CHAPTER 2: BACKGROUND STUDY

2.1 WETLAND FUNCTIONS AND INFLUENCING FACTORS.

2.1.1 Overview of important wetland functions.

Wetlands serve important ecological functions in retaining and releasing precious water supplies during times of drought, purifying water from waterborne diseases and sedimentation, provide habitats for a variety of species and helps to slow down severe flooding events of river systems. Wetlands are furthermore utilised in terms of crop cultivation and wetland vegetation is used for grazing, craft making and thatching.

2.1.2 Overview of important influencing factors.

(This part is prepared from notes by Haigh, 2002).

2.1.2.1 Climate.

Rainfall: The six wetlands selected are inland wetlands that rely on rainfall and groundwater for their water supply. Rainfall becomes a source for runoff (surface inflow), which contributes to groundwater recharge through water that enters a wetland (subsurface inflow) or water that falls directly on the wetland. The pattern of the rainfall in the region must be well understood (Ellery, 2002) (Appendix 2).

Temperature: plays a role in the biomass production and species composition.

2.1.2.2 Drainage system.

Each selected wetland forms part of an integrated drainage system. The excess water supply is discharged into a river or stream and thus forms part of an open, integrated drainage system. They may or may not receive water from a fluvial source such as a river or stream (Ellery, 2002).

2.1.2.3 Hydrology.

i) Water balance.

The simplified equation explains the water balance of wetlands as: Storage = (rainfall + surface inflow + subsurface inflow) – (evapotranspiration + surface outflow + subsurface outflow) (Haigh, 2002).

The size of the wetlands storage component varies seasonally and annually (large during the wet season or flood phase and small during the dry season).

ii) Sediment erosion, transportation and deposition.

Running water has the ability to erode, transport and deposit sediment. This ability is largely dependent upon stream velocity. The faster the runoff the more sediment it is capable of carrying and when sediment-laden runoff is slowed down (small gradient or the obstruction to free flow e.g. dense vegetation), so its ability to carry sediment in suspension is reduced. However, while some of this sediment is most useful in reclaiming gullies in wetlands, excessive amounts of sediment will have a negative effect on rehabilitation measures due to the smothering of vegetation colonizing open areas.

2.1.2.4 Geomorphology.

i) Wetland soils.

- Soil forms common to South African wetlands are described by the Soil Classification Working Group (1991) as follows:
  - Champagne (has an organic O horizon). The Champagne form consists of a soil layer with greater than 10% organic carbon.
  - Katspruit, (has an Orthic A horizon over a G horizon).
  - Willowbrook (has a Melanic A horizon over a G horizon).
  - Rensburg (has a Vertic A horizon over a G horizon).

- Soil forms common in temporary wetlands (and non-wetland areas):
  - Kroonstad.
  - Westleigh.
  - Longlands.
  - Estcourt.

Soil maps showing the distribution of different soil forms exist for all parts of South Africa. These maps are very useful in showing the distribution of wetlands. Soils are useful for indicating if a drained area used to be a wetland and working out the extent of wetland loss. Temporarily wet soils tend to be anaerobic for shorter periods where the water table is less close to the soil surface than seasonally wet soils. Both of these soils alternate between being anaerobic and aerobic, indicating a zone with a fluctuating water table. The soil is gray with many mottels (yellow – reddish colour due to iron oxidation). When a wetland is drained and the water regime is changed the soils retain their characteristic colour signatures.

Furthermore anaerobic conditions (saturated soil in a wetland) tend to have the highest organic matter content. Soil with a very high organic matter content is referred to as peat. Cool climatic conditions are ideal for the accumulation of peat. Wetlands with peat soils are referred to as bogs or fens.

ii) Geomorphic agents.

- Peat and organic matter accumulation contribute to the aggradation of the land surface.
- Chemical sedimentation accumulation in the soil causes a volume increase in the soil, leading mainly to vertical expansion and therefore to a lowering of gradient in the upstream direction.

iii) Soil erosion.

The main agents of soil erosion are wind and water. The faster these agents move the more soil can be eroded. The clay percentage in the soil also plays a significant roll in the erodibility of the soil. The loss of protective plant cover through land use practices (deforestation, over-grazing, ploughing and fire) makes the soil vulnerable to being swept away by wind and water. Erosion of wetlands may result in deep gullies which drain the water rapidly from the wetland and make the water regime much drier and therefore reduce the values of the wetland (Kotze, 2000).

2.1.2.5 Wetland vegetation.

The presence of plants that are adapted to certain water regimes may also be used as indicators. In South Africa most sedge species are confined to wetland areas. Within wetlands three wetness zones are recognised, namely permanent, seasonal and temporary (Kotze, 1999). Vegetation surveys done by Eckhardt *et al*. (1993 a) observed a decrease in species diversity in wetlands to the species-richness of other vegetation types.

Stress to wetland vegetation should only be related to the changes in environmental conditions outside the normal range encountered by plants. Environmental conditions characteristic of wetlands are not stressful to wetland plants. When dryland plants are exposed to wetland conditions outside their normal range (e.g. waterlogging, low availability of oxygen to roots, high concentrations of ferrous iron, sulphide or salt), these conditions are seen to be stressful to the dryland plants and not to the wetland plants (Otte, 2001).

2.2 REHABILITATION AND RESTORATION OF WETLANDS.

2.2.1 Aims and goals of wetland rehabilitation.

The Working for Wetlands programme (WfWetlands) aim is to actively restore South Africa's precious water resource through wetland rehabilitation with the added benefits of poverty alleviation and creating wetland awareness.

2.2.1.1 Rehabilitation goals.

i) Regain the wetland functions:

1. Flood attenuation and base flow support.
2. Sediment trapping e.g. to stop the sedimentation of storage dams.
3. Stop wetland degradation and erosion.
4. Improve water purification.

5. Conserve biodiversity and rare ecological habitats.
6. Prevent the hydrological functioning of the wetland from becoming impaired or lost by raising the water table, improve the ground water recharge and re-wet desiccated (dry) areas.
7. Improve the wetland function of retaining and releasing precious water during times of drought.
8. Revegetate the uncovered riverbanks.
9. Regulate surface erosion, grazing and the cutting of vegetation for fodder or handcrafts.
10. Prevent the increase of siltation in the wetland due to runoff from the surrounding catchment area by offsite mitigation measures, such as grazing control.
11. Improve the density and quality of the vegetation cover.
12. Removal of alien trees in the wetland.
13. The rehabilitation measures should include both ecological and engineering design principles in order to ensure that they are most affected for the purpose they are intended.

ii) Wetland awareness and training.

Social upliftment (Poverty relief, employment opportunities and skills development).

2.2.2 Rehabilitation measures.

Wetland rehabilitation should firstly be dealt with in a catchment context that involves the identification of alternative land use practices such as rotational grazing of rangeland, conservation tillage, eradication of alien invasive trees etc. If alternative practices are adopted in the catchment the degradation forces acting on the wetland will reduce. However, if the improved practices are not sufficient for the specific wetland rehabilitation, only then should bioengineering and physical structures be contemplated in the wetland. Rehabilitation measures applicable to the study are discussed in Appendix 3.

2.3 ENVIRONMENTAL INDICATION.

2.3.1 Background.

Management actions on wetland rehabilitation need to be reviewed to improve on the rehabilitation plan as the project proceeds. It is necessary for the responsible authority to monitor the rehabilitated wetlands in order to determine its success. Wetland monitoring facilitates the comparison between different wetland situations over time and is an important component of any wetland rehabilitation project.

The Wetland Rehabilitation Manual (Kotze *et al.*, 2001) recognized three levels of detail for monitoring wetland rehabilitation, namely:

- *Routine monitoring* required for all minor wetland rehabilitation projects to identify corrective action and evaluate initial success.
- *Comprehensive monitoring – rapid assessment*, required for all major and selected minor wetland rehabilitation projects to identify corrective action, evaluate success and provide lessons for further rehabilitation.
- *Comprehensive monitoring – detailed*, applied to only a few selected wetlands that would serve as reference sites to increase understanding of underlying processes.

Wetland types differ in complexity, size, biodiversity, geomorphology, hydrology and levels of disturbance, therefore monitoring should be customized for the specific rehabilitation objective. These objectives will in turn determine what indicators should be used for an individual project.

Muller and Pretorius (2002) explained that the term “indicator” stems from the Latin verb ‘indicare’ meaning to disclose or to point out. They mentioned furthermore that a set of indicators could assist in understanding the current state of an environmental system and trends in that system.

Nell *et al*. (2001) highlighted the fact that the term "indicator" is used in diverse ways according to the subject of concern. The problem is that certain conditions are confused with the term indicator (J.P. Nell, *pers. comm*). For example: "Indicators" used by the Land-use and Wetland / Riparian Habitat Working Group (2001) to help the delineator find the outer edge of the temporary zone in the wetland and include terrain morphological unit, soil wetness factor, soil form and vegetation. The term indicator was thus given to these four specific biophysical conditions to determine the position of the wetland and not the wetland's environmental condition.

Indicators have two important features, namely: quantification of information and the simplification of complex phenomena (Hammond *et al*., 1995). The quantification of information includes measuring, counting, scaling or rating. The simplification of complex phenomena is achieved by classification into classes or describing it qualitatively based on a person's observations, perceptions, insights and attitudes (Hammond *et al*., 1995; Kotze *et al*. 2001).

A good understanding of the cause-effect relationship between wetland functions in relation to driving force, pressure, state, impact and response is necessary in order to identify and list indicators. With any information, there are limitations to their use and therefore the acceptability of any indicator depends on the availability and confidence of the data as well as the interpretation of the indicator (Muller and Pretorius 2002).

Existing indicator sets throughout South Africa have been reviewed and are discussed under section 2.3.4. The identification and listing of provisional list of indicators for rehabilitated wetlands are dealt with under section 2.3.6.

2.3.2 Indication selection criteria.

The quality of an indicator or a set of indicators includes three criteria: consistency, reliability and predictive capacity (Romstad, 1999). Nell *et al.* (2001) referred to the indicators selection criteria described in the State of the Environment Report by Balance and King (1999) as the following:

- **Policy relevance.**
  The users must be able to see the connection between the indicator and critical decision making and policies, otherwise it is unlikely to motivate action.

- **Simplicity.**
  It is important for the target audience and general public to understand the information. Indicators should be simple and easy to interpret.

- **Validity.**

- The indicator must provide a representative picture of the environmental conditions (e.g. pressure on the environment);
- Scientifically defensible measurement techniques must be used to collect the data;
- Indicators should be theoretically well founded in technical and scientific terms;
- and based on international standards and international consensus about its validity.
- The indicator must be based on science and reveal a cause – response relationship (e.g. society's response).

- **Time series data.**
  Time series data provide information to show trends over time.

- **Availability of affordable data.**

  It is important that indicators should be feasible and cost-effective in data collection, processing and dissemination.

- **Ability to aggregate information.**

  It would be better if an indicator can combine information on a range of issues.

- **Freedom from bias.**

  Complete freedom from cultural and geographic bias is hard to achieve as many indicators are rather ethnocentric and therefore, far from universally applicable.

- **Sensitivity to changes and variability.**

  An important diagnostic quality of an indicator must be its sensitivity to temporal changes and spatial variability. Can the indicator pick up small changes in the system? For monitoring purposes, it would be necessary to determine in advance how large or small changes can be.

  Indicators must help detect rates of change over time and opportunity to identify land management trends leading to or departing from conditions identified as sustainable.

  A time-sensitive indicator must also be a good predictor and an early-warning tool to allow monitoring and anticipation, through extrapolation of established time series or simulation modeling of undesirable evolution any trends towards non-sustainable management conditions. Similarly, the spatial variability of land conditions and the diversity of social structures influence the selection of relevant indicators.

- **Provision of standard and threshold values.**

  The standard reference values of an indicator must be indicative of the reversibility of a given land degradation process leading to non-sustainability and the possible cost of controlling it. An indicator should have a target or threshold against which to compare it so that users are able to assess the significance of the values associated with it.

- **Ease of data collection.**

  The scale and nature of the measured variables of the indicators in use must be appropriate for evaluating purposes. The implementation of indicators is often limited by the inappropriate data.

- **Versatility of data transformation and communication.**

  The information derived from the indicators must enable the responsible authorities to communicate on sustainable issues (e.g. to compare the current status of the wetland with the initial wetland conditions). The transformation of raw data into functional parameters (e.g. change rates, depletion ratios, risk and vulnerability indices). Indicators should lend themselves to linkage with models, forecasting and information systems.

2.3.3 The DPSIR framework.

A set of indicators need to be structured in a coherent way in order to be useful in State of the Environment Reporting (Muller and Pretorius, 2002). Balance and King (1999) used the DPSIR reporting system (Figure 1) to describe environmental issues in terms of the following categories:

- **Driving forces** Human influences and activities (e.g. agriculture, population growth) combined with environmental conditions (e.g. water, wind) support the change in wetland functions.
- **Pressures** Pressures on the environment as a result of the driving forces (e.g. water pollution, drainage of the wetland).
- **State** The current state of the environment and recent trends in environmental quality.
- **Impacts** These are the consequences of the pressures on the environment (e.g. reduction in biodiversity, desiccation of wetland soil).
- **Responses** The human response to environmental change. This includes policies and management strategies to reduce environmental damage, rehabilitate

damaged environments, and encourage sustainable development.

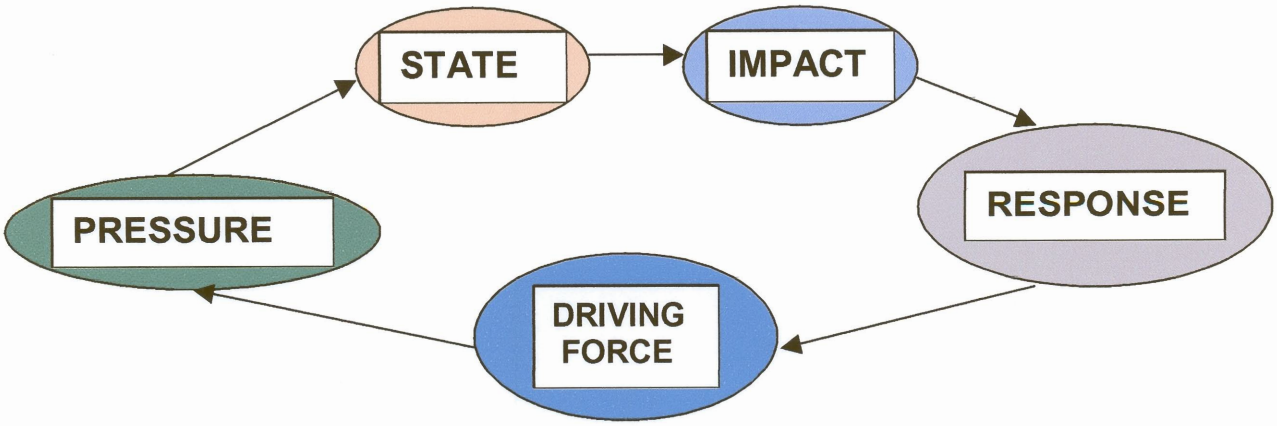

Figure 1: The "Driving Force-Pressure-State-Impact-Response" framework.

The Pressure-State-Response framework remains in a continuous state of evolution, forming a feedback mechanism that can be monitored and used for assessment of land quality (Nell *et al.*, 2001).

In relation to the Driving Force-Pressure-State-Impact-Response framework, rehabilitated wetlands are a *response* to the complexity of driving forces, pressures and impacts that influence the function of the wetland (Table 1). Response indicators provide standard and norms for the rehabilitation done on wetlands. The response is the result of several driving forces (e.g. water, wind, agriculture, peat mining) both past and current on the biophysical condition of the wetland as well as on the rehabilitation structures within the wetland.

Table 1: Driving Force-Pressure-State-Response framework for rehabilitated wetland sites (adopted from Nell *et al.*, 2001).

DRIVING FORCES Rain intensity Time of rainfall Wind Slope	Urbanization	Mining (e.g. peat, sand, clay)	Industrialization	Agriculture	Tourism	Forestry
PRESSURE	• Drainage • Water pollution • Infrastructure • Water abstraction	• Drainage • Water pollution • Infrastructure • Water abstraction • Substrate destruction	• Drainage • Water pollution • Infrastructure • Water abstraction	• Drainage • Water pollution • Infrastructure • Water abstraction • Grazing • Cultivation	• Pollution • Infrastructure • Water abstraction	• Drainage • Infrastructure • Water abstraction • Cultivation
POSITIVE STATE	• Constructed wetlands for sewerage water • Rehabilitated wetlands • Managed wetlands	• Constructed wetlands for polluted mine water • Rehabilitated wetlands • Managed wetlands	• Constructed wetlands for polluted mine water • Rehabilitated wetlands • Managed wetlands	• Wetland awareness • Rehabilitated wetlands • Managed wetlands	• Wetland Conservation • Wetland awareness • Managed wetlands	• Wetland awareness • Rehabilitated wetlands • Managed wetlands
NEGATIVE STATE	• Degraded wetlands • Wetland loss	• Degraded wetlands • Wetland loss	• Degraded wetlands • Wetland loss	• Degraded wetlands • Wetland loss	• Over utilisation	• Degraded wetlands • Wetland loss
IMPACT	**Air:** Quality **Biodiversity** - **Fauna:** loss in wetland sp. - **Flora:** loss of wetland vegetation **Soil:** degradation, desiccation of wetland soil, loss of substrate loss, erosion, sedimentation. **Water:** Quality & quantity	**Air:** Quality **Biodiversity** - **Fauna:** loss in wetland sp. - **Flora:** loss of wetland vegetation **Soil:** degradation, desiccation of wetland soil, loss of substrate loss, erosion, sedimentation. **Water:** Quality & quantity	**Air:** Quality **Biodiversity** - **Fauna:** loss in wetland sp. - **Flora:** loss of wetland vegetation **Soil:** degradation, desiccation of wetland soil, loss of substrate, erosion, sedimentation. **Water:** Quality & quantity	**Air:** **Biodiversity** - **Fauna:** loss in wetland sp. - **Flora:** loss of wetland vegetation **Soil:** degradation, desiccation of wetland soil, substrate loss, erosion, sedimentation. **Water:** Quality & quantity	**Air:** **Biodiversity** - **Fauna:** loss in wetland sp. - **Flora:** loss of wetland vegetation **Soil:** degradation, desiccation of wetland soil, loss of substrate, erosion, sedimentation. **Water:** Quality & quantity	**Air:** **Biodiversity** - **Fauna:** loss in wetland sp. - **Flora:** loss of wetland vegetation **Soil:** degradation, desiccation of wetland soil, loss of substrate, erosion, sedimentation. **Water:** Quality & quantity
RESPONSE	• Policy and legislation • Management strategies (wetland rehabilitation) • Regulations (Environmental Impact Studies) • Norms and Standards • Communication, Education & Public Awareness (CEPA)	• Policy and legislation • Management strategies (wetland rehabilitation) • Regulations (Environmental Impact Studies) • Norms and Standards • Communication, Education & Public Awareness (CEPA)	• Policy and legislation • Management strategies (wetland rehabilitation) • Regulations (Environmental Impact Studies) • Norms and Standards • Communication, Education & Public Awareness (CEPA)	• Policy and legislation • Management strategies (wetland rehabilitation) • Regulations (Environmental Impact Studies) • Norms and Standards • Communication, Education & Public Awareness (CEPA) • Improved Farming Systems	• Policy and legislation • Conservation measures • Management strategies • Regulations (Environmental Impact Studies) • Norms and Standards • Communication, Education & Public Awareness (CEPA)	• Policy and legislation • Management strategies (wetland rehabilitation) • Regulations (Environmental Impact Studies) • Norms and Standards • Communication, Education & Public Awareness (CEPA)

2.3.4 Studies on environmental indication in South Africa.

2.3.4.1 Inland water systems.

The South African national environmental indicators developed for inland water systems are listed in Table 2.

Table 2: South African national environmental indicators for inland water systems (Muller and Pretorius 2002).

Water quantity	Intensity of use of surface water resources. Intensity of use of ground water resources. Total surface water used per sector. Total ground water used per sector. Total surface water resources per capita. People dependent on ground water resources. Surface water affordability.
Water quality	Surface water salinity. Ground water salinity. Surface water nutrients. Ground water nutrients. Surface water microbiology. Ground water microbiology. Surface water toxicity.
Freshwater ecosystem integrity	Riparian vegetation. Aquatic macro-invertebrate composition. Fish community health. Aquatic habitat integrity.

2.3.4.2 Wetland systems.

i) **Indicators used by the Land-use and Wetland / Riparian Habitat Working Group (2001).**

In order to identify the permanent, seasonal and temporary zones of a wetland, the delineator must give careful consideration to four specific "indicators": As mentioned under section 1.6.1 the term "indicator" was given to these four specific biophysical conditions to determine the position of the wetland and not the wetland's environmental condition.

- The terrain morphological unit (refer to Figure 3 on page 36).
- Soil form (refer to 2.1.2.4 i)).
- Soil wetness factor (refer to 2.1.2.4 i)).
- Vegetation (refer to 2.1.2.5) and (2.3.6 i) c)).

The Land-use and Wetland / Riparian Habitat Working Group (2001) mentioned that the Soil Wetness Factor and the Terrain Morphological Unit tend to be the most important in practice as the vegetation responds relatively quickly to changes in soil moisture or disturbances.

ii) Potential biophysical indicators listed by the Wetland Rehabilitation Manual (Kotze *et al.*, 2001).

- Wetland spatial area and pattern.
- Wetland landform.
- Geomorphological features of gully / headcut erosion.
- Properties of the soil (e.g. texture, dispersiveness).
- Physical structures (e.g. gabions).
- Hydraulic properties of the wetland (e.g. flow patterns).
- Hydrologic regimes of the wetland (e.g. distribution of hydrological zones).
- Water quality.
- Vegetation species composition.
- Animal species composition and other properties (e.g. breeding).
- Properties of individual plants (e.g. survival of revegetation).
- Vegetation structure.
- Disturbance.
- Catchment properties.

2.3.5 Indication of wetlands using remote sensing data.

2.3.5.1 Image processing techniques known to be suitable for wetland monitoring.

The most common and widely used image processing techniques suitable for high resolution remote sensing sensors used on wetland rehabilitation studies were evaluated as part of the broader literature study. Literature searches were conducted in available sources, like published books and scientific papers obtained from libraries, as well as additional searches in "grey" sources, i.e. local and regional publications, internal reports, expertise etc.

From the available sources in the literature no studies were found that used high resolution remote sensors to monitor the rehabilitation done on wetlands. Anderson and Perry (1996) used the high resolution DMSV system to map the natural wetlands in Virginia. Gross and Klemas (1986) mentioned that high spectral resolution spectrometry appears to have significant value for remote sensing studies of wetland vegetation. Haigh and Illgner (2001) acquired digital infrared images of the Featherstone Kloof with the Kodac DCS 420 camera.

i) Kodac DCS 420 camera:

Image processing techniques recorded by Haigh and Illgner (2001) were described as follows:

The images were transferred from the PCMCIA card and imported into Adobe Photo Deluxe image processing software using DCS 420 TWAIN drivers. Image brightness and contrast were corrected using a module in Photo Deluxe. The images were then exported as Tagged files (tif).

The next step was to import the images (in tif format) into TNTMips professional GIS software, for processing. TNTMips (version 6.1 and 6.4) was used for mosaicing and georeferencing the images. Individual images were mosaiced using the mosaic module in TNTMips. This involved defining tie points (identical features) to join two images. An average of 20 tie points per image pair was used as well as 2^{nd} order polynomial rubbersheeting algorithms to mosaic the images. Image seams were joined using a feathering distance of 40 pixels and contrast matching using a reference image. The images were mosaiced into strips running the length of the valley. The strips were in turn mosaiced together to produce an image covering the valley with the Featherstone Kloof wetland.

Mosaiced images of the valley were printed for the purpose of conducting the ground-inspection component of the geo-referencing purpose. With the use of a Trimble Geo-Explorer II GPS, the positions of features that could clearly be identified on both the printed image and on the ground were recorded. The position of the feature was calculated by taking the mean of 10 positions recorded at 5 second intervals at that feature. Post-processing differential correction was performed on the GPS rover files containing the recorded positions. Base files for the purposes of post-processing differential correction were obtained from Telkom's base station in Port Elizabeth. Pathfinder office software (v.2.11) was used for correcting the positions recorded. The error associated with these positions is expected to be less than 2 m.

Secondly, the geo-referencing process involved geo-referencing the mosaiced digital image of Featherstone Kloof using TNTMips. The geo-referencing module in TNTMips (v.6.4) was used to geo-reference the image. The image was projected using the Gauss Conformal projection with a central meridian of 27 degrees East. The Clark 1880 ellipsoid was used as the reference ellipsoid. The image was rectified using the Plane Projective algorithm in TNTMips.

ii) Landsat TM.

Van der Linde (1995) processed the Landsat TM data using GEMSTONE software to generate images using the 6 daytime colour bands (1; 2; 3; 4; 5 and 7) to survey peatlands. Swamp forest and sedge-reed fen could be distinguished from one another, but could not confirm whether peat has formed in the wetland or not. With the help of a colour-ratio combination all peatlands displayed dark green and it was possible to locate them.

Following is a short review of remote sensing applications in wetland related studies.

2.3.5.2 Wetland inventories.

i) Aerial photography.

Remote sensing techniques, such as black and white (BW) aerial photography, have through the years been used in the management of natural resources. Whitlow (1984), Lyon (1993) and Marneweck *et al.* (1999) used black and white aerial photography in the delineation of wetlands. Aerial imagery provides the capability to reconstruct previous land-use patterns using archived images. It forms a base to study former patterns even though no map was prepared at the time.

Thompson *et al.*, (2002)'s assessment of black and white (BW), true colour (RGB) and colour-infrared (CIR) aerial photographs for the use in wetland mapping compared the wetland signatures on the dataset visually with those from the imagery of other data sets. Thompson *et al.* (2002) mentioned that extreme flooding conditions as well as extreme droughts might also create problems for accurate RGB and CIR wetland photo interpretation. Wetland and vegetation mapping prefer colour-infrared (CIR) imagery, because the film records a wider range of colours and tones than true colour (Thompson *et al.*, 2002).

ii) Landsat & Digital Elevation Models.

More recently, a methodology for using satellite image data has been proposed by Thompson *et al.* (2002) for mapping wetlands across South Africa using the multi-temporal datasets of the Landsat TM and Landsat ETM+ imagery. Thompson *et al.* (2002)'s recommended methodology is to produce an initial land-cover map in order to exclude areas where wetlands are likely not to occur (e.g. woodland areas) and areas where it would not be possible to distinguish the wetlands from the surrounding vegetation (e.g. cultivated areas). The tasseled CapTransformation (TCT) was applied to the Landsat image. The TCT is used to extract brightness, greenness and wetness indices from a Landsat image. An unsupervised classification was applied to the results of the TCT and a wetland class was isolated. Wetlands were finally mapped using an integrated modeling approach that combined spectrally defined, potential wetland areas mapped from the satellite imagery, with a DEM-defined landscape wetness potential model, in order to determine final wetland boundaries (Thompson *et al.*, 2002). Wetland inventory studies done by Thompson *et al.*, (2002), Dely *et al.* (1999) and Gibson (2003) indicate that neither ASTER (15 m resolution) nor Landsat TM (30 m resolution) could detect small size wetlands in the study areas. It is not necessarily the case that wetlands do not exist, but rather that they are too small or spectrally similar to the surrounded vegetation (L. Gibson, *pers. comm.*).

Thompson *et al.* (2002) investigated the use of pan-enhanced imagery using the Landsat 7 imagery for wetland mapping. Although the visual quality improved, the process itself was not suitable for large areas, detailed mapping applications and digital classification techniques. The imagery can be used for spectrally homogenous features with clearly definable boundaries.

2.3.5.3 Wetland features.

McCarthy (2002) commented that satellite remote sensing methods are essential for characterizing various wetland features and patterns (e.g. flooding patterns, sub-surface peat fires, land cover classification) of the Okavango Delta in Botswana. The satellite data used in the Okavango Delta study by McCarthy (2002) was the high resolution Landsat MSS (Multi Spectral Scanner), TM (Thematic Mapper) and ETM (Enhanced TM), MAS (MODIS Airborne Simulator) as well as the lower resolution NOAA AVHRR (Advanced Very High Resolution Radiometer), ERS-2 ATSR (Along Track Scanning Radiometer) and Terra MODIS (Moderate Resolution Imaging Spectroradiometer).

i) Hydrology and geophysiology.

Studies by Gumbricht *et al.* (2000) used 10-day composite NOAA derived Normalized Difference Vegetation Index (NDVI) images at 7.6 km resolution for the period 1982-1998 and four sets of 2 km resolution NOAA images representing different seasons to create a land cover classification as well as red-green-blue (RGB) colour images for visualizing the Okavango Delta in Botswana. To estimate the annual flooding, 93 10-day composite NOAA scenes from the years 1992, 1993 and 1995 in 1 km resolution were used. Two different sets of RGB images were created for visualization and a linear stretch with 99% saturation using bands 3 (r), 2 (g) and 1 (b) as well as a RGB image using 1 as blue, a ratio of bands and 3 for green and 2 for red. These images were used for creating animations, and geo-correcting all scenes individually. By using the RGB images as backdrops the water content was classified in five classes and individually calibrated for each scene. Clouds were separately classified by using bands 1, 4 and 5. A three-dimensional contextual and weighted filter – using the preceding and proceeding 10-day composites as the third dimension - smoothed the initial water classification and cloud-free composites were used. From the filtered images the average time of water coverage and an animation of the annual flood was created.

The following satellite images were used by McCarthy *et al.* (2002) to determine the flooding patterns of the Okavango Delta: NOAA (AVHRR) satellite images (period 1985 to 2000), Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) (period dates earlier than 1985) data in 500 m resolution, projected to the same coordinate system as the NOAA (AVHRR) satellite images. ERS-2 ALONG track Scanning Radiometer (ATSR) and Landsat TM and Enhanced TM (ETM) scenes were used for calibration and evaluation of the classification accuracy.

ii) Vegetation.

Empirical studies examining vegetation indices derived from satellite image data have become one of the primary information sources for monitoring vegetation conditions and mapping land cover change (Teillet *et al.*, 1997). According to Teillet *et al.* (1997) the most widely used vegetation index in this context is the Normalized Difference Vegetation Index (NDVI), which is a function of red and near-infrared spectral bands with the optimum location being in the 850 – 880 nm range. Gumbricht *et al.* (2000) used NDVI images derived from NOAA 10-day composites to analyse the annual vegetation cycle in 6 different physiographic regions in the Okavango Delta. The NDVI images were 3-D filtered and smoothed in the same way as the water images (Hydrology and geophysiology). For each scene the average NDVI was extracted for each area and used for calculating an average NDVI cycle, using a 2-month un-weighted moving average function.

McCarthy and Gumbricht (2001) used a snap shot high resolution Landsat TM image with high temporal frequency, low resolution satellite data for the classification of ecoregions of the dynamic Okavango Delta. They concluded that for a regional scale the use of low-resolution multi-temporal images for deriving flooding frequency was a requirement for correctly separating between ecoregions of different types.

iii) Peat fires.

In the study conducted by Gumbricht *et al.* (2001), ATSR data were used to study the annual peat fire cycle from 1999 to 2000. AVHRR and MODIS data were used to study fire development over the dry season and MODIS Airborne simulator and Landsat ETM data were used for high spatial resolution studies of single dates over the study area.

iv) Water quality.

No literature was found on studies concerning determining water quality in wetlands with the use of remote sensing. It is understandable therefore that there is a lack of evidence for determining the cumulative effect of wetlands on water quality. Remote sensing techniques can be applied to detect ocean colour by measuring the spectra of the water-leaving radiance, looking at the spatial distribution of chlorophyll, suspended material and yellow substance, red tide detection and coastal current studies in monitoring coastal water environments. Ocean colour remote sensing proves to be a powerful tool in understanding the process of oceanic biology and physics (Delu, 2001).

2.3.6 Selection of indicators.

A Wetland Workshop was held on 10 April 2002. A team of environmental and remote sensing experts interacted and shared their collective opinions on indicators that could be used to monitor the rehabilitation done on degraded wetlands with remote sensing methods. A list of potential indicators for rehabilitated wetlands was compiled (Table 3).

The indicators chosen for rehabilitated wetlands are response indicators that focus on the biophysical condition and utilisation of the wetland as well as the physical condition of the rehabilitation structures within the wetland. The response is the result of several driving forces (e.g. water, wind, agriculture, peat mining), both past and current, on the biophysical condition of the wetland as well as on the rehabilitation structures. Attention was given to ensure that the potential indicators comply with the requirements listed under the indication selection criteria (1.6.2) and therefore determined that indicators used with remote sensing sensors have to be readily measured variables that help to detect rates of change over time in order to establish the condition of the system (Syers *et al.*, 1995). Proportion of change of a given biophysical condition per unit time measured in % or ha / year or metres is the proposed unit of measurement for the indicators to be used.

Table 3: Summary of indicators for the monitoring of rehabilitated wetlands with the use of remote sensing applications.

Purpose:	It is necessary for the responsible authority to monitor the rehabilitated wetlands over the long term.			
Policy relevance:	Management actions on wetland rehabilitation need to be reviewed.			
Target:	The biophysical condition and wetland utilization of the wetland as well as the physical condition of the rehabilitation structures within the wetland.			
Description:	Facilitate the comparison between different wetland situations over time.			
Relation to the Driving Force-Pressure-State-Impact-Response (DPSIR):	A **Response** indicator. The response is the result of several driving forces (e.g. water, wind, agriculture, peat mining) both past and current on the biophysical condition of the wetland as well as on the rehabilitation structures within the wetland.			
Unit of measurement:	Proportion of change of a given biophysical condition per unit time measured in %, ha / year or measurement in metres.			
Measurable phenomena:	**Biophysical conditions.**	**Indicators.**	**Comments.**	**Frequency of measurement**
	Geomorphology.	**Erosion.** **Sedimentation.**	Active / Stable erosion. Siltation behind the structure.	Once every 3 months. Once every 3 months.
	Hydrology.	**Open water.** **Wet surface area.** **Water quality.**	Water table lift behind structure. Wetland zones (permanent, seasonally, temporary wet) Colour of water.	Once every 3 months. 3-5 years. Once every 3 months.
	Biodiversity (Flora).	**Wetland vegetation.** **Terrestrial vegetation.** **Alien vegetation.** **Bare soil.**	Vegetation species change as a result of the change in the wetland's wet surface area (permanent, seasonally, temporary wet). Wetland condition includes: wetland vegetation indicator species, alien species and extent of bare soil.	3-5 years. 3-5 years. 3-5 years. Once every 3 months.
	Wetland utilization	**Indicators**	**Comments**	**Priority**
		Disturbances • Cultivation. • Harvesting wetland vegetation. • Burned scars. • Grazing. • Trampling.	Community wetland awareness by utilizing the wetland in a sustainable way.	3-5 years.
	Rehabilitation measures	**Indicators**	**Comments**	**Priority**
	Earthworks, concrete structures, gabions, revegetation.	**Physical structure.**	Physical condition of the structure and revegetated area.	Once every 3 months.

i) Biophysical conditions:

a) Geomorphology.

- **Erosion.**

° Measures the distance in metres of an advanced headcut erosion site.

° Determines active or stable erosion features.

- **Sedimentation.**

° Siltation behind the structure indicates lower energy levels.

° Structures acting as silt traps to prevent sedimentation downstream.

b) Hydrology.

- **Open water.**

° Indicates water table lift behind the structures and therefore promotes the re-wetting of the wetland.

- **Wet surface area.**

° Change in the hydrological zones of the wetland (permanently, seasonally, temporary wet)

- **Water quality.**

° Remote sensing techniques can be applied to detect ocean colour by measuring the spectra of the water-leaving radiance. It is not certain if water quality can be detected in wetlands.

c) Biodiversity (Flora).

For comprehensive rapid-assessment monitoring, a change in hydrology can be inferred from change in vegetation by noting the extent to which hydrophytic plant species increase or decrease in abundance (Kotze and Marneweck, 1999). Wetland conditions include wetness zone indicator species (Table 4), the presence of alien species and the extent of bare soil as a result of poor or failed revegetation.

- **Wetland vegetation.**

Table 4: Summary of Vegetative Indicators by Wetness Zone (Land-use and Wetland / Riparian Habitat Working Group, 2001).

VEGETATION	TEMPORARY	*SEASONAL*	PERMANENT/SEMI-PERM
Herbaceous	Predominantly grass species; mixture of species which occur extensively in non-wetland areas, and hydrophytic plant species which are restricted largely to wetland areas	Hydrophytic sedge and grass species, which are restricted to wetland areas.	Dominated by: 1) Emergent plants, including reeds (*Phragmites australis*), a mixture of sedges and bulrushes (*Typha capensis*), usually > 1m tall; or 2) Floating or submerged aquatic plants
Woody	Mixture of woody species, which occur extensively in non-wetland areas, and hydrophytic plant species, which are restricted largely to wetland areas.	Hydrophytic woody species, which are restricted to wetland areas.	Hydrophytic woody species, which are restricted to wetland areas. Morphological adaptations to prolonged wetness (e.g. prop roots)

- **Terrestrial vegetation.**
  - Terrestrial species colonize desiccated areas in the wetland. A change in the hydrological regime of the wetland will have an effect on the occurrence of these species.
- **Alien vegetation.**
  - Identification of the alien species.
  - Determine the densities of the alien species.
  - Success of the different eradication actions taken (manual clearing and biological control).
- **Bare soil.**
  - Indicates sedimentation, old construction sites or sparsely vegetated areas.

ii) Wetland utilization:

d) Community wetland awareness:

Cultivation and disturbance indicators have been included to measure the success of wetland awareness campaigns and resource utilization courses. An integral part of wetland rehabilitation is to create wetland awareness in communities. Knowledge of the sensitive areas of a wetland should be understood and applied. Using the example of Mbongolwane wetland the newfound awareness and sustainable utilization of the wetland has yet to be translated into practical action. Disturbance and cultivation indicators will enable the authorities to measure if wetland awareness was successful or not.

- **Disturbances.**
  - Cultivation (commercial and subsistence plots).
  - Harvesting wetland vegetation.
  - Burned scars.
  - Grazing.
  - Trampling.

iii) Rehabilitation measures:

- **Physical structures (earthworks, concrete structures, gabions, revegetation) (Appendix 3).**

  (Described by the Wetland Rehabilitation Manual (Kotze *et al.*, 2001).
  - Have the structures been installed in the right location?
  - Have the structures been constructed according to the technical specifications?
  - Environmental requirements (e.g. building and litter cleared from the construction site).
  - Stability of the structures (e.g. wash-aways or short circuiting).
  - Determine the revegetation survival rate.

iv) Monitoring period.

The Wetland Rehabilitation Manual (Kotze *et al.* 2001) suggests that short-term monitoring would be for the first six years of project development and long-term monitoring for at least 20 years.

v) Monitoring frequency.

The Wetland Rehabilitation Manual (Kotze *et al.*, 2001) suggests a frequency once every three months and no longer than every three years. The monitoring frequency of every five years is suggested by Nell *et al.*, (2001) for the land use change indicator and by Muller and Pretorius (2002) (State of the Environment reporting) for aspects concerning water quantity, riparian vegetation and aquatic habitat integrity.

With regard to the change in wet surface area, vegetation zones (permanent, seasonal and temporary wet), harvested wetland vegetation and cultivation impacts the monitoring period is suggested to be 3-5 years because the vegetation responds to disturbances and the hydrological changes in soil moisture. Eckhardt *et al.* (1993a) and Eckhardt *et al.* (1993b) confirmed the important role that the soil moisture plays within the wetland is often clearly reflected by the type of vegetation that occurs in the area. Alien vegetation may also fall in this suggested monitoring frequency of 3-5 years.

Monitoring the rehabilitation structure, it could be catastrophic to have a monitoring period every 3-5 years. The condition of the rehabilitation structures will already be evident after one rainy season. It is important to detect structural damage as soon as possible before the erosion increases in the wetland. The monitoring frequency is therefore suggested to be once every three months for erosion, sedimentation, open water behind the structure, revegetation and bare soil. The Wetland Rehabilitation

Manual (Kotze *et al.*, 2001) mentioned that after three months the revegetated survival rate could be determined.

Water quality in a wetland changes considerably over time. The water contamination pattern must be determined and therefore a monitoring frequency of once every three months is recommended if water quality can be detected with remote sensing techniques.

Thus, the monitoring period and frequency depend on the indicators chosen for a specific rehabilitation project.

3.1 MATERIAL AND METHODS

3.1.1 Study areas.

Major role-players like wetland researchers, Working for Wetlands and the Working for Water Programme, the Department of Water Affairs and Forestry, Department of Environmental Affairs and Tourism, Department of Agriculture and the Mondi Wetlands Project (an NGO) were consulted before the selection of the rehabilitated wetland sites for the project. Suitable wetland sites had to reflect the many wetland types that differ in complexity, size, biodiversity, geomorphology, hydrology and levels of use, ranging from "pristine" to severely degraded.

3.1.1.1 Selection criteria for the different wetlands.

Site information:

- Wetland rehabilitation work on the wetland had to be completed or in progress.
- Baseline data for each wetland had to be available.
- Different wetland shapes and sizes.
- Rehabilitated wetlands had to fall in different climatic regions.

3.1.1.2 Selected rehabilitated wetlands (Figure 2).

1. Kromme River Wetland
2. Mbongolwane Wetland
3. Wilge River Wetland
4. Seekoeivlei Wetland
5. Zoar Wetland
6. Rietvlei Wetland

Figure 3 (page 37) describes the location of the selected rehabilitated wetlands within the different terrain units and wetland types and Table 5 (page 38, 39) gives a summary of the site description of the rehabilitated wetlands that were selected.

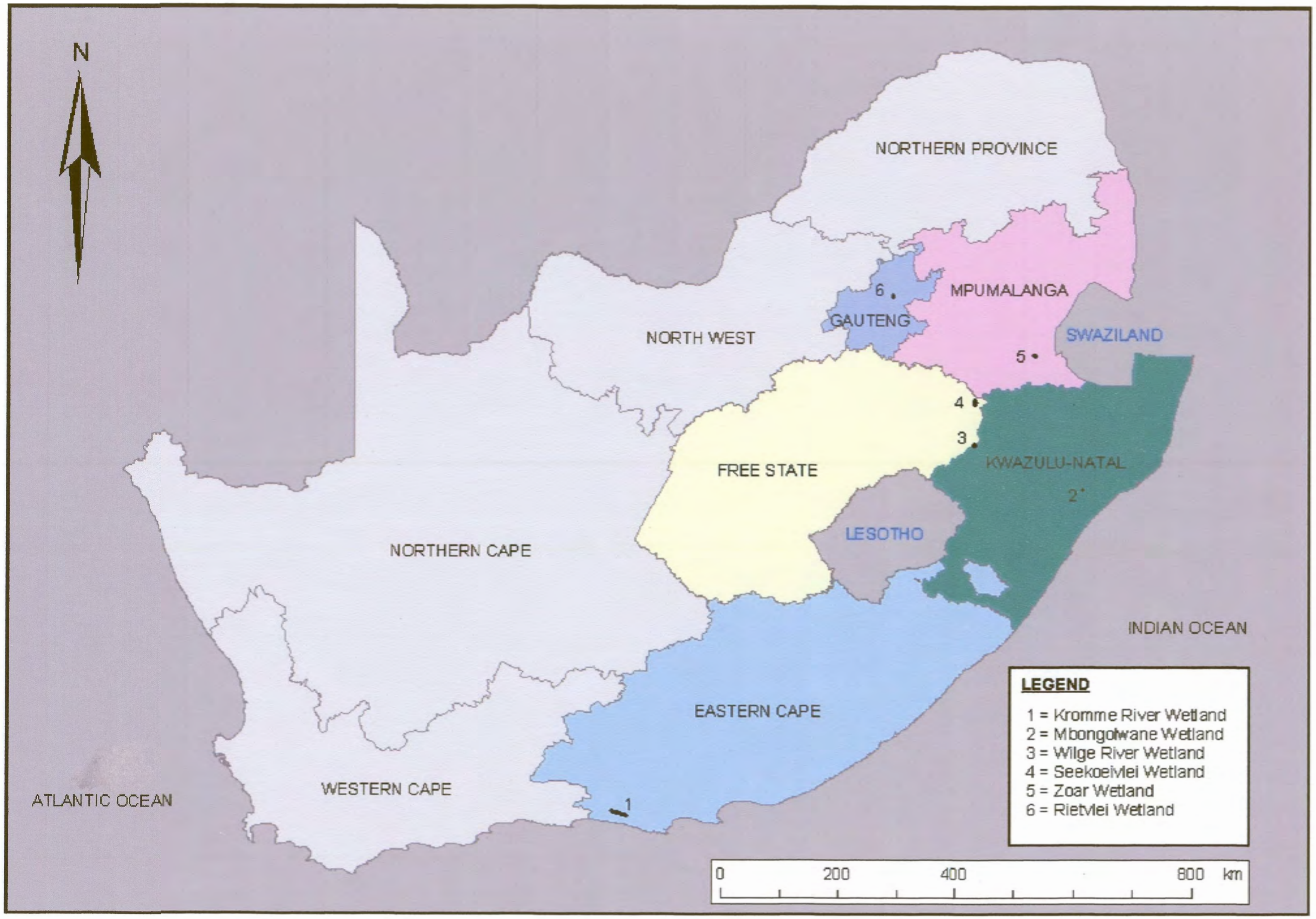

Figure 2: The location of the six rehabilitated wetland study sites in South Africa.

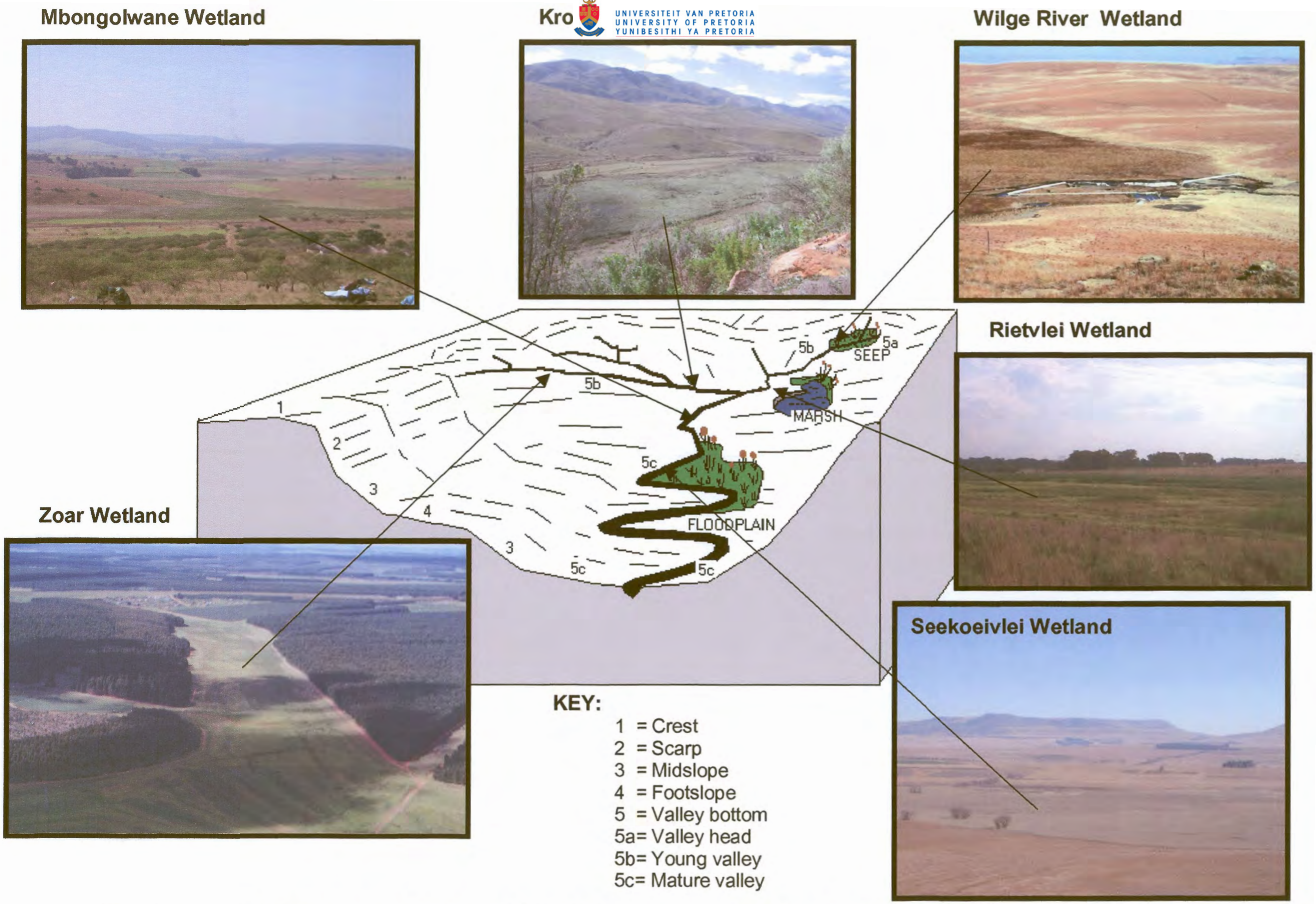

Figure 3: The location of the selected rehabilitated wetlands within the different terrain units and wetland types (Adapted from Kotze *et al.*, 1994).

3.1.1.3 Rehabilitated wetlands site description (Table 5).

Table 5: Summary information of each wetland chosen.

Wetland	Province	Municipality / Local Authority	Closest Town	Land use sectors	Land ownership	Abiotic factors		Biotic factors (Habitat types)	Wetland type
Kromme River	Eastern Cape	Joubertina	Joubertina	Commercial agricultural sector	Privately-owned	**Altitude:**	420 - 260 m	Tall emergent – dominant species: palmiet (*Prionium serratum*) with mixed grass/sedge.	Palustrine: Peatland (fen) complex, with tall emergent zones and grass/sedge meadows.
						Climate:	Winter and summer rainfall		
						Topographical setting:	Steep narrow Cape Fold valley		
						Geomorphology: Terrain unit	Valley bottom (Young valley)		
						Hydrology: Hydrological regime	Permanently wet		
						Catchment / River name:	Kromme river		
						Topographic setting:	Southern sea board		
						Wetland form:	Linear feature		
Mbongolwane	KwaZulu-Natal	Eshowe / Ntuli Tribal Authority	Eshowe	Small-scale and commercial agricultural sector	Communally-owned	**Altitude:**	580 m (Amatigulu) 520 m (Uvova)	Tall emergent with mixed grass/sedge meadow	Palustrine with tall emergent zones and grass/sedge meadows
						Climate:	Summer rainfall region		
						Topographical setting:	Strong undulating landscape.		
						Geomorphology: Terrain unit	Valley bottom (valley head)		
						Hydrology: Hydrological regime	Seasonally to semi-permanently wet,) feature.		
						Catchment / River name:	Matigulu river		
						Topographic setting:	Eastern sea board		
						Wetland form:	Winding feature		
Wilge River	Free State	Harrismith	Harrismith	Natural condition without any significant human impacts.	Lies over three privately owned farms	**Altitude:**	1700 m	Tall emergent with mixed grass/sedge	Palustrine: Peatland (fen) complex, with tall emergent zones and grass/sedge meadows.
						Climate:	Summer rainfall region		
						Topographical setting:	Strong undulating		
						Geomorphology: Terrain unit	Valley bottom (valley head to young valley)		
						Hydrology: Hydrological regime	Permanently wet		
						Catchment / River name:	Wilge river		
						Topographic setting:	Interior on the escarpment		
						Wetland form:	Curved feature in the shape of a "M" from the south.		

Wetland	Province	Municipality / Local Authority	Closest Town	Land use sectors	Land ownership	Abiotic factors		Biotic factors (Habitat types)	Wetland type
Seekoeivlei	Free State	Harrismith / Memel	Memel	Seekoeivlei Nature Reserve – previously used for agriculture (since 1870)	Dept. Tourism, Environmental and Economic Affairs, Free State.	**Altitude:**	1700 m	Tall emergent with mixed grass/sedge meadow	Floodplain with oxbows and palustrine wetlands, including tall emergent zones and grass/sedge meadows.
						Climate:	Summer rainfall region		
						Topographical setting:	Undulating landscape.		
						Geomorphology: Terrain unit	Floodplain and valley bottom (mature valley)		
						Hydrology: Hydrological regime	Permanently wet		
						Catchment / River name:	Klip river		
						Topographic setting:	Interior on the plateau		
						Wetland form:	Meandering feature		
Zoar	Mpumalanga	Piet-Retief	Piet-Retief	Forestry (since 1970)	Mondi Forest Area	**Altitude:**	1375 m	Grass meadow	Palustrine, with grass meadows.
						Climate:	Summer rainfall region		
						Topographical setting:	Undulating landscape.		
						Geomorphology: Terrain unit	Valley bottom (young valley)		
						Hydrology: Hydrological regime	Seasonally wet.		
						Catchment / River name:	A tributary of the Hlelo river		
						Topographic setting:	Interior on the plateau		
						Wetland form:	Linear feature		
Rietvlei	Gauteng	Tshwane	Centurion Irene	Rietvlei Nature Reserve - previously used for agriculture and peat mining. Water abstraction and gray water release.	Tshwane City Council	**Altitude:**	1500 - 1520 m	Tall emergent with mixed grass/sedge meadow	Palustrine: Peatland (fen) complex, with tall emergent zones and grass/sedge meadows.
						Climate:	Summer rainfall region		
						Topographical setting:	Undulating landscape.		
						Geomorphology: Terrain unit	Valley bottom (young valley)		
						Hydrology: Hydrological regime	Permanently wet		
						Catchment / River name:	Sesmyl Spruit (Rietvlei and Grootvlei tributaries)		
						Topographic setting:	Interior on the plateau		
						Wetland form:	Linear feature		

3.1.1.4 Identification of test sites.

In order to measure the management action done on rehabilitated wetlands it will be necessary for the responsible authority to monitor the condition of the wetlands over the long term. Not only the biophysical condition and the utilization of the wetland but also the rehabilitation structures need to be monitored to determine if the management actions taken were successful.

The general acceptance after the preliminary field visit (Appendix 4) was to focus specifically on the problems that existed in each wetland and the rehabilitation measures which had been implemented to address such problems. It was therefore decided to use the rehabilitation structures within each wetland as test sites. Topographical maps of each wetland indicating the position of each rehabilitation structure, a summary of the problems, the rehabilitation actions taken and the desired results to be achieved after rehabilitation are mentioned in detail in section 3.1.2.