reduce the velocity of the flow, thereby increasing its opportunity to perform a water rehabilitation function. The most important factor affecting the "roughness coefficient" is the vegetation - the greater the frictional resistance offered by the vegetation the higher the roughness coefficient.
		2) The higher the mean flow velocity, the greater the ability of water to transport particles of increasing grain size (Hjulstrom, 1935 in Kotze <i>et al.</i> , 1994). Flow velocities through wetlands are typically lower than in river channels and the surrounding landscape, and wetlands thus provide important areas where the settling of suspended sediment may occur. Suspended sediment may be detrimental to water quality in itself, and it may also carry other adsorbed pollutants (Boto and Patrick, 1979 in Kotze <i>et al.</i> , 1994). Turbidity, caused by suspended particles, attenuates light penetration, thereby decreasing photosynthesis (and oxygen production) by submerged aquatic plants. Costly filtration and flocculation processes are generally necessary to free water of particulate matter before it can be used for industrial or domestic purposes (Begg, 1986 in Kotze <i>et al.</i> , 1994). High sediment loads are also costly in that they lead to storage capacity loss in dams, an important problem in South Africa (Conley <i>et al.</i> , 1987 in Kotze <i>et al.</i> , 1994).
		3) Wetland plants provide substantial surface area for the attachment of microbes, both above-ground and below-ground, due to the aerobic rhizosphere around roots.
		4) Nitrogen may also be removed through uptake by vascular plants and subsequent "burial", when the plants die and organic matter accumulates in the sediments. DeLaune <i>et al.</i> (1986, in Kotze <i>et al.</i> , 1994) showed that in a freshwater marsh, a large proportion of the nitrogen incorporated in the vegetation accumulates mainly as organic nitrogen in accreted sediment.
		5) While wetland plant material is a source of BOD, the presence of wetland vegetation can also improve purifying capacity by trapping particulate organic matter, and providing sites of attachment

Wetland type/hydrological class.	Attributes and characteristics.	Contribution of attributes and characteristics towards its ability to perform various hydrological functions.
		for decomposing micro-organisms (Hemond and Benoit, 1988 in Kotze et al., 1994).
		6) The high plant productivity of many wetlands promotes the high rates of mineral uptake by vegetation, thereby promoting their water purification value.
		7) During the growing season there is generally a high rate of nutrient uptake from the water and sediments by emergent and submerged wetland vegetation. Increased microbial immobilisation of nutrients and uptake by algae and epiphytes also leads to retention of inorganic forms of nitrogen and phosphorus. Thus, there is seldom a net export of nutrients during the growing season. Lee <i>et al.</i> (1975 in Kotze <i>et al.</i> , 1994) consider this pattern to be beneficial because wetlands are most efficient at trapping nutrients during the growing season, the time when the potential for alga blooms to occur is at its highest.
		8) Wetland vegetation plays three major roles in erosion control: (1) it binds and stabilises soil, (2) it dissipates wave and current energy and (3) it traps sediment (Carter <i>et al.</i> , 1978 in Kotze <i>et al.</i> , 1994). Wetland vegetation has evolved under conditions of frequent flooding, and species such as <i>Phragmites australis</i> have a high capacity for binding sediments as well as for recovering rapidly from physical damage caused by flooding.
		<ol> <li>Toxic substances such as root secretions have been shown to kill pathogenic bacteria (Seidel, 1970; Rogers, 1983 in Kotze <i>et al.</i>, 1994).</li> </ol>
		Summary: Of any of the zones, the permanent wet areas have the greatest potential to decrease the velocity of flow due to the high friction value of the vegetation typically associated with this zone (also, due to the flat nature of palustrine type wetlands, they naturally decrease the velocity of flow, even in the absence of vegetation). Due to the permanent wet nature of the soils, it is mostly anaerobic. Although the wetland plants provide substantial surface area for the attachment of microbes, both above-ground and below-ground, due to the aerobic rhizosphere around roots, this process is not as significant in this zone as it is in the seasonal wet zone which is marked by dry (aerobic) and wet (anaerobic) cycles.
		Because of the longer prevalence of anaerobic conditions, water purification functions associated

Wetland type/hydrological class.	Attributes and characteristics.	Contribution of attributes and characteristics towards its ability to perform various hydrological functions.
		with organic matter are more efficient in the permanent wet zone than in the other zones. The prolonged anaerobic conditions of the permanent wet zone promoted flood attenuation and regulation more so than the seasonal wet zone due to conditions (anaerobic) promoting the aggregation of organic material.
Seasonally wet	Anaerobic/aerobic conditions	<ol> <li>Denitrification may be enhanced further in wetlands which are alternately wet (anaerobic) and dry (aerobic). High levels of nitrogen loss have been shown to occur under such conditions (Patrick and Wyatt, 1964; McRae <i>et al.</i> 1968; Reddy and Patrick, 1984 in Kotze <i>et al.</i> 1994).</li> <li>See numbers (3) to (6) as for permanent wet.</li> </ol>
	Organic content	1) See number (1) as for permanent wet.
	Soils	1) See number (1) as for permanent wet.
	Vegetation: Typically dense and tall with high frictional value	1) The most important factor affecting the roughness coefficient is the vegetation - the greater the frictional resistance offered by the vegetation the higher the roughness coefficient. The seasonal wet areas are usually characterised by vegetation which offers moderate to high resistance to stream flow. The vegetatio typically does not offer as much resistance as the permanent wet areas, and are typically not as tall. Vegetation is typically sedges and grasses. From a certain point, where the water flows over the vegetation, their friction value decreases because of their limited height. Therefore, closely associated with the aerobic/anaerobic conditions, its ability to perform a water purification function is not as good as that of the permanent areas, but is still significant.
		2) See numbers (3) to (9) as for permanent wet.
		Summary: Due to the seasonal nature of flooding, aerobic and anaerobic conditions are more favourable for performing water purification functions than in the permanent zone. The seasonal zone is therefore the most important location for water purifying processes dependant on an aerobic/anaerobic environment.
		Although the frictional value of the seasonal wet zone is not as high as that of the permanent wet

Wetland type/hydrological class.	Attributes and characteristics.	Contribution of attributes and characteristics towards its ability to perform various hydrological functions.
		zone, it is still sufficient in most cases, depending on the ratio of inflow and surface area, to decrease the velocity sufficiently enough for all water purifying processes to take place (due to the flat nature of palustrine type wetlands, they naturally decrease the velocity of flow, even in the absence of vegetation)
		The seasonal wet zone is usually characterised by having a lower organic content than the permanent wet zone due to more oxygen, which promotes the decay of organic material. Processes associated with organic matter are therefore not as efficient in the seasonal wet zone as in the permanent wet zone, but still contribute significantly towards water purification through these processes.
		The contribution of organic soils in withholding water, thereby performing a flood attenuation and regulation function, is less so than in the case of the permanent wet zones where there is usually a thicker layer of organic material due to the anaerobic conditions which is more characteristic of the permanent wet zone than of the seasonal wet zone.
Temporary wet		The temporary zone is the transitional zone between the wetland and the surrounding dry land. Because of their usually limited surface area, the limited water volumes they receive, absence of significant aerobic/anaerobic conditions, limited organic material (due to relative short periods of anaerobic conditions) and average plant productivity, temporary wet areas do not contribute significantly to the hydrological functions, e.g. water purification, typically associated with palustrine floodplain type wetlands. Temporary wet areas are, however, more capable of performing hydrological functions than the surrounding dry land and could represent important sites for these functions where no other, or very little of the other, more capable hydrological units occur.

# 10. Plates



**Plate 1:** Note the grey matrix (depleted matrix) and the yellow colouring (high chroma) where Fe<sup>2+</sup> has been oxidised (Fe<sup>3+</sup>) and has accumulated (redox concentration).



Plate 2: Note the grey ped surface (Iron depletion).



**Plate 3:** The yellow and red high chroma colours represent mottles (redox concentrations), while the black spot is a manganese concretion (redox concentration). The grey areas between the bright yellow and red areas are reduced matrix (redox depletion).



Plate 4: Note the red (high chroma) lines that have developed along the plant roots (pore linings or oxidized rhizospheres).



Plate 5: A lump of soil that was broken open after 30 minutes exposure to the atmosphere. Note the red margin compared to the grey interior - the Fe<sup>2+</sup> was oxidised when exposed to oxygen to change from the colourless Fe<sup>2+</sup> (still present in the grey interior) to the coloured Fe<sup>3+</sup> (on the margins).

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# 12. Glossary

(Taken and adapted from Kotze et al. 2005).

Aerobic: having molecular oxygen (O<sub>2</sub>) present.

**Anaerobic:** not having molecular oxygen (O<sub>2</sub>) present.

**Aquiclude:** an impermeable layer that confines an aquifer, preventing the water in it from moving upward or downward into adjacent strata. Shale and some igneous rocks often form aquicludes.

- Aquifer: a water-bearing layer of soil, sand, gravel, or rock that will yield usable quantities of water to a well or spring.
- **ATP:** Adenosine triphosphate, the molecule which is the source of energy for most metabolic processes in living organisms.
- **Catchment:** all the land area from mountaintop to seashore which is drained by a single river and its tributaries. Also referred to as a drainage basin or (in North America) a watershed. Each catchment in South Africa has been sub-divided into secondary catchments, which have in turn been divided into tertiary catchments. Finally, all tertiary catchments have been divided into inter-connected quaternary catchments. There are a total of 1946 quaternary catchments. These provide the basis on which catchments are sub-divided for integrated catchment planning and management (see DWAF [1994; 1996] in Kotze *et al.*, 2005).
- **Channel (of a river or stream):** an open conduit, either natural or artificial, which periodically or continuously contains *flowing* water, which may be shallow or deep, permanently, seasonally or temporarily flowing, but always has clearly defined margins.
- **Chroma:** the relative purity of the spectral colour, which decreases with increasing greyness.
- **Clay:** naturally occurring inorganic soil particles which are very fine (i.e. <0.002 mm in diameter).
- **Decomposition:** the breakdown of dead organic matter into simpler substances.
- **Delineation (of a wetland):** to determine the boundary of a wetland based on soil, vegetation, and/or hydrological indicators (see definition of a wetland).
- **Depression:** a basin-shaped area of land lacking a natural outlet for water, which collects in the depression provided that it does not drain away through the soil.
- **Ecosystem:** an assemblage of plants, animals and other organisms interacting with each other and with the non-living components of their environment.
- **Endorheic:** pertaining to a drainage system with no surface outlet, drainage being inwards (see **Pan**).
- **Eutrophic:** rich in nutrients and hence having excessive plant growth which kills animal life by deprivation of oxygen (Skinner & Zalewski, 1995 in Kotze *et al.,* 2005).
- **Eutrophication:** nutrient or pollutant enrichment of water, mainly with nitrogen and phosphorus; it may lead to excessive plant growth. Such enrichment may come about

by natural processes, but rapid enrichment may occur as a result of agrochemical runoff, the introduction of sewage effluent, etc. The biological changes caused by eutrophication can be separated into those which are a direct result of the enrichment (e.g. excessive plant growth) and those which are an indirect result (e.g. changes in the fish community as a result of reduced oxygen concentrations).

**Evaporation**: the change from a liquid or solid state to a vapour.

- **Evapotranspiration:** loss of water to the atmosphere through a combination of evaporation and transpiration
- **Floodplain:** a flat expanse of land bordering a river channel, which is characteristically flooded by bank overspill from the river channel. It may, however, never be flooded.
- **Functions:** the physical, chemical, and biological processes that characterize wetland ecosystems, such as flood-water retention, erosion and sedimentation control, denitrification, provision of habitat for organisms, and support of aquatic life.
- **Gley:** soil material that has developed under anaerobic conditions as a result of prolonged saturation with water. Grey, and sometimes blue or green colours predominate, but **mottles** (yellow, red, brown and black) may be present and indicate localized areas of oxidation.
- **Groundwater:** sub-surface water in the zone in which permeable rocks, and often the overlying soil, are saturated under pressure equal to or greater than atmospheric (Soil Classification Working Group, 1991 in Kotze *et al.*, 2005).
- **Gully (erosion)**: the visible manifestation of poor land-use practices, which have resulted in increased volume and velocity of rainfall runoff water.
- **Headcut:** erosion that progresses headwards into a wetland, creating a gully behind it, draining the wetland.
- **Hillslope:** a slope situated outside a valley bottom, where the colluvial (i.e. in response to gravity) movement of materials predominate.
- **Hue:** the dominant spectral colour which is related to the dominant wavelength of light. It is the attribute of colours that allows them to be designated as red, green, blue, or any intermediate combination of these colours.
- **Hydric soil:** soil that, in its undrained condition, is saturated or flooded long enough during the growing season to develop anaerobic conditions favouring the growth and regeneration of hydrophytic vegetation (vegetation adapted to living in anaerobic soils).
- **Hydroperiod:** the hydrological signature describing the temporal pattern of water level fluctuations, and is characterised by the timing, frequency, duration and extent of flooding.
- **Hydrophyte:** any plant that grows in water or on a substratum that is at least periodically deficient in oxygen as a result of soil saturation or flooding; plants typically found in wet habitats.

Hydrology: the study of water, particularly the factors affecting its movement on land.

Indicator: a measurable variable for the characteristics of an ecosystem. *Biological* indicator - provides information on the living organisms in the ecosystem and the

impact of processes on these organisms. *Physical indicator* - gives information about features such as landscape, wetland extent and diversity, hydroperiod, sediment accretion, salinity, etc.

- **Inventory:** wetland inventory is the process of determining and recording where wetlands are, how many wetlands are in a given area, and their characteristics
- **Marsh**: a herbaceous wetland dominated by emergent herbaceous vegetation (usually taller than 1 m), such as the common reed (*Phragmites australis*), which may be seasonally wet, but are usually permanently or semi-permanently wet.
- **Mottles:** soils with variegated colour patters are described as being mottled, with the "background colour" referred to as the matrix and the spots or blotches of colour referred to as mottles.
- **Munsell colour chart:** a standardized colour chart which can be used to describe hue (i.e. its relation to red, yellow, green, blue, and purple), value (i.e. its lightness) and chroma (i.e. its purity). Munsell colour charts are available which show that portion commonly associated with soils, which is about one fifth of the entire range.
- **Palustrine (wetland):** all non-tidal wetlands dominated by persistent emergent plants (e.g. reeds), emergent mosses or lichens, or shrubs or trees (see Cowardin *et al.* 1979).
- **Pan:** endorheic (i.e. inward draining; lacking an outlet) basins typically circular to oval, usually intermittently to seasonally flooded. Also referred to as playas.
- **Peat:** organic soil material with a particularly high organic matter content which, depending on the definition, usually has at least 20% organic carbon by weight.
- **Ped:** a unit of soil structure such as a crumb, prism, block or granule, which is formed by natural processes.
- **Perched water table:** the upper limit of a zone of saturation in soil, separated by a relatively impermeable unsaturated zone from the main body of groundwater.
- **Perched wetland:** where the wetland water table is much higher than the regional water table.
- **Permanently wet soil:** soil which is flooded or waterlogged to the soil surface throughout the year, in most years.
- **Ramsar Convention:** an inter-governmental treaty which provides the framework for international co-operation for the conservation of wetland habitats.
- **Red Data species:** all those species included in the categories of endangered, vulnerable or rare, as defined by the International Union for the Conservation of Nature and Natural Resources.
- **Rehabilitation (wetland):** the reinstatement of these driving ecological functions to a level close to the original system (but seldom fully attaining it) so as to improve the wetland's capacity for providing services to society.
- **Riparian:** the area of land adjacent to a stream or river that is influenced by streaminduced or related processes. Riparian areas which are saturated or flooded for prolonged periods would be considered wetlands and could be described as **riparian**
**wetlands**. However, some riparian areas are not wetlands (e.g. where alluvium is periodically deposited by a stream during floods, but which is well drained).

**Runoff:** total water yield from a catchment, including surface and subsurface flow.

**Rushes:** a general term usually applied to plants of the genus *Juncus*.

- **Saline:** inland waters which have salts measuring 0.5 parts per thousand or more. Where these salts are derived from the sea the waters are referred to as haline.
- **Sand:** particles smaller than gravel and larger than silt (i.e. 0.02-2.0 mm in diameter).
- Seasonally wet soil: soil which is flooded or waterlogged to the soil surface for extended periods (>1 month) during the wet season, but is predominantly dry during the dry season.
- **Sedges:** grass-like plants belonging to the family *Cyperaceae*, sometimes referred to as nutgrasses. Papyrus is a member of this family.
- **Seep:** an area in the landscape where the land surface intersects with the water table so that the subsurface water percolates in a diffuse manner from the soil surface.
- **Sesquioxide:** a binary compound of a metal and oxygen in the proportion of 2 to 3, as Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub>. The term sesquioxides is also used generally to describe free iron (Fe<sup>3+</sup>), aluminium (Al<sup>3+</sup>) and manganese (Mn<sup>4+</sup>) oxides in the soil.
- Silt: particles smaller than sand and larger than clay (i.e. 0.02-0.002 mm in diameter).
- Saturated: the soil is considered saturated if the water table or **capillary fringe** reaches the soil surface (Soil Survey Staff, 1992), resulting in the spaces between the soil particles being filled with water.
- **Sustainable use:** use of natural resources which allows that resource to renew itself, and which is within biological limits and meets the ecological, social and economic needs of humans such that the future is not compromised for the present (a temporal dimension), and geographic area(s) are not compromised for other geographic area(s) (a spatial dimension).
- **Swamp:** wetland dominated by trees or shrubs (U.S. definition) in Europe, a forested fen. In some areas reed-dominated wetlands are also called swamps.
- **Temporarily wet soil:** soil which is flooded or saturated close (i.e. within 50 cm) to the surface for periods > 2 weeks during the wet season in most years. However, it is seldom flooded or saturated to the surface for longer than a month.
- **Terrain unit:** the physical shape and form of the landscape. McVicar *et al.* (1991) differentiates between the crest, scarp, mid-slope, foot slope and valley bottom terrain morphological units. Wetlands are usually found in the valley bottom terrain morphological unit. However, unit 5 may also occur as a depression on a crest (1), mid-slope (3), or foot slope (4), and is then described as 1(5), 3(5), or 4(5) respectively.



**Transpiration:** the transfer of water from plants into the atmosphere as water vapour.

- **Valley bottom**: the lowest lying of the terrain unit morphological classes, lying between the slopes of the adjacent landscape.
- **Value:** the relative lightness of colour and is a function of the total amount of light. It is therefore the shade (darkness) or tint (lightness) of a colour. Also called brightness, lightness, shade and tone.
- **Values:** usually associated with goods and services that society recognizes as worthy, desirable, or useful to humans. Wetland values arise from the functional ecological processes associated with wetlands, and are also determined by human perceptions, the location of a particular wetland, the human population pressures on it, and the extent of the resource. Some examples of wetland values are: aesthetics, passive recreation, and education and research opportunities.

Vlei: a colloquial South African term for wetland.

Water table: the upper limit of the groundwater.

- Weir: mass gravity damming structures, where stability comes from the mass of the structure, serving to collect sediment and water
- Water balance: the balance between a wetland's water input and output.
- Water regime: when and for how long the soil is flooded or saturated.
- Waterlogged: soil or land saturated with water long enough for anaerobic conditions to develop.

# 13. Web Links

The following Internet sites (taken from Kotze *et al.*) contain information related to various aspects of wetland ecology, management and conservation. Please note that web sites change addresses or are sometimes closed down, so that some the addresses supplied herein might become obsolete over time. The sites have been divided into various categories to simplify the recovery of relevant information.

These categories include:

- Processes and formation
- Prioritisation
- Assessment
- Rehabilitation structures
- Rehabilitation techniques
- Monitoring
- Institutional factors
- Planning
- General

Categorized wetland links with similar and additional categories are also available from the following web page: http://rbwinston.home.mindspring.com/wetland.htm#c.

#### Processes and formation

History of wetlands in Conterminous United States <a href="http://water.usgs.gov/nwsum/WSP2425/hydrology.html">http://water.usgs.gov/nwsum/WSP2425/hydrology.html</a>

National water summary on wetland resources - glossary http://water.usgs.gov/nwsum/WSP2425/glossary.html

Mondi Wetland Project - resources http://www.wetland.org.za/ShareNet/Shareindex.htm

California Coastal Commission procedural guidance for the review of wetland projects in California's coastal zone - Chapter 2: An overview of mitigation processes and procedures. <u>http://www.coastal.ca.gov/web/wetrev/wetch2.html</u>

Protecting British Columbia's wetlands: A citizen's guide <a href="http://www.wcel.org/wcelpub/1996/11580/welcome.html">http://www.wcel.org/wcelpub/1996/11580/welcome.html</a>

Wetlands processes (functions) and values <u>http://h2osparc.wq.ncsu.edu/info/wetlands/funval.html</u>

# **Prioritisation**

Wetland restoration bibliography <u>http://www.npwrc.usgs.gov/resource/literatr/wetresto/wetresto.htm</u>

River corridor and wetland restoration - Ten essentials http://www.epa.gov/owow/wetlands/restore/update8.htm

Restoration <u>http://ucs.orst.edu/~williaor</u>

Riverine wetlands: Succession and restoration <u>http://limnologie.univ-lyon1.fr/</u>

AWRA 1999 Annual summer speciality conference proceedings <a href="http://www.awra.org/proceedings/Montana99/Salminen/index.htm">http://www.awra.org/proceedings/Montana99/Salminen/index.htm</a>

Project evaluation criteria http://www.coastalconservancy.ca.gov/scwrp/criteria.htm

Info: IA wetlands and riparian areas <u>http://www.ag.iastate.edu/centers/iawetlands/Decision.html</u>

Tidal wetland restoration, creation and enhancement in California <u>http://www.habitat-restoration.com/tidal.htm</u>

USGS water resources in Mississippi http://wwwmswater.usgs.gov/ms\_proj/main/reports.html

# Assessment

Wetland functions, values and assessment <u>http://water.usgs.gov/nwsum/WSP2425/functions.html</u>

Assessment methodology - Mid River wetland restoration <u>http://www.mrwetlandrestoration.com/assessment.htm</u>

Introduction: HGM bibliography <u>http://itre.ncsu.edu/cte/hgmbib.html</u>

Wetland Science Institute technical articles - wetland assessment <u>http://www.pwrc.usgs.gov/WLI/techassm.htm</u>

Wetland assessment procedures <u>http://www.wetland.org/wap.htm</u>

Coastal wetland ecosystem protection project - Rapid assessment technique <a href="http://www.state.ma.us/czm/waRAPIDA.HTM">http://www.state.ma.us/czm/waRAPIDA.HTM</a>

Wetland publications

http://www.wes.army.mil/el/wetlands/wlpubs.html

(Note: Wetland Engineering Handbook is a very useful resource within this list of publications)

Wetland Engineering Handbook - Section 2 http://www.wes.army.mil/el/wetlands/pdfs/wrpre21/sec2.pdf

Stony Creek wetland assessment project http://www.crwc.org/projects/stonycreekwet/scwetproject.html

Wetlands: Biological assessment methods and criteria development workshop proceedings. September 18-20, 1996. Boulder, California. http://www.epa.gov/owow/wetlands/wgual/bcproc.html

New England biological assessment of wetlands work group <a href="http://www.epa.gov/region01/eco/wetland">http://www.epa.gov/region01/eco/wetland</a> <a href="http://www.epa.gov/owow/wetlands/wqual/bio">http://www.epa.gov/region01/eco/wetlands/wqual/bio</a> <a href="http://www.epa.gov/owow/wetlands/wqual/bio">http://www.epa.gov/region01/eco/wetlands/wqual/bio</a> <a href="http://www.epa.gov/owow/wetlands/wqual/bio">http://www.epa.gov/region01/eco/wetland</a>

Wetland bioassessment fact sheet <u>http://www.epa.gov/owow/wetlands/wgual/bio\_fact/</u>

Mondi Wetland Project - resources http://www.wetland.org.za/WetlandFix/WetlandFix1/part1.htm

#### **Rehabilitation structures**

Beneficial uses of dredged material: Wetland restoration <a href="http://www.wes.army.mil/el/dots/budm/wetland.html">http://www.wes.army.mil/el/dots/budm/wetland.html</a>

Stream restoration and protection <a href="http://www5.bae.ncsu.edu/programs/extension/wqg/sri/proceedings.htm">http://www5.bae.ncsu.edu/programs/extension/wqg/sri/proceedings.htm</a>

EPA New England - Wetland restoration and creation projects guidelines <u>http://www.epa.gov/region01/eco/wetlands/</u>

Abstracts on ecosystem management for stream corridor and wetland restoration <u>http://www.oregonwri.org/basin-info/education.htm</u>

NC State University - Extension wildlife - Wetlands <u>http://www.ces.ncsu.edu/nreos/wild/wildlife/wetland.html</u>

The use of sediment diversions in fluvial powered wetland restoration <a href="http://www.hort.agri.umn.edu/h5015/97papers/giedd.html">http://www.hort.agri.umn.edu/h5015/97papers/giedd.html</a>

Wetland restoration and creation http://water.usgs.gov/nwsum/WSP2425/restoration.html

Overview, Habitat restoration services, Adopt-a-stream <a href="http://www.streamkeeper.org/habitat/index.htm">http://www.streamkeeper.org/habitat/index.htm</a>

Determining if a wetlands project id major or minor <u>http://www.dec.state.ny.us/website/dcs/freshwet/freshwet04.html</u>

CAE publication - Benefits of constructed and restored wetlands <u>http://farm.fic.niu.edu/cae/caepubs/delaney.html</u>

Construction specifications for conservation practices <a href="http://www.ia.nrcs.usda.gov/design/cspec.html">http://www.ia.nrcs.usda.gov/design/cspec.html</a>

Wetland Engineering Handbook - Sections 3, 4, 5 & 7 http://www.wes.army.mil/el/wetlands/pdfs/wrpre21/sec3.pdf http://www.wes.army.mil/el/wetlands/pdfs/wrpre21/sec5.pdf http://www.wes.army.mil/el/wetlands/pdfs/wrpre21/sec7.pdf

Mondi Wetland Project - resources http://www.wetland.org.za/WetlandFix/WetlandFix3/part3.htm

#### **Rehabilitation techniques**

Mondi Wetland Project - resources http://www.wetland.org.za/WetlandFix/WetlandFix3/part3.htm

Landowner's guide: Wetland restoration techniques <u>http://www.dnr.state.mi.us/wildlife/landowners\_guide/Habitat\_Mgmt/Wetland/</u> <u>Wetland\_Restoration\_Techniques.htm</u>

PCA restoration working group http://www.nps.gov/plants/restore/calendar.htm

RRC: Manual of river restoration techniques <a href="http://www.gest.demon.co.uk/rrc/mot.htm">http://www.gest.demon.co.uk/rrc/mot.htm</a>

Riparian ecosystem creation and restoration http://www.npwrc.usgs.gov/resource/literatr/ripareco/ripareco.htm

Wetlands - Volume 17, number 3 http://www.sws.org/wetlands/abstracts/volume17n3/brown.html

NPS - park geology - Disturbed lands restoration - restoration techniques <u>http://www.aqd.nps.gov/grd/distland/toolbox/restorationtechniques.htm</u>

Wetland creation and restoration: The status of the science <a href="http://www.epa.gov/OWOW/wetlands/kusler.html">http://www.epa.gov/OWOW/wetlands/kusler.html</a>

Restoration and reclamation review http://www.hort.agri.umn.edu/h5015/rrr.htm

Watershed restoration technical circular no.6 1999 http://www.env.gov.bc.ca/fsh/wrp/rapp/tc6/index.html Peatland restoration guide <u>http://peatmoss.com/pm-env.html</u>

Temperate wetlands restoration guidelines <a href="http://www.esg.net">http://www.esg.net</a>

Stream corridor restoration handbook <a href="http://www.usda.gov/stream-restoration">http://www.usda.gov/stream-restoration</a>

Soil bioengineering http://www.wsdot.wa.gov/eesc/cae/design/roadside/ddmbio.htm http://www.wcc.nrcs.usda.gov/wtec/soilbio.html http://www.rolanka.com http://www.sotir.com/pubs/publish/publish.html http://www.sotir.com/pubs/publish/publish.html http://www.an.ec.gc.ca/doc/cuf\_factsheets/soil-bioeng-e.html http://www.state.ak.us/local/akpages/Fish.Game/habitat/geninfo/webpage/ techniques.htm http://h2osparc.wq.ncsu.edu/descprob/strmbnks.html http://www.wetland.org.za/WetlandFix/WetlandFix4/part4.htm

Links

http://www.interfluve.com/links.htm[#wetlands]

Better wetlands

http://www.ia.nrcs.usda.gov/enhance/bwtoc.html http://www.ks.nrcs.usda.gov/wetlands/wetindex.htm

Planting the seed: A guide to establishing aquatic plants http://www.on.ec.gc.ca/glimr/data/planting-seed/intro.html

Wetland management <a href="http://h2osparc.wg.ncsu.edu/info/wetlands/manage.html">http://h2osparc.wg.ncsu.edu/info/wetlands/manage.html</a>

Managing your restored wetland <a href="http://pubs.cas.psu.edu/freepubs/uh086.html">http://pubs.cas.psu.edu/freepubs/uh086.html</a>

Wetland Engineering Handbook - Section 6 http://www.wes.army.mil/el/wetlands/pdfs/wrpre21/sec6.pdf

#### Monitoring

From Sod farm to wetland: an urban restoration for education <u>http://www.hort.agri.umn.edu/h5015/96papers/bower.htm</u>

Wetland mitigation issues and regulations - New Hampshire <u>http://nhresnet.sr.unh.edu/planning/guide/docs/wdoc21.txt</u>

Restoration, protection and creation http://www.wes.army.mil/el/workshop/RE16.html Hamilton army airfield - Wetland restoration feasibility study <a href="http://www.spn.usace.army.mil/hamilton/">http://www.spn.usace.army.mil/hamilton/</a>

Evaluating the performance of non-compensatory wetland restoration projects <a href="http://www.coastal.ca.gov/web/weteval/we8.html">http://www.coastal.ca.gov/web/weteval/we8.html</a>

Estuary online

http://www.abag.ca.gov/bayarea/sfep/news/newsletter/est9904.html

Marshbird monitoring http://www.mpl\_pwrc.usgs.gov/marshbird/mmw.html

3 ways to monitor a wetland <a href="http://www.epa.gov/volunteer/spring98/pg11.html">http://www.epa.gov/volunteer/spring98/pg11.html</a>

Deciding what to measure <a href="http://www.epa.gov/volunteer/spring98/pg17.html">http://www.epa.gov/volunteer/spring98/pg17.html</a>

Monitoring wetlands: A flexible approach <a href="http://www.epa.gov/volunteer/fall98/wwmoni10.html">http://www.epa.gov/volunteer/fall98/wwmoni10.html</a>

Wetland Engineering Handbook - Section 8 http://www.wes.army.mil/el/wetlands/pdfs/wrpre21/sec8.pdf

#### Institutional factors

Economic valuation of wetlands http://www.ramsar.org/lib val e index.htm

Ramsar: People and wetlands - The vital link <u>http://ramsar.org/cop7\_doc\_16.3\_e.htm</u>

Issues, perspectives, policy and planning processes for integrated coastal area management. http://www.fao.org/docrep/W8440e/W8440e02.htm

Rural community natural resource base http://www.ag.iastate.edu/centers/rdev/1997cmbo/chpt2.html

PCR environment - Wetlands plan http://www.pcrguam.com/draftwetlands.htm

Accelerating co-operative riparian restoration and management <u>http://www.or.blm.gov/nrst/whoweare/strategic\_plan.htm</u>

#### **Planning**

Resolution VII.17 on restoration as an element of national planning for wetland conservation and wise use. http://www.ramsar.org/key res vii.17e.htm

Wetland planning area reports and GIS analysis http://www.mawpt.org/Arkansas Plan/reports and analysis.html

Coos Bay restoration inventory report http://www.lcd.state.or.us/coast/demis/docs/fuss/fussrpt.htm

River corridor and wetland restoration - Science resources http://www.epa.gov/OWOW/wetlands/restore/science.html

Properties of common hydric soils and non-hydric soils of King county, Washington. Useful for planning wetland restoration / creation projects http://soilslab.cfr.washington.edu/ESC311-507/1997/Sasha/section6.htm

WetNet - Wetland links http://www.glo.state.tx.us/wetnet/links.html

Wetland restoration - ecological planning beyond the birdbath http://www.cciw.ca/ecowatch/adoptapond/urbanoutback/part12.html

13 steps to a restoration project http://den2-s11.aqd.nps.gov/grd/distland/toolbox/13steps

Habitat rehabilitation project categories http://www.on.ec.gc.ca/glimr/data/habitat-rehabilitation/hab3.html http://www.on.ec.gc.ca/glimr/data/habitat-rehabilitation/intro.html#toc

Natural resources conservation service - Wetland Institute: Conservation practice standards http://www.pwrc.usgs.gov/wli/constds/wlicps.htm

Wetland Engineering Handbook - Section 1 http://www.wes.army.mil/el/wetlands/pdfs/wrpre21/sec1.pdf

#### General

WetNet - Wetland publications http://www.glo.state.tx.us/wetnet/pubs.html

Tidal wetland restoration bibliography http://www.neers.org/frames/biblwetld.html

Restoration, creation and recovery of wetlands http://www.stolaf.edu/depts/biology/mnps/papers/galat.html

Literature

http://www.npwrc.usgs.gov/resource/literatr/ripareco/discuss.htm

A guide to restoration ecology http://www.lib.washington.edu/fish/subjects/restoration.html

Restoration and reclamation review http://www.hort.agro.umn.edu/h5015/m.htm http://water.usgs.gov/nwsum/wsp2425/restoration.html

Principles for the ecological restoration of aquatic resources <a href="http://www.epa.gov/owow/restore/principles.html">http://www.epa.gov/owow/restore/principles.html</a>

Riverine wetlands - Succession and restoration <u>http://limnologie.univ-lyon1.fr/htdocs\_limno/publications.html</u>

Restoring lowa's agricultural wetlands http://www.ia.nrcs.usda.gov/wetlands/wet\_restore.html

Restoration and creation research reports http://www.wes.army.mil/el/wetlands/list.html#4 http://www.wes.army.mil/el/wetlands/pdfs/wrpre19.pdf http://www.wes.army.mil/el/wetlands/pdfs/wrpre21.exe http://www.wes.army.mil/el/wetlands/wlpubs.html

The Ramsar convention's resources on wetland restoration: Sources of restoration training <u>http://ramsar.org/strp\_rest\_training.htm</u>

Links to restoration project web pages <u>http://ramsar.org/strp\_rest\_links.htm</u>

Links to web-based restoration tools <a href="http://ramsar.org/strp">http://ramsar.org/strp</a> rest links tools.htm

# Other relevant sites:

WATERSHEDS wetland information page <a href="http://h2osparc.wg.ncsu.edu/info/wetlands/">http://h2osparc.wg.ncsu.edu/info/wetlands/</a>

Unversite Claude Bernard - Lyon: Web site on riverine wetlands (France) <u>http://limnologie.univ-lyon1.fr/</u>

Canadian Sphagnum Peat Moss Association Web site <a href="http://peatmoss.com">http://peatmoss.com</a>

Wetland Fix <a href="http://www.wetland.org.za/WetlandFix/WFIndex.htm">http://www.wetland.org.za/WetlandFix/WFIndex.htm</a>

British Columbia Ministry of Environment, Lands and Parks: Riparian assessment and prescriptions procedure http://www.env.gov.bc.ca/fsh/wrp/rapp

University of Florida: Centre for Wetlands website - Publications <a href="http://www.enveng.ufl.edu/wetlands/publication/pubatop.htm">http://www.enveng.ufl.edu/wetlands/publication/pubatop.htm</a>

EPA - Office of wetlands, oceans and watersheds: Wetlands web site <a href="http://www.epa.gov/owow/wetlands/">http://www.epa.gov/owow/wetlands/</a>

Numerous wetland links http://www.mindspring.com/~rbwinston/wetland.htm#mitigation

USDA - Water quality information centre <u>http://www.nal.usda.gov/wgic/</u>

USGS Northern prairie wildlife research centre: Wetland restoration bibliography <a href="http://www.npwrc.usgs.gov/resource/literatr/wetresto/wetresto.htm">http://www.npwrc.usgs.gov/resource/literatr/wetresto/wetresto.htm</a>

Society of Wetland Scientists - Wetland related sites <a href="http://www.sws.org/wetlandweblinks.htm">http://www.sws.org/wetlandweblinks.htm</a>

Wetlands international - AEME web site http://www.wetlands.agro.nl/wetl ramsar.html

Wetland international Asia Pacific - Indonesia program <a href="http://www.wetlands.or.id/">http://www.wetlands.or.id/</a>

Bureau of Land Management - Riparian recovery initiative: References and brochures <a href="http://www.a.blm.gov/riparian/tech.htm">http://www.a.blm.gov/riparian/tech.htm</a>

Peatland Ecology Research Group - Publications and Thesis <u>http://alpha.eru.ulaval.ca/gret-perg/en\_publications.htm</u>

# 14. List of organisations involved in wetland conservation.

(Adapted from Kotze *et al.*)

Department of Agriculture: Directorate of Resource Conservation P/Bag X250, Pretoria, 0001. (012) 3196000

Department of Environmental Affairs & Tourism (National) P/Bag X447, Pretoria, 0001. (012) 3103695 <u>http://www.environment.gov.za/</u>

Department of Environmental Affairs (Provincial) Eastern Cape - (041) 3338891 Free State - 0861102185 Gauteng - (011) 3551937 KwaZulu-Natal - (033) 3471820 Mpumalanga - (013) 7594043 Northern Cape - (0531) 811121 Northern Province - (015) 2959300 North West - (0140) 895126 Western Cape - (021) 4833925

Department of Water Affairs and Forestry P/Bag X313, Pretoria, 0001. (012) 2999111 <u>http://www.dwaf.gov.za/</u> (Includes links to the Working for Water Project)

Highlands Crane Group P/Bag X11, Parkview, 2122. (011) 48961102 ewtsa@global.co.za

Institute of Natural Resources P/Bag X01, Scottsville, 3209. (033) 3460796

International Mire Conservation Group (IMCG) Piet-Louis Grundling Tel: +27 12 843 5246 Fax: +27 12 843 5205 Cell: 084 548 5439 E-mail - grundling@sanbi.org http://www.imcg.net

Overberg Crane Group P.O. Box 541, Caledon, 7230. (0281) 48905

Rand Water P.O. Box 1127, Johannesburg, 2000. (011) 6820911 Mondi Wetland Project Gauteng - P.O. Box 44189, Linden, 2104. (011) 8844773 KwaZulu-Natal - (031) 2013126 Western Cape - (021) 7011397 E-mail - <u>info@wetland.org.za</u> <u>http://www.wetland.org.za</u>

KwaZulu-Natal Crane Foundation P.O. Box 905, Mooi River, 3300. (033) 2637248

South African Crane Working Group (033) 2632750

Umgeni Water P.O. Box 9, Pietermaritzburg, 3200. (033) 3411111

Universities: Rhodes - Water Research Institute - (046) 6222428 Water Research Commission P.O. Box 824, Pretoria, 0001. (012) 3300340

Wildlife and Environment Society of South Africa KwaZulu-Natal - 100 Brand Road, Durban, 4001. Gauteng - P.O. Box 44344, Linden, 2104.

Working for Wetlands South African National Biodiversity Institute (SANBI) Private Bag X101, Pretoria, 0001 South Africa Tel: +27 12 843 5246 Fax: +27 12 843 5205 http://www.sanbi.org/