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Evaluation of remote sensing sensors for monitoring of rehabilitated wetlands

by

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Summary

Title:	Evaluation of remote sensing sensors for auditing and monitoring of rehabilitated wetlands.
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This study contributed to the development of a procedure for monitoring rehabilitated wetlands. Eleven measurable indicators were identified that could be used with the application of remote sensing techniques to monitor the impacts of rehabilitation measures on selected wetlands, namely: erosion, sedimentation, open water, wet surface area, water quality, wetland vegetation, terrestrial vegetation, alien vegetation, bare soil, disturbances (e.g. cultivation) and rehabilitation structures. A general overview enlightens the use of different sensors, their capabilities, limitations as well as associated costs. The high resolution remote sensing sensors evaluated were:

- Airborne sensors (DuncanTech CIR and Kodak DCS 420 Near Infrared)
- Satellite recorded sensors (Landsat TM and Landsat ETM, EROS, SPOT 5).

A generalized land cover classification was done for all six study areas. The classification was recoded into seven classes by using image interpretation and the measurable indicators identified, namely:

Class 1: *Erosion / bare soil / harvesting wetland vegetation*,

Class 2: *sedimentation*,

Class 3: *open water*,

Class 4: *wetland vegetation* that reflects the hydrological conditions of the wetland,

Class 5: *terrestrial vegetation / bum scars*,

Class 6: *alien vegetation* and

Class 7: *cultivation*.

The exact location of the rehabilitation structures was recorded using a GPS.

Ten of the eleven selected indicators were represented in the wetland study areas, the exception being water quality. Issues related to mapping these indicators are the optimum time of year, the bands required and the spatial resolution to produce accurate maps versus the cost of data and time to process the data. The resolution of the data plays a vital role in the mapping process, depending on what the objective of the mapping is. The structures were visible on all the images, but the best results were from the Kodak DCS 420 Near Infrared and DuncanTech CIR images.

To map and monitor the status of the rehabilitation structures, the data should be of resolution 1 m or better. This would make it possible to detect structural damage, erosion activity, open water behind the structure and the movement of headcuts and gully erosion. For mapping vegetation, multispectral data with band width 0.52 to 0.90 μm is of great importance and should be of ground resolution 1.8 m or better. However, indicators must be monitored over time. In order to monitor rehabilitated wetland vegetation over a longterm period, the compatible images must represent the same season but from different years. It is recommended that future possible studies include the analysis of vegetation dynamics linked with the hydrology to investigate the change in wetland vegetation after rehabilitation. The choice between the different remote sensing sensors will largely depend on the application of the sensor, state of the rehabilitation structure or the vegetation response to the rehabilitation measures.

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

The protection and wise use of South Africa's wetlands will contribute to the sustainable management of South Africa's water resources. Wetlands are nature's way of purifying water from waterborne diseases, retaining and releasing precious water supplies during times of drought, preventing siltation of dams and slowing down severe flooding of river systems (Working for Water Programme Eastern Cape, July 2002). As a result of bad land utilization and practices the destruction of South Africa's wetlands is estimated at approximately 50% in some catchment areas. (Working for Water Programme Eastern Cape, July 2002). The Working for Water and Working for Wetlands (WfWetlands) initiatives set out not only to restore South Africa's precious water resources in terms of wetlands but also to help develop the country's human resources.

The WfWetlands programme is in fact a multi-departmental initiative between 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). The core function of WfWetlands is to rehabilitate wetlands with the added benefits of poverty alleviation and creating wetland awareness. (P.L. Grundling, *pers. comm*). Wetland-related rehabilitation does not only imply the eradication of alien invasive trees from the sensitive areas but also focuses more on technical and structural rehabilitation work. (Working for Water Programme Eastern Cape, July 2002).

WfWetlands is the only major wetland initiative presently active in South Africa. Millions of Rands are spent every year on wetland-related projects and it is of great importance to measure their success. It is therefore crucial to determine the most cost-effective procedure to audit and monitor rehabilitated wetlands. This project is an ideal platform for the evaluation of various appropriate remote sensing sensors on biophysical conditions, wetland utilization and structural rehabilitation work to test whether they could be used as management tools in the auditing and monitoring processes.

1.2 NATIONAL AND INTERNATIONAL EFFORTS

The importance of wetlands are recognised on the national and international scene, motivating the reasons for the research objectives on page 7.

1.2.1 Ramsar Convention on Wetlands

It was highlighted in the Strategic Plan for Working for Wetlands (2003) that the growing concern over the extent of wetland loss around the world eventually reached sufficient magnitude to prompt the creation of an instrument of international law, the Ramsar Convention on Wetlands, in 1971.

The Ramsar Convention, to which South Africa is one of 136 contracting parties, has strongly and consistently emphasised the importance of wetland rehabilitation. Resolutions adopted by Conferences of the Parties on this subject have emphasised that wetland restoration programmes that are ecologically, economically and socially feasible, and that are coordinated with wetland protection, provide substantial benefits for both people and wildlife.

Recognising that efforts to restore wetlands are still sporadic, and that there is a lack of general planning at the national level, contracting parties are urged to establish national programmes and priorities for wetland restoration (Strategic Plan for Working for Wetlands, 2003). Wetland rehabilitation is sometimes a cheaper option than trying to restore the wetland and all it functions. Wetland rehabilitation works towards the ultimate goal of wetland restoration.

It is significant that, for many years, the most powerful legislation to protect wetlands was contained in the Conservation of Agricultural Resources Act (1983). Much of the expertise required for designing wetland rehabilitation interventions and monitoring their success is also found within the Department of Agriculture (DoA). This is not surprising, since agriculture and wetlands are tightly intertwined in a number of respects. The importance of this multi-dimensional relationship was formally recognised by the Ramsar Convention, through the adoption of a resolution on agriculture, wetlands and water resources at its 8th Conference of Parties in 2002. The DoA thus has a clear mandate with respect to wetland conservation and rehabilitation, primarily from the perspective of ensuring the sustainable use of agricultural natural resources (Strategic Plan for Working for Wetlands, 2003).

Wetland conservation and sustainable use comprises one of the eight themes under the Environment Initiative of the New Partnership for Africa's Development (NEPAD). The draft strategy and action plan for giving effect to this theme contains a number of objectives that incorporate rehabilitation. Rehabilitation will be a core component of the actions taken to move towards the strategy's proposed vision that "African countries and their people have healthy and productive wetlands and watersheds that can support fundamental human needs (clean water, appropriate sanitation, food security and economic development) in a healthy and productive environment" (Strategic Plan for Working for Wetlands, 2003). Presently the Water Act of 1998 sets the trend in legislation dealing with wetlands.

1.2.2 Agenda 21.

Agenda 21 was adopted at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992. Agenda 21 is the global environmental strategy for sustainable development, which resulted from the Conference and called for improved environmental information for decision making (Balance and King, 1999). South Africa, as a signatory of Agenda 21, is committed to follow this approach, at national and local levels (Mzuri Consultants, 2002). Agenda 21 comments specifically on the need for indicators to be developed to provide a solid base for decision making at all levels as well as the need for countries to monitor water resources and water quality.

The support that the science can provide for the sustainable development process is firstly: to strengthen the scientific basis for sustainable management to be able to develop capacity for predicting the responses of terrestrial, freshwater, coastal and marine ecosystems and biodiversity to short-and long-term perturbations of the environment, and develop further restoration ecology. Secondly to improve long-term scientific assessment so that the knowledge acquired may be used to provide scientific assessments (audits) of the current status and the range of possible future conditions.

Countries have been requested to use Quality-of-life indicators (covering e.g. health, education, social welfare, state of the environment, and the economy) in their attempts to measure their progress in achieving sustainable development. This worldwide commitment was again confirmed at the Johannesburg Declaration on Sustainable Development, 2002:

"We, the representatives of the people of the world... assume a collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development - economic development, social development and environmental protection - at local, national, regional and global levels."

The Plan of Implementation adopted by the World Summit on Sustainable Development (WSSD) provides a further perspective on the potential for wetland rehabilitation to provide benefits on a large scale. The plan emphasises that actions are required at all levels to "reduce the risks of flooding and drought in vulnerable countries by, inter alia, promoting wetland and watershed protection and restoration".

The Working for Wetlands programme (WfWetlands) is actively involved and strives to fulfil obligations of South Africa's national policy and South Africa's commitment to international conventions and regional partnerships with conservation, rehabilitation and sustainable use of wetland ecosystems. WfWetlands is also training its workforce on a variety of wetland rehabilitation related aspects: wetland identification, delineation, rehabilitation techniques, wise-use, monitoring, etc. in terms of implementation of restoration measures. The vision of WfWetlands in order to monitor rehabilitated wetlands forms the basis of the research in this study to evaluate remote sensing sensors to determine whether they can be used in monitoring and auditing rehabilitated wetlands.

1.3 RESEARCH OBJECTIVES

1.3.1 To identify various indicators that can be used to audit and monitor the impacts of rehabilitation on wetlands.

1.3.2 To evaluate high resolution remotely-sensed image data, such as two airborne sensors (DuncanTech CIR and Kodak DCS 420) and four satellite recorded sensors (Landsat TM and Landsat ETM, EROS, SPOT 5), to detect the rehabilitation structures and the selected indicators for the monitoring of rehabilitated wetlands.

1.3.3 To make recommendations regarding the time of year for data acquisition, the bands required and the spatial resolution to produce accurate maps versus the most cost-effective procedure (cost of data and time to process the data) for the auditing and monitoring of rehabilitated wetlands.

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.

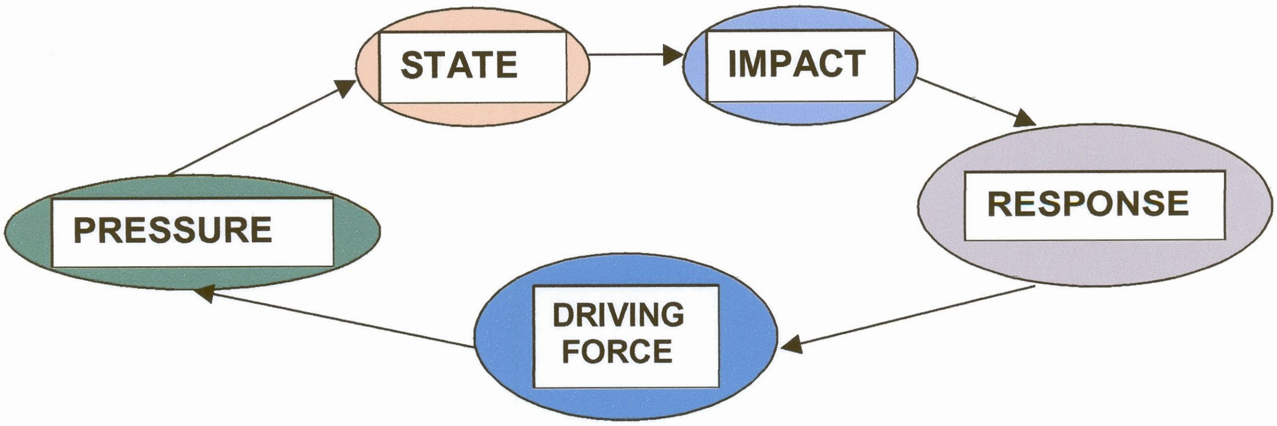

Figure 1: The "Driving Force-Pressure-State-Impact-Response" framework.

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 2nd 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.

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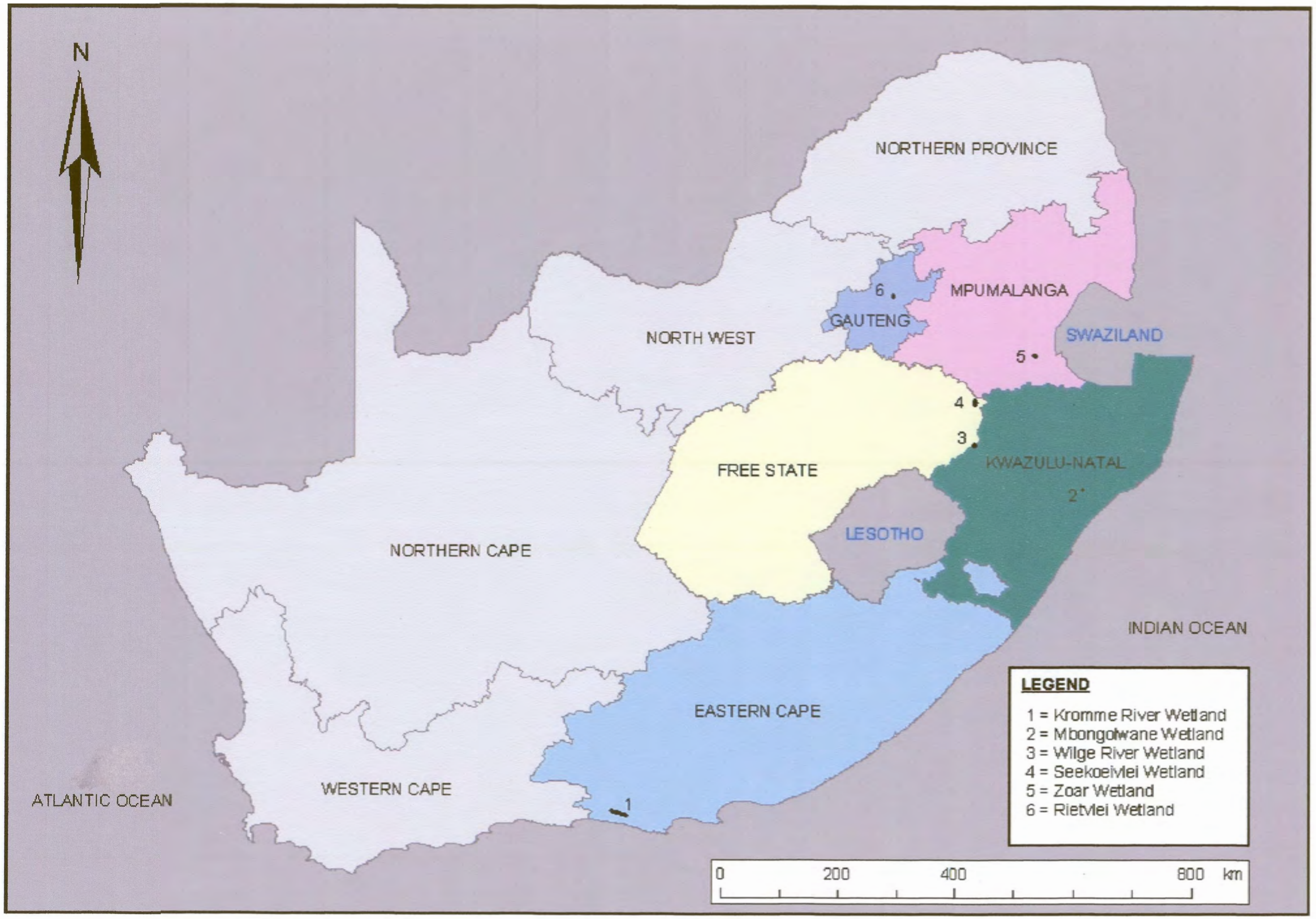


Figure 2: The location of the six rehabilitated wetland study sites in South Africa.

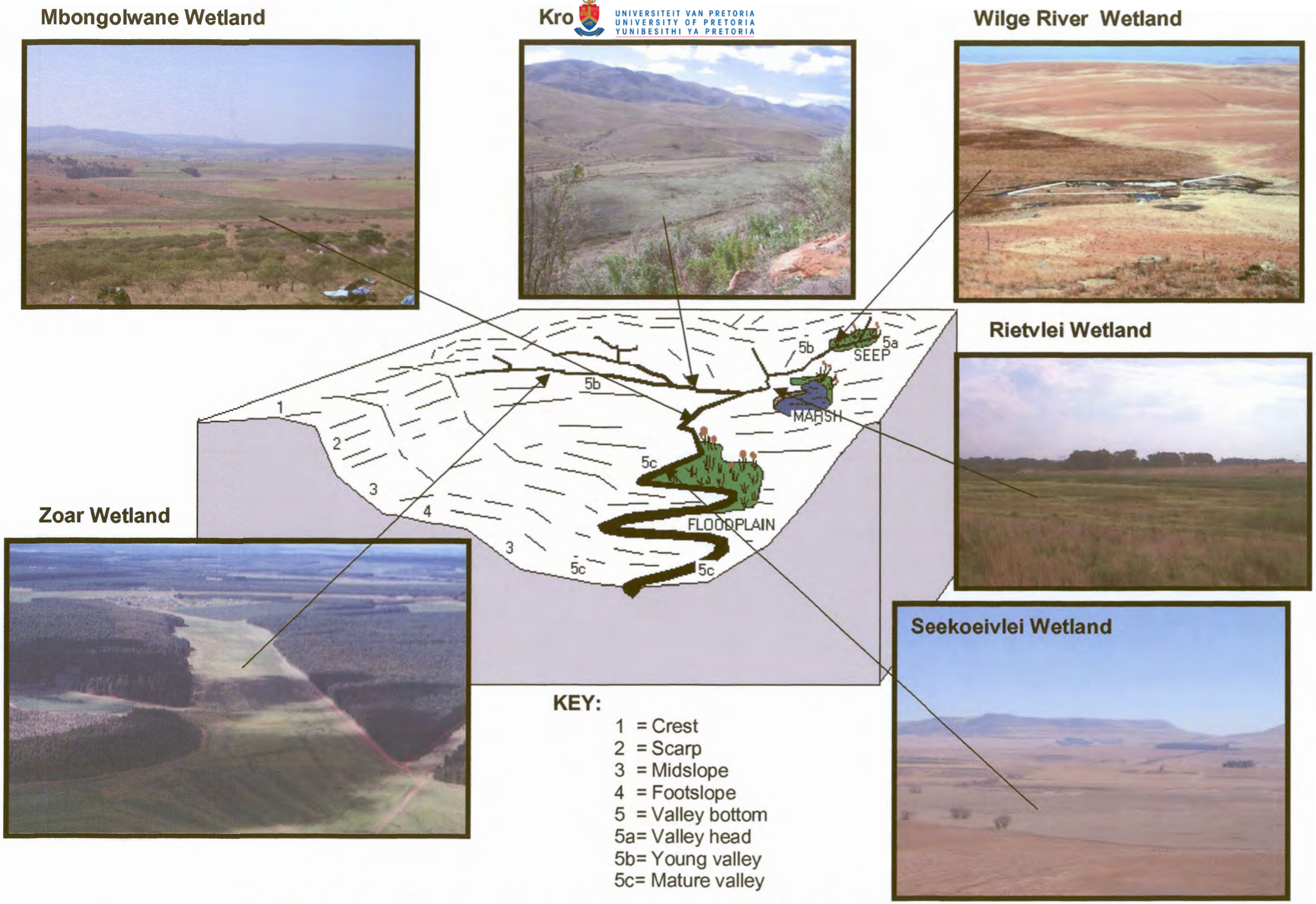


Figure 3: The location of the selected rehabilitated wetlands within the different terrain units and wetland types (Adapted from Kotze *et al.*, 1994).

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

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.

CHAPTER 3: MATERIAL AND METHODS

3.1.2 General literature, maps and other data.

3.1.2.1 Kromme River:

i) General description of the wetland site.

The Kromme River wetland is situated in the upper catchment of the Kromme River (Eastern Cape). The 48 km peatland complex is a long linear feature within a steep narrow Cape fold valley, on privately owned land (Figure 4). The Kromme River wetland is one of the largest peatlands in the Eastern Cape (Haigh *et al.*, 2002).

Figure 4: The Kromme River wetland.

Parallel ridges of the Cape Fold mountain range to the north and south define the Kromme River valley. Numerous tributaries drain into the Kromme River from these steep slopes (25% - 40%). The river flows in an East-Southeast direction. Incised alluvial fans have developed at a number of places where tributaries entered the main axis between Kromdraai, Kompanijsdrif and at Hendrikskraal, Jagersbos and Hudsonvale (Figure 5) (Haigh *et al.*, 2002).

Figure 5: Topographical map section of the Kromme valley with 1954 aerial photograph showing an alluvial fan at Hudsonvale.

The dominant plant species found in this wetland is *Prionium serratum* (Figure 6). Some areas contain wet grassland and sedges.

Figure 6: Palmiet (*Prionium serratum*).

The average long-term rainfall data (Figure a in Appendix 2) (ARC-ISCW, 2002) indicates that the maximum rainfall occurs in August, October and November although rain does fall throughout the year. The region of the Kromme River wetland receives approximately 700 mm of rain annually (ARC-ISCW, 2002). According to Haigh *et al.* (2002) the principal rainy season seems to be during the winter months.

The climatic regime for the area is characterized by high-energy flood events and frequent fires. The combination of shallow sandy soils and steep slopes with this climatic regime predisposes this valley for rapid deterioration through erosion, once the natural land cover has been disrupted (Haigh *et al.*, 2002).

A summary of landscape changes in the Hudsonvale peat basin is described from aerial photographs of 1942 (earliest obtainable), 1954 (before the new road was constructed), 1961, 1969 and 1986 (Appendix 5) (Haigh *et al.*, 2002).

- Incisement (erosion) of banks, channels and headcuts.
- Headcut stabilization and migration.
- Siltation of channels, sandbanks.
- Hydrological regime – smaller channels networking the sandbank.
- Revegetation.
- Land cultivation.
- Alien vegetation encroachment.
- Density of vegetation.
- Vegetation species.
- Over-grazing.
- Bare soil.
- Visibility of water.
- Size of the fluvial plume.
- Migration of the confluence point of two rivers.
- Infrastructure.

ii) Rehabilitation information (Gamtoos Irrigation Board, 2002).

The problems in the Kromme River wetland are mainly due to the land use practices, namely:

- Agricultural activities (clearing, over-grazing and draining of the wetland).
- Roads, causeways and storm drains resulting in erosion.
- Alien vegetation infestation.
- Fires.
- Sand mining.

These land use practices resulted in the destruction of the wetland and caused the loss of valuable wetland functions. The erosion of alluvial soils (sandy and not dispersive) derived from Table Mountain sandstone caused massive downstream sedimentation. Increasing flood events and siltation cause severe damage to the Churchill and Impofu dams (Gamtoos Irrigation Board, 2002).

In 1998, at least eight major headcuts in the Kromme River were identified, and since then, seven have been repaired with gabion structures. Other problems like channel bank erosion expose the bedrock (Figure 7) (Haigh *et al.*, 2002).

Figure 7: Extensive channel bank erosion exposing bedrock. Horizons of dark organic, sometimes peat-like material, alternating with lighter coloured sands (relatively poor in organic material) reveal the episodic nature of the sediment supply from the tributary catchments.

iii) Rehabilitation objectives (Gamtoos Irrigation Board, 2002).

1. Flood attenuation and base flow support to the storage dams.
2. Stop further sedimentation of the storage dams.
3. Stop further degradation and erosion of the wetlands.
4. Water purification.
5. Conservation of rare habitat and enhancement of natural biodiversity.
6. Poverty relief and skills development.

iv) Offsite actions required (Gamtoos Irrigation Board, 2002).

1. Removal of alien vegetation infestation (*Acacia mearnsii*) in the riparian zone.
2. Stakeholder involvement.
3. Training and education, safety awareness and productivity control.
4. Ongoing environmental monitoring.
5. Improve catchment management (control of fires, clearing, erosion on slopes and paths, and over-grazing).

v) Monitoring & Maintenance (Gamtoos Irrigation Board, 2002).

1. Follow–up monitoring and maintenance visits by the Design Engineer and Implementing Agent to monitor the stability of the structures.
2. Rehabilitation monitoring by Senior Project Manager with assistance from a Technical Advisor.
3. Monitor the revegetation and riverbank stability through long-term fixed point photography.
4. Control of invasive plant species.
5. Fencing-off the structure to exclude animals (Figure 8).
6. Monitor the headward movement of the headcut at Kompanjesdrif.

Figure 8: The area around the structure must be fenced off to prevent over-grazing and trampling by cattle.

The photos of each rehabilitation structure were taken during the preliminary field visit (9 July 2002). Figure 9 describes the wetland rehabilitation site layout details and Table 6 gives a summary of the problems, rehabilitation actions taken and the desired results to attain after the rehabilitation.

vi) Wetland Rehabilitation site details.

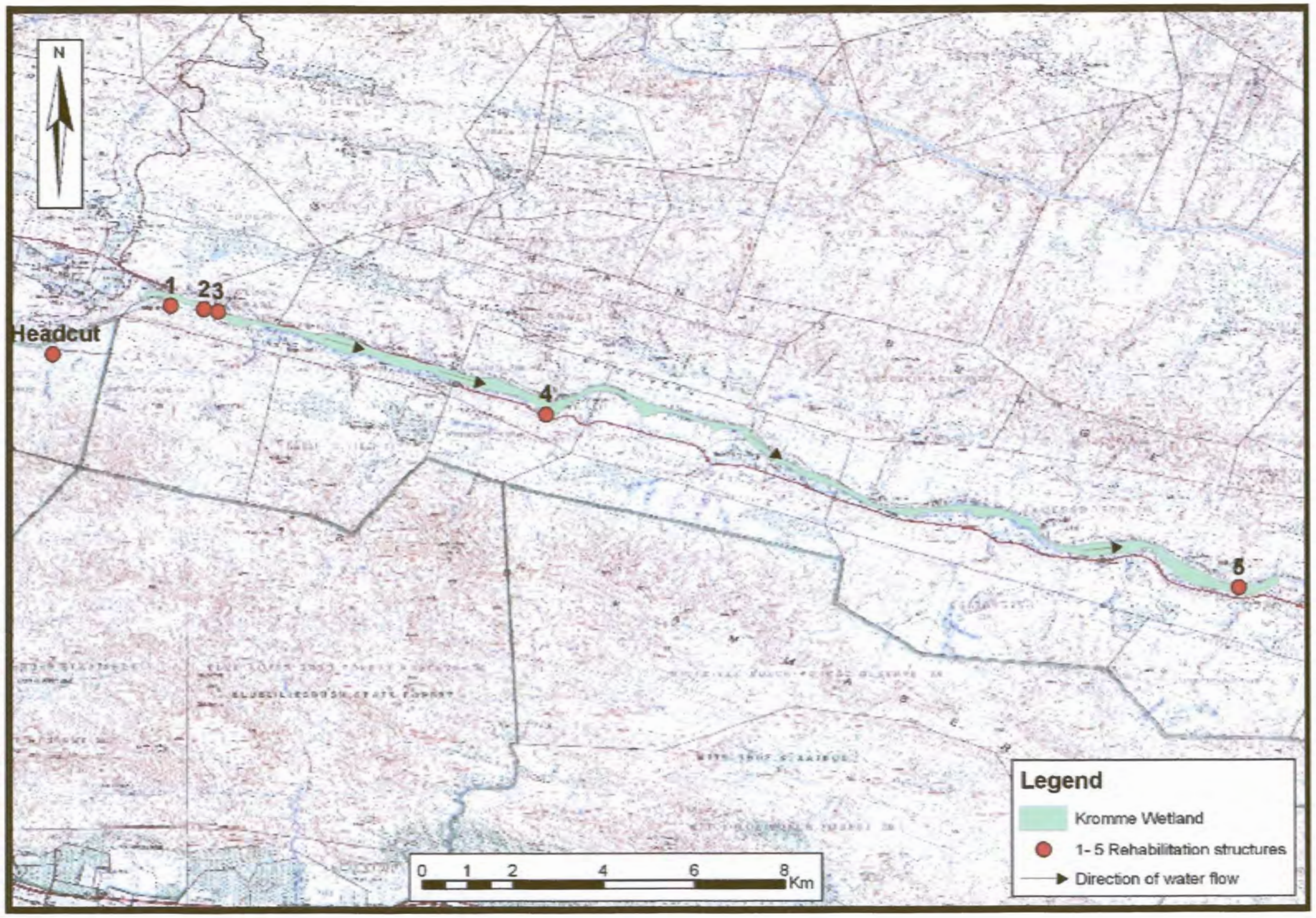


Figure 9: Topographical maps (3324 CD, 3324CC, 3323 DD) showing the locations of the rehabilitation structures 1- 5 as well as the headcut of the Kromme Wetland in the Eastern Cape.

Table 6: Kromme River Wetland: Summary of the problems, rehabilitation actions taken in 2001/2002 and the desired results to be attained after the rehabilitation.

Site no.	Problems	Rehabilitation action	Desired results
23° 58' 22" 33° 52' 21"	Headcut erosion at a side tributary in the upper catchment area (Figure 9 & 10). The fynbos vegetation differs from the palmiet (*Prionium serratum*) that dominates the main wetland in the Kromme River.	Gabion and concrete structure.	• Structures must act as silt traps. • Rehabilitation of indigenous vegetation. must protect the soil.
1 23° 59' 45" 33° 51' 46"	Eroded river channel in river bed of 8.5 m wide and 3.5 m deep.	3.5 high concrete gravity structure (Figure 11) 4 m wide at bottom and 8.5 m overflow width build on rock foundation.	• Structures must act as silt traps. • Rehabilitation of indigenous vegetation must protect the soil. • Lift water table. • Dissipate the energy of floods. • To prevent further erosion of the wetland.
2 24° 00' 19" 33° 51' 48"	Headcut 2.5 m deep and 9.5 m wide eroded river channel within riverbed.	2.5 m high concrete gravity structure (Figure 12) 3m wide at bottom and 9.5 m overflow width build on rock foundation across a narrow section of the river below a headcut.	• Structures must act as silt traps. • Rehabilitation of indigenous vegetation. must protect the soil. • Lift water table. • Dissipate the energy of floods. • To prevent further erosion of the wetland.
3 24° 00' 08" 33° 51' 51"	Headcut 5.5 m deep and 17.5 m wide eroded channel within riverbed.	5.5 m high concrete gravity structure (Figure 13) 6 m wide at bottom and 17.5 m overflow width build on rock foundation.	• Structures must act as silt traps. • Rehabilitation of indigenous vegetation. must protect the soil. • Lift water table. • Dissipate the energy of floods. • To prevent further erosion of the wetland.
4 24° 04' 12" 33° 52' 59"	Headcut 3.0 m deep and 11.0 m wide eroded river channel within riverbed.	Gabion weir (Figure 14). The area needs to be sloped to enable the revegetation of the riverbanks with indigenous vegetation.	• To prevent further erosion of the wetland. • Prevent down stream sedimentation. • Stabilise river banks.
5 24° 12' 29" 33° 55' 09"	Headcut 3.0 m deep and 21.0 m wide eroded river channel within riverbed.	Gabion weir on soil foundation (Figure 15). 3.0 m high gravity structure, 4 m wide at bottom and 21.0 m overflow width.	• To prevent further erosion of the wetland. • Regain part of the wetland that has eroded away. • Decrease siltation • No alien plant infestation

Figure 10: Landscape around the headcut at a tributary of the Kromme River. This rehabilitation was done in a first order stream and not in a wetland.

Figure 11: Close-up photo of the headcut rehabilitation structure at a tributary of the Kromme River. This rehabilitation structure will not form part of the Wilge River Wetland study but indicates rehabilitation measures in the catchment.

Figure 12: Rehabilitation structure 1: Concrete Weir being constructed.

Figure 13: Rehabilitation structure 2: Concrete Weir being constructed.

Figure 14: Rehabilitation structure 3: Concrete Weir being constructed.

Figure 15: Rehabilitation structure 4: Gabion weir at Kompanjiesdrif.

Figure 16: Rehabilitation structure 5: Gabion weir at Hudsonvale. Note the revegetation on the sides.

3.1.2.2 Mbongolwane Wetland:

i) General description of the wetland site.

The Mbongolwane wetland in KwaZulu-Natal is situated 40 km west of Eshowe. This wetland plays an important role in terms of its hydrological importance to the Amatikulu catchment as well as its cultural and natural resource value to the Ntuli Tribe.

Land use in the wetland area incorporates the utilization of the wetland as an important resource in terms of:

- Water use.
- Grazing.
- Cultivating crops.
- Forestation.
- Medicinal plants.
- Plant material for craft making and thatching.

A diversity of different dominant vegetation types can be found on the hydrological zones in the wetland, namely: reed marsh (*Phragmites australis* [Cav.] Steud.), bulrush marsh in permanently waterlogged areas; sedge marsh (*Cyperus latifolius)* in permanently to seasonally waterlogged areas; and wet grassland in temporarily waterlogged areas (Figure 17) (Kotze, 1999).

Mbongolwane wetland is situated in a summer rainfall region. The maximum rainfall months are December, January and February (Figure b in Appendix 2) (ARC-ISCW, 2002). Mbongolwane receives approximately 900 mm of rain annually.

Figure 17: Part of the Mbongolwane wetland with cattle grazing on the wet grassland and harvested sugar cane in the foreground.

About 10% of the wetland is currently used for subsistence agriculture practices (Kotze, 1999). No heavy machinery, pesticides and artificial fertilizers are used and the cultivated areas are frequently rotated to allow the natural vegetation to re-grow.

A root crop (*Colocasia esculenta*), referred to by the Zulu people as "madumbes" (Figure 18), is the most commonly grown crop at Mbongolwane wetland and is grown mainly in *Cyperus latifolius* marsh (Kotze, 1999).

Traditional methods used to cultivate madumbes are less harmful to the wetland than large-scale, mechanized cultivation. However, cultivating the sensitive areas in the wetland (areas with high erosion potential, support important habitats or species or are important drinking water supply areas) can influence the functional value of the wetland (Kotze, 1999).

Madumbes, maize and pumpkins are grown mainly in *Cyerus latifolius* marsh (seasonally wet zone). Mixed vegetable patches (including maize, potatoes, tomatoes, cabbages, pumpkins and legumes) are found predominantly in the wet grassland areas (temporarily wet zones) (Kotze, 1999).

The easily digestible starchy rhizomes and the young leaves (used as "marog" / spinach) of the madumbe plant provide a dietary supplement to maize (Kotze, 1999).

Figure 18: A root crop (*Colocasia esculenta*) referred to by the Zulu people as madumbes.

Harvesting of plant material from the wetland takes place during the months December to June for "ikhwane" (*Cyperus latifolius)* and the end of April for reeds (*Phragmites australis*).

Ikhwane (*Cyperus latifolius)* is an important resource for making traditional wedding gifts (Figure 19), and the reeds (*Phragmites australis*) are used for thatching houses (Kotze, 2000).

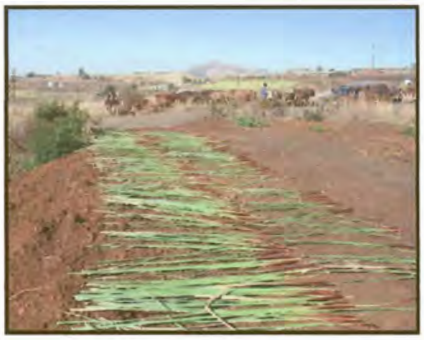


Figure 19: Harvesting Ikhwane for making sleeping mats and bags.

ii) Rehabilitation information.

The wetland is situated in the upper Amatikulu catchment. Two large headcuts were identified: one in the wetland at a site called Amatigulu, the second is on a stream that enters the wetland called Uvova.

Aerial photographs of the two sites, Amatigulu (Figure 20) and Uvova (Figure 21) clearly show landscape changes from 1937 to 1991.

Summary of landscape changes deduced from aerial photographs:

- Erosion channels and headcuts.
- Hydrological regime.
- Land cultivation.
- Density of vegetation.
- Bare soil.
- Visibility of water.
- Infrastructure.

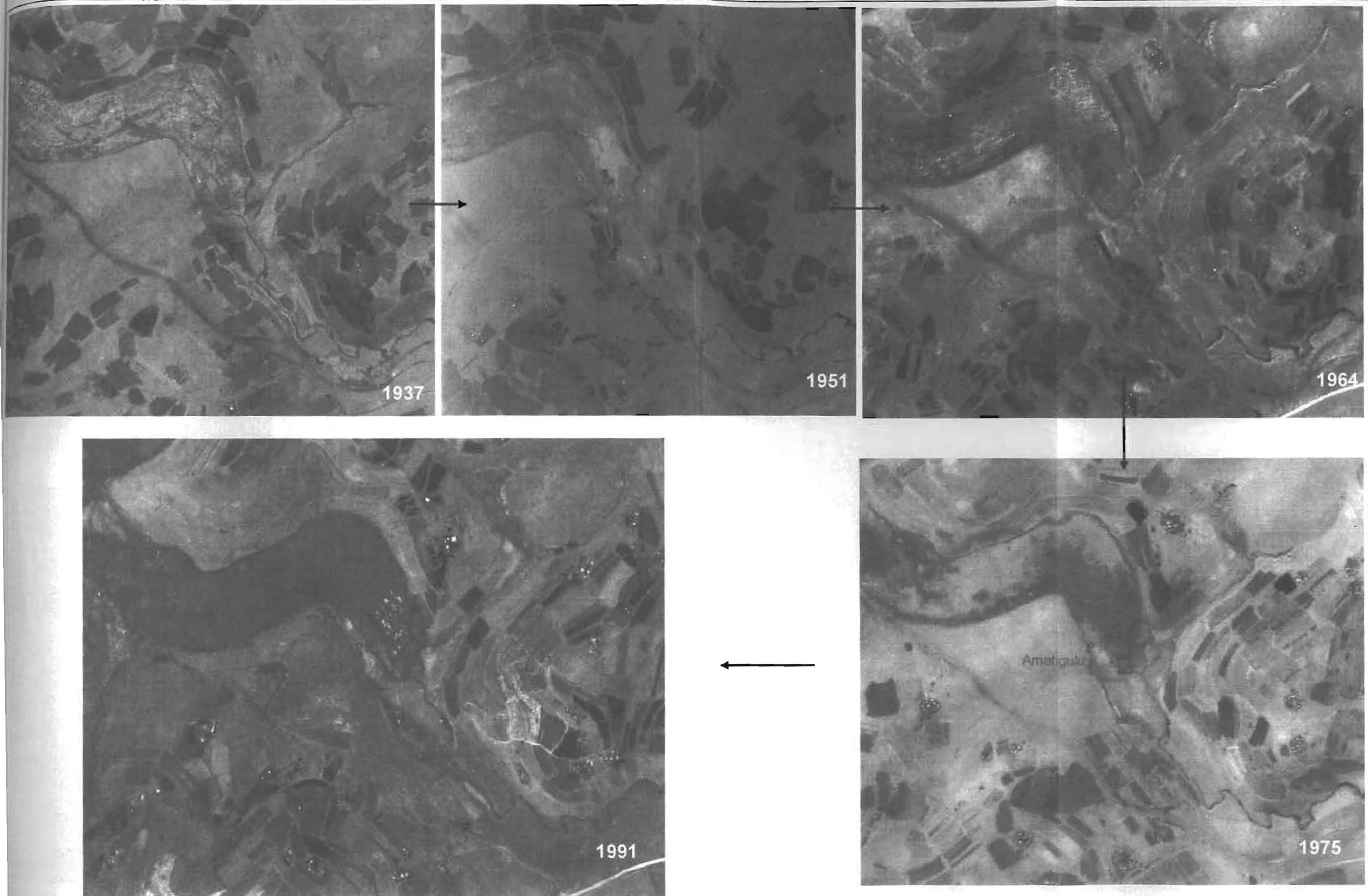


Figure 20 : Site 1 : Amatigulu. Aerial photographs depicting landscape changes.

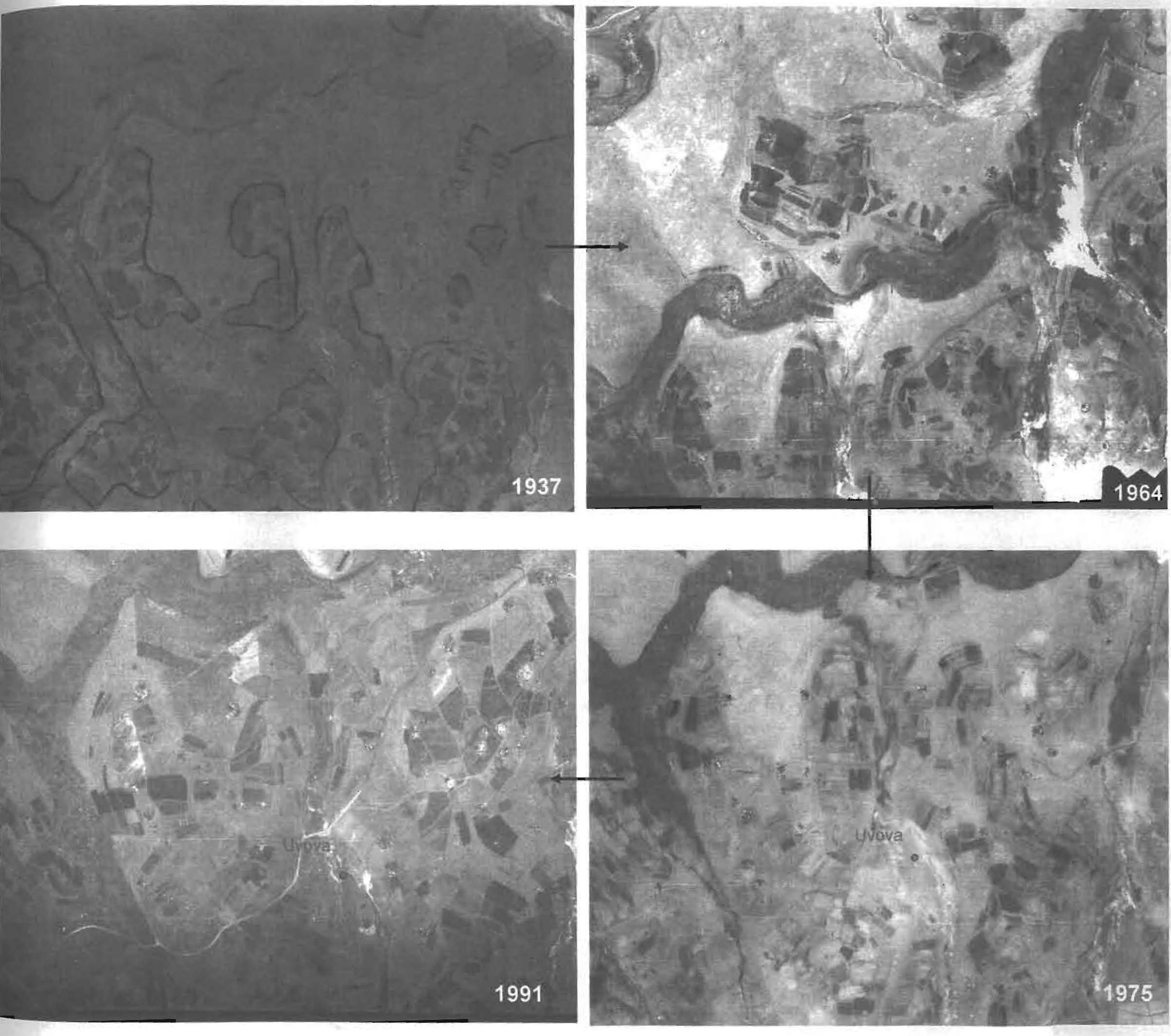


Figure 21 : Site 2 : Uvova. Aerial photographs depicting landscape changes.

Land use practices (Figure 22) like the cultivation of sugar cane, using natural veld for grazing, cropland and homesteads, increase the sediment deposits and nutrient backflow into the river system. These wetland threats place increasing pressure on the wetland's water purification capability. This situation also increases the susceptibility to diseases like cholera and bilharzias and needs to be monitored.

Figure 22: Some of the activities which impact on Mbongolwane Wetland: Sugar cane, forestation, cash crops, washing clothes.

iii) Rehabilitation objectives.

1. Flood retention and base flow support.
2. Stop further degradation and erosion of the wetland.
3. Poverty relief and skills development.

iv) Offsite actions required.

1. Stakeholder involvement.
2. Training and education, safety awareness and productivity control.
3. Catchment land use planning.

v) Monitoring & Maintenance.

1. Monitoring the rehabilitation structure by the Senior Project Manager with assistance of a Technical Advisor.
2. Diseases like cholera and bilharzia need to be monitored.
3. Monitor flood retention and base flow support.
4. Monitor the headward movement of the headcut.
5. Poverty relief and skills development.
6. Monitor the overall hydrological state of the upstream area of Amatigulu and Uvova.
7. Monitor the deposition of sediment downstream of the structure.

vi) Wetland Rehabilitation site details.

The Mbongolwane wetland in KwaZulu-Natal meanders for 12 km. There are two sites at Mbongolwane that had work scheduled for 2002/3. Two large chutes were planned, one in the wetland at Amatigulu, the second is on a stream which enters the wetland at Uvova. The concern at the Amatigulu site is the area of wetland under threat from the continued and extensive movement of the headcut and the associated gully. This wetland area is largely permanently saturated and characterized by diffuse flow. The hydrological consequences of further erosion are therefore potentially very significant. It would therefore be important to monitor the overall hydrological state of this upstream area.

Figure 23 describes the wetland rehabilitation site layout details and Table 7 gives a summary of the problems, rehabilitation actions taken and the desired results to attain after the rehabilitation.

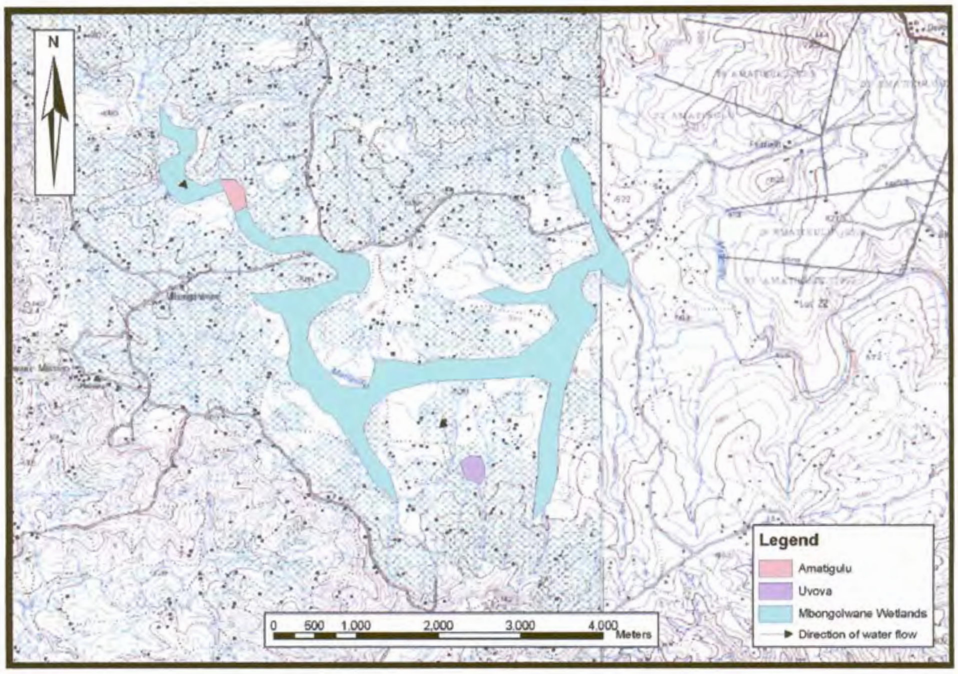


Figure 23: Topographical maps (2831CC & 2831 CD) showing the locations of the two rehabilitation structures (Uvova and Amatigulu).

Table 7: Mbongolwane Wetland: Summary of the problems, rehabilitation actions taken in 2002 and the desired results to be attained after the rehabilitation.

Site no.	Problems	Rehabilitation action	Desired results
1 Amatigulu S 28°55.00" E 31°12'33"	Head cut of 3 m, which was eroding upstream and eroding further and further into the wetland with each summer rainfall period (Figures 24, 25, 26, 27 and 28).	A large concrete filled geocell chute with baffles	• Dissipate the energy of floods. • Prevent further erosion of the wetland.
2 Uvova S 28°56'45" E 31°14'07"	An active headcut situated in the Uvova stream. The stream enters the Mbongolwane wetland (Figures 29 and 30).	A concrete filled geocell chute with baffles	• Dissipate the energy of floods. • To prevent further erosion of the wetland. • Reduce the extent of Sediment generated and deposited in the main body of the wetland.

Preparatory work of shaping both the chutes at a 1:5 slope was planned for the dry winter period (started at June 2002 and carried into July). The first field visit at each of these sites took place on 4 July 2002.

After 6 weeks of structure work at each site, 600 mm of rain fell in the catchment between 16 – 22 July 2002. This heavy downpour event was totally out of season. The Mbongolwane wetland falls in a summer rainfall region, the maximum rainfall months are: December, January and February (Figure b in Appendix 2) (ARC-ISCW, 2002).

Astrup (2002) commented that all the preparatory work at both the sites was totally destroyed (Figure 24). Flood waters gushed through the sites and caused serious erosion on the chute preparation (Figure 25, 26, 27, 28, 29 and 30). Astrup (2002) explained further that it was impossible to start again with chute preparation due to water flow and the loss of precious work time. The risk of spring rains would threaten chute preparation work started at this stage. Large volumes of water flowed through the Amatigulu site right up until August. A decision was taken to re-plan a structure for the winter of 2003 (M. Astrup, *pers. comm.*).

Figure 24: Amatigulu site. View of the damaged geocell chute after July 2002 floods. Note the lush green grass after the rains.

Figure 25: Before flooding. Photo taken downstream on 4 July 2002 at the Amatigulu site.

Figure 26: After flooding. Photo taken downstream after July 2002 at the Amatigulu site. Geocell chute preparation at 1:5 gradient (Photo: M. Astrup).

Figure 27: Before flooding. Photo taken up stream on 4 July 2002 at the Amatigulu site.

Figure 28: After flooding. Photo taken upstream after July 2002 at the Amatigulu site. Geocell chute preparation at 1:5 gradient (Photo: M. Astrup).

Figure 29: Before flooding. Photo taken on 4 July 2002 at the Uvova site.

Figure 30: Uvova site damage to chute preparation after July 2002 floods (Photo: M. Astrup).

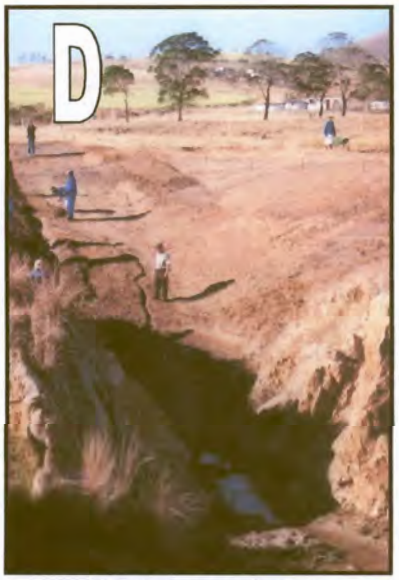
At the Uvova site a re-assessment was done, together with Mr. Bill Russel (WfWet consultant), for the construction of:

A 25 - m long sand bag groyne (Figure 31 a) to divert the stream flow away from the headcut site of the donga, together with an earthen embankment with a small buttress weir 300 mm high and 45 m long (Figure 31 b) across the stream so as to evenly spread water flow. In addition, a 500 mm high earthen embankment (storm drain) (Figure 31 c) was constructed directly above the headcut site so as to ensure water does not enter at this point. Reparation work on the Uvova site was done during September and October 2002 (Figure 31 d).

Sandbag groyne to divert stream to right-hand course away from headcut. This is a temporary structure while stream formalizes channel to the right.

Buttress weir under construction. 50mm PVC piping will carry base flow into headcut site.

Earthen embankment (500 mm) high storm drain to keep floodwater away from headcut on left. Large earthen *embankment and buttress weir visible on* top left of photo.



Preparation for geocell chute work.

Figure 31: Reparation work on the Uvova site was done during September and October 2002 (Photo: M. Astrup).

A concrete chute is planned for where the stream flow enters the drainage line (Figure 32). The position will be about 400 m below the headcut.

Figure 32: An eroding headcut situated on the Uvova stream. The stream enters the Mbongolwane wetland. Photo taken on 4 July 2002.

3.1.2.3 Wilge River Wetland:

i) General description of the wetland site.

The Wilge River wetland is also known as Bedfordview or Watervalvlei wetland. The Wilge River wetland is situated in the upper catchment of the Wilge River in the north-eastern Free State near Harrismith and stretches over three privately owned farms.

These are:

- Bedford (21845). Owner: Mr. Piet Blom. This portion of wetland contains peat.
- Chatsworth (388). Owner: Mr. George Gallaway.
- Wilge River (319). Owner: Mr. Willem de Jager.

An aerial survey of the Wilge catchment by Rand Water revealed a headcut at the outlet of a wetland on the farm Wilge River 319 (hereafter referred to as the Wilge River wetland). The wetland rehabilitation has been performed on this portion of wetland in the upper catchment of the Wilge River (N. Collins, *pers. comm.*) (Figure 33).

Figure 33: The Wilge River Wetland and rehabilitation structure at the headcut.

The Wilge River wetland is of international conservation value. It is not only stated to be the best conserved high altitude palustrine type wetland within the whole of South Africa but also serves as an important habitat for globally endangered species like the Whitewinged Flufftail (Taylor, 1997). This is one of only ten known sites in the country where this bird is found (Figure 34). Furthermore this wetland contains one of the oldest known peat deposits on the Highveld (10 500 years old) (P. Grundling, *pers. comm.*; Marneweck *et al.*, 2001).

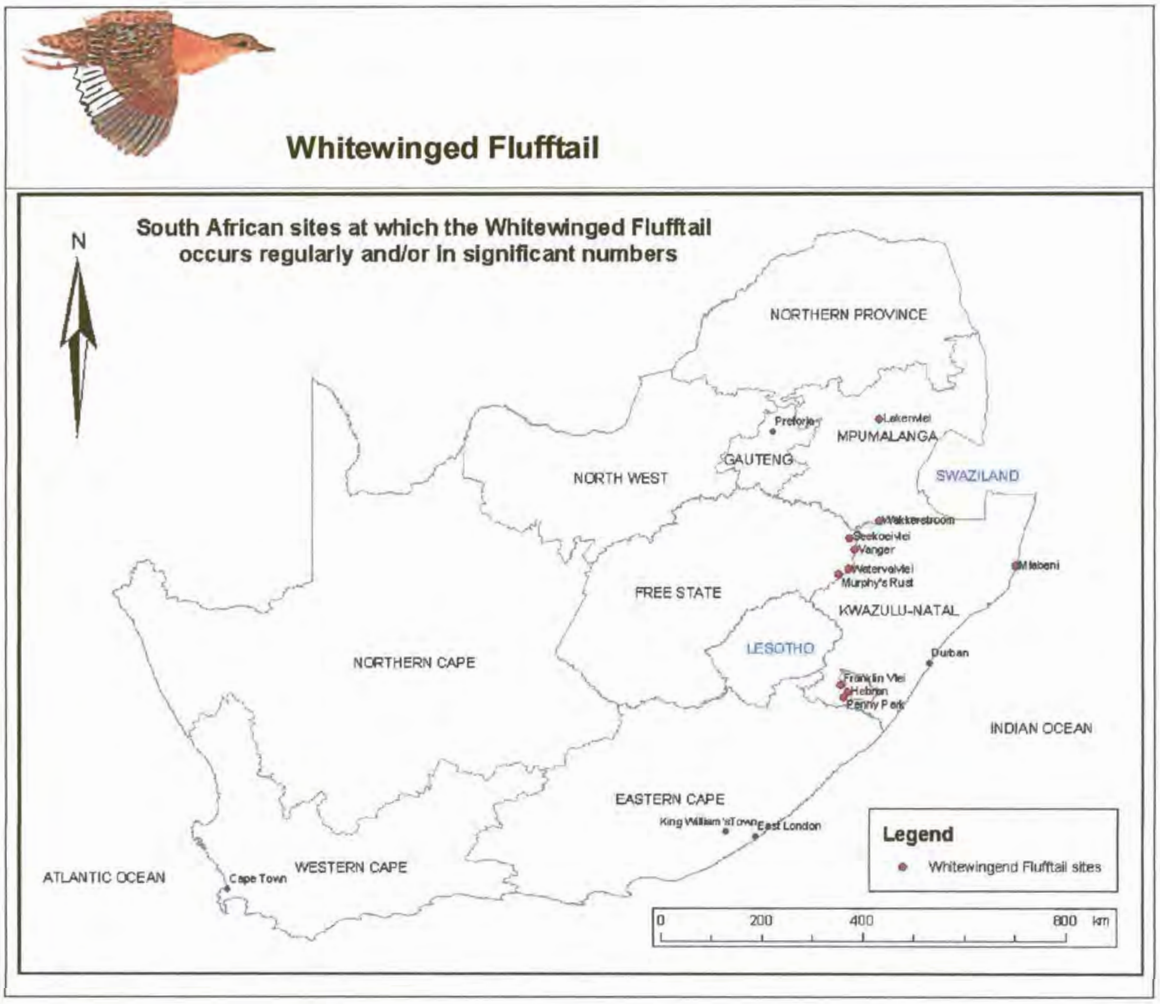


Figure 34: Wilge River Wetland is one of the sites were the Whitewinged Flufftail occurs regularly and/or in significant numbers (Taylor and Grundling, 2003).

Grazing is the main land-use activity within the wetland (Free State Department of Tourism, Environmental and Economic Affairs, 1997). The maximum rainfall occurs during December, January and February (Figure c in Appendix 2) (ARC-ISCW, 2002).

ii) Rehabilitation information

The Wilge River Wetland is one of the last unspoiled wetlands in South Africa. Since 1997 the Free State Department of Tourism, Environmental and Economic Affairs has been actively involved in wetland rehabilitation within this area with funding from Rand Water (N. Collins, *pers comm.*). The wetland is situated in the valley bottom with a flat channel. In its present state the wetland is used for grazing and watering of cattle and game. These are the main land uses and disturbances in the area. The wetland vegetation cover is 100% natural vegetation - not over-grazed (Free State Department of Tourism, Environmental and Economic Affairs, 1997).

According to N. Collins (*pers comm.*), the extensive headcut erosion (Figure 35) was possibly caused by the road crossing lower down the wetland (Figure 36). Erosion causes open water bodies and vegetation degradation. Tunnel erosion is evident in the seepages. These sensitive areas are being trampled by cattle. The wetland is used for watering of cattle; therefore the headcut area must be fenced off to prevent trampling by cattle (N. Collins, *pers comm.)*.

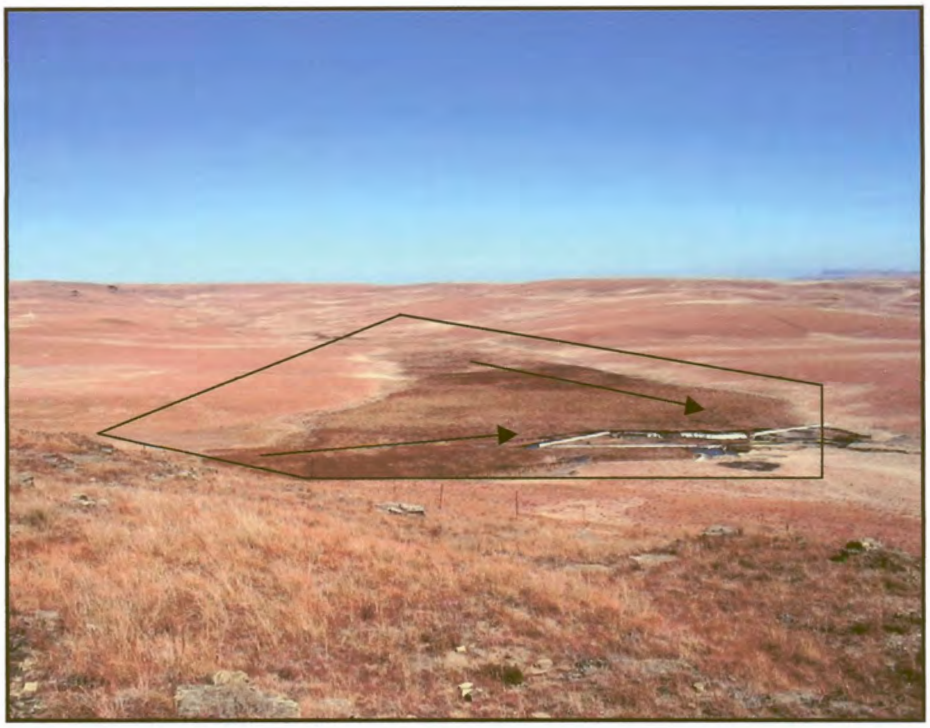


Figure 35: A headcut (consisting of a headcut and a channel) were found in the Wilge River. The remote sensing imagery will focus on the area indicated.

Figure 36: Road crossing downstream of the rehabilitation structure.

iii) Rehabilitation objectives (Collins and Thompson, 2002).

1. Flood retention and base flow support.
2. Stop further degradation and erosion of the wetland.
3. Sediment trapping.
4. Nutrient attenuation.
5. Prevent the hydrological functioning from becoming impaired or lost.
6. Conservation of rare habitat and enhancement of natural biodiversity.
7. Social upliftment (poverty relief and skills development).

iv) Offsite actions required.

1. Stakeholder involvement (Collins and Thompson, 2002).
2. Training and education, safety awareness and productivity control (Collins and Thompson, 2002).
3. Impacts of the proposed pump storage scheme in the upper part of the wetland and it's catchment need to be determined.

v) Monitoring & Maintenance.

1. Follow-up visits to the completed rehabilitation work will be done regularly for the first year after completion by the Senior Project Manager with assistance from a Technical Advisor and thereafter annually by the Department.
2. Monitor the re-established species composition through vegetation surveys.
3. Fencing around the rehabilitation structure to prevent grazing by animals.

vi) Wetland Rehabilitation site details.

The photos of the rehabilitation structure were taken during the preliminary field visit (1 July 2002). Table 8 gives a summary of the problems, rehabilitation actions taken and the desired results to attain after the rehabilitation, and Figure 37 describes the wetland rehabilitation site layout details.

Table 8: Wilge River Wetland: Summary of the problems, rehabilitation actions taken and the desired results to be attained after the rehabilitation (Collins and Thompson, 2002).

Site no.	Problems	Rehabilitation action	Desired results
1 28°13'38" 29°33'31"	Headcut (45 m) and channel (95 m donga) erosion (Figure 38)	Structural erosion control is needed. **Headcut:** - 30 m sloping: hyson cells (1:4), 15 m concrete basin, 100 m soil berm, 300 m fencing and revegetation (Figure 39). **Donga:** - 95 m sloping: hyson cells, 10 m concrete basin, channel plugs: gabions filled with rock.	• Stabilise the headcut • Stabilise headcuts developing on the banks of the channel • Dissipate the energy of floods. • To prevent further erosion of the wetland causing the affected wetland area to be drained.

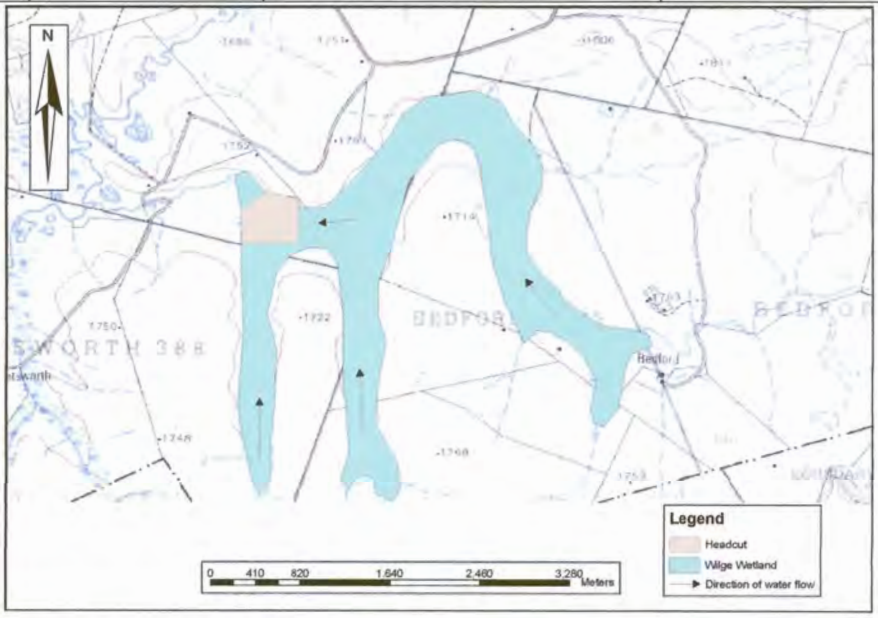


Figure 37: Topographical map (2829BA) showing the location of the rehabilitation structure.

Figure 38: Close up of the headcut rehabilitation structure.

Figure 39: Re-established wetland vegetation in the foreground.

3.1.2.4 Seekoeivlei Wetland:

i) General description of the wetland site.

The Seekoeivlei Wetland is divided in to two parts, namely: Southern Seekoeivlei in the Seekoeivlei Nature Reserve and the Northern Seekoeivlei. The Northern Seekoeivlei is the wetland area that stretches north from the Seekoeivlei Nature Reserve (Collins and Thompson, 1996). This study will focus on the Southern Seekoeivlei.

The Seekoeivlei wetland (Figure 40) is situated north of the town Memel in the Free State. The wetland in the Reserve covers approximately 3000 ha of the 12 000 ha of the Klip River flood plain that is one of the main contributors of water to Gauteng via the Vaal dam (Collins and Thompson, 1996). The Klip River is the main drainage line into which several smaller rivers and watercourses flow (Eckhardt *et al.*, 1993 a). The Reserve belongs to the Dept. Tourism, Environmental and Economic Affairs, Free State (Seekoeivlei Nature Reserve Brochure, 2002).

Figure 40: The Seekoeivlei wetland near Memel.

Aspects that make this wetland special are the fact that it is the largest wetland area on the escarpment and that it was declared under the Ramsar Convention as a wetland of international importance in March 1996 (Collins and Thompson, 1996). Furthermore it serves as an important water sponge for the Vaal River catchment area. The rainfall varies between 700 and 1000 mm per year with the maximum long-term average during December, January and February (Figure d in Appendix 2) (ARC-ISCW, 2002). Eckhardt *et al.* (1993 a) documented that the precipitation takes place, mostly in the form of thunderstorms, between November and March and that midsummer droughts occur towards the end of December until the middle of January.

This unique habitat is visited by scarce and endangered crane species. The last hippopotamus was hunted down here in 1894. In 1999 hippos were again introduced to the area (Seekoeivlei Nature Reserve Brochure, 2002).

Vegetation surveys done by Eckhardt *et al.* (1993 a) observed a decrease in species diversity if the species-richness of this community is compared with that of other vegetation types. The wetland community, *Eragrostis plana-Eragrostis curvula* grassland, occurs on wet, clay, eutrophic soils. The *Eragrostis plana-Agrostis lachnantha* plant community was described by Eckhardt *et al.* (1993 b) as a plant community associated with seasonal waterlogged soils or flooded areas. This major community is characterized by species in Table 9. Eckhardt *et al.* (1993 b) documented the silt and alluvium deposits along the banks and in some areas even peatlands can be found. The occurrence of peatlands in the environment gives the environment a high conservation status (Eckhardt *et al.*,1993 b).

Table 9: Diagnostic species of the *Eragrostis plana* – *Agrostis lachnantha* Wetlands (Eckhardt *et al.*, 1993 b).

Agrostis lachnantha	*Juncus inflexus*
Conyza bonariensis	*Trifolium africanum*
Pseudognaphalium oligandrum	*Persicaria attenuata*
Mariscus congestus	*Hermarthria altissima*
Phragmites australis	*Cyperus fastigiatus*
Verbena brasiliensis	*Cineraria lyrata*
Veronica anagallis-aquatica	*Leersia hexandra*

ii) Rehabilitation information.

The major impacts are the drainage channels, which were dug as agricultural methods to drain the wetland (Collins and Thompson, 1996). These alterations changed the hydrology of the wetland system. Today the Klip River flows through the western part of the wetland. Numerous horseshoe pans are evident on the eastern side of the wetland and indicate that the Klip River originally flowed on the eastern side of the wetland. The Survey general map Seekoeivlei no. 341 dated 1860 confirmed this fact. Ten years later (1870) the flow of the river was noted on the western side of the wetland.

The channels dug by the farmers (Figure 41) caused the Klip River to overflow its banks less frequently. This had a negative impact on the wetland system and wetland functions were lost (Collins and Thompson 1996).

Figure 41: Photo taken at Merel's vlei. This erosion channel forms the main flow of the Klip River.

iii) Rehabilitation objectives (Collins and Thompson, 1996).

1. Improve the natural wetland functions (e.g. flood attenuation).
2. Prevent the deviation of the Klip River.
3. Supply high quality water to the Gauteng region via the Vaal dam.
4. Employment opportunities for the local community and skills development.
5. Revegetate the uncovered riverbanks.
6. Control and stabilise the erosion dongas and headcuts.
7. Regulate surface erosion, grazing and the cutting of vegetation for fodder.
8. Prevent the increase of siltation in the wetland due to runoff from the surrounding catchment area by offsite mitigation measures, such as grazing control.
9. Improve the density and quality of the vegetation cover.

iv) Offsite actions required (Collins and Thompson, 1996).

1. Stakeholder involvement.
2. Create ecotourism.
3. Catchment management.

v) Monitoring & Maintenance (Collins and Thompson, 1996).

1. To monitor water purification, water samples will need to be taken at the major inflows of the wetland.
2. Plant communities change because of the changes in the hydrological regime of the wetland. Long-term fixed-point photography by the Dept. Tourism, Environmental and Economic Affairs, Free State are used for monitoring.
3. Follow-up visits to monitor the stability of the rehabilitation structures by the Implementing Agent.
4. Monitor bank erosion by measuring the rate of sedimentation and

the revegetation of wetland plant species.

5. Monitoring the ecological value (habitat for wetland dependent plant and animal species, enhancing the biodiversity of the region) through fixed-point photography, bird counts and vegetation surveys.
6. Monitoring the economical value (record products provided to the surrounding community and the amount of visitors to the Seekoeivlei Nature Reserve). This would only be possible when the rehabilitation of the wetland increases the biodiversity and the ecological integrity of the wetland is restored.

vi) Wetland Rehabilitation site details.

The rehabilitation done at the Southern Seekoeivlei Wetland implied the usage of eight channel plugs and two erosion prevention structures (Collins and Thompson, 1996). The photos of each rehabilitation structure were taken during the preliminary field visit (2 July 2002). Figure 42 describes the wetland rehabilitation site layout details and Table 10 gives a summary of the problems, rehabilitation actions taken and the desired results to attain after the rehabilitation.

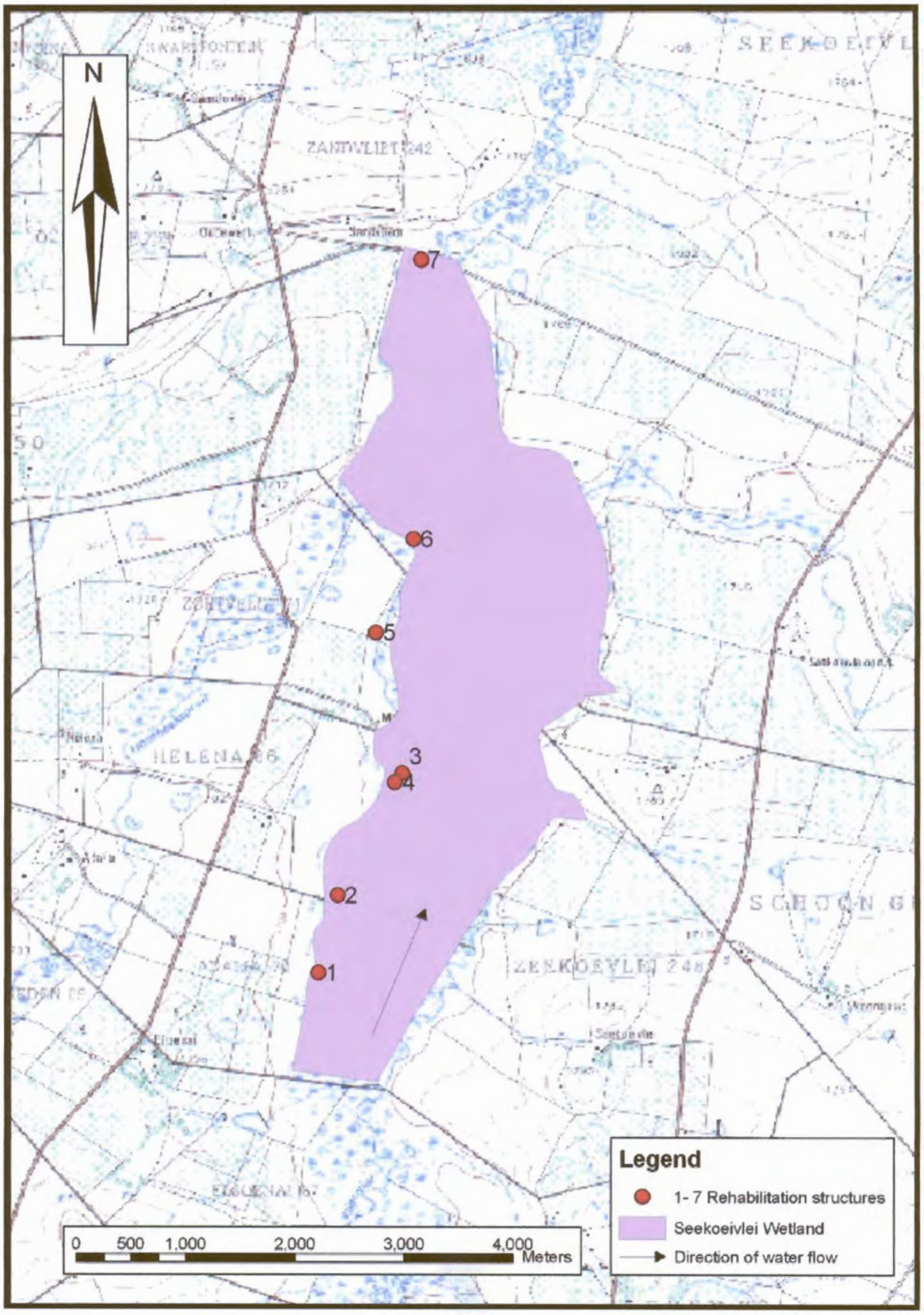


Figure 42: Topographical map (2729DA) showing the locations of the rehabilitation structures.

Table 10: Seekoeivlei Wetland: Summary of the problems, rehabilitation actions taken in 1996 and the desired results to attain after the rehabilitation (Collins and Thompson, 1996).

Site no.	Problems	Rehabilitation action	Desired results
1 29°34' 41" 27°35' 56"	Drainage channel eroding the wetland (Figure 43).	Concrete weir has been constructed (Figure 44).	• Structure must act as a silt trap. • Lift the water table • Dissipate the energy of the floods. • Prevent further erosion of the wetland.
2 29°34' 47" 27°35' 33"	Drainage channel eroding the wetland.	Concrete weir (Figure 45) has been constructed.	• Stabilise bank erosion (Figure 46). • Structure must act as a silt trap. • Lift the water table. • Dissipate the energy of the floods. • Prevent further erosion of the wetland.
3 29°35' 06" 27°34' 57"	Merel's vlei. River channel erosion and bank erosion.	Gabion structure constructed in 1997/8 (Figure 47). Measures to stabilise bank erosion.	• Stabilise bank erosion. • Structure must act as a silt trap. • Lift the water table. • Dissipate the energy of the floods. • Prevent further erosion of the wetland.
4 29°35' 04" 27°34' 59"	Merel's vlei. Channel erosion and bank erosion.	Concrete weir has been constructed and features below the water surface (Figure 48).	• Stabilise bank erosion. • Structure must act as a silt trap. • Lift the water table. • Dissipate the energy of the floods. • Prevent further erosion of the wetland.

Site no.	Problems	Rehabilitation action	Desired results
5 29° 34' 58" 27° 34' 15"	River channel erosion and bank erosion.	Gabion structure (Figure 49).	• Stabilise bank erosion. • Structure must act as a silt trap. • Lift the water table. • Dissipate the energy of the floods. • Prevent further erosion of the wetland.
6 29° 35' 10" 27° 33' 48"	River channel erosion and bank erosion.	Lift the existing structure higher and close it up with plugs (Figure 50).	• Stabilise bank erosion. • Structure must act as a silt trap. • Lift the water table. • Dissipate the energy of the floods. • Prevent further erosion of the wetland.
7 29° 35' 12" 27° 32' 25"	Northern border of the Seekoeivlei Nature Reserve. River channel erosion and bank erosion.	Gabion structure in the flow of the Klip River (Figure 51).	• Stabilise bank erosion. • Structure must act as a silt trap. • Lift the water table. • Dissipate the energy of the floods. • Prevent further erosion of the wetland.

Figure 43: Site no. 1. Area north of the confluence of the drainage channel that stretches from east to west across the width of the floodplain.

Figure 44: Site no. 1. Concrete weir.

Figure 45: Site no. 2. Concrete weir.

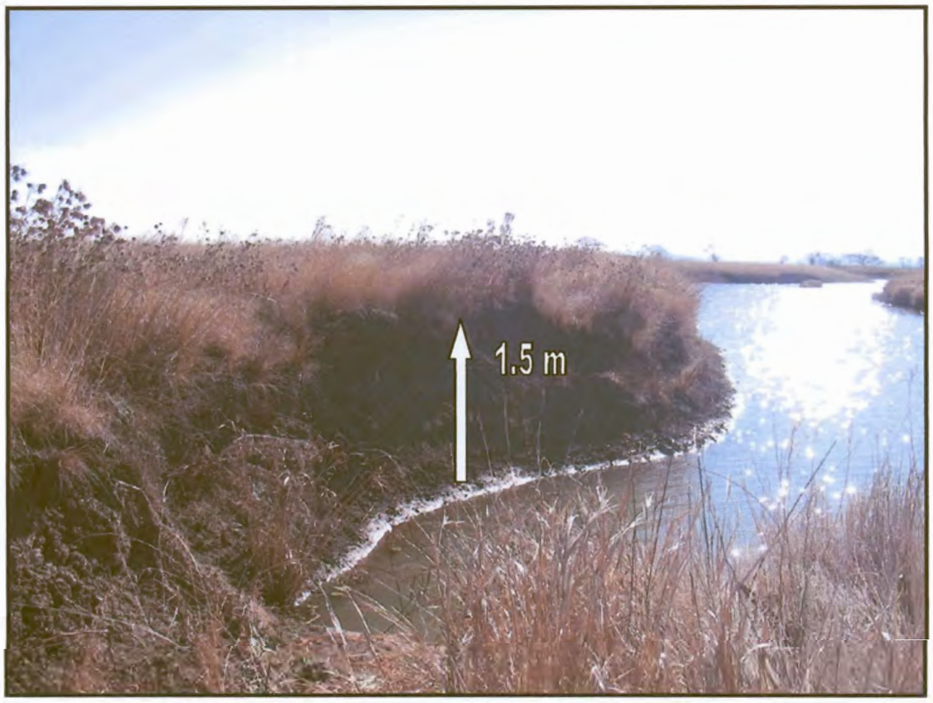


Figure 46: Site no. 2. Bank erosion.

Figure 47: Site no. 3. Merel's vlei. The gabion structure was Constructed in 1997/8. Measures were put in place to try and stabilise the bank erosion.

Figure 48: Site no. 4. Merel's vlei. A small weir drowned below the water surface.

Figure 49: Site no. 5. Gabion structure.

Figure 50: Site no. 6. The work involved lifting the existing structure higher, strengthening the structure and closing the drain holes (1997). Note that most of the plugs have been washed out.

Figure 51: Site no. 7. The Northern border of the Seekoeivlei Nature Reserve. A gabion structure was constructed in the flow of the Klip River to promote the flooding of the floodplain and to raise the water table.

3.1.2.5 Zoar Wetland:

i) General description of the wetland site.

The Zoar Wetland is situated in Eastern Mpumalanga in the upper part of the catchment of the Hlelo River. The wetland length is 3 600 m and the widest part is 600 m.

Mondi Forestry has been the landowner for the last 30 years (Figure 52). Private owners own the land up-and downstream of the wetland. The maximum rainfall for the area occurs during November, December and January (Figure e in Appendix 2) (ARC-ISCW, 2002).

Figure 52: The Zoar wetland in a Mondi Forestry area. Photo taken on 3 July 2002 after a veld fire.

ii) Rehabilitation information.

Rennies Wetland Project, now the Mondi Wetlands Project (MWP) started rehabilitation work at the Zoar wetland in September 2000. The rehabilitation took two years to complete. The Zoar wetland has been completely destroyed by the drainage of the wetland for agricultural purposes 60 years ago. The eight drains running parallel down the length of the wetland caused the desiccation of the wetland (Figures 53 & 54).

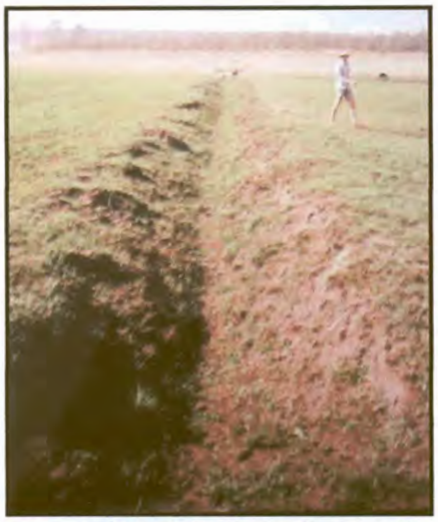


Figure 53: Drain in the wetland before rehabilitation (80 m long and 0.7 m deep). Photo taken from Mondi Wetlands Project report (2000).

Figure 54: Artificially straightened channel before rehabilitation. Photo taken from Mondi Wetlands Project report (2000).

Because the wetland remained unflooded for 60 years, terrestrial vegetation replaced the aquatic plants. The only indication of a once forgotten wetland was the sign of water flowing in the deep drains and some sedge species. *Pinus* and *Eucalyptus* plantations were planted in the wetland area. To determine the buffer distance from where plantations should begin, it was important to delineate the wetland. An initial study of the soils confirmed that the area had indeed once been part of a highly saturated system, probably wet throughout the year. The plantation trees in the wetland had to be removed for successful rehabilitation (Figure 55).

Figure 55: Photo of the Zoar wetland after the plantation trees were removed from the wetland (Photo: D. Lindley).

The channel erosion in the drains was 0.5 – 3 m deep and up to 4 m wide at some places. It was decided to construct a series of clay plugs every 20 – 50 m using the clay from the mound next to the drain to level the mound with the surrounding land and thereby diverting water into the wetland. Water runoff attempting to re-enter the gully / drain could cause problems of side-cutting. In order to overcome this, the plugs have been sited fairly close together in order to keep the water level in the gully / drain fairly high

(Haigh, 2002). The 0.5 m deep drains have plugs 0.5 m broad at the top and the 1 m deep drains must have 1 m broad at the top (Mondi Wetlands Project, 2000).

These clay plugs act like dam walls, lifting the water table, dissipating the water energy in rewetting the once dry wetland. On 6 January 2002 the Zoar wetland flooded for the first time in 60 years (Figure 56).

Figure 56: View of a flooded Zoar wetland. Note how the clay plugs act like dam walls (Photo: D. Lindley).

iii) Rehabilitation objectives.

1. Stabilise the channel erosion in the drains.
2. Structures must act as silt traps.
3. Flood retention and base flow.
4. Raising the water table.
5. Ground water recharge.
6. Removal of plantation trees in the buffer zone and wetland.
7. Conservation of wetland habitat and biodiversity.
8. Wetland awareness and training.
9. Regain wetland functions.

iv) Offsite actions required.

1. Stakeholder involvement.
2. Training and education in wetlands awareness.
3. Ongoing environmental monitoring.
4. Improve catchment management (control fires, over-grazing, draining wetlands and plantations in wetland areas).

v) Monitoring & Maintenance.

1. Follow-up monitoring and maintenance visits by the Implementing Agent to monitor the stability of the structures.
2. Re-establishment of wetland plant species. Changes in plant communities as a result of the change in the hydrological zones of the wetland (long-term fixed point photography).
3. Monitor wetland bird life ("The return of the birds is a sure sign of successful rehabilitation" – Duncan McKenzie, MWP field assistant in KwaZulu-Natal).

vi) Wetland Rehabilitation site details.

The photos of the rehabilitation structures were taken during the preliminary field visit (3 July 2002).

Figure 57 describes the wetland rehabilitation site layout details and Table 11 gives a summary of the problems, rehabilitation actions taken and the desired results to attain after the rehabilitation.

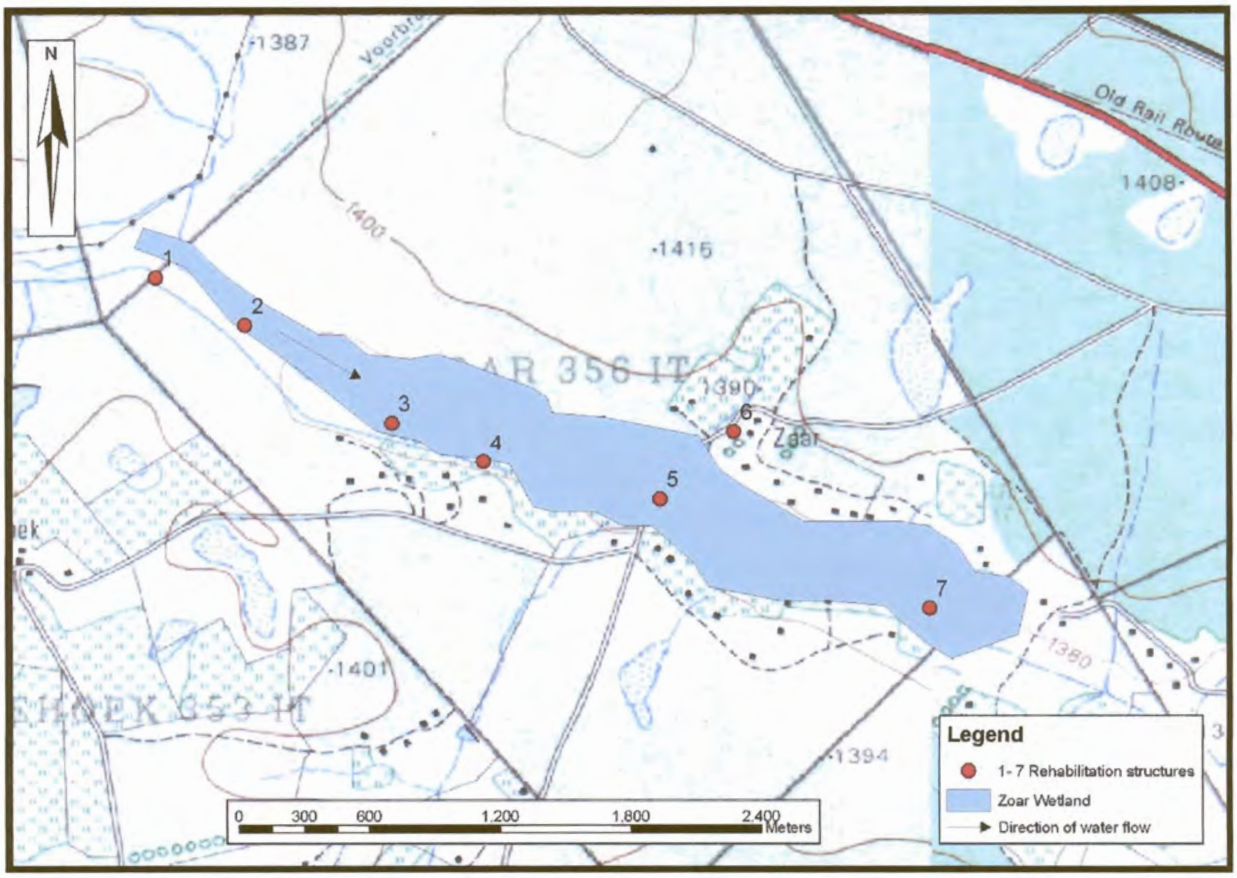


Figure 57: Topographical map (2630CD) showing the locations of the rehabilitation structures.

Table 11: Zoar Wetland: Summary of the problems, rehabilitation actions taken and the desired results to attain after the rehabilitation.

Site no.	Problems	Rehabilitation action	Desired results
1 S 30°28' 04.0" E 26°50' 34.0"	Zoar wetland North border. Eroded channel (Figure 58)	Built in clay plugs . The plugs must be keyed into the sides so that erosion cannot form around the plugs. Plugs must be well compacted.	• Dissipates the water energy. • Prevent channel erosion. • Spread the water and re-wet the wetland.

Site no.	Problems	Rehabilitation action	Desired results
2 S 30°28' 17.0" E 26°50' 41.0"	Main natural channel artificially straightened (Figure 59).	Channel must be emplaced	• Dissipate the energy of the floods. • Prevent channel erosion. • Spread the water and re-wet the wetland.
3 S 30°28' 39.0" E 26°50' 56.0"	Controlled service road cuts through the wetland and compacts the wetland soils resulting in the road acting as a dam wall hindering surface and subsurface flow (Figure 60).	Stop using the road.	• Dissipate the energy of the floods. • Prevent channel erosion. • Spread the water and re-wet the wetland.
4 S 30°28' 53.0" E 26°51' 02.0"	Drains (Figure 61).	Ideal time to burn is at the end of winter and the beginning of spring. Built in clay plugs. The plugs must be keyed into the sides so that erosion can't form around the plugs. Plugs must be well compacted.	• Spread the water and re-wet the wetland that will result in • Cool fires that are not so damaging to the organic matter/peat accumulating in a wetland. • Dissipate the energy of the floods. • Prevent channel erosion.
5 S 30°29' 19.0" E 26°51' 07.0"	Dirt road with culverts (Figure 62 & 63). Main drain with smaller drains along the side	Enlarge the culverts underneath the road to Facilitate the more evenly spread of water to the wetland down stream.	• Spread the water across the width of the wetland downstream. • Stabilise channel erosion.
6 S 30°29' 30.0" E 26°50' 57.0"	Drain inside a (1m wide, 1m deep) tributary feeding into the wetland (Figure 64). They use this tongue as a fire break between the plantations but burned it at the wrong time of the year	Ideal time to burn is at the end of winter and the beginning of spring. Built in clay plugs every 30m and 0.5m broad at the top. The plugs must be keyed into the sides so that erosion can't form around the plugs. Plugs must be well compacted.	• Spread the water and re-wet the wetland that will result in • Cool fires that are not so damaging to the organic matter/peat accumulating in a wetland. • Dissipate the energy of the floods. • Prevent channel erosion.
7 S 30°29' 59.0" E 26°51' 23.0"	Zoar wetland South border (Figure 65) of the Mondi fence. Headcut on private property erodes back into the wetland.		• Stabilise the headcut erosion • Dissipate the energy of the floods.

Figure 58: Site no 1: Clay plugs in a badly eroded channel at the northern border with private owners.

Figure 59: Site no 2: Main natural channel.

Figure 60: Site no 3: Service road controlled by Mondi Forestry.

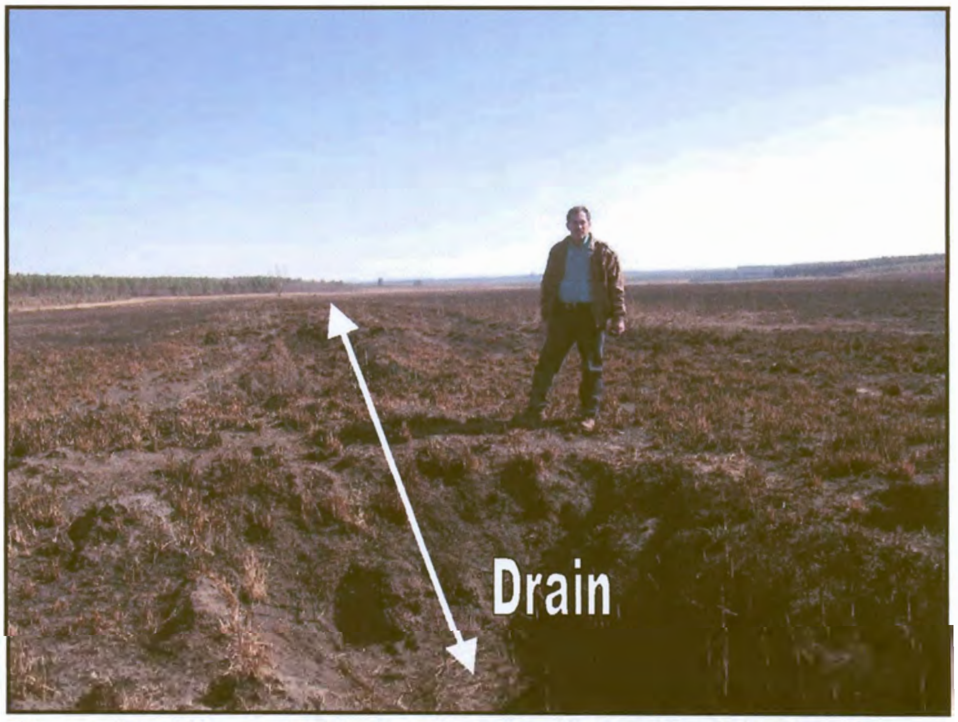


Figure 61: Site no 4: Drains draining the wetland lead to the desiccation of the wetland.

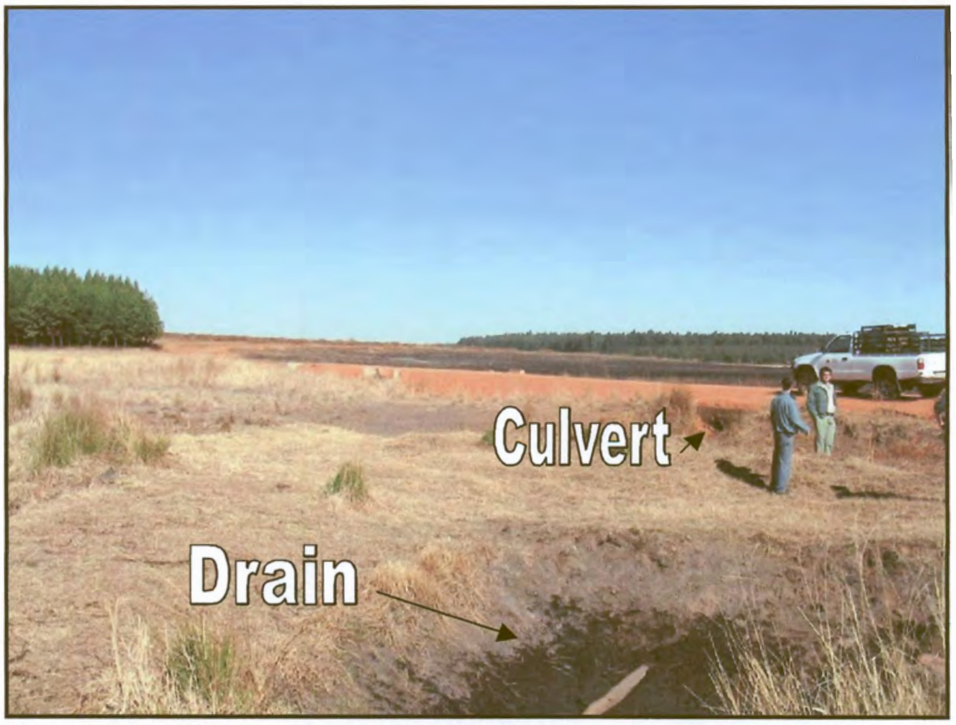


Figure 62: Site no. 5: Dirt road with culverts. The culverts concentrate the flow of the water and cause eroded channels.

Figure 63: Site no. 5: Main drain with smaller drains along the side. Clay plugs act like dam walls.

Figure 64: Site no 6: Note the drain in the burned tributary area that feeds into the wetland.

Figure 65: Site no 7: Zoar wetland southern border with private owners. Headcut erodes back into the wetland.

3.1.2.6 Rietvlei:

i) General description of the wetland site.

The Rietvlei Wetland Rehabilitation project lies within the 3800 ha Rietvlei Nature Reserve near Irene – owned and managed by the City Of Tshwane (Rietvlei Nature Reserve Brochure, 2002). The Rietvlei Dam provides 15% of Pretoria's water and the wetlands on the reserve are regarded as a rare asset (Rietvlei Nature Reserve Brochure, 2002).

The Rietvlei Wetland Complex falls within the Rocky Highveld Grassland zone of the Grassveld Biome, with an average summer rainfall between 600 - 750 mm per annum (Low & Rebelo, 1996). The maximum rainfall for the area occurs during November, December and January (Figure f in Appendix 2) (ARC-ISCW, 2002).

It is underlain by dolomite of the Malmani Subgroup, and it supports (or did historically) various dolomitic springs and with a terrain morphology consisting of undulating plains and pans (Grundling and Marneweck, 2000).

According to Grundling and Marneweck (2000), the peatland complex comprises three distinct sections: the southern and northern peatland basins linked by a central floodplain wetland. Both peatlands can be described as tall emergent (reed-sedge), valley-bottom fens and are located in the catchment of the Sesmyl Spruit.

The Rietvlei peatland complex was dated at 1 290 BP at a depth of 0.23 m and 7 130 BP at a depth of 1.3 m, indicating a peat accumulation rate of about 0.18 mm/year (Scott and Vogel, 1983). The peat can be described as a reed-sedge peat, fibrous to fine grained in texture and with an average pH of 4.5 (ranging from pH 3.5 to pH 8) (Grundling and Marneweck, 2000).

The Rietvlei Dam is located just downstream of the northern portion of the wetland complex and was built during the Great Depression and completed in 1934 (Rietvlei Nature Reserve Brochure, 2002). A smaller dam (the Marais Dam) is located in the central portions and serves as a sludge dam for the Rietvlei dam (Rietvlei Nature Reserve Brochure, 2002). Many smaller seeps and mixed grass / sedge meadows occur in the nature reserve and they feed into the Rietvlei Peatland Complex (Grundling and Marneweck, 2000).

ii) Rehabilitation information.

Grundling (2002) explained the important reasons for rehabilitating the Rietvlei Wetland:

- promotes wastewater purification through the natural systems of reeds and peat;
- addresses the control of alien, invasive plant species;
- protects vital habitats associated with the globally important grasslands biome;
- exemplifies innovation in combating land degradation;
- stems the emission of carbon stored in the peat substrate; and
- creates wetland awareness and education.

This study will only focus on the southern peatland section where the rehabilitation structures have been constructed.

The southern peatland is impacted by:

- infrastructure,
- agriculture,
- sewage outfall,
- peat mining
- water abstraction activities,
- service roads
- power lines
- pipelines

Grundling and Marneweck (2000) documented that *Phragmites australis* and *Carex cernua* are the dominant vegetation species on the southern peatland, and reflect the permanent wet conditions of the peatland. Furthermore they explained that mixed grass / sedge meadows occur on the edges of the peatland and on some of the abandoned peat working surfaces and indicate seasonal to semi-permanent wet conditions (Figure 66).

The grass / sedge meadows on some of the abandoned peat working surfaces suggest that the current vegetation and the distribution thereof may not be a reflection of the historic and natural hydrological regime of the wetland but rather of a system altered and degraded by anthropogenic impacts, especially draining and peat mining, the sewage water outfall and causeways across the peatland (Grundling and Marneweck, 2000). According to a study done by Venter *et al.* (2003), a specific pioneer community dominated by *Persicaria* species established on the rehabilitated ditches and *Cyperus* dominated communities occurred on areas that were mined extensively. These mined areas have not been rehabilitated and no *Phragmites* species occur on them. *Phragmites australis* reed communities, with *Phytolacca octandra*, were prominent on the least disturbed sites (Venter *et al.*, 2003).

Figure 66: The Rietvlei wetland. Previous peat mining activities can be seen in the foreground of the wetland.

Grundling and Marneweck (2000) stated that this wetland was severely degraded by peat mining activities. They furthermore explain the desiccation of the central and southern sector of the peatland as a result of the peat mining and extensive draining of the wetland by a system of drains. The drains, stream diversion and flow concentration have resulted in extensive erosion in the central and downstream section of this peatland (Figure 67) (Grundling and Marneweck, 2000).

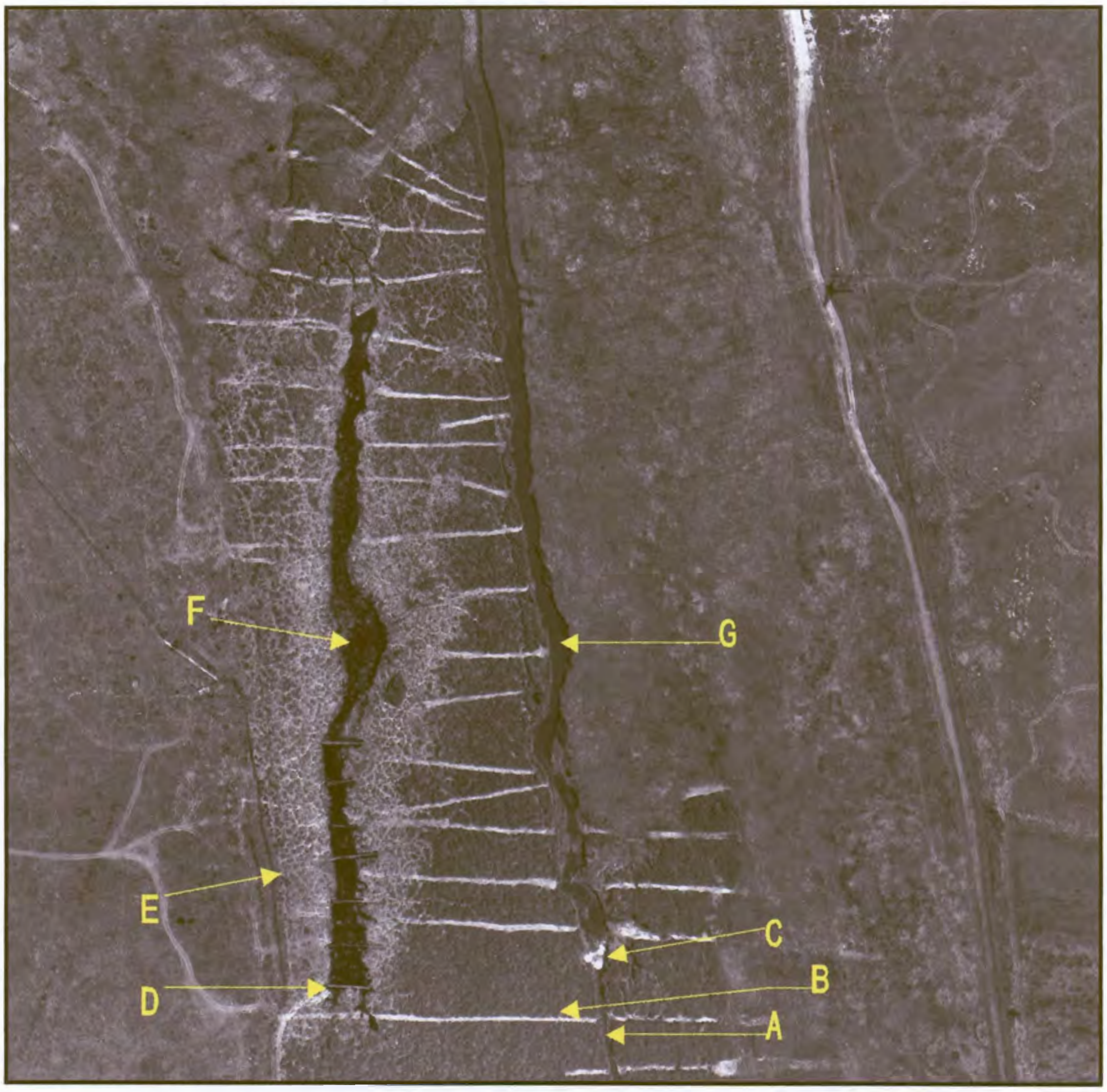


Figure 67: Aerial photograph (2000) indicating remnants of a drain (A) responsible for the desiccation of the wetland. Transects (B) were cut through the Phragmites to be able to delineate the wetland before rehabilitation could commence. Note the headcuts (C) & (D), irrigation furrow (E), shallow erosion feature (F) and donga (G).

The main areas of concern for rehabilitation were summmarised by Grundling and Marneweck (2000) as:

- abandoned peat mining activities;
- water abstraction activities;
- dry peat and peat fires;
- drains and dams associated with the peat excavations;
- drains and irrigation furrows associated with agriculture;
- causeways and erosion associated with the peat excavation and service roads;
- the main stream diversion just upstream of the Rietvlei dam;
- sewage outfall, both quality and quantity; and
- exotic invasive plant species.

iii) Rehabilitation objectives (Grundling and Marneweck, 2000).

1. Restore the original geometry and topography (cross-sectional and longitudinal profile) of the peatlands and the floodplain.
2 Re-vegetation to increase roughness, which has a strong effect on water movement through the system. Using either specified seed mix where appropriate and/or vegetation removed from other stable sites within the wetland.
3. Arrest headcut and donga erosion within the complex and control the preferential flow of water.
4. Re-wetting of desiccated (dry) peatland areas.
5. Sloping of steep slopes and edges of old peat mining work faces and stream channels.
6. Backfilling with wetland soil of drains and trenches in places.
7. Where necessary, regularly spaced culverts (or pillars) should be placed along the roads and causeways in order to limit channeling of water along the roads, backing up of water behind the roads and

desiccation of the peat below the roads.

8. Runoff should rather be controlled and propagation of dormant bulbous species encouraged.
9. 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.

iv) Offsite actions required (Grundling and Marneweck, 2000).

1. Impacts also need to be studied on a catchment level.
2. Removal of exotic invasive plant species.

v) Monitoring & Maintenance (Grundling and Marneweck, 2000).

1. The rehabilitation measures which are prescribed should be audited during rehabilitation, and monitored for a period thereafter, until full rehabilitation is assured and stability demonstrated.
2. Monitoring should also include the monitoring of changes in the catchment and the potential impact thereof on the Rietvlei Peatland Complex.

Figure 68: The area between site no. 4 and site no. 5.

vi) Wetland Rehabilitation site details.

Grundling and Marneweck (2000) came to the conclusion that the desiccation in both the southern and northern portion of the peatland complex combined with the concentration of stream flow by causeways, channeling for agricultural purposes and an increased stream volume from the sewage outfall, resulted in erosion and the incising of the stream channels in the wetland. They furthermore mentioned that the erosion problem has been enhanced by the removal of topsoil and vegetation on the slopes of the valley for pot soil mixes. Currently, the higher flow rates as a result of the release of large volumes of sewage water worsen the erosion problem (Grundling and Marneweck, 2000).

Power lines, fences and grazing have had a minor impact on the wetland. However, the large areas of *Populus sp.*, *Eucalyptus sp.* and *Acacia mearnsii* trees contribute to the further degradation of the wetland (Grundling and Marneweck, 2000).

Headcut erosion began as a result of an unattended drainage furrow that was used to drain the peat during the peat mining operation. A causeway was constructed to access the peat mining operation. This compounded the erosion in the furrow by concentrating the water flowing through it.

Figures 69 & 70 describe the wetland rehabilitation site layout details and Table 12 gives a summary of the problems, rehabilitation actions taken and the desired results to attain after the rehabilitation. The photos of each rehabilitation structure (Figure 71 – 85) were taken during the preliminary field visit (26 January 2003).

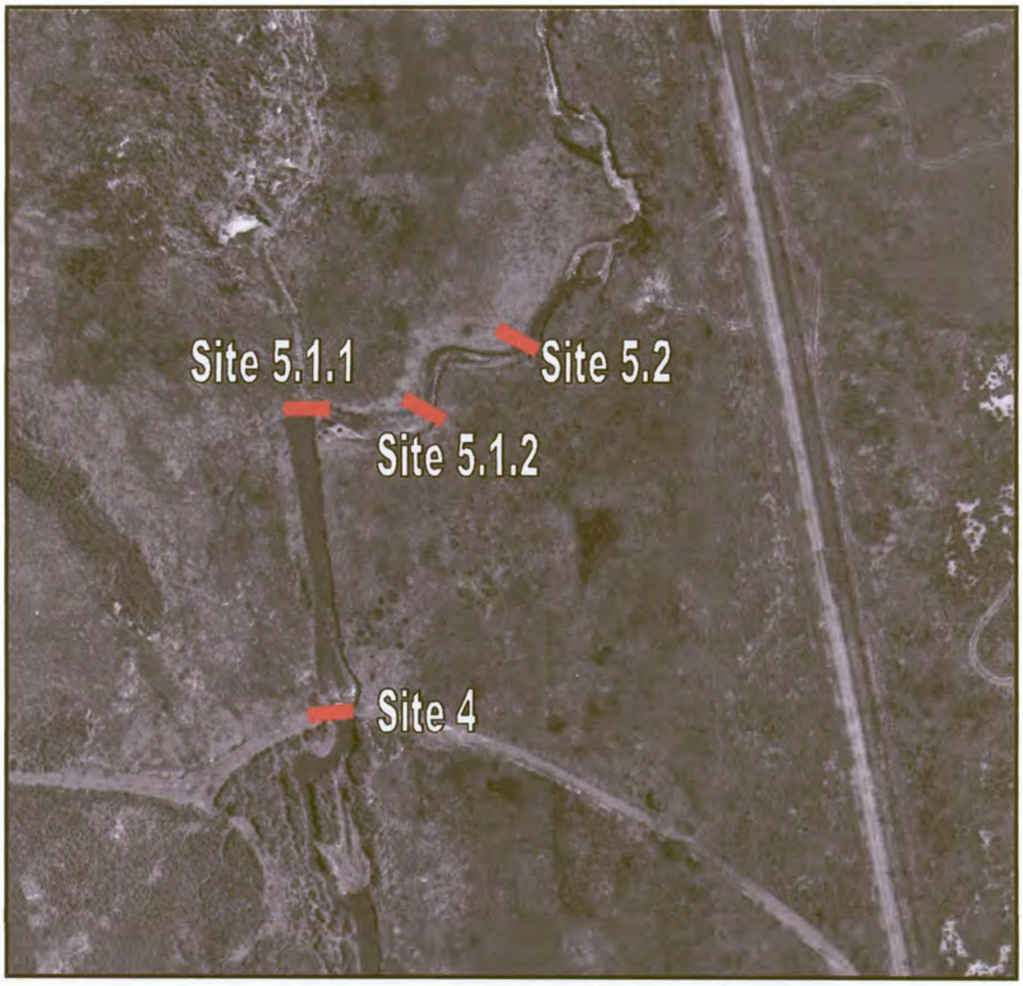


Figure 69: Aerial photograph (2000) indicates the area before rehabilitation was done at sites no. 4 – 5.2.

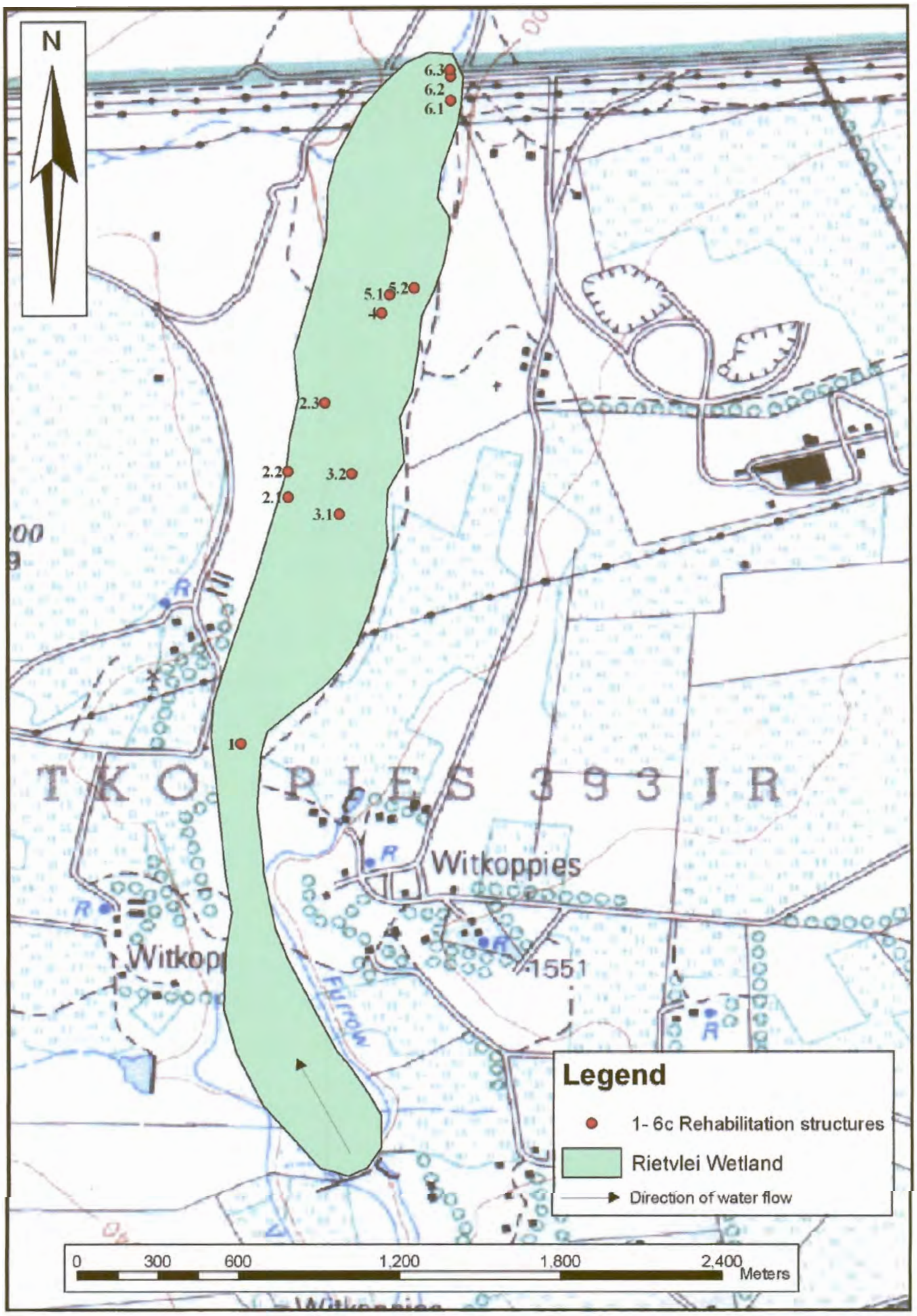


Figure 70: Topographical map (2528CD) showing the locations of the rehabilitation structures.

Figure 71: Site no. 1. A man-made drift was built across the entry point into the Rietvlei Nature Reserve. Due to this the flow of water has been concentrated.

Figure 72: Site no. 1. Energy dissipaters were constructed along the drift to spread the flow and dissipate the energy.

Figure 73: At site no. 2.1 the shallow erosion gully was stabilized with grass bales.

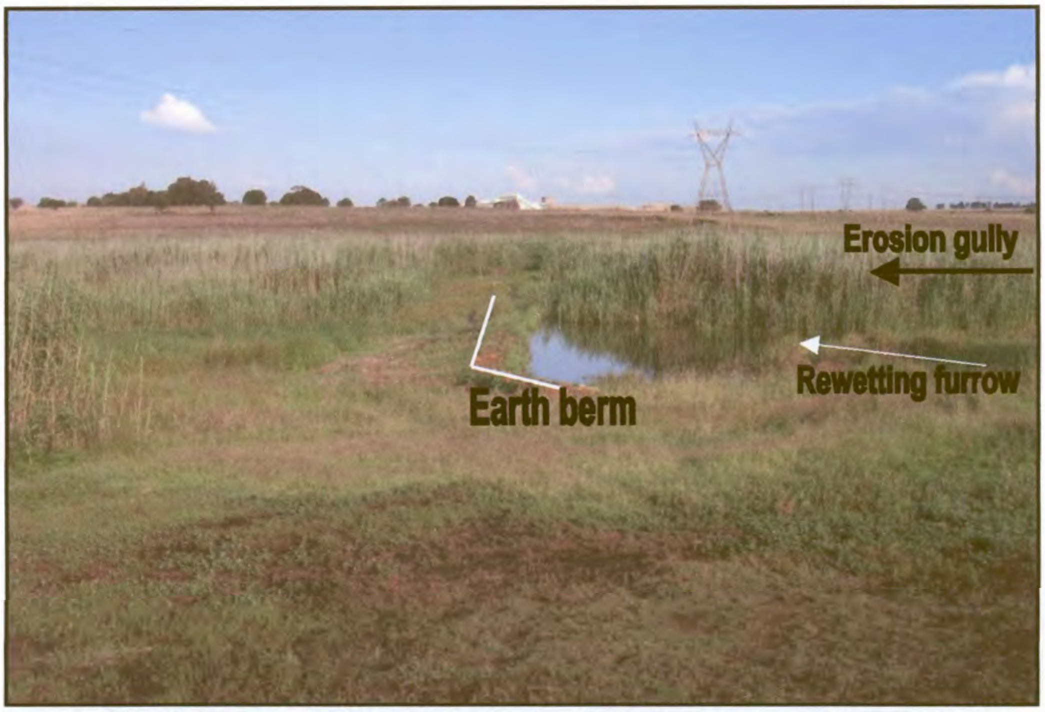


Figure 74: Site no. 2.3. Water damming behind the earth berm at the bottom end of a shallow erosion gully. Re-vegetation of desiccated areas is taking place down-and upstream of the structure.

Figure 75: Headcut and donga (incised drainage channel) at site no. 3.1. The donga sides need to be sloped and re-vegetated.

Figure 76: Site no. 4. Eroded culverts on the road crossing were replaced by a concrete weir.

Figure 77: Site no. 4. A bypass furrow used during the construction of a concrete weir in the causeway was blocked to prevent channel erosion.

Figure 78: Site no. 4. A causeway was applied as a structure to disperse water and to raise the water level in the wetland. Downstream of the structure the erosion was stabilised by using rock packs.

Figure 79: Site no. 5.1. A bypass furrow has been constructed to allow the construction of a gabion weir to facilitate the raising of the water table and to disperse the water.

Figure 80: Construction of a gabion in progress at site. no. 5.1.1. Flooding is taking place.

Figure 81: Site no. 5.1.2. Sedimentation taking place behind the structure.

Figure 82: Gabion structure at site no. 5.2. Note the difference in the water table upstream and downstream of the structure.

Figure 83: Site no. 6.1. Note the higher water table behind the structure. The bent grass on the bank of the channel indicates a previous flooding event.

Figure 84: A drowned gabion structure between sites no. 6.1 and 6.2 due to an increase in back flooding from the structure at site no. 6.3.

Figure 85: Site no. 6.3. The bypass furrow must be closed and the energy must be dissipated to prevent the concentration of water resulting in channel erosion.

3.1.3 Identification of suitable indicators.

3.1.3.1 Kromme River Wetland

1. Decrease of sedimentation downstream of structure.
2. Stabilization of riverbank / donga erosion.
3. Stabilization of headcut erosion.
4. No further infestation of alien vegetation.
5. Recovery of wetland plants on riverbanks / donga.
6. Restore part of the wetland that has eroded away.
7. Higher water table.
8. Monitor the headward movement of the headcut at Kompanjesdrif.

3.1.3.2 Mbongolwane Wetland.

1. Stabilization of erosion.
2. Restoration of wetland vegetation.
3. Wetland vegetation zones.
4. Open water damming and sedimentation behind structures – rewetting of the wetland area.
5. Increasing or decreasing of cultivated areas in the wetland. Determine if cultivation takes place in sensitive areas in the wetland.

3.1.3.3 Wilge River Wetland.

1. Stabilization of the erosion in the wetland.
2. Recovery of wetland vegetation.
3. Wetland vegetation zones.
4. Rewetting of the area behind the structure.

3.1.3.4 Seekoeivlei Wetland (Collins and Thompson, 1996).

1. Monitor the wetland vegetation changes north of the drainage channel as a result of the changes in the hydrological regime of the wetland.
2. Structures must act as silt traps.
3. Stabilization of erosion in the wetland.
4. Open water behind the structure.

3.1.3.5 Zoar Wetland.

1. Re-establishment of wetland plant species. Changes in plant communities as a result of the change in the hydrological zones of the wetland.
2. Stabilisation of the channel erosion in the wetland.
3. No plantation trees in the wetland area and buffer zone.
4. Rewetting of the wetland.
5. Water behind the structures.
6. Sediment behind the structures.

3.1.3.6 Rietvlei Wetland (Grundling and Marneweck, 2000).

1. Re-establishment of wetland plant species. Changes in plant communities as a result of the change in the hydrological zones of the wetland. Figure 67 indicates the area between site no. 4 and site no. 5. Terrestrial plant species have invaded the area. If the structures act successfully as energy dissipaters and re-wet the peat and wetland, then these terrestrial species will disappear and wetland vegetation will dominate.
2. Re-wetting of the wetland.
3. Sedimentation behind the structure.
4. Open water damming behind the structure.
5. Stabilisation of the channel erosion in the wetland.

3.1.4 Remote sensing sensor selection.

In order to evaluate the different remote sensing sensors, a decision was taken that, where possible, at least two different sensor's imagery per wetland will be compared. The issues related to the mapping of the biophysical conditions and utilisation of a wetland are the optimum time of year, the bands required and the spatial resolution to produce accurate maps versus the cost of data and time to process the data. By comparing two different sensor's imagery on the same wetland, the research objective 1.3.3 could be fulfilled.

The Digital Multi-Spectral Video (DMSV) was to be used as one of the two airborne sensors to be evaluated (Appendix 4). However, due to unforeseen circumstances the DuncanTech CIR sensor was used instead.

Landsat images for each wetland were made available for the purpose of this project by the Department of Agriculture. They will be used in the recommendations regarding the most cost-effective procedure for the auditing and monitoring of rehabilitated wetlands. To prevent unnecessary duplication of image collection in an area, Mr. Mark Thompson from Geospace was willing to check their database to see if images were available for the different wetlands. Unfortunately, no images could be used.

3.1.4.1 Kromme River Wetland:

The wetland is a long linear feature in the Eastern Cape. SPOT 5 satellite imagery and Kodak DCS 420 (Near-infrared) are the two sensors to be compared on the same wetland. The Kodak DCS 420 (Near-infrared) sensor is operated by Dr. Tony Palmer, ARC – Range and Forage Institute – Grahamstown (Eastern Cape). The decision to use the Kodak DC 420 (Near-infrared) camera was made to be cost-effective for the project budget as well as to compare single band (Near-infrared) with other conventional multi-colour images.

3.1.4.2 Mbongolwane Wetland:

At Mbongolwane it will be necessary to look at the wetland vegetation, cultivated areas and the two rehabilitation structures. For this wetland it was decided to use Duncan Tech CIR and EROS.

3.1.4.3 Wilge River Wetland:

The main reason for choosing Duncan Tech CIR is because this wetland has only one rehabilitation structure and is otherwise in a generally good condition. The area immediately adjacent to the structure is susceptible to change and therefore it is not necessary to photograph the rest of the wetland.

3.1.4.4 Seekoeivlei Wetland:

The Seekoeivlei wetland in the Seekoeivlei Nature Reserve covers approximately 3 000 ha of the 12 000 ha Klip River flood plain. For this large wetland it was therefore decided to use the EROS imagery to look at the entire wetland system on the Seekoeivlei Nature Reserve.

3.1.4.5 Zoar Wetland:

The Zoar wetland length is 3 600 m and the widest part is 600 m. In order to observe the wetland vegetation it was decided to use the DuncanTech CIR for the entire wetland system.

3.1.4.6 Rietvlei Wetland:

The Rietvlei wetland on the Rietvlei Nature Reserve is regarded as a rare asset in Pretoria (Gauteng). Due to the fact that this wetland was not part of the project in the beginning and because of budget constraints it was decided to make use of an opportunity to piggy-back this project to a flight planned adjacent to this area. The DuncanTech CIR was also used for the Rietvlei wetland.

3.1.5 Identification of optimal time frame for data acquisition.

After some discussions with various wetland and remote sensing experts (Mr. Dirk Pretorius, Mrs. Eliria H. Haigh, Dr. Donovan Kotze, Mr. Mark Thompson, Mr. David Lindley, Mrs. René Glen, Mrs. Lesley Gibson and Mr. Nacelle Collins) concerning the ideal time for image collection it was concluded that there is no fixed date for any wetland. Vegetation peak growth phase in permanent and seasonal swamps is related to the rainy season (Gumbricht *et al.*, 2000). This is typically at the beginning of the wet season as this is just after the onset of rain and the wetlands are the first to become inundated with water and thus experience vigorous vegetation growth compared with the surrounding vegetation (Thompson *et al.*, 2002). Dely *et al.* (1999) and Gibson (2003) re-emphasise this consideration. On the other hand, Whitlow (1984) carried out aerial photography in the dry seasons when tonal differences between dambos (meadow grazing land) and the surrounding areas are enhanced. Van der Linde (1995) acquired Landsat TM satellite imagery during the dry season to establish the locality of peatlands which, if undisturbed, will be wet throughout the year.

Satellite imagery should therefore be acquired at the time of year where there is significant difference between wetlands and the surrounding non-wetland vegetation. The long-term average rainfall data (ARC-ISCW, 2002) (Appendix 2) for each study area suggests the following window of opportunity for each wetland (Table 13):

Table 13: "Window of opportunity" for image acquisition.

Wetland	Sensors	Time frame
Kromme River (Eastern Cape -Kareedouw)	Kodak DCS 420 (Near Infrared) SPOT 5	October – November
Mbongolwane (KwaZulu Natal – Eshowe)	DuncanTech CIR EROS	December – February
Seekoeivlei (Free State – Memel)	EROS LANDSAT	December – February
Wilge River (Free State - Harrismith)	DuncanTech CIR	December – February
Zoar (Mpumalanga – Piet Retief)	DuncanTech CIR	December – February
Rietvlei (Gauteng – Pretoria)	DuncanTech CIR	December – February

3.1.6 Image processing.

3.1.6.1 Classification and identification of indicator classes.

All the remote sensing images were geo-referenced to an ortho-rectified image data set with ground accuracy 15 – 45 m. An unsupervised Isodata classification with 20 classes was done for all imagery. Isodata is an interactive classification method. It repeatedly performs an entire classification, outputting a thematic raster layer and recalculating the statistics. The isodata method uses minimum distance to assign a cluster for each candidate pixel. A second classification was done using the first classification to subset the images. This was done where classes with similar spectral values could not be split from other classes. Subsets of some images were made using a buffer around the wetland to eliminate all the irrelevant data from the images. It was difficult to distinguish between grassland and wetland vegetation in study areas where the image acquisition date was not optimum for mapping the wetland vegetation. Classifications using band reflectance gave better results than band ratio classifications.

A very generalized land cover classification was done for all six study areas. Taking the proposed indicators into account (Table 3), the classification was recorded into seven classes by using image interpretation, namely:

- Erosion / bare soil / harvesting wetland vegetation,
- Sedimentation,
- Open water,
- Wetland vegetation,
- Terrestrial vegetation / burn scars,
- Alien vegetation and
- Cultivation.

Three disturbance indicators were applicable to the six wetland sites namely: *harvesting wetland vegetation*, *cultivation* and *burn scars.* Indicators that have not been used in the classification scheme were: *wet surface area* and *water quality.*

It was evident through the baseline data of each site and the preliminary field visit at each site that neither one of the six wetlands in the study suffered from water contamination, although the occurrences of minor water pollution incidences (such as at Rietvlei) were not ruled out. There has been no record of change in water colour at any one of the six wetlands which made these study sites unsuitable for the testing of water quality. Furthermore the open water areas were too small and shallow and the remote sensing images did not possess a blue band necessary to detect water quality. It was therefore decided not to use this indicator in the classification scheme.

Wetland vegetation reflects the hydrological conditions of the wetland (wet surface area). The reasoning behind this is the fact that the plant species composition changes as a result of the change in the wetland's hydrological regime. Depending on the resolution, wetland plant species and / or groups of plants known as wetland plant communities can be identified. Gumbricht *et al* (2000), documented a pronounced NDVI difference between permanent and seasonally swamps and the vegetation cycle is mainly related to the flow regime of the Okavango River. The wetland vegetation indicator will therefore reflect the wet surface area.

The position of the rehabilitation structures was recorded using a handheld GPS and does not form part of the classification.

3.1.6.2 Description of classes.

i) Erosion / bare soil.

This class included all forms of erosion and bare soil. In some instances unvegetated construction sites and areas of wetland vegetation harvesting were included in this class.

ii) Sedimentation.

This class included sediment deposits in the wetland and behind rehabilitation structures.

iii) Open water.

This class included all rivers, streams and open water areas. It would also include water behind rehabilitation structures.

iv) Wetland vegetation.

This class included the whole range of wetland vegetation, from permanent, seasonal and temporary wetland zones. The image acquisition date was not always spectrally significant in order to distinguish between wetland vegetation and the re-growth of alien vegetation or sugar cane farming.

v) **Terrestrial vegetation / burn scars.**

This class included all forms of natural vegetation including areas that were burned.

vi) **Alien vegetation.**

All forms of alien vegetation are included into this class (including planted plantations, wind breaks and re-growth of removed alien plants in rivers).

vii) **Cultivation**

This class included all commercial and subsistence farming activities. It also included old farmlands and orchards.

3.1.7 Calculation of the efficiency.

3.1.7.1 Field data collection.

The main aim of the preliminary fieldwork (1-10 July 2003) was to establish where the rehabilitation structures were, what problems were encountered and what the desired results of the structure should be. Classification of the different vegetation types at each wetland was made difficult because the preliminary field data were only collected at the rehabilitation structures and not for detailed vegetation mapping. For this reason only one broad vegetation zone could be mapped, namely: wetland vegetation. Rietvlei was the only wetland where detailed vegetation surveys have been done in the wetland zones (Venter *et al.*, 2003).

Field data collection was done before images were acquired and thus not synchronized with the acquisition of the images due to the time constraints brought about by the acquisition date of the DuncanTec CIR imagery.

3.1.7.2 Cost estimation of all evaluated sensors.

Different remote sensor images with different resolutions were used for each wetland. The cost estimation included the total area (ha) of image cover (Appendix 6), the total study or wetland area (ha) covered by the image and the total area (ha) around the rehabilitated structures covered by imagery (Table 14). A cost estimation for all evaluated sensors is presented in Table 15.

Table 14: Remote sensor imagery covering the rehabilitated area around the structures.

Wetland	Rehabilitation structure sites	Remote sensor imagery covering rehabilitated area (ha) around the structures
Kromme River	Site 1 Site 2 Site 3 Site 4 Site 5	3.8 ha 3.3 ha 1.9 ha 17.0 ha 11.8 ha **37.8 ha**
Mbongolwane	Uvova Amatigulu	11.5 ha 29.0 ha **40.5 ha**
Wilge River	Headcut	**7.7 ha**
Seekoeivlei	Site 1 Site 2 Site 3 & 4 Site 5 Site 6 Site 7	3.7 ha 2.5 ha 8.0 ha 7.3 ha 4.9 ha 9.6 ha **36 ha**
Zoar	There were no exceptional sites. The whole wetland area was measured (**135 ha**).	
Rietvlei	Site 1 Site 2-5 Site 6	8.1 ha 57.3 ha 9.4 ha **74.8 ha**
The total area (ha) around the rehabilitated structures covered by imagery: Each area (ha) covering the rehabilitation structures as well as the rehabilitated area down-and upstream of the rehabilitation structure was measured and a total area for each wetland determined.		

Table 15: Cost estimation for evaluated sensors.

Wetland	Sensor	Resolution	Total Cost				Price covering: (R/ha)		
				Total area covered by the imagery	Total wetland area covered by imagery (ha)	Total area around the rehabilitated structures covered by imagery (ha)	Total area covered by the imagery	Total wetland area covered by imagery	Total area around the rehabilitated structures covered by imagery (ha)
Kromme River	SPOT 5 Kodak DCS 420	10m 1.0m	R30 400.00 R22 000.00	379 200 ha 2 010 ha	3 70.7 ha	37.8 ha	R0.080/ha R10.94/ha	R82.00/ha R59.34/ha	R804.23/ha R582.00/ha
Mbongolwane	EROS DuncanTech CIR	1.8m 0.25m	R12 600.00 R10 400.00	19 128 ha 1 578.0 ha	349 ha	40.5 ha	R0.65/ha R6.60/ha	R36.10/ha R256.79/ha	R311.00/ha R256.79/ha
Wilge River	DuncanTech CIR	0.5m	R5 875.00	1 602 ha	7.7 ha	7.7 ha	R3.66/ha	R762.98/ha	R762.98/ha
Seekoeivlei	Landsat EROS	30m 1.8m	R6 000.00 R12 600.00	3.4 milj ha 17 325 ha	976.3 ha	36 ha	R0.001/ha R0.73/ha	R6.15/ha R12.90/ha	R166.00/ha R350.00/ha
Zoar	DuncanTech CIR	0.25m	R7 400.00	708 ha	135.1 ha	135.1 ha	R10.45/ha	R54.77/ha	R54.77/ha
Rietvlei	DuncanTech CIR	0.5m	R9 975.00	1 706 ha	130.7 ha	74.8 ha	R5.84/ha	R76.31/ha	R133.35/ha

Total Cost excludes positioning fee & data processing.

Total wetland area covered by imagery (ha): Wetland delineation was done on 1:50 000 topographical maps to determine the total wetland area. The wetland area covered by the remote sensor imagery was digitally measured in ha.

The total area (ha) around the rehabilitated structures covered by imagery: Each area (ha) covering the rehabilitation structures as well as the rehabilitated area down - and upstream of the rehabilitation structure was measured (Table 14) and a total area for each wetland determined.

In determining the total wetland area (in ha) that had to be covered by imagery the following steps were taken:

- Wetland delineation was done on 1:50 000 topographical maps to determine the total wetland study area.
- The wetland study area covered by the remote sensor imagery was measured in ha.

The total area (in ha) around the rehabilitated structures covered by imagery, was determined in the following way:

- Each area (in ha) covering the rehabilitation structures as well as the portions down - and upstream of the rehabilitation structure was measured (Table 14) and a total area for each wetland determined.

DuncanTech CIR was used on four out of the six wetlands. The fact that all four wetlands could be covered in one flight made the total cost of the DuncanTech CIR sensor for each of the four wetlands much lower than the cost of flying one wetland at a time. This, however, made it difficult to select a suitable flight time that would insure cloudless conditions over all four of the wetlands. This approach influences the correct time for data acquisition for specific wetlands that differ from the rest.

3.1.7.3 Remote Sensor Data.

Table 16 lists the suggested window of opportunity for each wetland as well as the actual date that image acquisition was done for each wetland.

Table 16: Image acquisition dates.

WETLAND	SENSOR	WINDOW OF OPPORTUNITY	DATE
Kromme River	SPOT 5 Kodak DCS 420 (near infrared)	October – mid November.	10 February 2003 22 January 2003
Mbongolwane	EROS DuncanTech CIR Landsat	December	24 December 2002 09 June 2003

WETLAND	SENSOR	WINDOW OF OPPORTUNITY	DATE
Wilge River	DuncanTech CIR	January - February	08 April 2003 09 June 2003
Seekoeivlei	EROS Landsat	January - February	20 December 2002
Zoar	DuncanTech CIR	December, January and February	09 June 2003
Rietvlei	DuncanTech CIR	December, January and February	09 June 2003

3.1.8 Validation of data.

3.1.8.1 Field assessment.

The fieldwork assessment information acquired from the various wetland rehabilitation implementing agents was used, together with the results from the remote sensor images, to identify the function of the rehabilitation structures. The effect of the rehabilitation measures on the ability of the wetland to perform the various hydrological functions was identified as well. Photos taken during the fieldwork visits together with subsets of the various remote sensors images are discussed in Phase 5, section 11.2.

Fieldwork at the Kromme River wetland took place on 21 March 2003 to verify the processed SPOT 5 and Kodak DCS 420 (Near infrared) images. The Image acquisition date for SPOT 5 was 10 February 2003 and for Kodak DCS 420 (Near infrared), 22 January 2003.

Due to unforeseen and unavoidable delays experienced with the acquisition of the DuncanTech CIR imagery because of technical problems and unsuitable weather conditions, no continuation of the fieldwork for the remaining five wetlands could commence. The acquisition of the first set of DuncanTech CIR imagery was on 8 April 2003 and the second on 9 June 2003. The acquisition dates of both sets of imagery were not 100% optimal in terms of identifying seasonal wetland characteristics (refer to Table 3, Time frame for image acquisition). Data processing for the remaining five wetlands took a further 3 months. It was necessary to collaborate with the different wetland's contact persons to gather useful information such as photos that were taken at the rehabilitation structure sites. Feedback reports of the wetland conditions were gathered from field visits of the remaining five wetlands from different wetland contact persons.

The following field visits took place:

- Rietvlei - 26 January 2003.
- Mbongolwane – 18 January 2003 and 30 April 2003.
- Wilge River – 9-10 March 2003.
- Seekoeivlei – 9-10 March 2003, July 2003.
- Zoar - 26 May 2003.

A combined field visit to the two wetlands in the Free State was hampered by the fact that the image acquisition date for Wilge River wetland was on 8 April 2003 and again on 9 June 2003 (DuncanTech CIR) and 24 December 2002 (EROS) for the Seekoeivlei wetland.

CHAPTER 4: RESULTS

4.1 RESULTS

4.1.1 Which indicators were detectable with which sensor type?

(Described by Grundling and Van den Berg, 2004)

4.1.1.1 Landsat ETM and Landsat TM Images.

Images of both Landsat TM and Landsat ETM were used. They were tested in two wetlands namely, Mbongolwane and Seekoeivlei. It became evident that these sensors are not suitable for mapping wetland indicators because of thier characteristics (Table 17). The spatial resolution of the data is not adequate, although the spectral band width would make it a good option. Bands 2-5 and 7 would work very well for mapping vegetation, soil and water. The multispectral bands (2-5 and 7) of Landsat were used to do a resolution merge with the panchromatic EROS data. The process is explained in the section EROS (4.1.1.3)

Table 17: Landsat TM and Landsat ETM+ characteristics.

Band Number	Spectral Range (μm)	Ground Resolution (m)
1 Blue	0.45 to 0.515	30
2 Green	0.525 to 0.605	30
3 Red	0.63 to 0.690	30
4 Near IR	0.75 to 0.90	30
5 SW IR	1.55 to 1.75	30
6 Thermal	10.40 to 12.50	60
7 SW IR	2.09 to 2.35	30
PAN	0.52 to 0.90	15

The images cover an area of 185 x 185 km and the coverage is repeated every 16 days within 233 orbits. The characteristics of Landsat TM are similar to those of Landsat ETM, the main difference being that Landsat TM does not have a panchromatic band and only one thermal band.

4.1.1.2 SPOT 5.

Appendix 6 contains an A3 size map of the SPOT 5 imagery covering the Kromme River wetland area. Although this data was relatively expensive (Table 16) to acquire for such a small area, it proved to be useful for mapping the rehabilitation sites and vegetation classes. Even though the structures were not that obvious it was possible to identify the site with the assistance of GPS points collected. Differences between the different vegetation, sediment deposits, degraded land and erosion could easily be mapped using only three bands (Table 18). This sensor proved to be very good for vegetation mapping of larger areas (with a resolution of 10 m), but for monitoring rehabilitation structures it was inadequate. Bands B1 to B3 spectral range 9 (Table 18) proved to be the best to map the wetland indicators. The spectral profile (Figure 86) indicates the following profiles: profile 1 is for wetland vegetation, profile 2 for sediment and profile 3 for natural vegetation that is predominantly Fynbos.

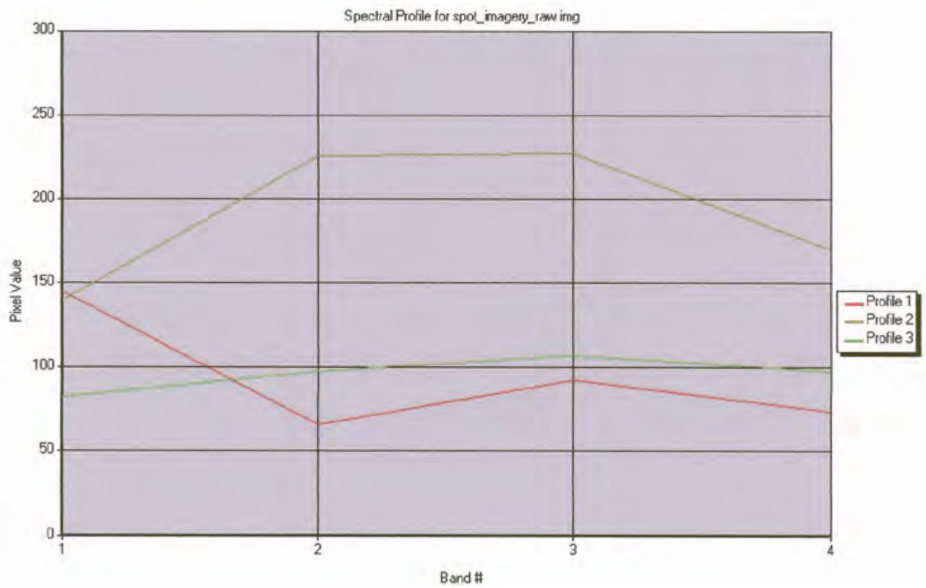


Figure 86: Spectral profile for SPOT 5 Imagery.

Table 18: SPOT 5 Characteristics.

Band Number	Spectral Range (μm)
B1 Green	0.50 to 0.59
B2 Red	0.61 to 0.68
B3 Near Infra Red	0.79 to 0.89
B4 SWIR (Short Wave Infrared)	1.58 to 1.75

Figure 89 is a subset of the SPOT 5 imagery showing some of the indicators that could be mapped (Figures 87 and 88) with verification in the field. Figure 90 shows the same area but classified into the indicator classes. The images cover an area of 60 x 60 m with a 10 m resolution for all four bands. Availability and quality of data are usually very good, depending on the cloud coverage over the study areas. It should be mentioned that a panchromatic band with 2.5 m (resample) resolution is available that could be used with the multispectral data to map the structures in more detail.

SPOT: Kromme River wetland – site 5.

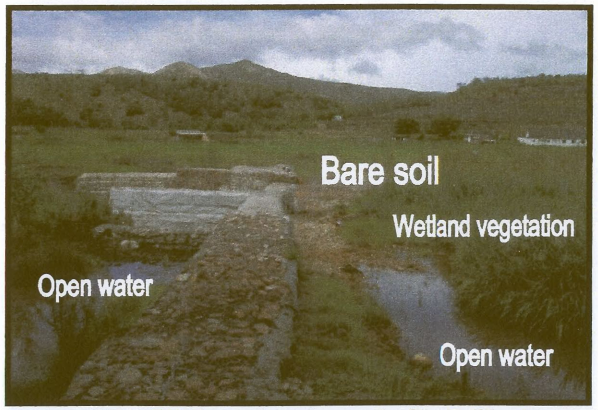


Figure 87: Gabion structure at site 5 (Hudsonvale) of the Kromme River Wetland.

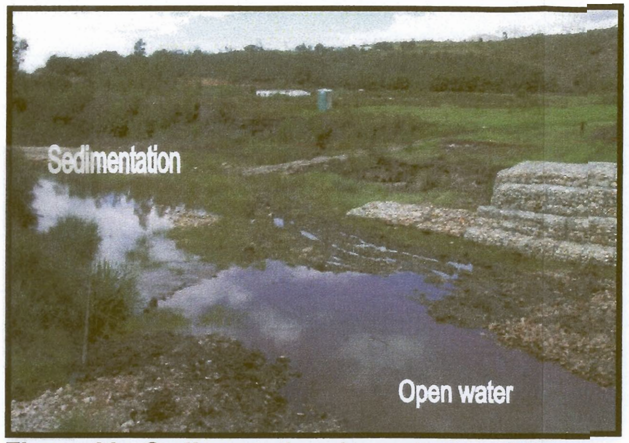


Figure 88: Sedimentation downstream of the gabion structure at site 5.

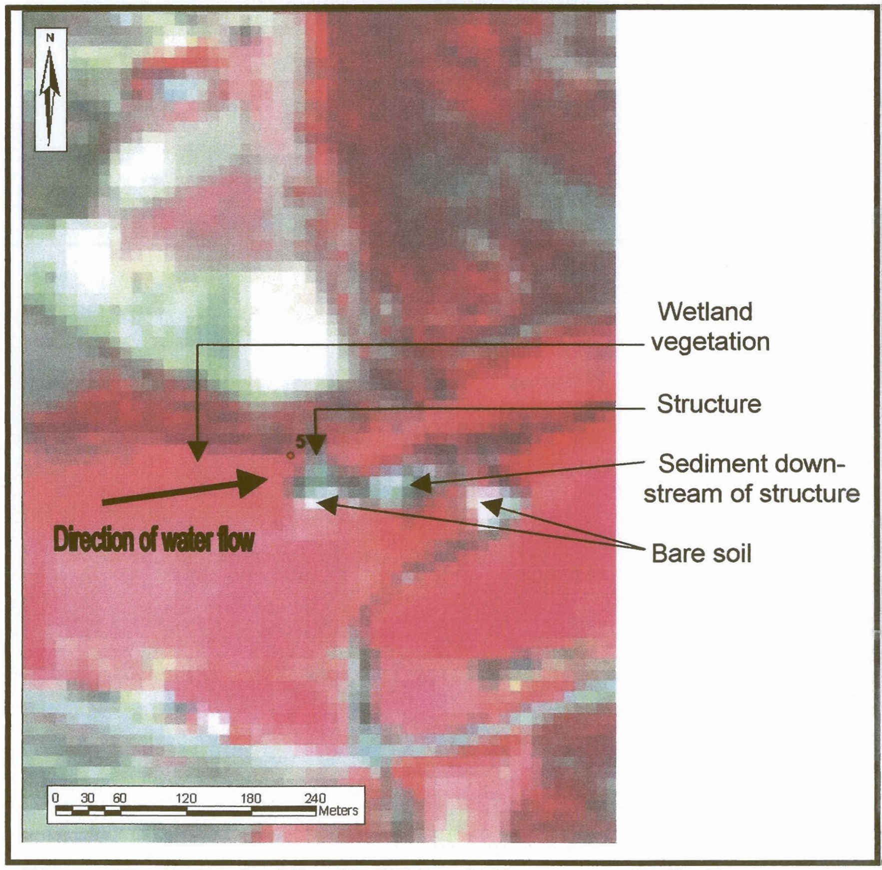


Figure 89: Subset of the SPOT 5 satellite image at site 5. Resolution: 10 m. Acquisition date: 10/02/2003.

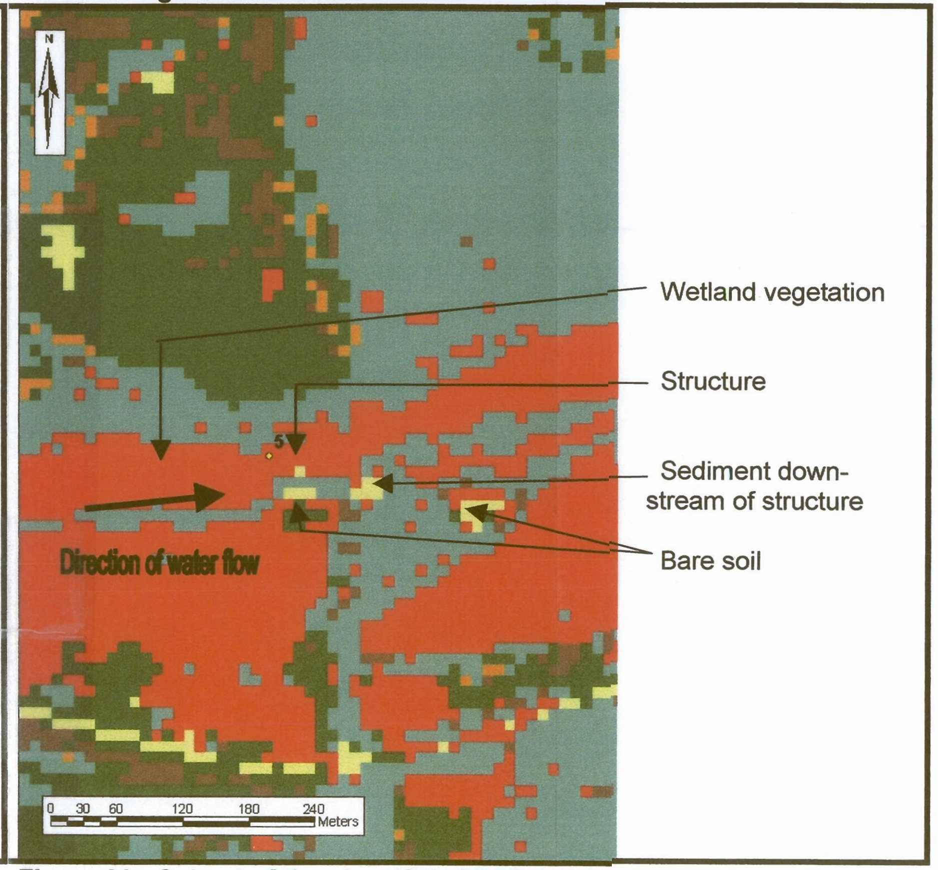


Figure 90: Subset of the classified SPOT 5 image.

4.1.1.3 EROS.

Appendix 6 contains A3 size maps of the EROS imagery covering Mbongolwane and Seekoeivlei wetland areas. The EROS A1 sensor has a panchromatic channel at 1.8 m resolution. A full EROS scene covers an area of 12.5 km x 12.5 km. These high resolution (1.8 m) images visually display the rehabilitation structures, sediment deposits and erosion (example 1) but proved not to be ideal for mapping vegetation (example 2). The reason for this is the fact that only one panchromatic band is available. The following subset examples from Mbongolwane and Seekoeivlei wetlands illustrate the visually effectiveness of this sensor.

Example 1: Mbongolwane wetland: Uvova. Photos depicting the site details are shown in Figures 91, 92, 94, 95 and 96. Figure 93 is a subset of the Uvova site (refer to example 1 used in section 11.2.5 DuncanTech CIR).

Example 2: Seekoeivlei wetland. Figure 97 is a subset of the EROS satellite image of sites 3 and 4. Figures 98, 99 and 100 are photos depicting the rehabilitation structures at sites 3 and 4. Figure 101 is a photo of an aerial view of flooded Seekoeivlei wetland covering sites 3 and 4.

EROS example 1: Mbongolwane wetland – Uvova.

Figure 91: Erosion downstream at the Uvova site.

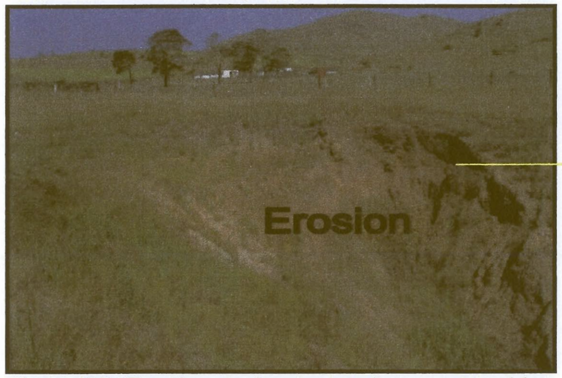


Figure 92: Erosion and revegetation on the sides at the Uvova site.

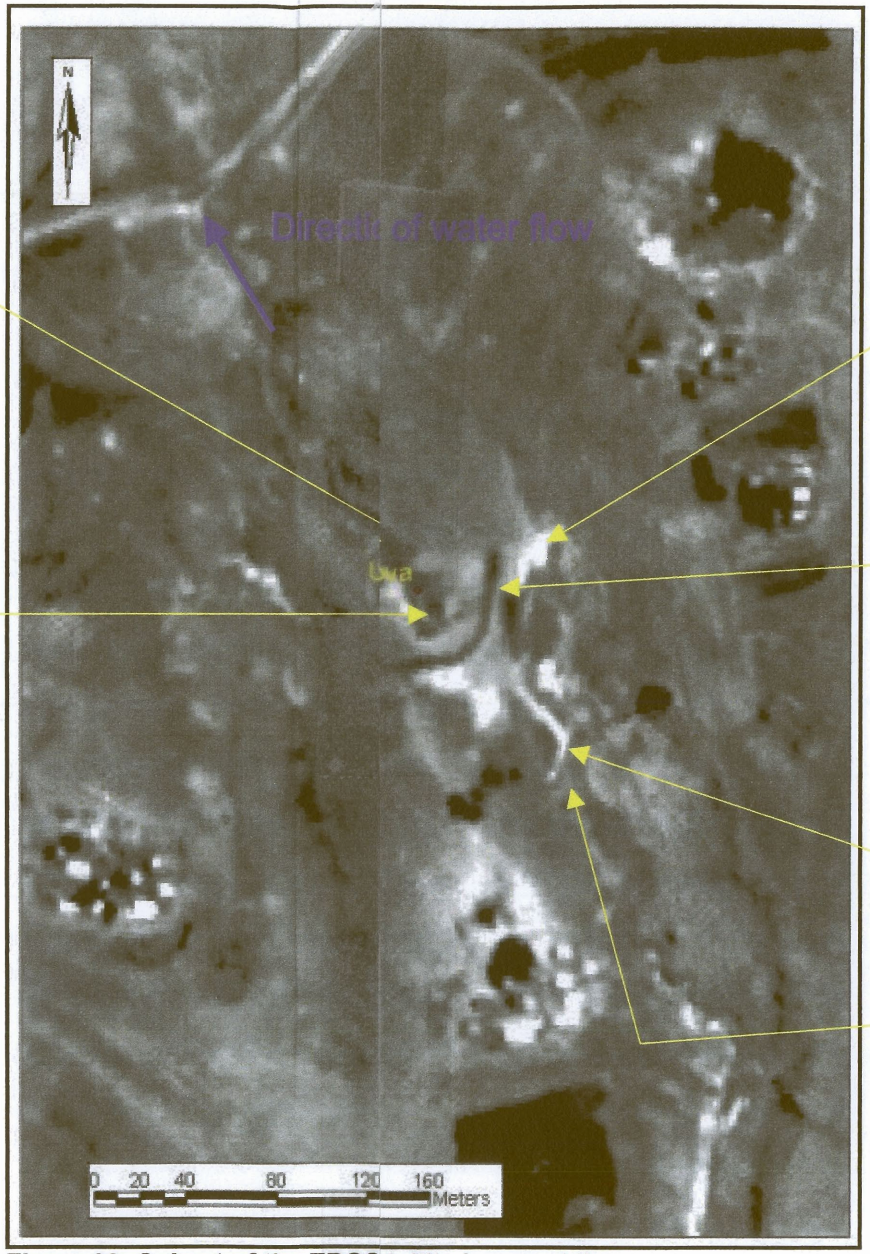


Figure 93: Subset of the EROSatellite image at the Uvova site. Resoluti: 1.8 m. Acquisition date: 24/12/2002.

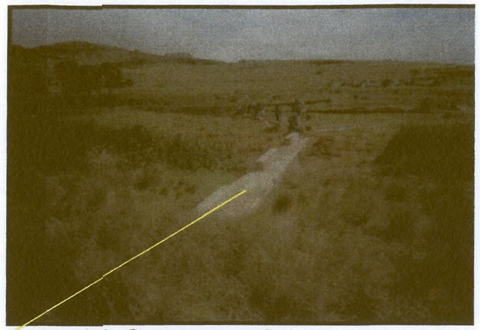


Figure 94: Concrete weir.

Figure 95: Earthen embankment.

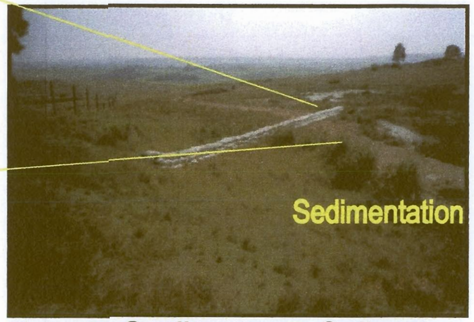


Figure 96: Sandbag groyne. Sediment Down- and upstream of the groyne.

EROS Example 2: Seekoeivlei wetland – site 3 and site 4.

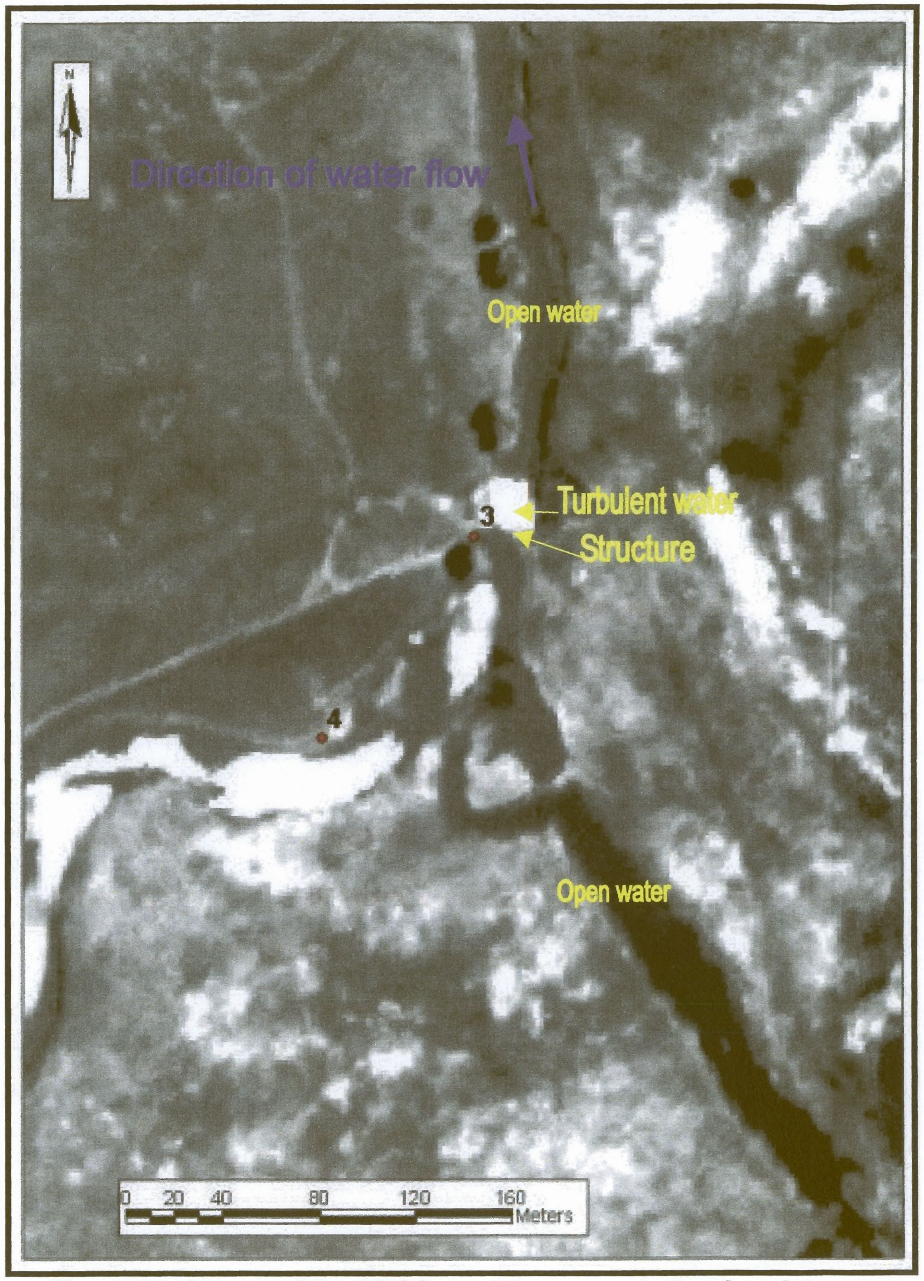


Figure 97: Subset of the EROS satellite image at sites 3 and 4. Resolution: 1.8 m. Acquisition date: 24/12/2002.

Figure 98: Site 3 at Merel's vlei. Photo taken July 2002.

Figure 99: Maintenance on the structure at site 3. Photo: J.v.d. Schyff (July 2003).

Figure 100: Site 4 at Merel's vlei. The weir is drowned below the water surface.

Figure 101: Aerial view of sites 3 and 4. Photo: G. Wandrag.

Example 3 of site 5 at the Seekoeivlei wetland shows that an EROS image together with other multispectral data with lower resolution could be used with success. Figure 102 is a subset of an EROS image at site 5 (resolution 1.8 m). For this project Landsat TM and Landsat ETM data were used with a resolution of 25-30 m (Figure 103). A resolution merge with a Browey transform and cubic convolution resampling technique was done with the data stretched to 8-bit values. The result of the resolution merge is a colour image with 1.8 m resolution which makes interpretation easer although some of the colour quality is lost (Figure 104). A resolution merge was done using the best 3 bands (Figure 105) from archived Landsat data available at ISCW. Figure 106 was taken at site 5 in July 2002. These images were used only for interpretation and not for classification. This technique could be used to interpret vegetation change but not for the visual inspection of rehabilitation structures. The erosion due to floodwaters along the edges of the rehabilitation structure at site 5 was not clear on the images. Figure 107 of site 5, taken in July 2003, shows the maintenance work that had to be done as a result of the side erosion at the structure. The sedimentation recorded on site, behind the structure, is a result of the intervention of man and not the success of the structure. Note the sandbags on the sedimentation bank in Figure 107.

It must be mentioned that the Landsat data used was data in the ISCW archive and did not fall into the optimum time periods or season to map wetland vegetation. The product could be further enhanced if multispectral data within the correct season would have been available. Multispectral bands between wavelengths of 0.52-0.90 nm with a ground resolution of 15 m or better would be a further enhancement to this product.

EROS example 3: Seekoeivlei wetland – site 5.

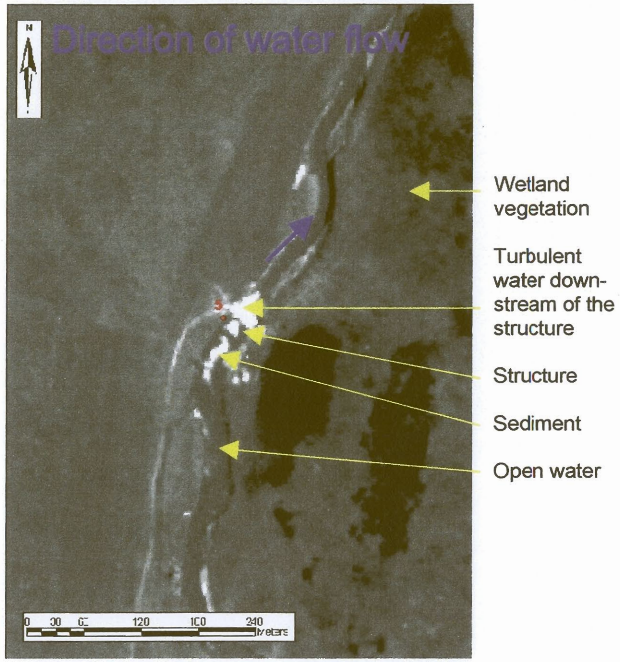


Figure 102: Subset of the EROS satellite image at Site 5. Resolution: 1.8 m. Acquisition date: 24/12/2002.

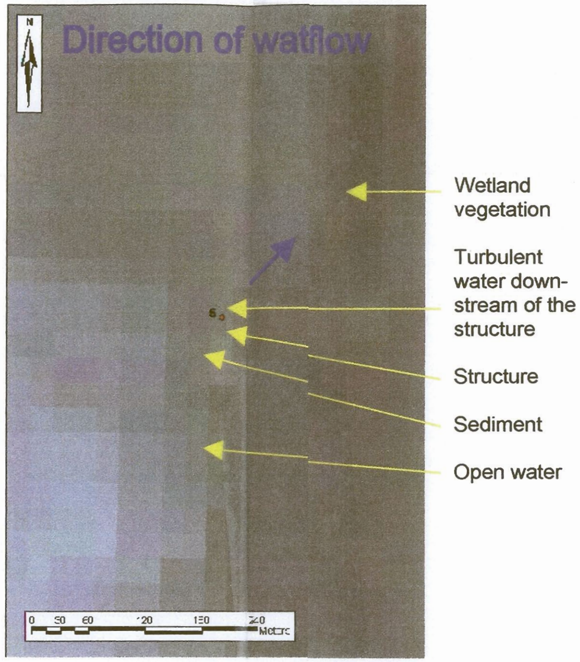


Figure 103: Subset of thendsat satellite image at Site 5. Restion: 30 m. Acquisition date: 1992, 1 and 2001.

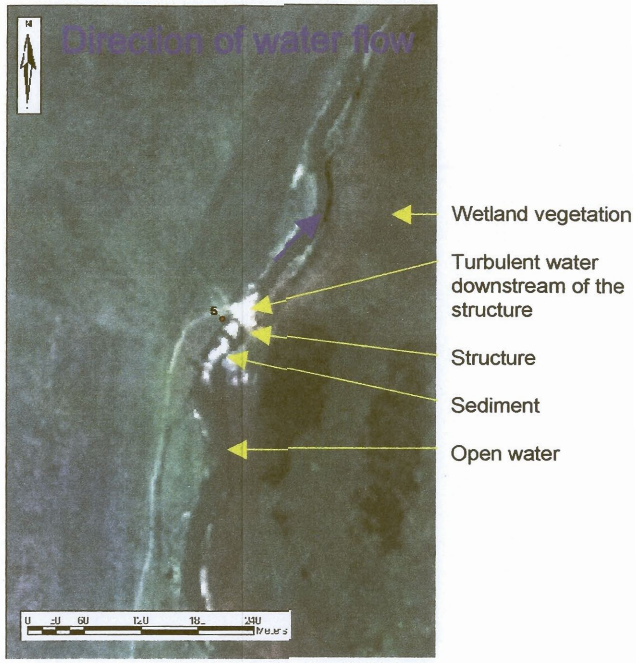


Figure 104: Pan multispectral resolution merge between EROS and Landsat. Resolution: 1.8 m.

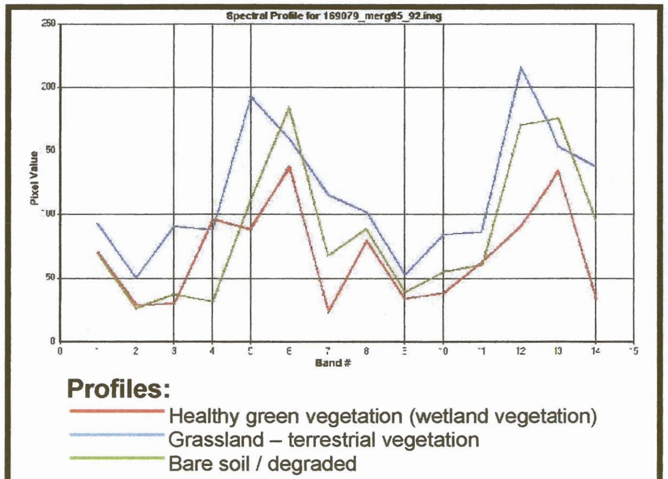


Figure 105: Spectral profile of Landsat TM layer stack image.

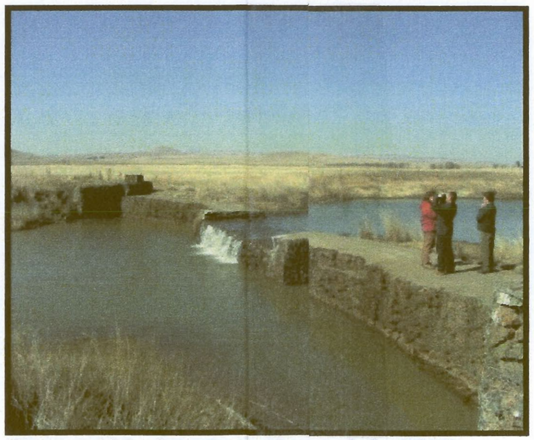


Figure 106: Site 5 photo en July 2002.

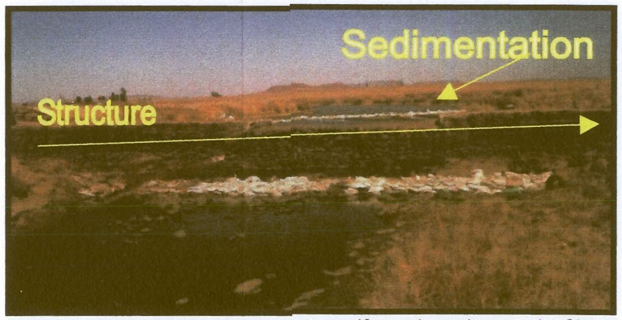


Figure 107: Maintenance on the structure at site 5. Photo: J.v.d. Schyff (July 2003).

4.1.1.4 KODAK DCS 420 (Near infrared).

This sensor was used at only one of the wetlands, namely Kromme River in the Eastern Cape. Appendix 6 contains an A3 size map of the KODAK DCS 420 (Near infrared) imagery covering the Kromme River wetland area. The image size is approximately 1.5 million pixels (1524 x 1012) with nominal pixel resolution of 0.6 m. The field of view is 914 m x 607 m when flown at 1000 m. Although the resolution of the sensor (1 m) is very good, the mosaic was not seamless, making data processing difficult and time consuming. Classifications and indices highlighted the mosaicing seams as differences in the spectral value of features, although it was the same feature on the ground. All 47 individual images were processed individually; edge matched and mosaiced after the classification. Seamless mosaics are considered to be important for wetland assessment.

All three bands were used and displayed as 1, 2, 3 (Red, Green, Blue). The primary reason for using red (R) and near-infrared (NIR) wavelengths is that they are useful for monitoring vegetation (Figure 108): Leaf chlorophyll absorbs energy in the visible-red to electromagnetic wavelengths (600-700 nm); crops with healthy leaves absorb higher levels of energy at these wavelengths. Healthy crops are also characterized by a good leaf-cell structure and leaf-water content. In the near-infrared wavelengths (800-900 nm) such characteristics cause a high reflectance response (Figure 108).

All three bands were used to optimize the spectral range in identifying the different wetland rehabilitation indicators (e.g. rehabilitation structure 5: Gabion weir at Hudsonvale, Figures 109 and 110). All the classes and structures were

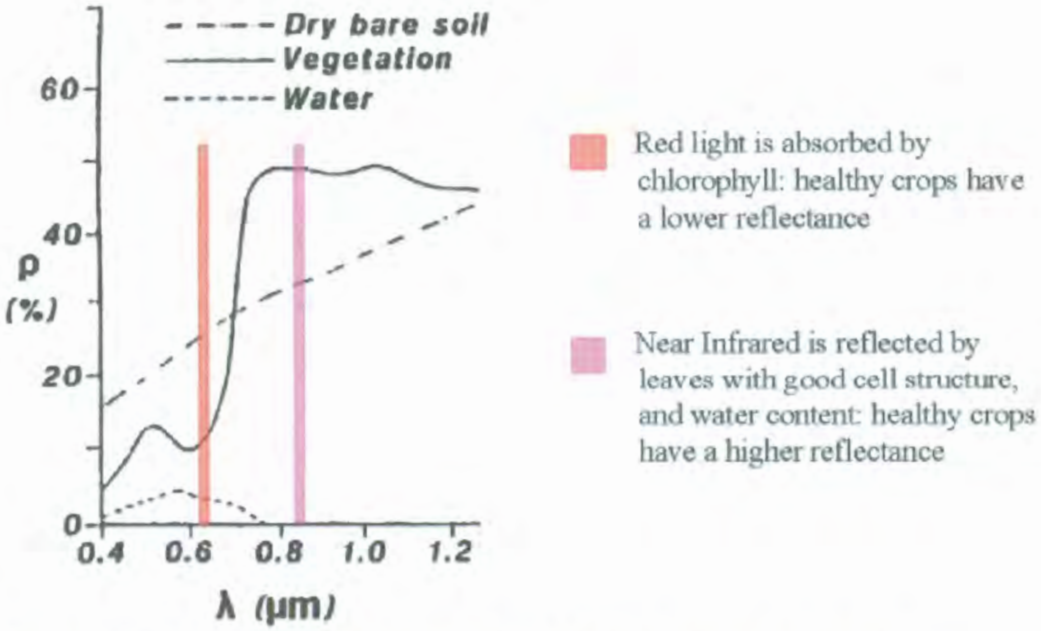


Figure 108: Reflectance values of KODAK240 (Near infrared).

mapped with ease (e.g. rehabilitation structure 5: Gabion weir at Hudsonvale, Figures 111 and 112). However, sediment deposits behind the rehabilitation structure 1 (a concrete weir, Figure 113) were highlighted successfully because they were not covered with shallow water (Figure 114). According to Campbell (2002), bare soil will display bright, vegetated land and water dark in the near infrared region, making it easy to determine the land-water body border. CIR film is suitable if the water is clear and not turbid. However, if the sediment deposits in this case were covered with water, the area would have displayed dark and if colonized with vegetation, it would display red. In the last two examples the sediment deposit would not be evident.

At Kompanjiesdrif (Figures 115 and 116, rehabilitation site 4: Gabion weir) measurement of the active headcut erosion could be determined successfully (Figure 117). It was also possible to map the wetland vegetation with this sensor. It is important to have adequate field points for the classification and verification of the data.

Kodak DCS 420 (Near infrared) example 1: Kromme River wend – site 5.

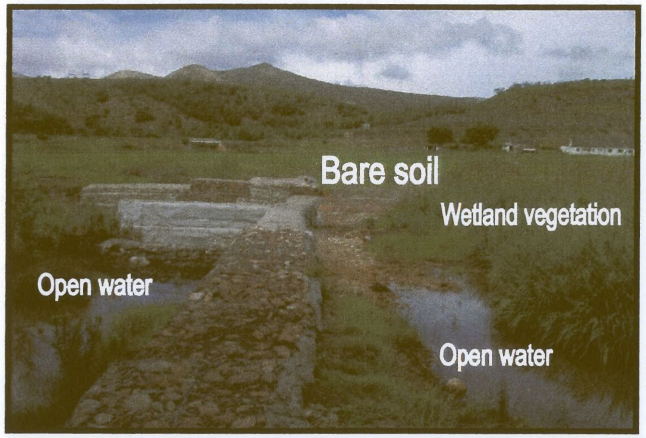


Figure 109: Gabion structure at site 5 (Hudsonvale) of the Kromme River Wetland.

Figure 110: Sedimentation downstream of the gabion structure at site 5.

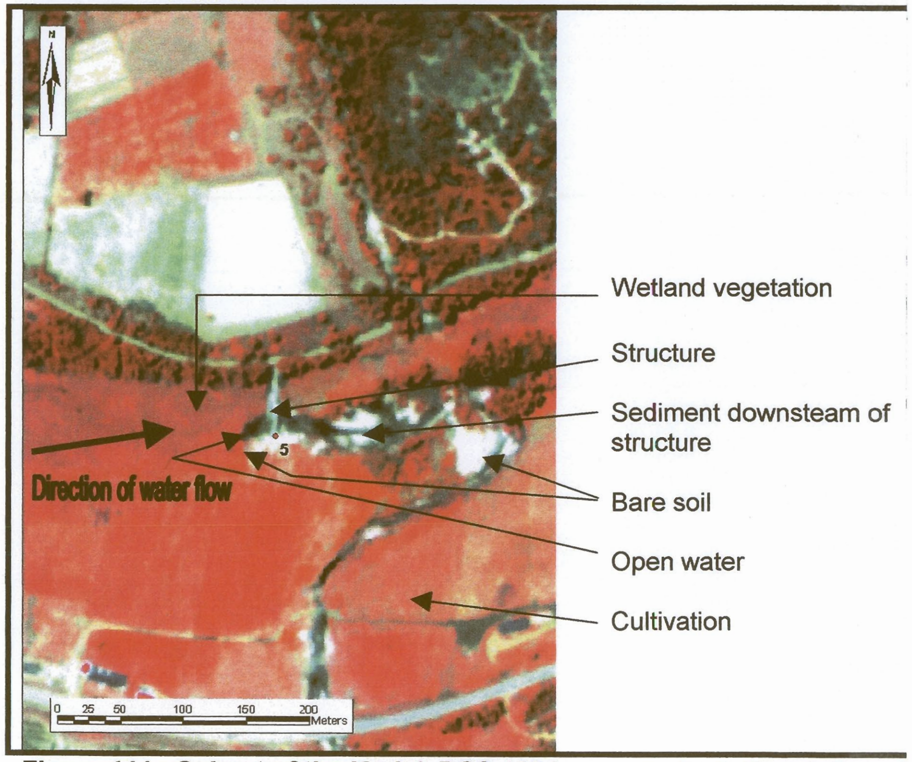


Figure 111: Subset of the Kodak DCS 420 image at site 5. Resolution: 1 Acquisition date: 22/01/2003.

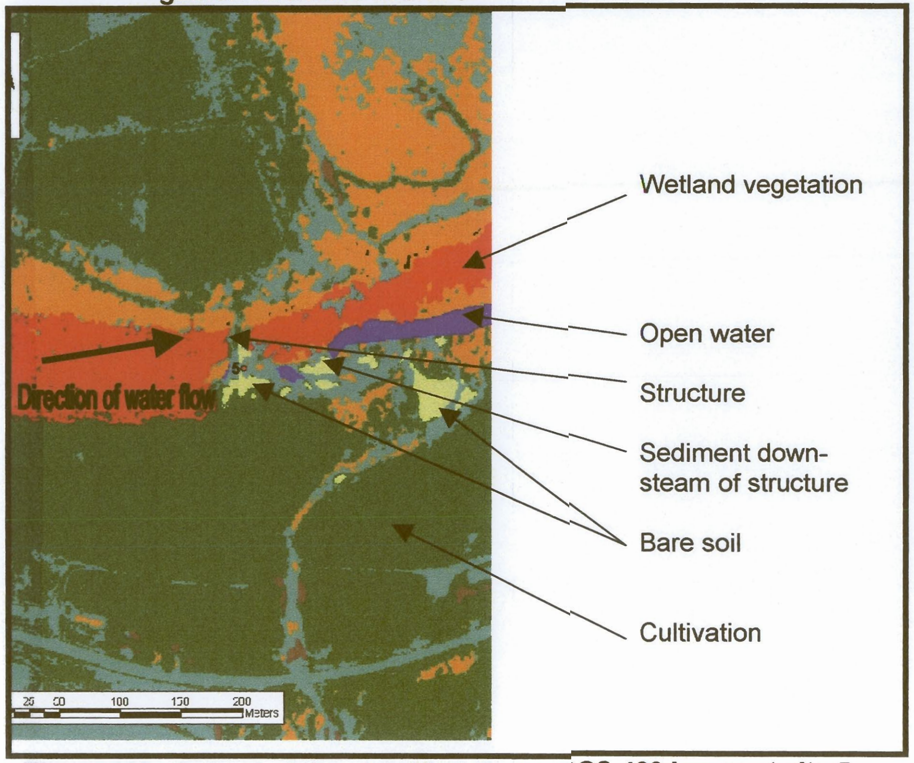


Figure 112: Subset of the classified Kodak DCS 420 image at site 5.

Kodak DCS 420 (Near infrared) example 2: Kromme River weid – sites 1 and 4.

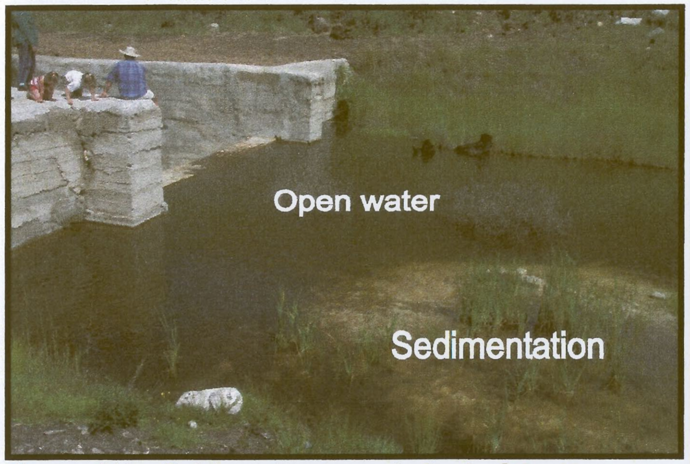


Figure 113: Gabion structure at site 1 of the Kromme River Wetland.

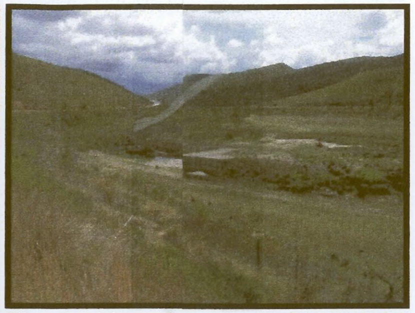


Figure 115: G:n structure at site 4 npanjiesdrif).

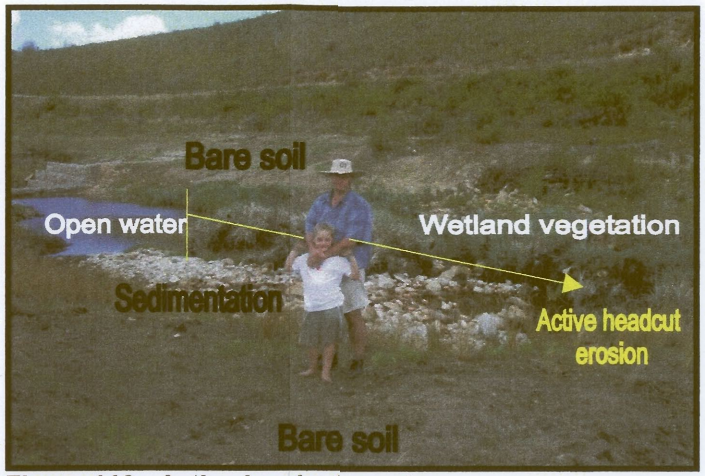


Figure 116: Active headcut erosion.

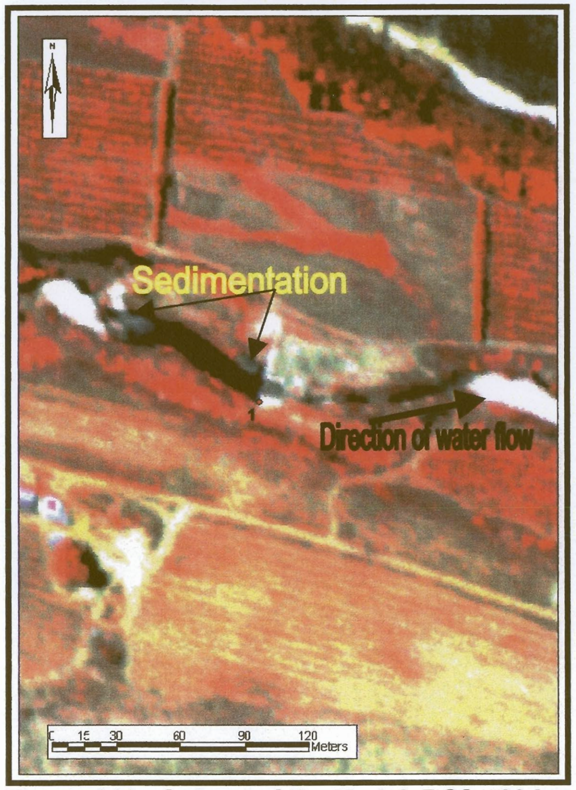


Figure 114: Subset of the Kodak DCS 420 image at site 1. Resolution: 1 m. Acquisition date: 22/01/2003

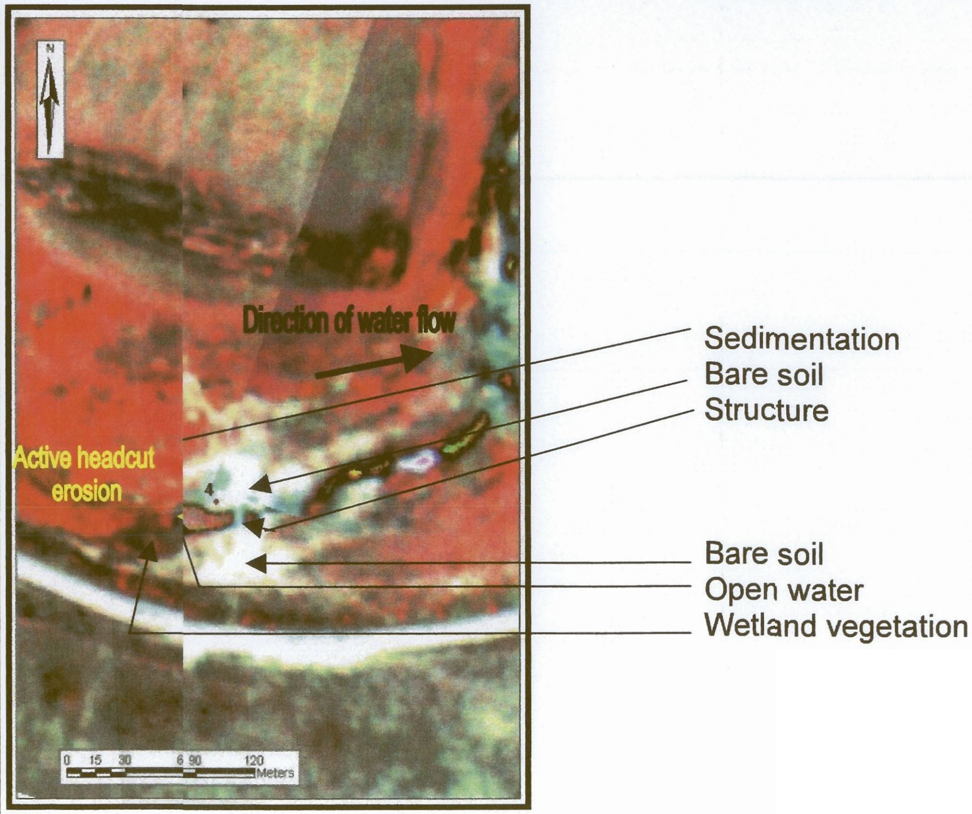


Figure 117: Set of the Kodak DCS 420 image at site 4. Rution: 1 m. Acquisition date: 22/01/2003

4.1.1.5 DuncanTech CIR.

DuncanTech's CIR configuration produces images with green, red and near infrared bands. The imaging sensors are sensitive to wavelengths ranging from about 400 nm to 1100 nm, with peak sensitivity at approximately 500 nm. The spectral values for wetland vegetation (Profile 1), bare soil (Profile 2) and natural vegetation (profile 3) as reflected in Figure 118 from the DuncanTech CIR Camera image for Mbongolwane.

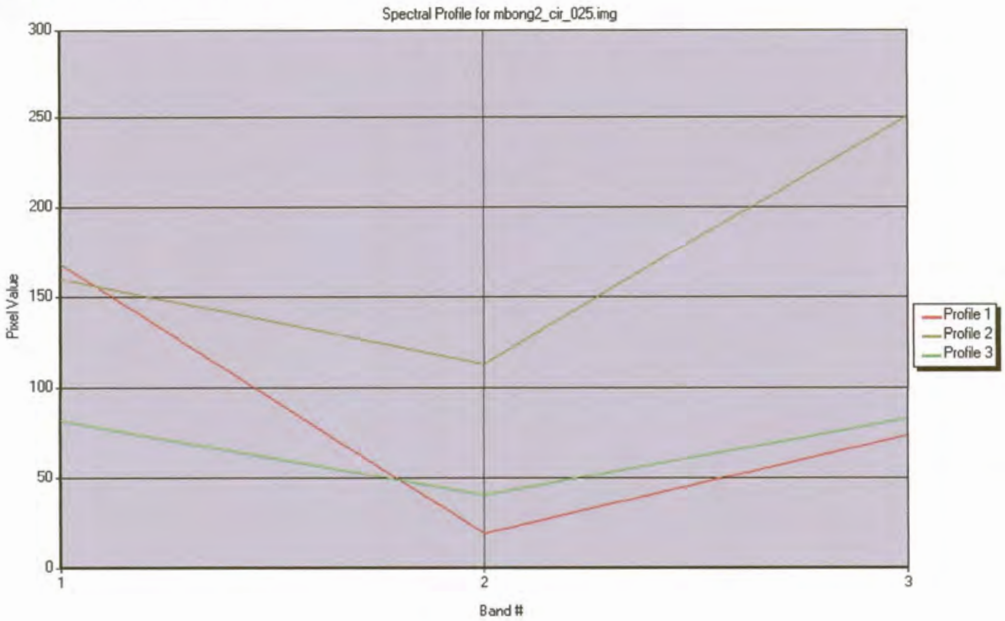


Figure 118: Spectral Profile for DuncanTech CIR.

Apart from the datasets being quite large and processing time being relatively long the data were very effective in mapping all the rehabilitated wetland indicators and structures. The following examples from Mbongolwane, Zoar and Rietvlei wetlands illustrate the effectiveness of this sensor.

Example 1: Mbongolwane wetland: Uvova.

Various wetland rehabilitation indicators and structures (Erosion - Figure 119; Concrete weir - Figure 120; Earthen embankment - Figure 121 and Sandbag groyne and sediment - Figure 122) are evident in Figures 123 and 124. They give a good indication of the level of detail this sensor is capable of. Figure 125 illustrates the level of detail including erosion, rehabilitation measures and sedimentation, using DuncanTech true colour imagery.

Example 2: Zoar wetland.

The main drain with clay plugs (Figure 126) and the road infrastructure (Figure 127) are evident in Figures 128 (DuncanTech CIR) and 129 (DuncanTech true colour). Dominant terrestrial vegetation replaced the aquatic plants in the wetland. Spectrally the wetland and grassland vegetation could not be adequately distinguished.

Example 3: Rietvlei wetland. The resolution for the DuncanTech CIR image of Rietvlei wetland was 0.5 m and not 0.25 m (as with Mbongolwane and Zoar). The Rietvlei wetland is situated near Irene and is therefore within the Johannesburg International Airport's Flight restriction area.

Site details at rehabilitation structure 4, 5.1 and 5.2 are shown in Figures 130 – 133. Figures 134 (DuncanTech CIR) and 135 (DuncanTech true colour) are subsets of the DuncanTech imagery and display the different wetland vegetation (tall and short emergent). It would be possible to map differences in vegetation types using the detailed field data collected by *Venter et al.* (2003) in the different wetland zones (permanent, seasonal and temporary). This could be processed together with an image acquired during the wet summer rainfall season and followed up with another image at the same time of the year but in a different year. This could be used for change detection and to monitor the status of the wetland. All the bands have been determined to be very useful in assessing vegetation characteristics.

DuncanTech example 1: Mbongolwane wetland – Uvova.

Figure 119: Erosion downstream at Uvova.

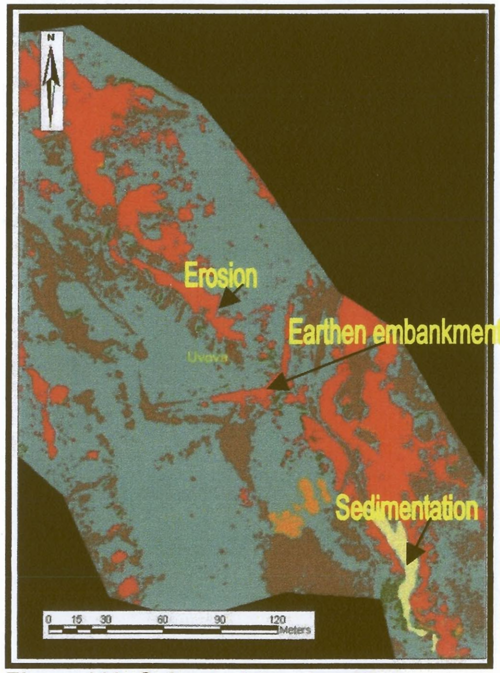


Figure 123: Subset of the classified DuncanTech CIR image at Uvova.

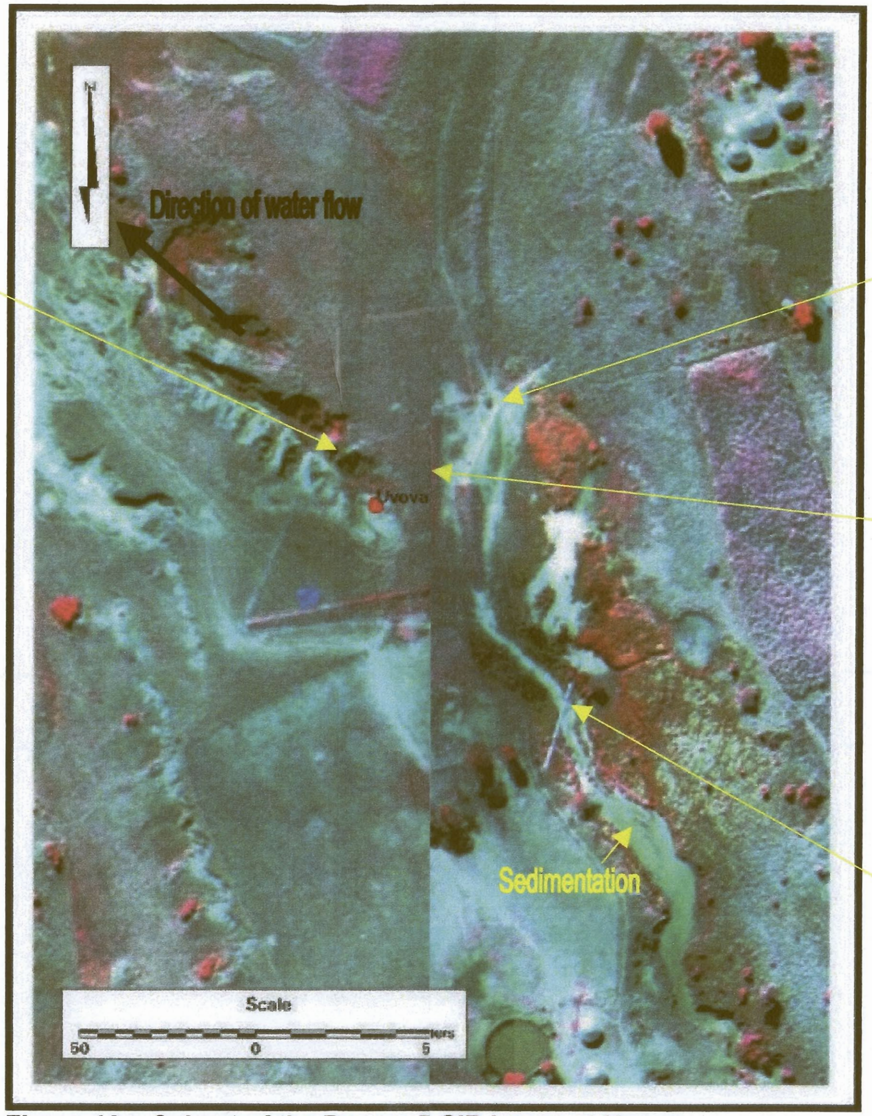


Figure 124: Subset of the DuncanT CIR image at Uvova. Resolution: 0.25 m. Acition date: 09/06/2003.

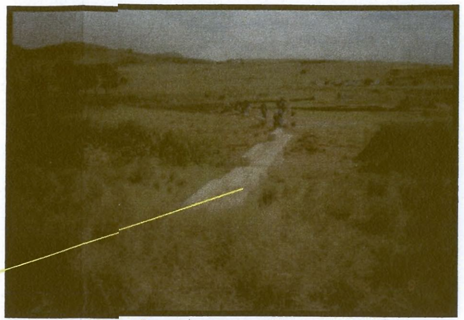


Figure 120: Concrete weir.

Figure 121: Earthen embankment.

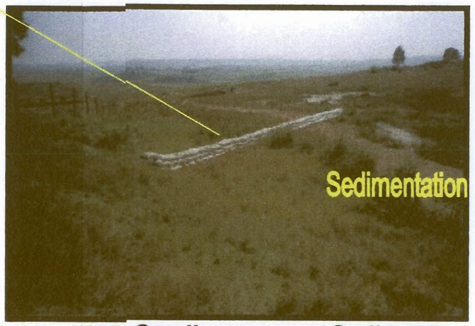


Figure 122: Sandbag groyne. Sediment Down - and upstream of the groyne.

DuncanTech example 1: Mbongolwane wetland – Uvova.

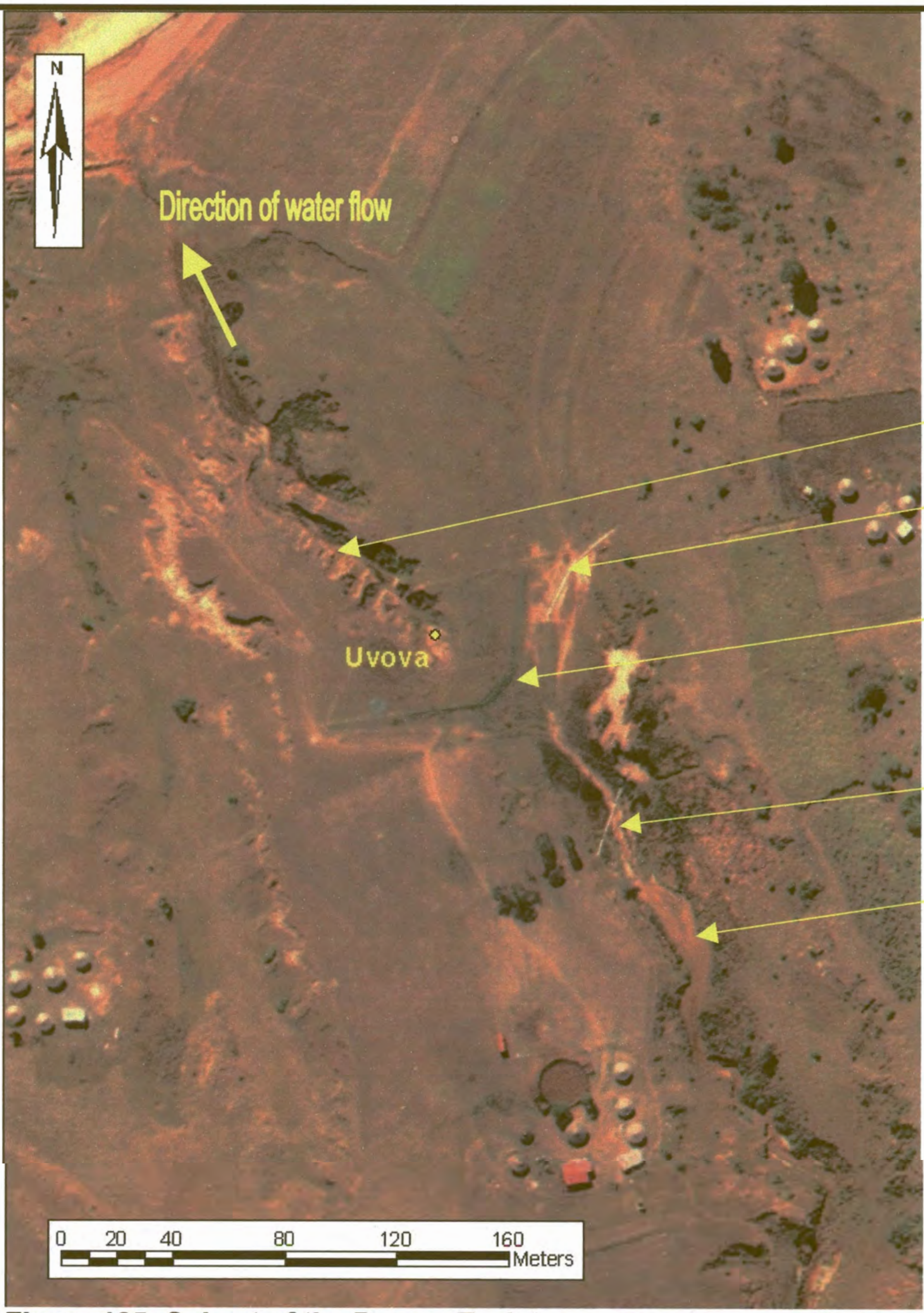


Figure 125: Subset of the DuncanTech true colour image at Uvova. Resolution: 0.25 m. Acquisition date: 09/06/2003.

DuncanTech example 2: Zoar wetland.

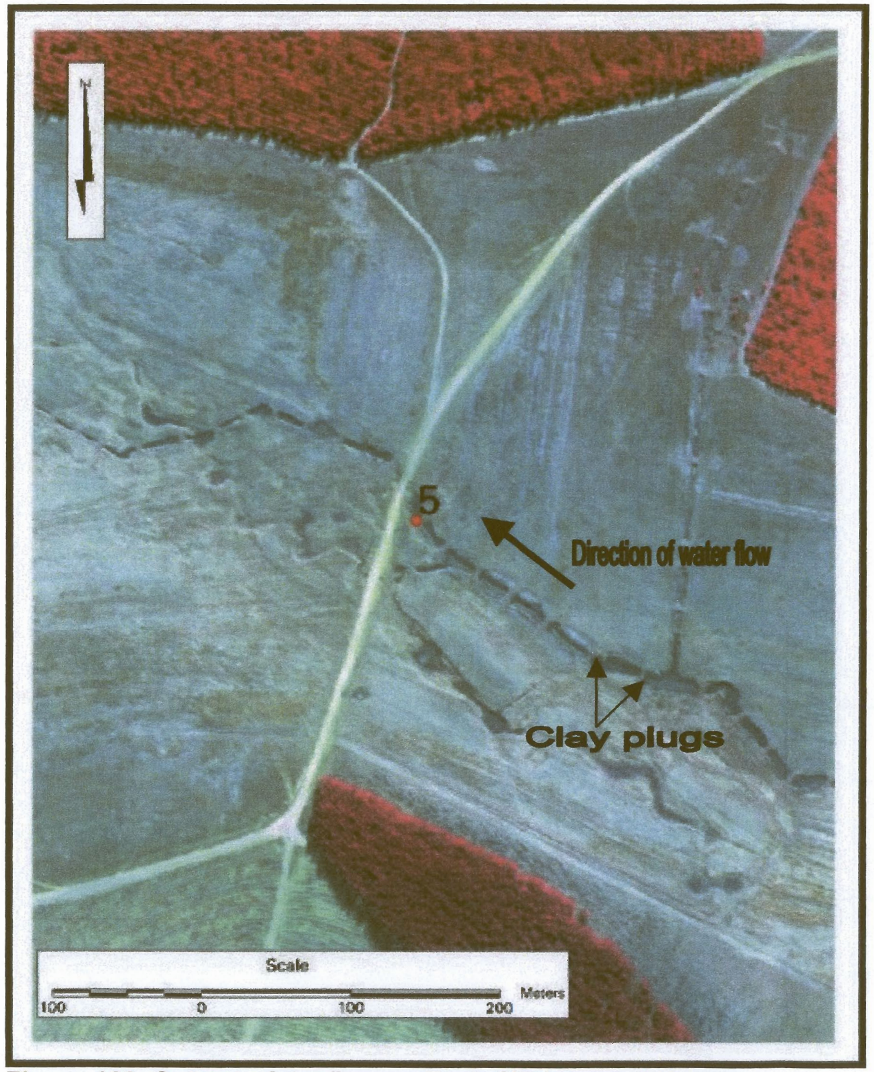


Figure 128: Subset of the DuncanTech CIR image at Uvova. Resolution: 0.25 m. Acquisition date: 09/06/2003.

Figu 26: Drains with clay plugs and evidence of wetness. Photo taken 26/05/2003.

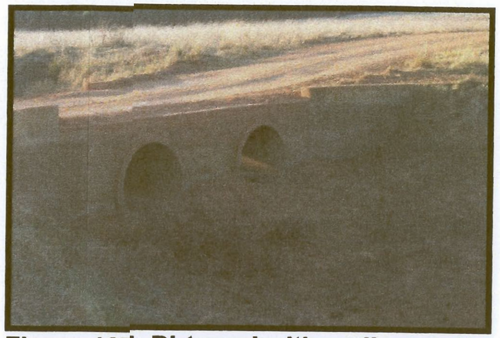
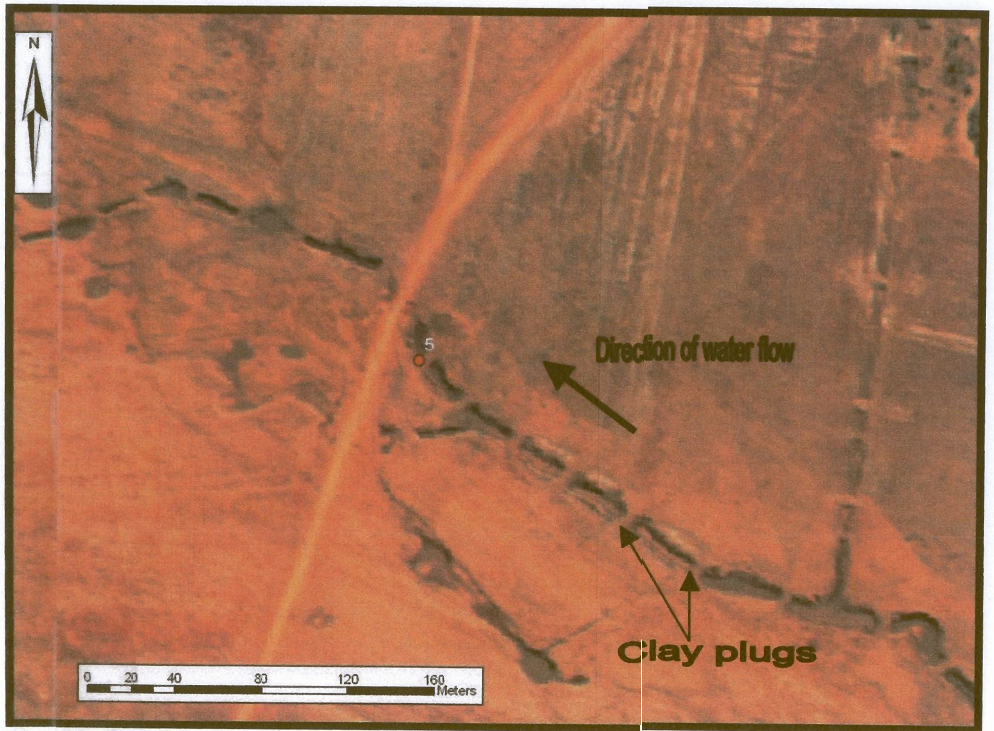


Figure 127: Dirt road with sedimentation deposited upstream of the culvert.



Figu 29: Subset of the DuncanTech true colour image Resolution: 0.25 m. Acquisition Date: 09/06/2003.

DuncanTech CIR example 3: Rietvlei wetland.

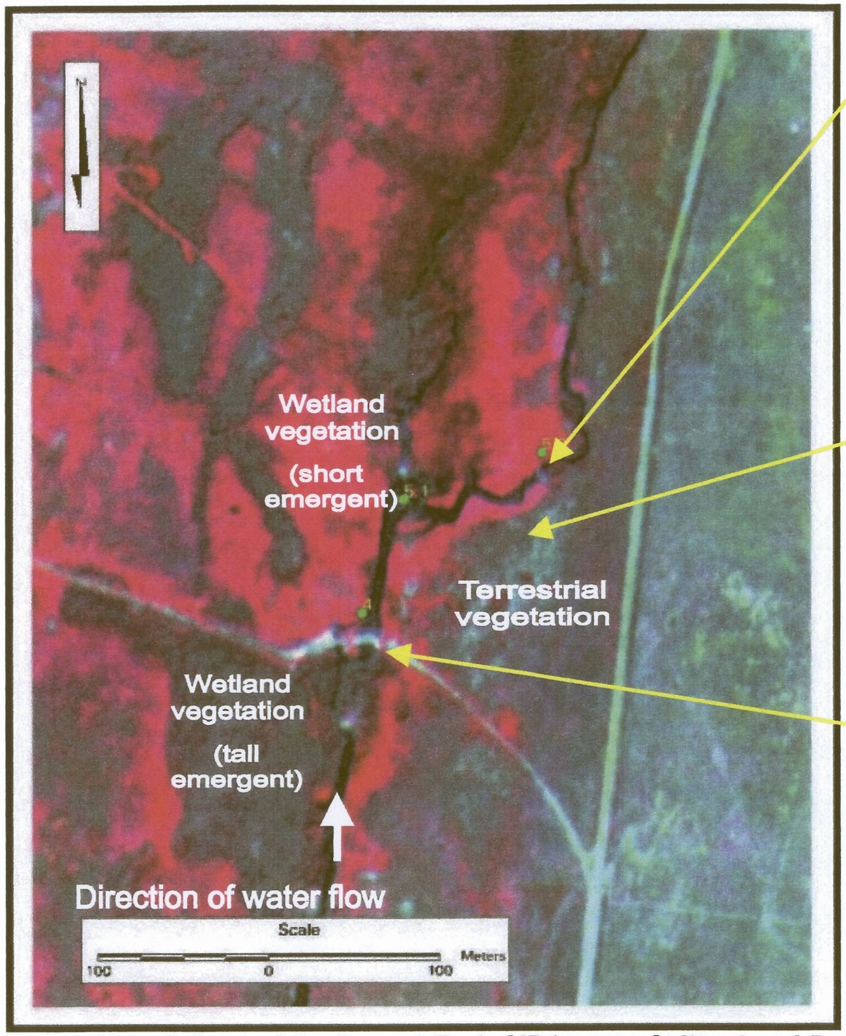


Figure 134: Subset of the DuncanTech CIR image of sites 4 and 5. Resolution: 0.5 m. Acquisition date: 09/06/2003.

Figure 1: Gabion structure at site 5.2. Nothe difference in the water table upeam and downstream of the strirure.

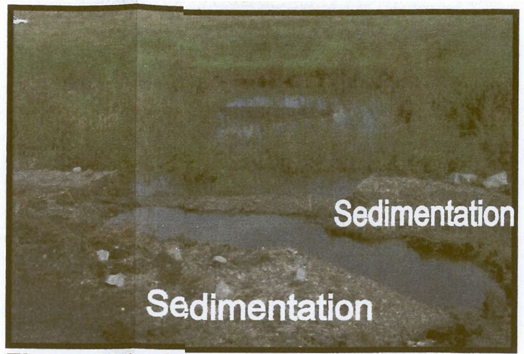


Figure 131: Site no 5.1.. Sedimentation taking place behind the structure.

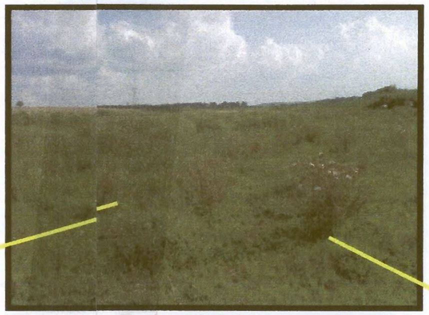


Figure 1: Terrestrial vegetation between structure 4 and 5.1 and 5.2.

Figure :: Concrete weir at site 4. Note thetland vegetation (tall engent, ***Phragmites australis***) bead the structure.

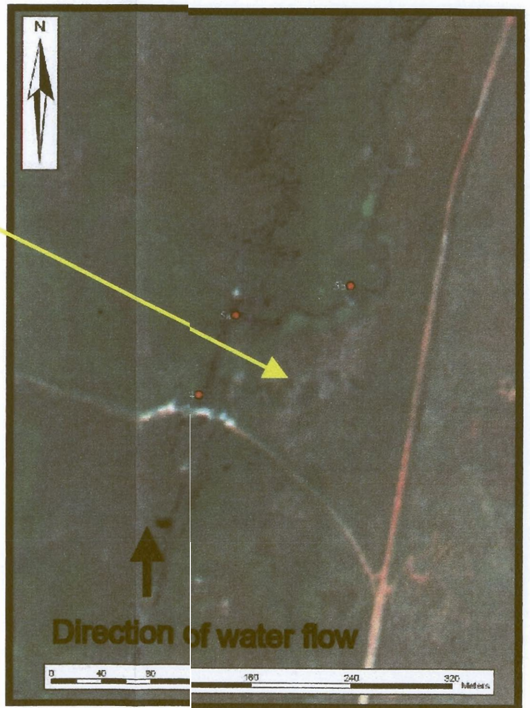


Figure 135: Subset of the DuncanTech true colour image. Resolution: 0.5 m. Acquisition date: 09/06/2003.

4.1.2 Comparison of the various remote sensing sensors.

Table 19 gives an evaluated summary for the various remote sensing sensors using categories of good, medium or poor for indicating user-friendliness as well as high, medium or low effectiveness in the indication of rehabilitated wetland indicators. Images from all high resolution sensors are more or less time consuming because of the data size. Seamlines in the mosaics are a result of the applied image processing techniques and software. This can drastically be reduced with different image processing techniques and software. All other processing and classification is nearly the same as for satellite imagery. The cost of well-trained staff, transport, equipment and data-processing facilities are often neglected or underestimated.

The different remote sensing sensors, SPOT 5 and Kodak DCS 420, Near infrared, (Figure 136 to 139) and EROS and DuncanTech CIR (Figures 140 to 146), are visually compared with each other.

4.1.2.1 Comparison of SPOT 5 and Kodak DCS 420.

A comparison between SPOT 5 and Kodak DCS 420 (Near infrared) images at the Kromme River Wetland rehabilitation structure 5 shows the extent of the difference in detail. Various wetland rehabilitation indicators and structures (gabion structure - Figure 136 and sedimentation - Figure 137) are vague in Figure 138 (SPOT 5), but clear and evident in Figure 139 (Kodak DCS 420, Near infrared). It gives a good indication of the level of detail these sensors are capable of.

Table 19: Evaluation summary for the various remote sensing sensors usin… …um and Poor for indicating user friendliness, Short, Medium, Long indicating data processing time as well as High, Medium and Low effectiveness in the indication of indicators.

Sensor	Landsat	SPOT 5	EROS	Kodak DCS 420 (Near Infrared)	DuncanTech CIR
Resolution	30 m	10 m	1.8 m	1 m	0.25 – 0.5 m
Image cover area	185 x 185 km	60 x 60 km	12.5km x 12.5km		
***Total Cost (R/ha) covering wetland area**	R 6.15 / ha	R82.00 / ha	R12.90 - R36.10 / ha	R59.34 / ha	Average R287.71 / ha
***Total Cost (R/ha) covering rehabilitation structures**	R166.00 / ha	R804.23 / ha	R311.00 – R350.00 / ha	R 582.00 / ha	Average R301.97 / ha
Availability of data	Good	Good	Good	Good	Good
Quality of data	Good	Good	Good	Medium	Good
Data processing time	Short	Short	Short	Long (Time consuming)	Medium
Sensor characteristics					
• **Strengths**	• 8 Bands (different classifications) • Readily available (due to cloud cover not always on specific date) • Good for regional mapping	• 4 Bands • Readily available (due to cloud cover not always on specific date) • Good for regional mapping	• Resolution • Readily available (due to cloud cover not always on specific date) • Cheap cost • Good for regional mapping	• Effective in mapping all the wetland indicators and structures • The primary reason for using red (R) and near-infrared (NIR) wavelengths is there usefulness for monitoring vegetation • Quality and availability of data is good • Resolution • Cost	• Effective in mapping all the wetland indicators and structures • Produce images with green, red, and near IR bands ideal for vegetation mapping. • The imaging sensors are sensitive to wavelengths (400 nm to 1100 nm).
• **Limitation**	• Coarse resolution • Minimum of ¼ sene available • Expensive for small areas	• Very expensive • Resolution is to coarse	• Only one panchromatic band is available (no colour) - Not ideal for mapping vegetation.	1. The image mosaic covering the study area consisted of 47 separate images. A seamless mosaic was considered to be important. 2. The differences in the pixel values are a result of the different exposure values of the images.	1. Datasets being very big and processing time being relatively long. 2. Expensive for relative small areas. Becoming available and competitive on areas 1000 ha and more. 3. Dependent on weather conditions 4. Logistics (Airplane, camera crew)
High, Medium and Low effectiveness in the indication of indicators.					
• Erosion	Low	Low	edium	High	High
• Sedimentation	Low	Low	edium	High	High
• Open water	Low	Low	edium	High	High
• Wet surface area	Medium	Medium	edium	High	High
• Water quality	Low	Low	w	Low	Low
• Wetland vegetation	Medium	Medium	w	High	High
• Terrestrial vegetation	Medium	Medium	w	High	High
• Alien vegetation	Medium	Medium	w	High	High
• Bare soil	Medium	Medium	edium	High	High
• Cultivation	Medium	Medium	edium	High	High
Rehabilitation structure	Low	Low	edium	High	High
Alternatives	A resolution merge between the best 3 bands form Landsat data and an EROS image (resolution 1.8 m) will enable visual inspection of the rehabilitation structures (medium effectiveness) and the vegetation with high effectiveness.	Panchromatic band with 2.5 m (resampled) resolution is available that could be used with the multispectral data to map the structures in more detail.	ROS together with other ıltispectral data avelengths bands 0.52- 90) with lower resolution 5 meters or better) could be ed with success in getation mapping.	PAR – Photosynthetic Active Radiation LAI – Leaf Area Index Spectrometer Soil moisture meter Vegetation Temperature	

* Refer to Table 15

Comparison of SPOT 5 and Kodak DCS 420 images: Krone River wetland - site 5.

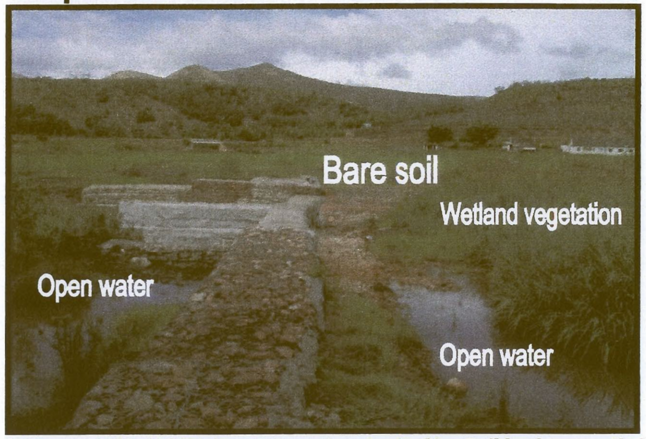


Figure 136: Gabion structure at site 5 (Hudsonvale) of the Kromme River Wetland.

Figure 137: Sedimentation downstream of the gabion structure at site 5.

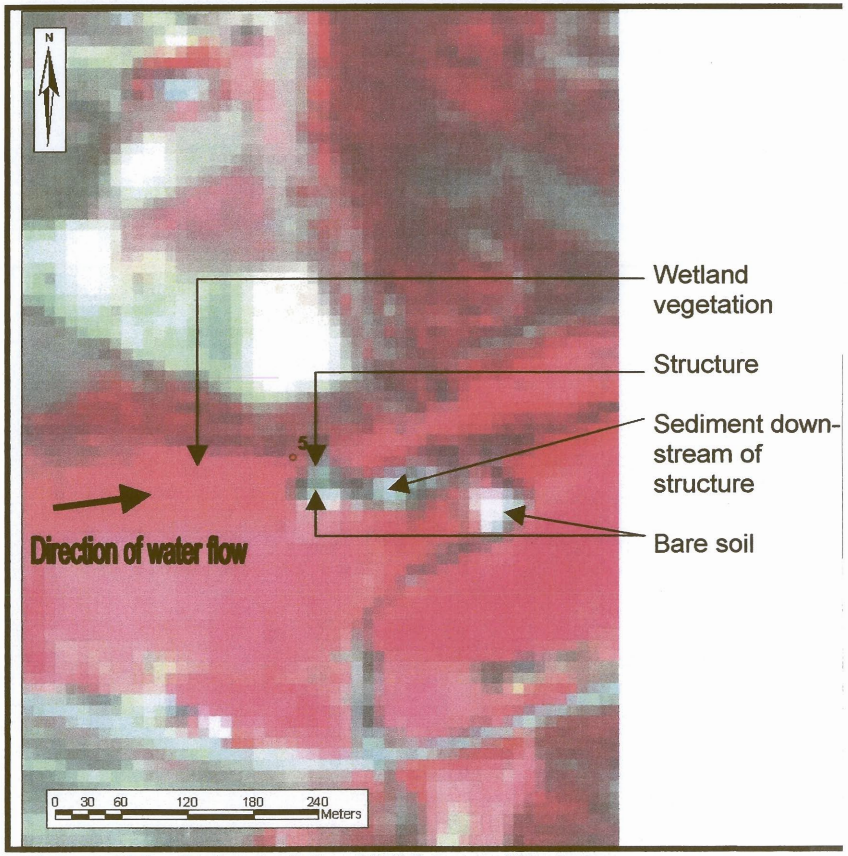


Figure 138: Subset of the SPOT 5 satellite image at site 5. Resolution: 10 m. Acquisition date: 10/02/2003.

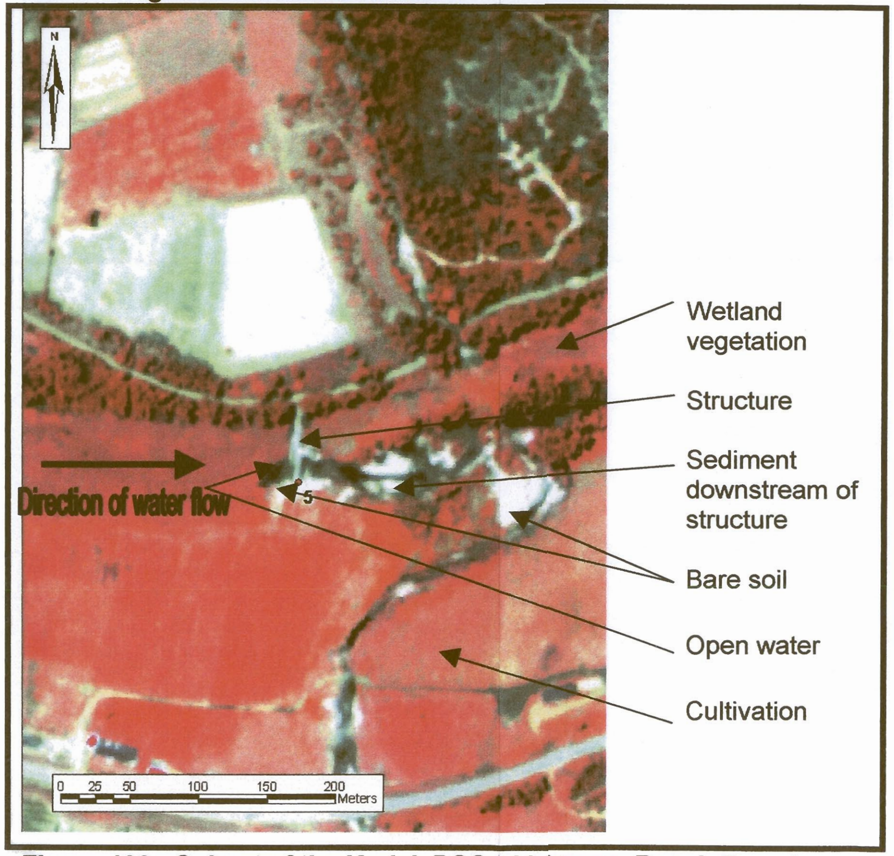


Figure 139: Subset of the Kodak DSC 420 image. Resolution: 1 m. Acquisition date: 22/01/2003.

4.1.2.2 Comparison of EROS and DuncanTech CIR.

A comparison between EROS and DuncanTech CIR images of the Amatigulu site at the Mbongolwane Wetland shows the extent of the difference in detail. Various wetland rehabilitation indicators and structures (headcut erosion - Figure 140; subsistence farming – Figure 142; harvesting of reeds – Figure 143 and diversion furrow - Figure 146) are vague in Figure 141 (EROS), but clear and evident in Figure 145 (DuncanTech). It gives a good indication of the level of detail these sensors are capable of.

Comparison of EROS and DuncanTech CIR images: Mbongolwe – Amatigulu.

Figure 140: Headcut erosion feature. Geocell chute preparations.

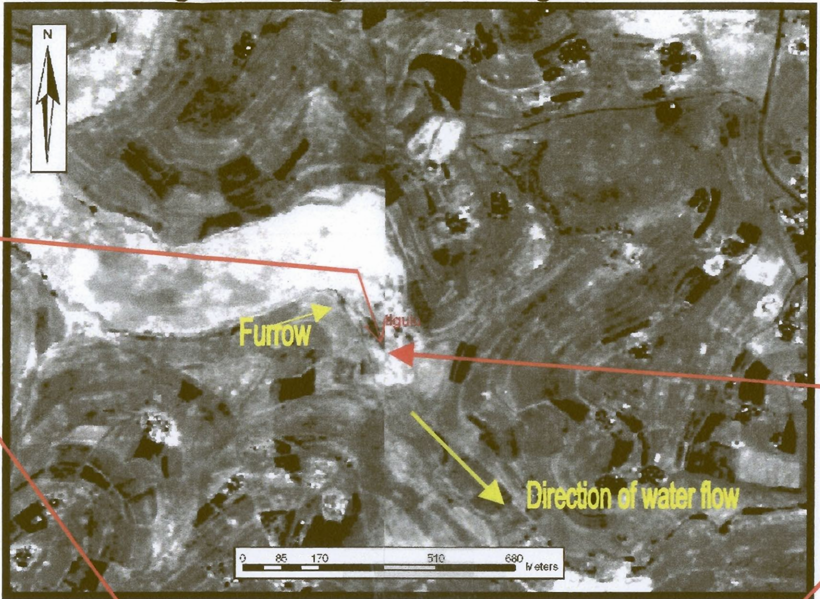


Figure 141: Subset of the EROStellite image at the Amatigulu site. Resolution: 1.8 m. quisition date: 24/12/2002

Figure 142: Subsistence farming.

Figure 143: Harvesting (*Phragmites australis*).

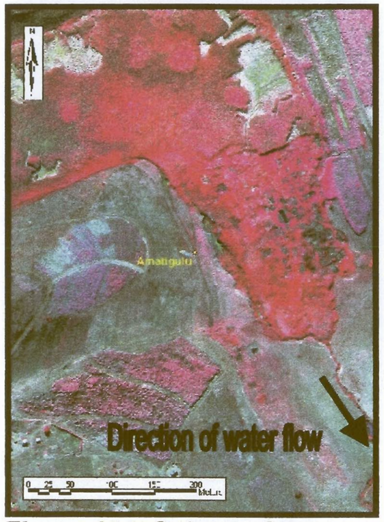
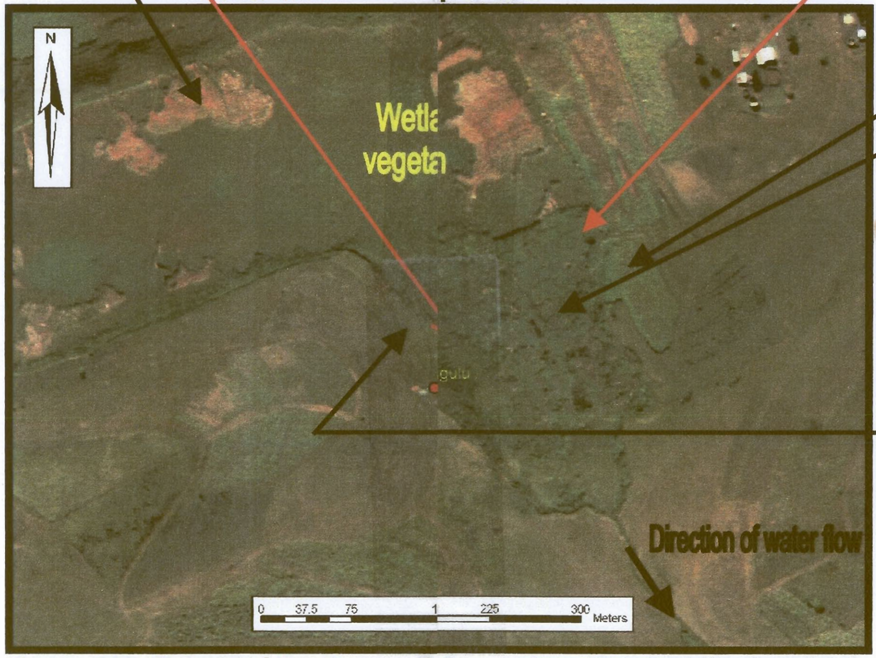


Figure 144: Subset of the DuncanTech CIR image At the Amatigulu site.



Cultivation
Commercial
Subsistence farming

Figure 145: Subset of the DuncanTe true colour image at the Amatigulu site. Resolution: 0.25 mequisition date: 09/06/2003.

Figure 146: Furrow diverting water away from the erosion feature for construction purposes.

4.2 LIMITATIONS AND RESTRICTIONS.

- The literature search involved inquiries with a time delay awaiting a response. In some cases no responses were received.
- Due to unforeseen circumstances and unsuitable flying weather the acquisition date of the DuncanTech imagery was not optimal in terms of the seasonal wetland characteristics.
- It was difficult to distinguish between sugar cane farming and grassland with wetland vegetation in study areas where the image acquisition date was not optimum for mapping the wetland vegetation (Mbongolwane, Zoar and Rietvlei wetlands).
- It was difficult to distinguish between wetland vegetation and the re-growth of alien vegetation in the Kromme River wetland. This problem also occurred with the Featherstone Kloof imagery (L. Haigh, *pers. comm.*)

CHAPTER 5: DISCUSSION

5.1 DISCUSSION

5.1.1 Description of selected indicators

- *Vegetation indicator mapping for relatively large areas.*

  The Multispectral data with band width 0.52 to 0.90 μm is of great importance and it should have a ground resolution of 1.8 m or better. It was possible to map the differences between wetland vegetation and other land cover classes with all the sensors. If detailed vegetation data were available it would be possible to map the different wetland vegetation zones with the data (resolution of 1.8 m – 0.5 m). This would make it easer to report on the status of the wetland rehabilitation.

- *Wetland zone vegetation mapping.*

  The season in which the image was acquired is very important. Wetlands in predominantly grassland biomes were very difficult to map because the images were not recorded at the optimum time. Spectrally the wetland and grassland vegetation were not adequately different.

- *Disturbance indicators.*

  The mapping and monitoring of disturbance indicators for land cover and land use practices around the wetland should be part of the rehabilitation and monitoring process. At the Kromme River and Mbongolwane wetlands, agricultural activities were clearly detected by the remotely sensed data.

- *The wet surface area indicator.*

  Could be detected as a result of the vegetation response to the hydrological conditions in the wetland. If the increase in flooding and increase in duration of the floods is sufficient, the changes in the hydrological regime of the wetland will imply a change in the plant communities (from terrestrial dominated species to more aquatic species). It is extremely difficult to monitor the functional value of stream flow regulation (flood attenuation, water storage, base flow maintenance and ground water recharge and discharge) because it is influenced by external events such as rainfall, land use in the catchment area and the wetness of the wetland. In order to monitor the success of re-wetting and stream flow regulation, it is reasonable to assume that when the channels flood more frequently, the objective has been achieved.

- *Rehabilitation structures.*

  To map and monitor the status of the physical rehabilitation structure, data should be of a resolution of 1 m or better. The best results were from the Kodac DCS 420 (Near infrared), and DuncanTech CIR images. This would make it possible to detect structural damage, *erosion* activity, *open water* behind the structure and the movement of headcuts and gully erosion. If a sediment deposit is covered with water, the area will display dark and if sediment banks are colonized with vegetation, the vegetation will display red. In the last two examples the *sediment* deposit as such would not be evident.

- *Water quality*

  Open water areas were very small and the remote sensing images did thus not possess a blue band necessary to detect water quality. The water quality indicator was therefore not included in the classification scheme.

5.2 RECOMMENDATIONS

- In South Africa, there are few monitored wetland rehabilitation projects. Target objectives must be set for each wetland type or a process established whereby the quality of wetlands overall is managed.

- Close cooperation should be established between implementing agencies (such as LandCare, Working for Water and Working for Wetlands), Department of Water Affairs and Forestry, Department of Environmental Affairs and Tourism, National Department of Agriculture and the Mondi

Wetlands Project to compile a database with spatial rehabilitated wetland indicator data, and to ensure that information / data are not duplicated or lost.

- It is important to have adequate field points for the classification and verification of vegetation data.

- An indicator must be monitored over time. It is recommended that future possible studies include the following:
    - Determine the link between climate and spatial patterns of hydrology and ecological processes.
    - Analyses of the vegetation dynamics linked with the hydrology to investigate the change in wetland vegetation after rehabilitation. Recommended study areas and remote sensors for a possible study would be DuncanTech CIR imagery for Mbongolwane, Rietvlei and Seekoeivlei wetlands and Kodak DCS 420 for the Kromme River wetland.
    - Determining the ideal season to provide the optimum contrast between the classes to be mapped. Possibly two or more image acquisition dates might be required to separate all the classes of significance.

- A workshop with appropriate parties to compile an action plan to integrate the remote sensing data into wetland rehabilitation management. The results of the workshop should be used as a basis to select the most appropriate sensor for specific rehabilitated wetland areas as a practical comprehensive monitoring case study.

- Wetland rehabilitated indicators can only gain significance when changes in the wetland condition are indicative of how people manage the wetland with consequent detrimental or beneficial results. Disturbance indicators for land use and land cover practices in the catchment area of each wetland need to be investigated in the monitoring process of the rehabilitated wetlands.

- It is absolutely vital that the data are sufficiently retrospective, collected at the right time intervals, readily available and sufficiently up-to-date to provide the time series for trend analysis (Nell *et al.*, 2001).

5.3 CONCLUSION

It became evident during the evaluation of the different sensors that the resolution of the data would play a vital role in the mapping process, depending on the objective of the mapping. The choice between the different remote sensing sensors will largely depend on the application of the sensor; state of the rehabilitation structure or the vegetation response to the rehabilitation measures.

Selected indicators for rehabilitated wetlands, except water quality, were represented in all the wetland study areas. It can be concluded that the indicators tested on all six of the different wetland study sites do represent rehabilitated wetlands in general.

This report can be regarded as the first phase in the investigation of remote sensing sensors with regard to rehabilitated wetlands. It gives a general overview of the different sensors, their capabilities, limitations as well as associated costs. However, it is important to carefully consider the different needs of assessment for each rehabilitated wetland, before any of the high resolution remote sensing sensors can be recommended as the ideal option for the monitoring and auditing of rehabilitated wetlands.

Indication of the status of a rehabilitated wetland by the use of remote sensing techniques will only be meaningful if the aims of a project have been met with affordable and available data and if the monitoring process is done more efficiently than on-ground techniques. However, ground truthing will always be a requisite with the use of remote sensing techniques.

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APPENDIX 1

ABBREVIATIONS.
GLOSSARY OF TERMS.

ABBREVIATIONS.

AVHRR	Advanced Very High Resolution Radiometer
ATSR	Along Track Scanning Radiometer
CIR	Colour Infrared
DEM	Digital Elevation Model
DMSV	Digital Multi-Spectral Video
ERS	European Remote Sensing Satellite
ETM	Enhanced Thematic Mapper
GIS	Geographic Information System
GPS	Global Positioning System
IRVI	Infrared Vegetation Index
MODIS	Moderate Resolution Imaging Spectroradiometer
MAS	MODIS Airborne Simulator
MSS	Multi Spectral Scanner
NASA	National Aeronautics and Space Administration
NDVI	Normalised Difference Vegetation Index
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
PCA	Principal Component Analysis
RGB	True colour
RS	Remote Sensing
SPOT	Systeme Pour L'Observation de la Terre
TC	Tasseled Cap Spectral Index
Terra MODIS	Moderate Resolution Imaging Spectroradiometer
TM	Thematic Mapper

GLOSSARY OF TERMS.

Aerobic:

Having molecular oxygen (O_2) present.

Anaerobic:

Not having molecular oxygen (O_2) resent.

Biodiversity:

The variety of life in an area, including the number of different species, the genetic wealth within each species, and the natural areas where they are found.

Bogs:

A mire (i.e. a peat accumulating wetland) that is hydrologically isolated, meaning that it is only fed by water falling directly on it as rain or snow and does not receive any water from a surrounding catchment.

Catchment:

All the land area from mountaintop to seashore, which is drained by a single river and its tributaries.

Delineation (wetland):

To determine the boundary of a wetland based on soil, vegetation, and/or hydrological indicators, usually on a map.

Estuary:

Where the river and sea meet and the fresh water from the river mixes with the seawater.

Fens:

A mire (i.e. a peat accumulating wetland) that receives some drainage from mineral soil in the surrounding catchment.

Geomorphic:

Shape or surface configuration / structure of a landscape.

Ground truthing:

To determine features by direct measurement in the field.

Groundwater:

Subsurface water in the zone in which permeable rocks, and often the overlying soil, are saturated.

Groundwater table:

The upper limit of the groundwater.

Hydrology:

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

Hydrophyte:

Any plant that grows in water or in soil that is at least periodically anaerobic as a result of saturation; plants typically found in wet habitats.

Marsh:

A wetland which is seasonally or permanently flooded / ponded, with soils which remain semi-permanently or permanently saturated, and which is usually dominated by tall (usually > 1.5 m) emergent herbaceous vegetation, such as the common reed (*Phragmites australis*).

Mire:

A peat accumulating wetland, including both bogs and fens.

Monitoring:

The systematic acquisition of data on biotic and abiotic components of an ecosystem over a time range.

Mottles:

Soils with variegated colour patterns 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.

Orthorectified:

Corrected to the actual geo-referenced points on the ground.

Palustrine (System):

The palustrine system groups together vegetated wetlands traditionally called marshes, swamps, bogs, fens and vleis, which are found throughout South Africa. Palustrine wetlands may be situated shoreward of river channels, lakes or estuaries; on river floodplains; in isolated catchments; or on slopes. They may also occur as islands in lakes or rivers.

Panchromatic:

Sensitive to all colours.

Peatlands:

Wetlands with very high organic matter accumulation, which is referred to as peat. Wetlands with peat soils are referred to as bogs or fens.

Rehabilitation:

Rehabilitation is used primarily to indicate improvements of a visual nature to a natural resource; putting back the natural resource into good condition or working order.

Remote sensing (RS):

A general term for techniques that are used for imaging the earth surface from an airborne or space borne sensor.

Permanently wet soil:

Soil, which is flooded or waterlogged to the soil surface throughout the year, in most years.

Resolution:

Spatial resolution of a remote sensing sensor, is an indication of how well a sensor can record spatial detail.

Restoration:

Restoration is returning a site to approximately its condition before alteration, including its predisturbance function and related physical, chemical, and biological characteristics; full restoration is the complete return of a site to its original state.

Riparian:

The area of land adjacent to a stream or river that is influenced by stream-induced or related processes. Riparian areas, which are saturated or flooded for prolonged periods, would be considered wetlands and could be described as riparian wetlands.

Runoff:

Total water yield from a catchment including surface and subsurface flow.

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:

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.

Supervised classification:

A classification method that uses statistics based on sample training to classify an image.

Temporarily wet soil:

The soil close to the soil surface (i.e. within 40 cm) is occasionally wet for periods > 2 weeks during the wet season in most years. However, it is seldom flooded or saturated at the surface for longer than a month.

Unsupervised classification:

A classification method that involves algorithms that examine a large number of unknown pixels and divide them into a number of classes based on natural groupings.

Vlei:

A colloquial South African term for a wetland.

Wet grassland:

An area, which is usually temporarily wet and supports a mixture of plants common to non-wetland areas and hydrohytic plants (predominantly grasses).

Wetland:

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 under normal circumstances supports or would support vegetation typically adapted to life in saturated soil (Water Act 36 of 1998); land where an excess of water is the dominant factor determining the nature of the soil development and the types of plants and animals living at the soil surface.

Wet meadow:

An area, which is usually seasonally wet and dominated by hydrophytic sedges and grasses, which are common only to wetland areas.

Wetland signatures:

Contrasting colours and shades of colour or black and white that are indicative of hydric conditions associated with wetlands.

APPENDIX 2

LONGTERM AVERAGE RAINFALL DATA FOR THE WETLAND SITES.

LONGTERM AVERAGE RAINFALL DATA

Supplied by ISCW, Agromet section.

KROMME

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
51.2	49.9	59.6	57.8	53.8	52.3	54.3	68.4	59.4	68.7	64.4	53.8	693.7

MBONGOLWANE

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
138.5	134.5	110.8	57.6	40.4	25.1	25.7	38.2	70.3	106.3	124.6	126.6	998.6

WILGE

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
136.05	123.3	98.9	46.7	22.3	10.1	10.1	21.2	37.6	80.6	102.8	119.3	809.1

SEEKOEIVLEI

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
136.9	119.6	81.1	40.9	18	9	8.8	16.3	36.7	85.9	109.4	125.7	788.6

ZOAR

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
141.6	110.7	86.9	45.6	18.3	10.4	8.8	13.9	35.2	93.8	126.4	144.1	835.8

RIETVLEI

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
122.9	102.5	84.5	38.9	18	6.7	6.2	8.7	20.3	46.3	110.5	115.5	680.6

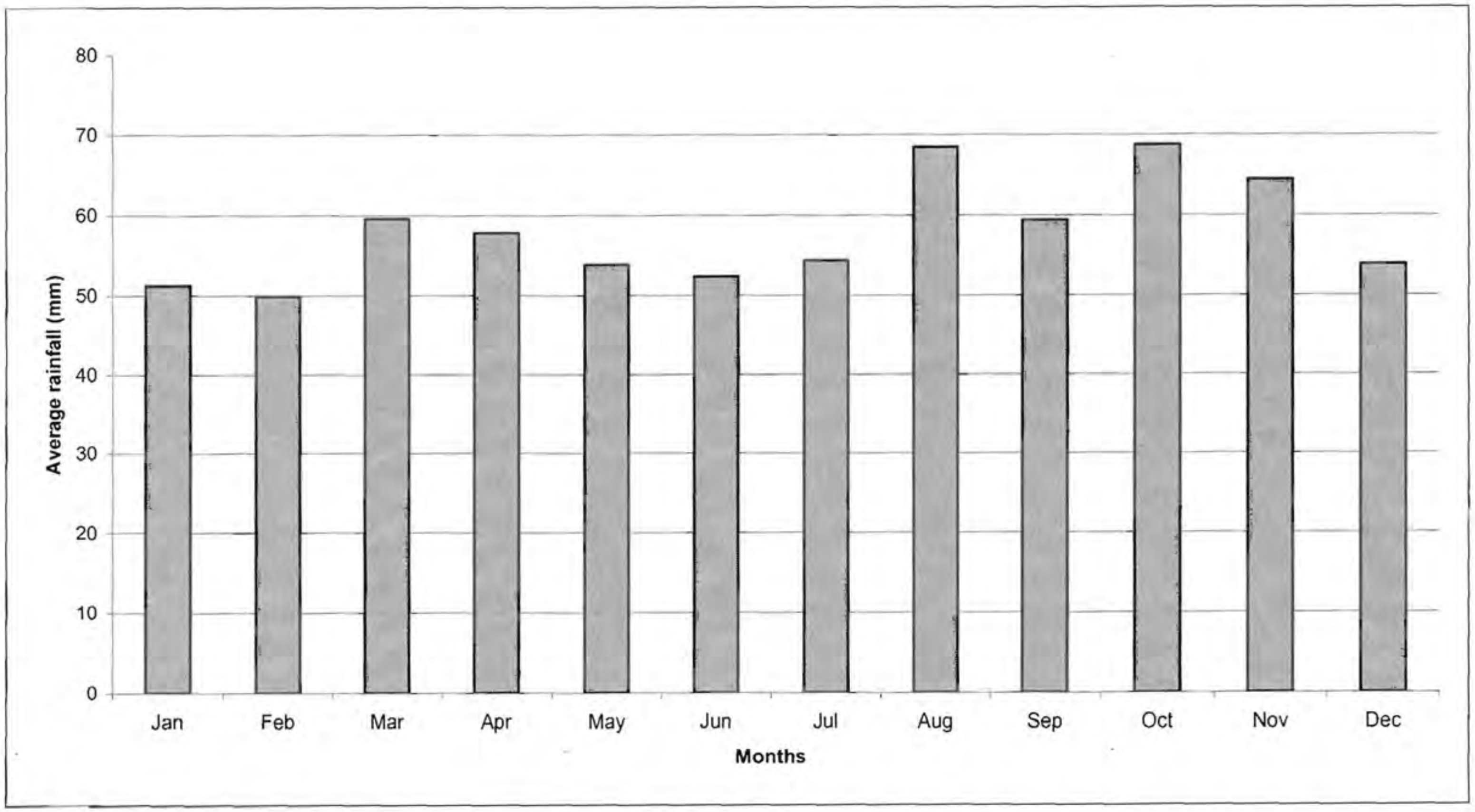

Figure a: Longterm average rainfall data in the Kromme River Wetland area indicate that the maximum rainfall occurs in August, October and November.

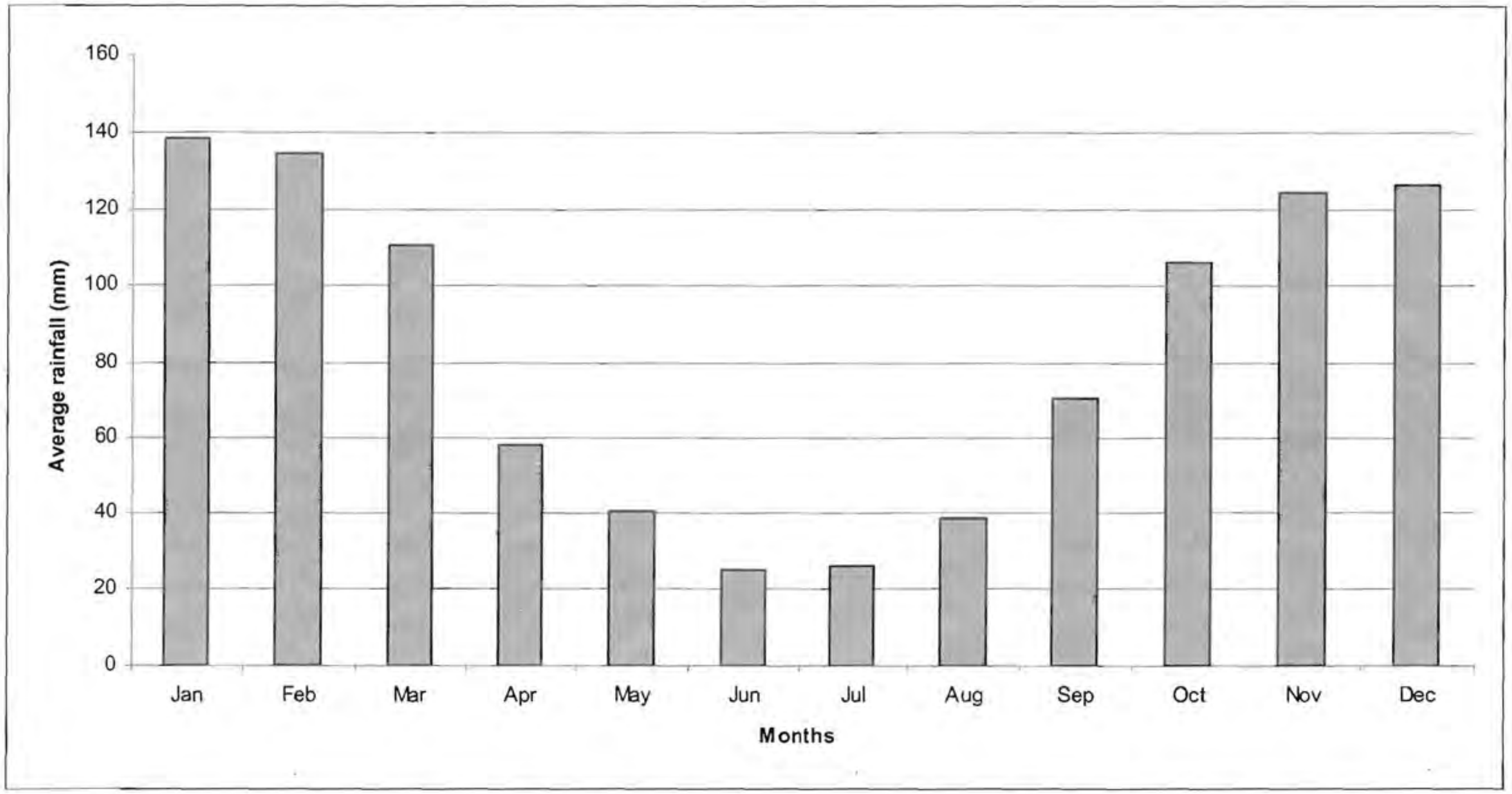

Figure b: Longterm average rainfall data in the Mbongolwane Wetland area indicate that the maximum rainfall occurs in December, January and February.

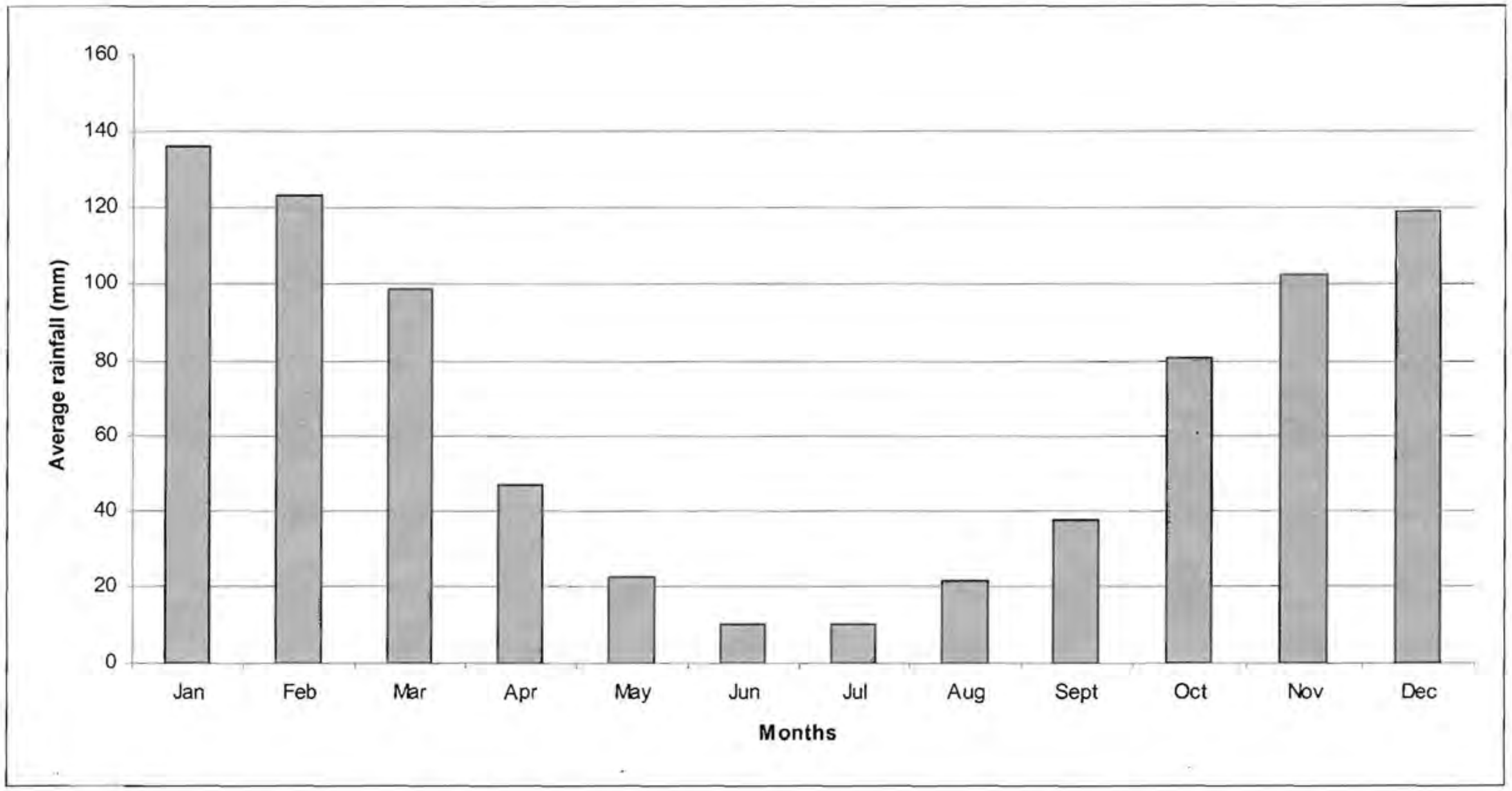

Figure c: Longterm average rainfall data in the Wilge River Wetland area indicate that the maximum rainfall occurs in December, January and February.

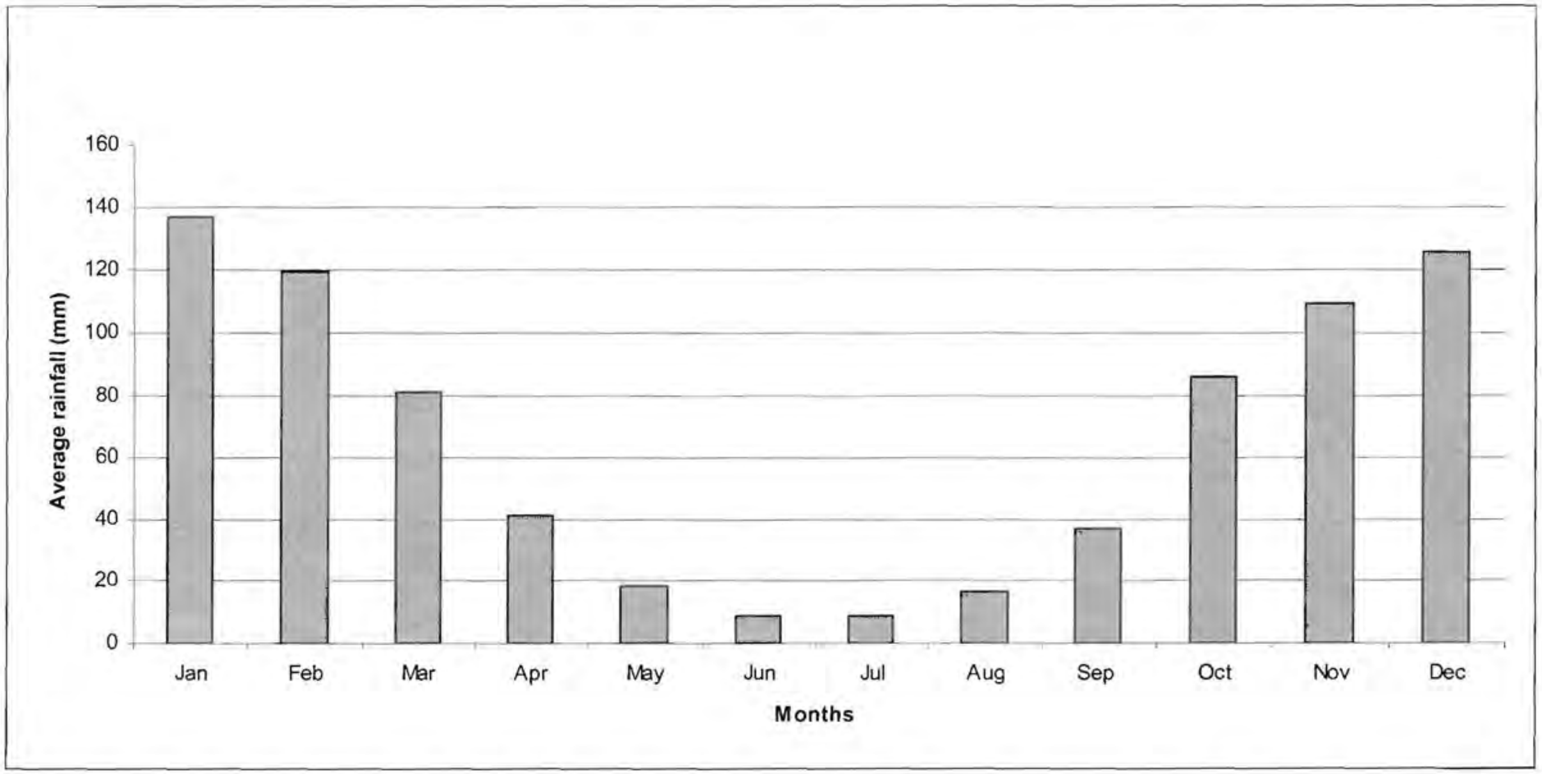

Figure d: Longterm average rainfall data in the Seekoeivlei Wetland area indicate that the maximum rainfall occurs in December, January and February.

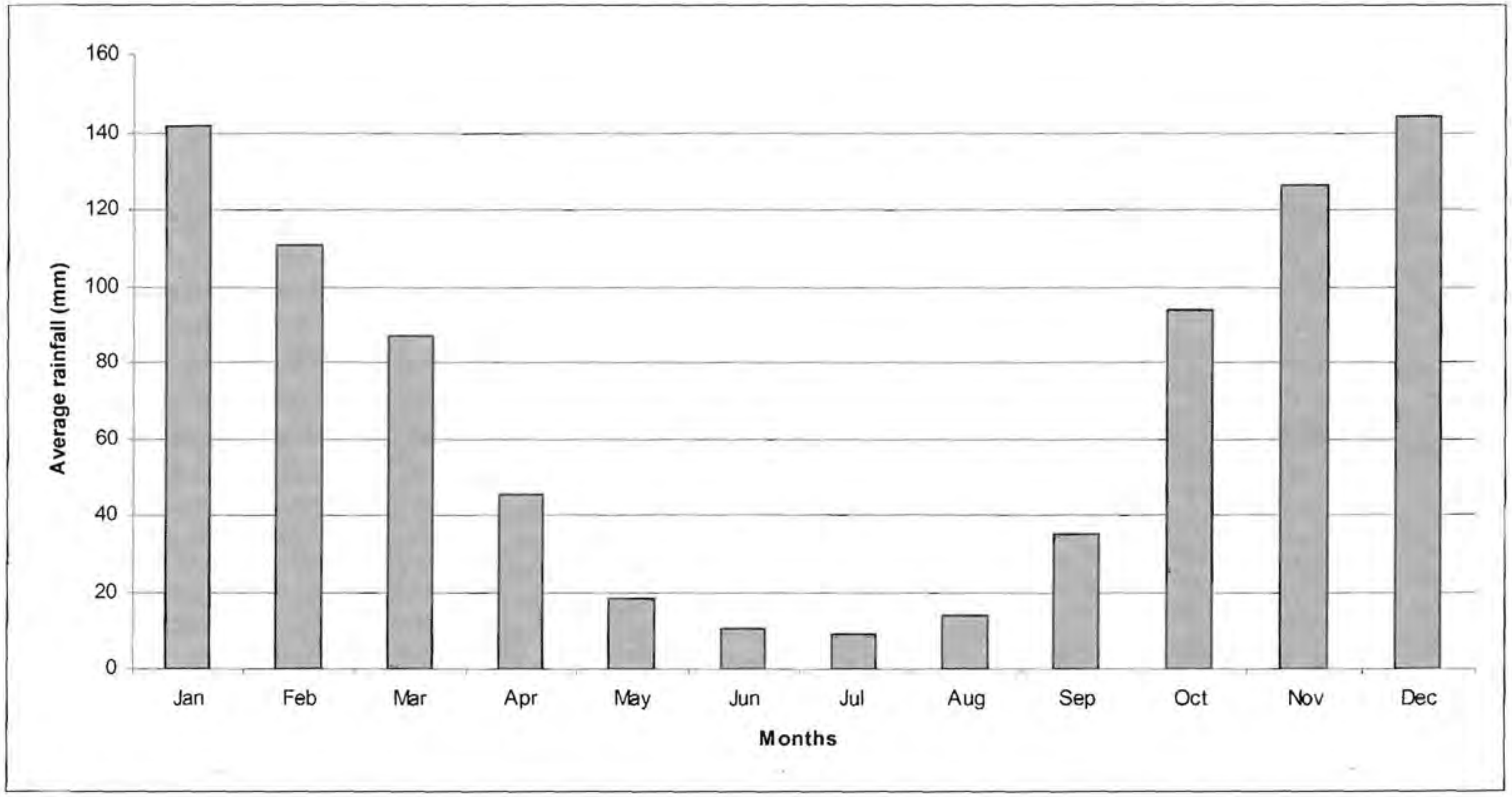

Figure e: Longterm average rainfall data in the Zoar Wetland area indicate that the maximum rainfall occurs in November, December and January.

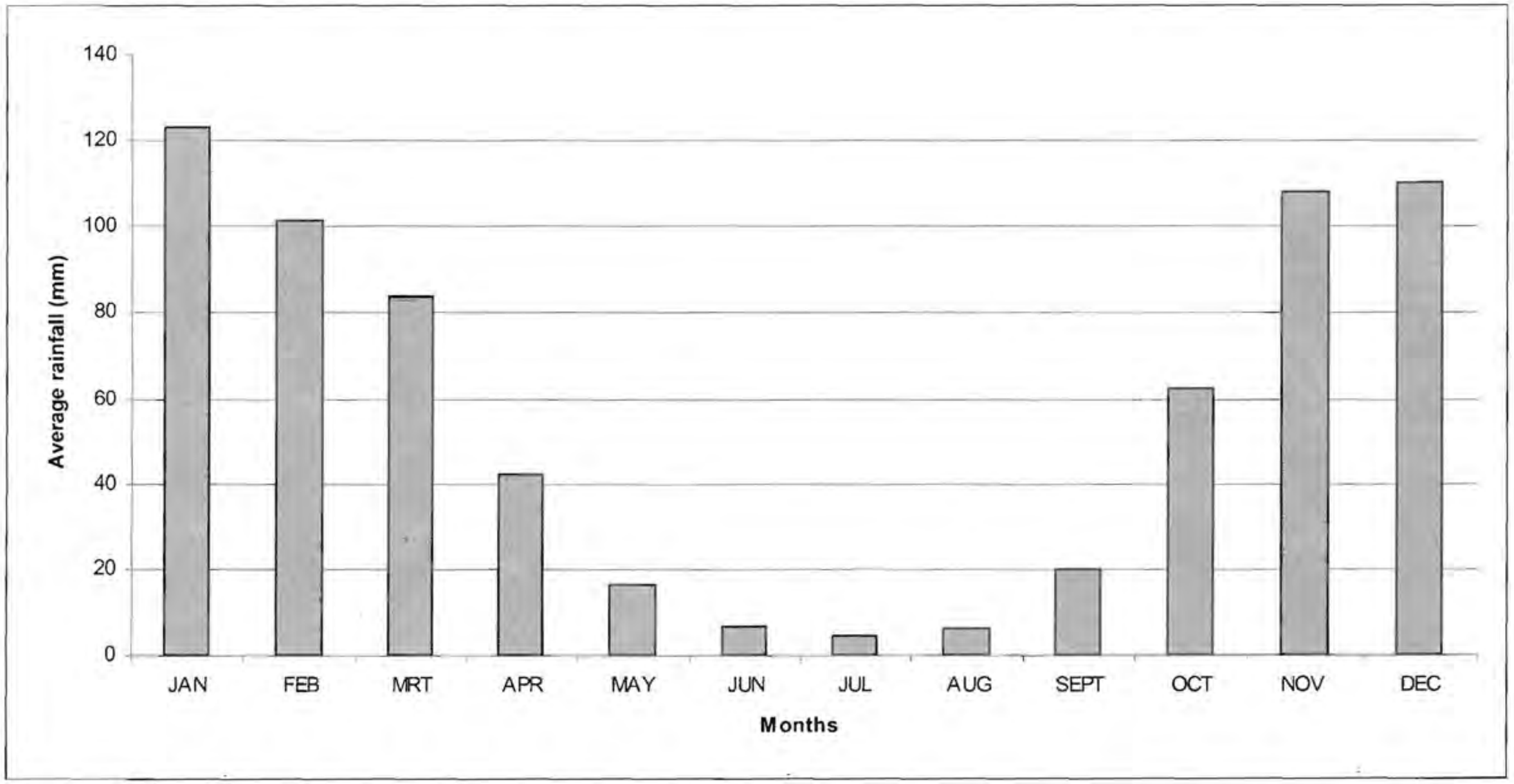

Figure f: **Longterm average rainfall data in the Rietvlei Wetland area indicate that the maximum rainfall occurs in November, December and January.**

APPENDIX 3

REHABILITATION MEASURES.

Rehabilitation measures applicable to the study.

(From notes prepared by Mr. Bill Russel (Haigh, 2002).

1. **Earth structures.**
   - **Earth plugs.**
     This method is to plug the gully or drain with soil plugs, thereby diverting concentrated water into the wetland. To prevent the runoff water to side-cut the gully / drain, the plugs have to be sited fairly close together in order to keep the water level in the gully / drain fairly high (Figure 1).

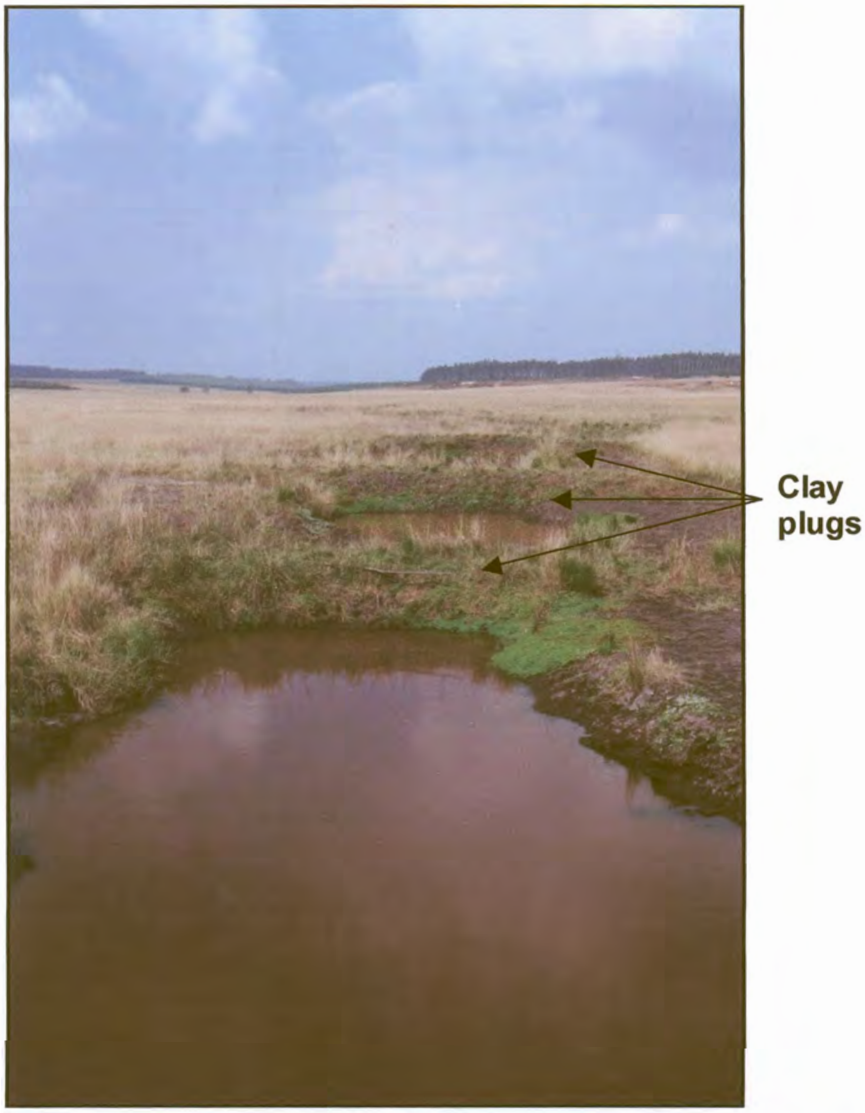

Figure 1: Water ponding behind clay plugs at the Zoar wetland after heavy rain. Photo: David Lindley.

- **Grass bales (Figure 2).**
  Cheap and effective way to stop erosion at low energy levels.

Figure 2: Grass bales used at the Rietvlei wetland.

- **Slope donga / gully sides (Figure 3 & 4)**
  Donga / gully sides need to be sloped and vegetated to halt lateral erosion by lowering the energy levels of the water (Haigh, 2002).

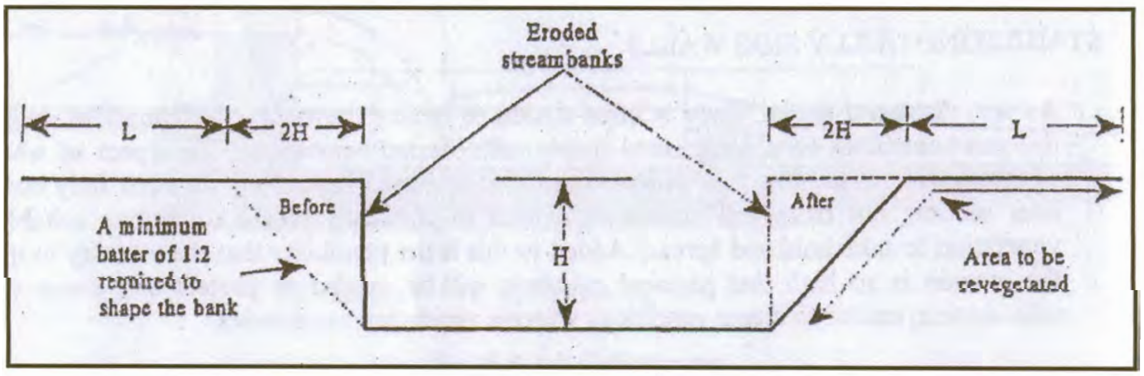

Figure 3: Sketch indicating the sloping of the donga sides and the area to be revegetated (Haigh, 2002).

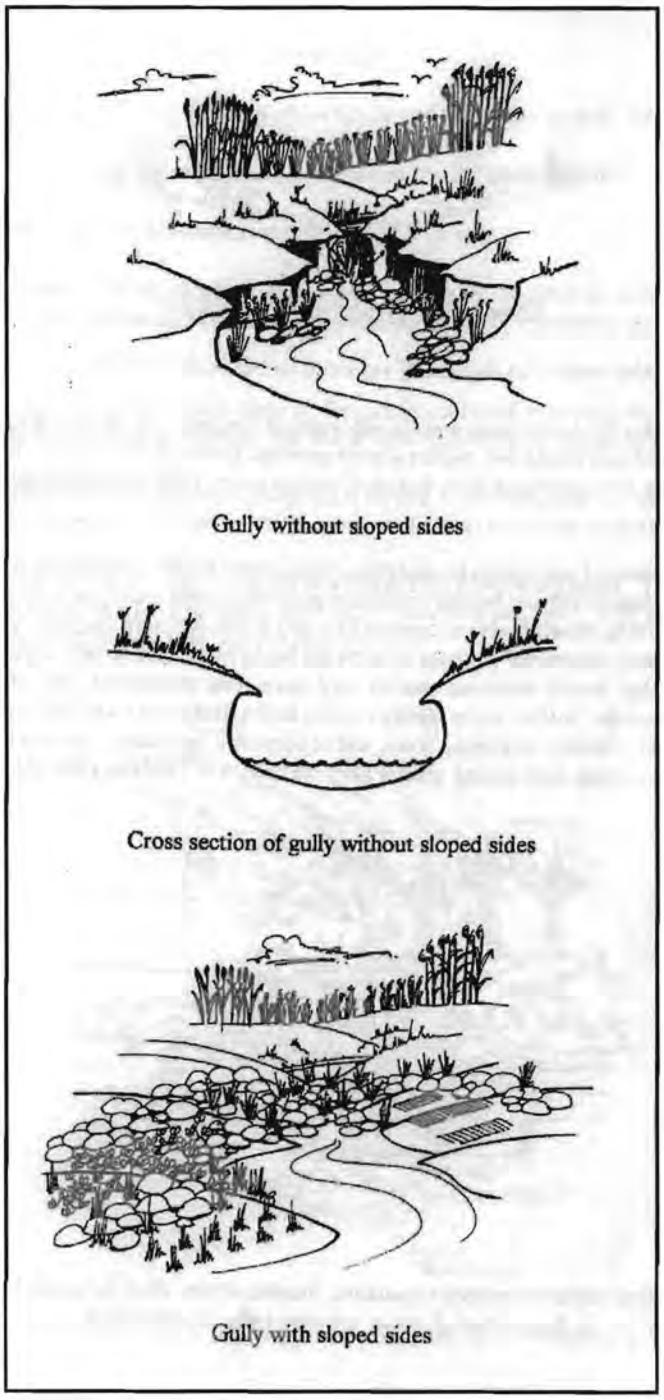

Figure 4: Sloping sides of a gully (Haigh, 2002).

- **Earthen embankment (Soil berm) (Figure 5).**
  The roll of an earthen embankment is to:
  1) Ensure that the floodwaters are forced through a constructed spillway;
  2) Cut off floodwaters from large areas of the wetland and cause changes in its functioning unless special provision is made downstream.

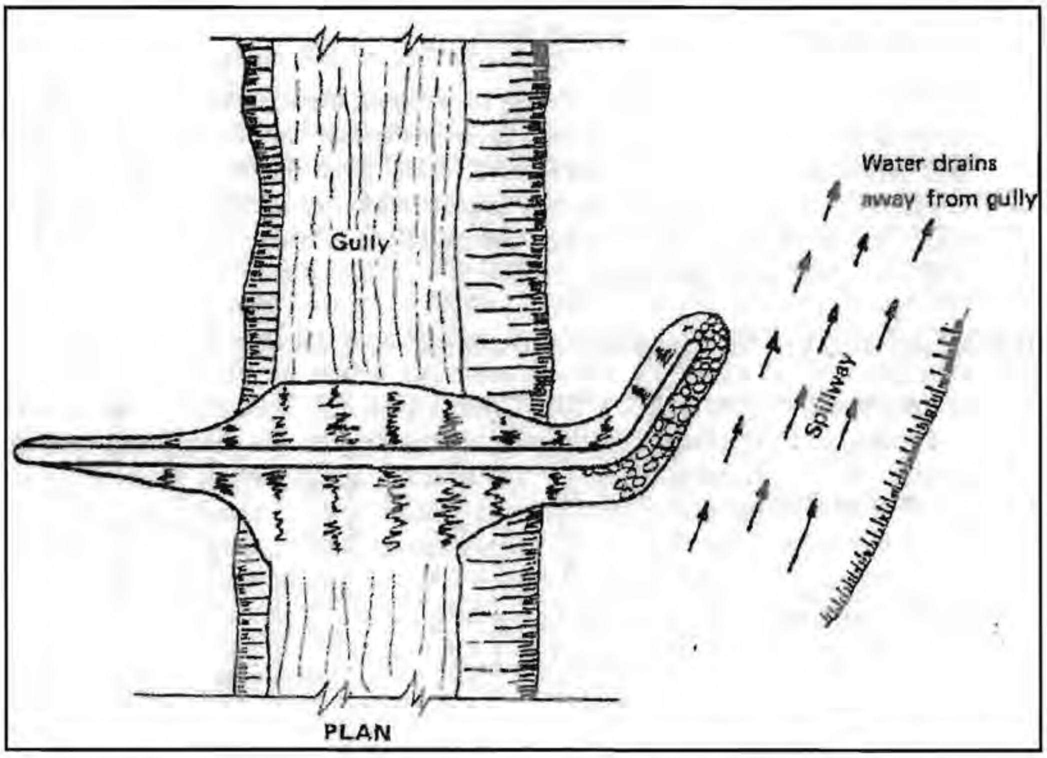

Figure 5: Earthen embankment diverting floodwaters (Haigh, 2002).

2. **Gabion structures (Figure 6 & 7).**
    - **gabion / reno energy dissipaters.**
      Gully control structures that keep floodwaters within the confines of the watercourse are required to cause both the deposition of sediment upstream and also to slow down the velocity of floodwaters downstream (Haigh, 2002).

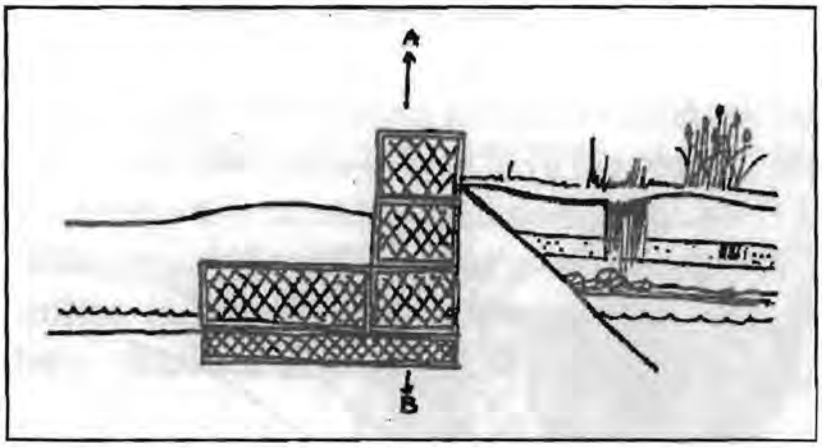

Figure 6: Cross section of recently constructed gabion structure (Haigh, 2002).

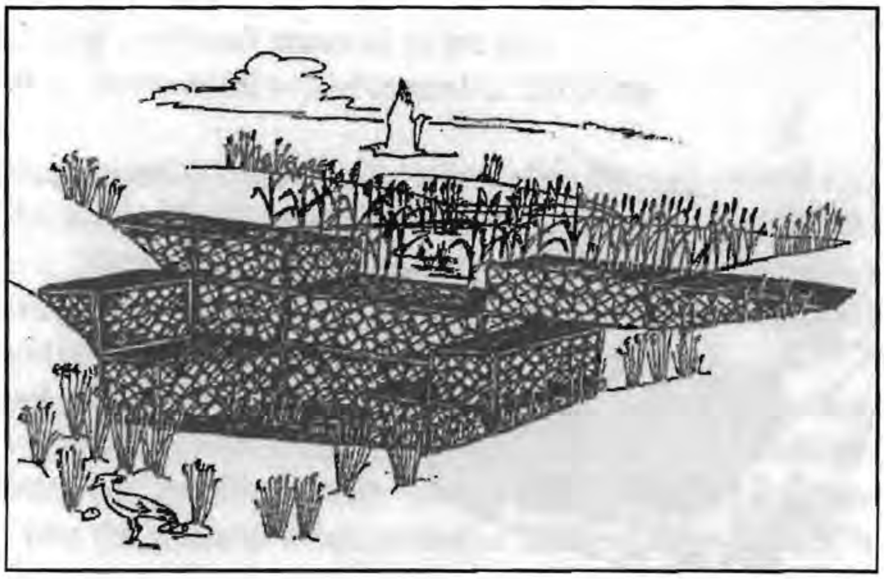

Figure 7: Suitably vegetated gabion structure (Haigh, 2002).

3. **Concrete structures.**
   - **Chute (Figure 8).**
     Chute structures may be defined as open canals with a steep slope (1:5 to 1:3) in which high energy water flows through a constructed spillway at super critical speed. They are used in areas where runoff has to enter a gully bed at a head- or side cut or as a spillway for an earthen dam (Haigh, 2002).

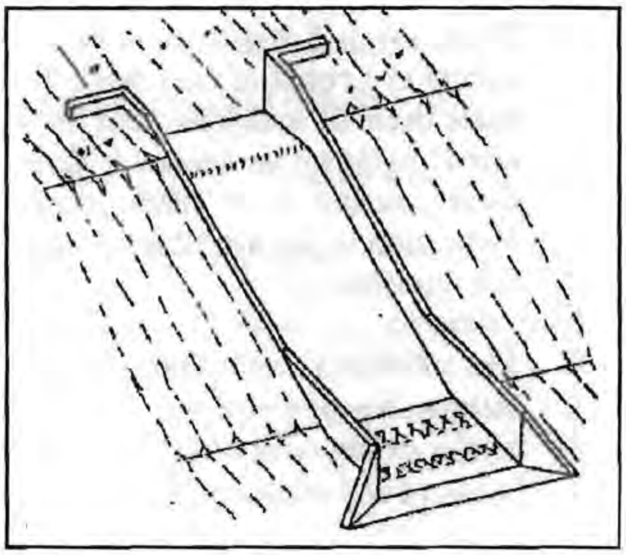

Figure 8: Chute design (Haigh, 2002).

   - **Groyne (Figure 9).**
     Stabilizing river and gully side-walls. Material that can be used:
   1. Sandbags
   2. Concrete

Figure 9: Groynes (Haigh, 2002).

- **Geo-cell (Figure 10 and 11).**
  Lining materials such as rubber compound tyres, rock-filled wire mattresses, gabion baskets or concrete cellular mattresses such as Geocell (Hyson cell), Armalite or inter-locking blocks could be considered if there is a concern that the topsoil and plantings will be washed away (Haigh, 2002).

Figure 10: Geocell lining at the Wilge wetland structure.

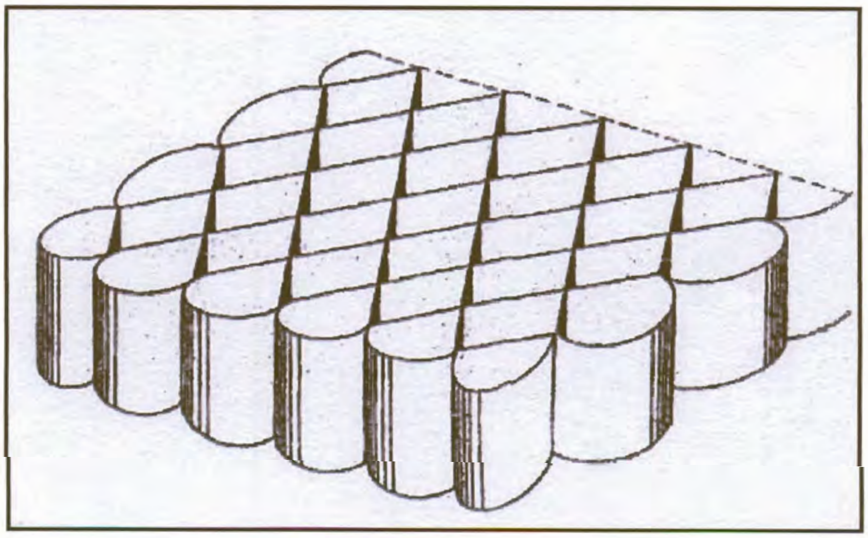

Figure 11: Sketch of Geocell (Hyson-cell) lining (Haigh, 2002).

- **Buttress weir (Figure 12).**
  These structures are made entirely of poured concrete and therefore need strong, durable rock slab foundation material on which to bond and greater skill in the construction (Haigh, 2002).

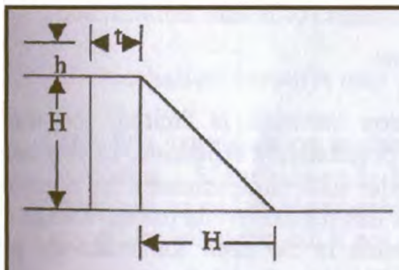

Fig. 5.8 (b) Buttress weir on *durable igneous rock*

- Use concrete mix C (Table 5.14)
- No 'plums' may be used in the concrete
- For cross section dimensions see below
- For key and shoulder walls see Figs. 5.8 (d)

* For any other condition of foundation consult an engineer.

1. Measure the length of available spillway (L)
2. $q = Q \div L$ in the units m^3 per sec per metre length
3. Consult table above for h and v
4. Consult table below for dimensions t and B. **All measurements are in millimetres**
5. *For any other foundation condition consult an engineer.or an experienced technician.

Figure 12: Buttress weir design (Haigh, 2002).

4. Revegetation of desiccated areas (Figure 13 & 14).

Wetland vegetation is generally good at controlling erosion by reducing wave and current energy; binding and stabilizing the soil; and recovers rapidly from flood damage (Kotze, 2000).

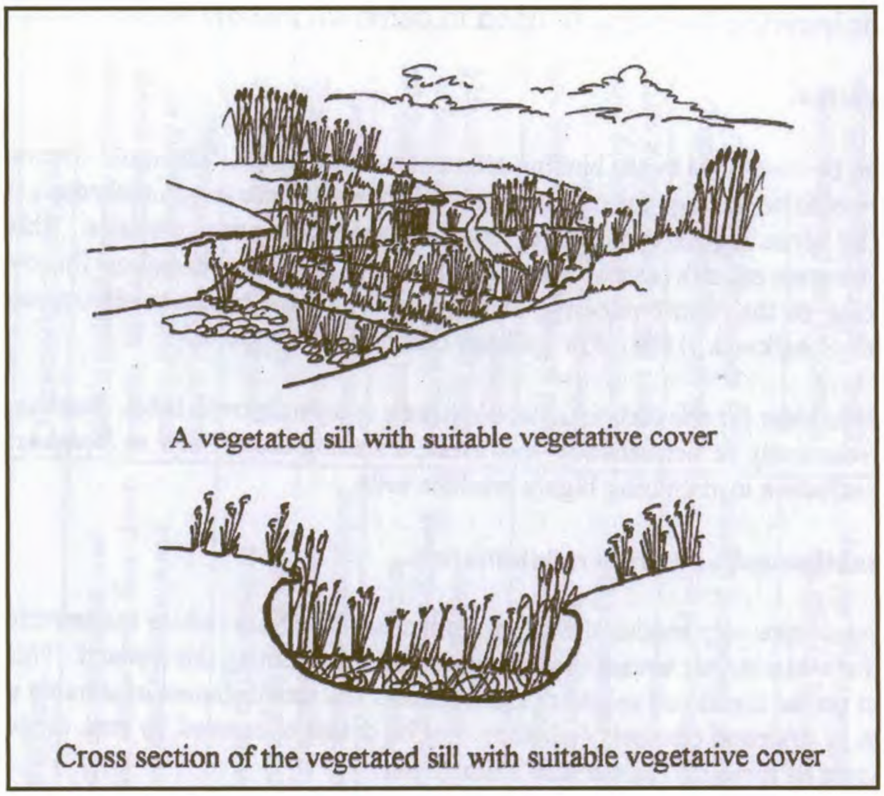

Figure 13: Sketch illustrating bioengineering (Haigh, 2002).

Figure 14: Bioengineering at the Wilge wetland structure.

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APPENDIX 4

FIELD VISIT AND PROGRESS REPORT.

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THE EVALUATION OF VARIOUS REMOTE SENSING SYSTEMS FOR USE IN THE AUDITING AND MONITORING OF REHABILITATED WETLANDS IN FIVE STUDY AREAS

FIELD VISIT- AND PROGRESS REPORT

(June - September 2002)

Compiled for Department of Agriculture:
Directorate Land and Resources Management

By

The Agricultural Research
Council: Institute for Soil, Water and Climate

And

Ihlaphosi Enviro Services cc

ARC • LNR

Report No: GW/A/2002/128

Project Leader: Chris Kaempffer

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YUNIBESITHI YA PRETORIA

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1) INTRODUCTION.

Working for Wetlands (WfWetlands) is a public private partnership between the Working for Water Programme, the Departments of Environmental Affairs and Tourism; National Department of Agriculture and the Mondi Wetland Project (an NGO). The core function of WfWetlands is to rehabilitate wetlands with the added benefits of poverty alleviation and creating wetland awareness. WfWetlands is the only major wetland initiative presently active in South Africa and it is important to measure and assure its success. This project is an ideal platform to evaluation various appropriate remote sensing systems on rehabilitated wetlands to test whether they could be used as management tools in the auditing and monitoring processes.

2) RESEARCH OBJECTIVES.

a) Identify various indicators that can be used to audit and monitor the impacts of rehabilitation in wetlands.
b) The evaluation of high resolution remotely sensed data such as DMSV (Near infrared), EROS, Kodak DCS 420 (Near infrared) and SPOT 5 images.
c) Recommendations are to be made regarding the most cost effective procedure for the auditing and monitoring of rehabilitated wetlands.

3) CURRENT STATUS OF THE PROJECT.

The current status of the project will be discussed in terms of each phase in which the project has been divided (refer to the Terms of reference).

a) **PHASE 1:**

i) Identifying local wetland authorities.

After numerous phone calls and e-mails the contact details and persons responsible for work done on each wetland were identified. (Appendix 1)

ii) Established contact with local authority and organized a meeting during field visit with them, yourselves, ISCW and NDA. Identify the time of field visit.

Contact was made with all the key-persons identified to inform them about the project. They were requested to provide any available baseline data and information. A date was confirmed to meet with them during the preliminary field visit (1-10 July 2002). Examples of these letters are presented in Appendix 2. All the relevant authorities were approached regarding permission to visit the wetland sites.

iii) Identify the most suitable time of image collection for the different wetlands with reference to most suitable date – and time frame and based on ecological parameters indicating the time when the info required, is most spectrally distinguishable.

After some discussions with the various wetland and remote sensing experts (Mr. Dirk Pretorius, Mrs. Eliria H. Haigh, Dr. Donovan Kotze, Mr. Mark Thompson, Mr. David Lindley, Ms. René Glen, Lesley Gibson and Nacelle Collins) concerning the ideal time for image collection it was concluded that there is no fixed date for each wetland. However, expert opinion suggests the windows of opportunity for each wetland as listed in Table 1.

Table 1: Image collection

Wetland	System	Time frame	Indicators
Kromme River – 25 200ha (Eastern Cape - Kareedouw)	Aerial photos Kodak DCS 420 (Near infrared) SPOT 5	Oct – mid Nov.	• Stabilization of erosion at various head cuts • Extent of the sedimentation • Restoration of wetland vegetation • Open water damming behind structures • Change in wet surface area • Cultivation
Mbongolwane – 1 400 ha (KwaZulu Natal – Eshowe)	Aerial photos DMSV (Near infrared) EROS	Dec Cultivation of Amadumbe (wetland plant) It gives good cover in December.	• Stabilisation of erosion • Restoration of wetland vegetation • Wetland zones • Open water damming behind structures – rewetting of the wetland area. • Cultivated areas
Seekoeivlei – 3 000ha (Free State – Memel)	EROS image LANDSAT	Jan- Feb	• Stabilization of erosion • Restoration of wetland vegetation • Open water damming behind structures • Change in wet surface area (Look at Oxbows)
Wilge River - 650ha (Free State - Harrismith)	DMSV (Near infrared)	Jan -Feb	• Stabilisation of erosion at head cut • Restoration of wetland vegetation
Zoar – 5 000ha (Mpumalanga – Piet Retief)	DMSV (Near infrared)	Dec, Jan and Feb	• Stabilisation of erosion • Restoration of wetland vegetation • Wetland zones • Open water damming behind structures – rewetting of the wetland area.
Rietvlei – 300 ha (Gauteng – Pretoria)	Aerial photos DMSV (Near infrared)	Dec, Jan and Feb Image collecting will only take place when funding is available.	• Stabilisation of erosion • Restoration of wetland vegetation • Rewetting of the wetland area.

For the purpose of wetland delineation, it is important to take photos 2-3 weeks after the start of the rainy season. (National Wetland Inventory, March 2002). The area adjacent to the wetland will still be relatively dry where as the wetland area will be wetter and thus more visible. The ideal time to observe and to collect images for, the different wetland zones and cultivated areas would be after the rainy season when the vegetation is in full bloom. It will thus be necessary to collect the rainfall data for each wetland area from previous years in order to form an opinion regarding the window of opportunities for the different wetlands.

Landsat images are available from National Department of Agriculture for each wetland. It will be used in the recommendations to be made regarding the most cost effective procedure for the auditing and monitoring of rehabilitated wetlands. To prevent double image collecting of an area, Mr. Mark Thompson was willing to check in the Geospace database if images were available for the different wetlands. Unfortunately, only images close to the wetlands were available that did not cover the wetlands.

Aerial photos are available for Mbongolwane, Kromme and Rietvlei wetlands.

(1) The reasoning behind the remote sensing systems chosen.

(a) Kromme River:

The wetland is a long linear feature in the Eatern Cape. To make it cost effective for the projects budget it was decided to make use of the Kodak DCS420 (Near infrared). Dr. Tony Palmer, who is stationed at Grahmstown, operates this system. At first SPOT 5 imagery was not listed as one of the remote sensing systems to be evaluated but if the budget would allow it, it would be a good exercise to compare the two systems on the same wetland. The interaction of all the indicators needs to be observed in this wetland.

(b) Mbongolwane:

At Mbongolwane it will be necessary to look at the different vegetation zones, cultivated areas and the two rehabilitation structures. For this wetland it was decided to use EROS and DMSV (Near infrared).

(c) Seekoeivlei:

The interaction of all the indicators needs to be observed in this wetland and therefore decided on EROS to look at the entire wetland system on the Seekoeivlei Nature Reserve as a whole.

(d) Wilge River:

The main reason for choosing DMSV (Near infrared) is because this wetland only has one rehabilitation structure at the headcut.

(e) Zoar:

By using DMSV (Near infrared) the entire wetland system and the different vegetation zones would be observed and the two remote system techniques compared for the same wetland.

(f) Rietvlei:

The Rietvlei wetland in the Rietvlei Nature Reserve is regarded as a rare asset in Pretoria (Gauteng). Initially not part of the project but due to its uniqueness it was included. To make it cost effective for the projects budget it was decided to make use of the DMSV (Near infrared) system of the Institute Soil Climate and Water witch is based in Pretoria.

iv) Deliverables.

A field visit- and progress report to be handed in on the 03 October 2002. (Hard copy + digital format).

v) Limitations to the report

- Between 17 and 22 July 2002 heavy, out of seasonal rainfalls were experienced at Mbongolwane. Flood damage occurred at two of the rehabilitation sites (Amatigulu and Uvova). The structures are still under construction and ought to be completed in November 2002. This can have a negative effect on image collecting if the structures are not completed.
- Rietvlei funding – a project proposal for Rietvlei was developed at the IMCG Symposium in France (13 – 23 July 2002) to apply for funding from the Global Peat Initiative (GPI) – sponsored by the Netherlands. We had to make changes to the proposal, and supply an endorsement letter from NDA plus the banking details of the ISCW. We are still waiting to hear if the proposal was successful or not. Decision expected by end of October 2002.

b) **PHASE 2:**

i) A desktop study on available general literature, maps and other data pertaining to the aims of the project.

The desktop study and a report will include the following:

- Baseline data known for each site.
- Image processing techniques known to be suitable for wetland monitoring (including satellite and remote sensing images available).
- Identifying and listing of provisional list of indicators, which could be used or identified by using remote sensing applications and techniques.

This part of the project already commenced with a literature search and the collection of baseline data for each wetland as well as the compiling of a list of indicators.

There is a reasonable amount of background information available on Mbongolwane, Kromme River and Rietvlei wetlands, including a few sets of aerial photos.

ii) Deliverables.

A baseline data report to be handed in on 11 November 2002.

iii) Limitations to the report.

- Baseline data for Zoar still unavailable. Various phone calls and follow-up have not yet delivered any results. However results are expected soon.
- The South African Wetland Action Group (SAWAG) meeting is to be held 28, 29 and 30 October in Cape Town. All prominent role players on wetlands will meet, as well as relevant parties for the identified projects. Baseline data and other information lacking for the report will be discussed (Appendix 3)
- Literature search involves inquiries that take time to respond to. Information gathered in German and French needs to be translated as well as each report and article needs to be evaluated.

c) **PHASE 3:**

i) **The preliminary field visit.**

(1) Kromme River, Mbongolwane, Seekoeivlei, Wilge River, Zoar.

The preliminary field visit for the five wetlands took place 1-5 and 8-10 July 2002. Representatives of the NDA, ISCW, and key persons of each wetland were part of the group. The itinerary for the preliminary field visit is attached in Appendix 4.

ISCW completed a project file in Arcview linking the following data gathered during the preliminary field visit:

- Wetland delineation on the 1:50 000 topographical maps.
- GPS waypoints around the wetland.
- Digital photos taken at each waypoint.
- Spreadsheet with wetland information collected on each site.

The opinion after the preliminary field visit was to focus specifically on the problems that existed in each wetland and on the rehabilitation measures that had been suggested to address such problems. Indicators were identified for each wetland that could be used to determine if the rehabilitation structures were successful or not (refer to Table 1).

(2) Rietvlei.

A preliminary field visit to the Rietvlei wetland on 28 August 2002 was combined with an arranged World Summit on Sustainable Development (WSSD) wetland tour to Rietvlei Nature Reserve in Gauteng.

Wetland information:

(a) Kromme (Eastern Cape).
Mr. Pierre Joubert, Mr. Edwil Moore and Mr. Chris Cowling accompanied the reacherch team to all the rehabilitation structures. Erosion, frequent fires and cultivated areas in the wetland were some of the main problems.

(b) Mbongolwane (Natal - Eshowe).
The research team visited Mbongolwane wetland on the 4th of July 2002. Vuyani Machi met with the team at the George Hotel and took the team to Mbongolwane. Sizakele Mthethwa accompanied the team all over the area. At two rehabilitation sites (Amatigulu and Uvova) the structures were still under construction during the visit. The research team also visited the communal vegetable garden and saw some small subsistence farming plots. Other human impacts on the wetland: washing and bathing in the wetland, sugarcane cultivation, some afforestation and sand mining. There is also the concern about possible cholera, bilharzia and malaria in the area. A planned broad walk across the wetland would enable the school children to cross the wetland safely everyday.

The key issues here are the small-scale cultivation plots, the size of a bathroom ($\pm$ 2 m X 2m). They were observed on aerial photos (1:30 000).

It is therefore necessary to be able to observe the proportions of cultivated plots on key areas. In 1995 Donovan Kotze did a baseline survey and he is keen to repeat the survey in December 2002 – January 2003.

This area has a high unemployment rate. WfWetlands and awareness campaigns are successful in training people about wetland benefits. The wetland lies in communal land and permission was requested from the Tribal authority to visit the area.

Traditional sleeping mats and conference bags @ R29.00 made from (Inkwane) *Cyperus latifolius* are a good example of sustainable utilization of the wetland resource and generates an income for the rural woman. The rehabilitation of the Mbongolwane wetlands is three-fold:

1. To secure the major gully
2. Rehabilitate the smaller dongas
3. Encourage farmers to withdrawal from sensitive areas in the wetland.

(c) Seekoeivlei (Free State - Memel).

Reports are available on past land use & disturbances. The name of the nature reserve in which the wetland occurs is called Seekoeivlei though the farm name is called Zeekoeivlei. The research team visited the wetland on the 2nd of July 2002 and was accompanied by the Reserve Manager – Mr. Georg Wandrag. Mr. Nacelle Collins from the Free State Department of Tourism, Environmental and Economic Affairs gave some valuable insight about the Seekoeivlei wetland.

(d) Wilge River (Free State - Harrismith).

According to Mr. Nacelle Collins the Wilge River wetland has been surveyed. The wetland stretches over three farms. These are:

- Bedford 2 1845 - The portion of the wetland containing peat is in this portion of the wetland.
- Chatsworth 388 - George Gallaway (083) 7022653
- Wilge River 319 - Willem de Jager (058) 62-32707 - The rehabilitation has been performed on this portion of the wetland, thus the reason why the wetland is called the Wilge wetland

The farmers were informed concerning the planned visit but were not able to join the team in the field that day. One rehabilitation structure was aimed to stop the head cut erosion.

(e) Zoar (Mpumalanga - Piet Retief).

During the field visit on the 3rd of July the wetland was dry and burned. Problem: fire break across the wetland. This needs to be addressed with mitigatory measures to ensure a win situation for all the parties involved. Mondi is the landowners on which the middle section of the wetland occurs. Land upstream and downstream belongs to private owners. However a good working relationship exists between the landowners.

(f) Rietvlei (Gauteng – Pretoria).

Appendix 5 contains information about the Rietvlei Wetland Rehabilitation

Project.

ii) Deliverable.
A visit- and progress report.

iii) Limitations to the report.

- Unfortunately Dr. Donovan Kotze (University of Natal) attended a conference 1-5 July 2002 and was not able to join the preliminary field visit team at Mbongolwane.

d) PHASE 4:

i) A preliminary field assessments and identification of test sites within each study site:

- Kromme River (Eastern Cape -Kareedouw).
- Wilge River (Free State – Harrismith).
- Seekoeivlei (Free State - Memel).
- Mbongolwane (KwaZulu Natal – Eshowe).
- Zoar (Mpumalanga – Piet Retief).
- Rietvlei (Gauteng – Pretoria) this was not part of the initial project proposal but is seen as a necessary extension of the project as only one peatland has been included in the proposal.

ii) Deliverable

- A report on the field assessment regarding possible changes and prognosis and subsequent recommendations also indicating the reasoning behind the selection of test sites as well as indicating their position.

iii) Limitations to the report

- Developments pending the South African Wetland Action Group (SAWAG) meeting: possible changes and prognosis and subsequent recommendations also indicating the reasoning behind the selection of test sites will be discussed as well as the fieldwork schedule (Appendix 3).

e) PHASE 5:

i) Carry out fieldwork to verify satellite and remote sensing images (processed by ISCW) and testing the suitability, accuracy and acceptability of identified indicators and possible recommendations with the support of ISCW – remote sensor. Determine and interpret cover patterns for each indicator listed and identified (vegetation, water, land use) in the above mentioned areas.

Compiling a report on all 6 study sites containing the information mentioned above as well as the following:

a) Fieldwork information and maps (map production and GIS done in assistance with ICSVCW remote sensor.
b) Determine if the identified indicators are represented in the wetlands as well as indicating whether the indicators are representative of the wetlands.
c) Existing and newly established knowledge of the indicators.
d) A validation of selected indicators after image processing will be done through

field observations to determine the accuracy of the indicators.

ii) Deliverables
A detailed suitability report (after approved draft in consultation with NDA and ISCW) on the accuracy and suitability of the selected indicators per wetland, with recommendations and possible other indicators to be investigated.

The deadline date for the final report is: 28 February 2002.

f) PHASE 6:
i) Reproduction of final maps and report by ISCW.

4) INTERNATIONAL SYMPOSIUM ON VEGETATION MONITORING
I will use this study as a basis for my MSc with Prof. George Bredenkamp (African Vegetation and Plant Diversity Research Centre, Department of Botany, University of Pretoria) and therefore wish to submit an abstract for a poster presentation at the:
International Symposium on Vegetation Monitoring
March 24 – 26, 2003,
Swiss Federal Research Institute WSL
Birmensdorf, Switzerland.

Appendix 1: Contact details of key persons.

Contact details of key persons.

NAME	INSTITUTION	TELEPHONE NO.	FAX NO.	CELL NO.	E-MAIL
Kromme River (Eastern Cape -Kareedouw)					
Mrs. Eliria H. Haigh	Institute for Water Research (IWR)	046 622 2428 or 046 603 8532	046 622 9427	083 256 6578	lilh@iwr.ru.ac.za
Mr. Pierre Joubert	Gamtoos Irrigation Scheme	042 283 0329		082 553 0947	gamtoos@lantic.net
Mr. Edwil Moore	Working for Wetlands – Joubertina	042 273 244			
Mr. Vincent Eagen		042 296 2855		082 737 0607	
Mbongolwane (KwaZulu Natal – Eshowe)					
Dr. Donovan Kotze	University of Natal - Institute of Natural Resources			082 548 9646	kotzeD@na.ac.za
Mr. Damian Walters	Mondi Wetlands Project, National Training Coordinator			083 684 8000	
Mr. Paulis Dlamini	Local Working for Wetlands Manager			083 656 5185	
Ms. Sizakele Mthethwa	(LandCare facilitator)			082 348 4237	
Mr. Vuyani Machi	(Farmers support group)			072 486 2579	
Seekoeivlei (Free State - Memel)					
Mr. Nacelle Collins	Dept. Tourism, Environmental and Economic Affairs, Free State)	058 622 3520		082 449 9012	nbc@ohs.dorea.co.za
Mr. Georg Wandrag	(Reserve Manager)	058 924 0183	058 924 0159	082 779 3410	kubu@intrcom.co.za
Wilge River (Free State - Harrismith)					
Mr. Nacelle Collins	Dept. Tourism, Environmental and Economic Affairs, Free State.)	058 622 3520		082 449 9012	nbc@ohs.dorea.co.za
Mr. Piet Blom & Mr. Jurie Blom	Farms. The portion of the wetland containing peat is in this portion of the wetland (Bedford 2 1845)	058 623 0070			
Mr. George Gallaway	Farmer (Chatsworth 388)		058 623 1816	083 702 2653	
Mr. Willem de Jager & Mr. Kobus de Jager	Farmer (Wilge River 319) The rehab has been performed on this portion of the wetland.	058 62 32707		083 629 9611	
Zoar (Mpumalanga – Piet Retief)					
Mr. David Lindley	Mondi Wetlands Project			083 222 9155	lindley@wetland.org.za
Mr. Francois Maritz	(Environmental manager for the whole of that area)			082 800 2165	Francois_maritz@mondi.co.za
Mr. Hagen Gevers	(Forester)	017 820 0205	017 820 0743	082 650 6958	
Mr. Mark Prigge	previous forester for Zoar				
Rietvlei (Gauteng – Pretoria)					
Mr. Riaan Marais	Rietvlei Nature Reserve Manager	012 345 2274			
Mr. Rodger Browne	Working for Wetlands	012 667 1815		082 358 8712	

Appendix 2: Examples of letters.

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FAX COVER PAGE

TO: George Gallaway (Piet & Jurie Blom)

DATE: 24 June 2002

FROM: Althea Grundling
Ihlaphosi Enviro Services cc
P.O. Box 912924
SILVERTON
0127

e-mail: peatland@mweb.co.za
tel/fax: (012) 808 5342

PAGES: 2

COMMENT:

Dear George Gallaway (Piet & Jurie Blom)

A project has been awarded to ISCW for a pilot study to evaluate various remote sensing systems for use in the auditing and monitoring of rehabilitated wetlands. A preliminary field visit to the Wilge wetland is planned for **1 July 2002.**

The main purpose for the preliminary field visits:

- It will serve as an introduction of the five wetlands involved in the study (Wilge River, Zeekoeivlei, Zoar, Mbongolwane and Kromme River) to the study team.
- Meet with and inform all key persons involved with the wetlands about the project.
- The idea is not to do intensive field surveys but to explore the wetland terrains on a broad scale. Baseline data has already been done for each one.

The Preliminary Field Visit Group:
Chris Kaempffer (Institute Soil Climate and Water - Pretoria) Cell: 083 287 4113
Eric Economan (Institute Soil Climate and Water - Pretoria) 012 310 2500
Elna van den Berg (Institute Soil Climate and Water - Pretoria) 012 310 2500
Terry Newby (Institute Soil Climate and Water - Pretoria) 012 310 2500
Tony Palmer (Institute Soil Climate and Water - Rhodes)
Dirk Pretorius (National Department of Agriculture) 012 319 7545
Georg Schutte (National Department of Agriculture) 012 319 7551
Althea Grundling (Ihlaphosi Enviro Services cc) 012 808 5342

Attached: The itinerary for the preliminary field visits.
The time planned for the visit **9:30 – 15:00.** We will phone on the 1st of July to arrange a suitable venue for us to meet you.

Groetnis
Althea Grundling

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

FAX COVER PAGE

TO: Kodus de Jager en Willem de Jager

DATE: 24 June 2002

FROM: Althea Grundling
Ihlaphosi Enviro Services cc
P.O. Box 912924
SILVERTON
0127

e-mail: peatland@mweb.co.za
tel/fax: (012) 808 5342

PAGES: 2

COMMENT:

Dear Kodus de Jager en Willem de Jager

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Althea Grundling (Ihlaphosi Enviro Services cc) 012 808 5342

Attached: The itinerary for the preliminary field visits.
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Groetnis
Althea Grundling

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FAX COVER PAGE

TO: Reserve Manager: Georg Wandrag
(058 924 0183 or 082 779 3410)

DATE: 13 Augustus 2002

FROM: Althea Grundling
Ihlaphosi Enviro Services cc
P.O. Box 912924
SILVERTON
0127

e-mail: peatland@mweb.co.za
tel/fax: (012) 808 5342

PAGES: 1

COMMENT:

Dear Geoge Wandrag

Herewith the information concerning the wetland project that was unsuccessfully e-mailed to you before the field visit at Zeekoeivlei on the 2nd of July 2002.

A project has been awarded to ISCW for a pilot study to evaluate various remote sensing systems for use in the auditing and monitoring of rehabilitated wetlands. A preliminary field visit to the Zeekoeivlei wetland took place on the 2nd **of July 2002.**

The main purpose of the preliminary field visits:

- It will serve as an introduction of the five wetlands involved in the study (Wilge River, Zeekoeivlei, Zoar, Mbongolwane and Kromme River) to the study team.
- Meet with and inform all key persons involved with the wetlands about the project.
- The idea is not to do intensive field surveys but to explore the wetland terrains on a broad scale. Baseline data has already been done for each one.

The Preliminary Field Visit Group:

Chris Kaempffer (Institute Soil Climate and Water - Pretoria) Cell: 083 287 4113
Eric Economan (Institute Soil Climate and Water - Pretoria) 012 310 2500
Elna van den Berg (Institute Soil Climate and Water - Pretoria) 012 310 2500
Dirk Pretorius (National Department of Agriculture) 012 319 7545
Althea Grundling (Ihlaphosi Enviro Services cc) 012 808 5342

Please accept my apologies for sending you the information now. I have attended a Symposium in France and had huge e-mail problems.

I will inform you soon concerning the development of the project.

Groetnis
Althea Grundling

Appendix 3: South African Wetland Action Group Meeting.

peatland

From: peatland <peatland@mweb.co.za>
To: <christa.le_roux@capetown.gov.za>; <rondevlei@sybaweb.co.za>; JONES, G, GENEVE, STUDENT <gjones@botzoo.uct.ac.za>; <BelcheA@dwaf.gov.za>; Lesley Gibson <Lesley@geobell.org.za>; <shawka@cncjnk.wcape.gov.za>; <impsond@cncjnk.wcape.gov.za>; <gvika@pawc.wcape.gov.za>; <patrick@wessa.wcape.school.za>; <Candice.Haskins@capetown.gov.za>; <Craig.Haskins@capetown.gov.za>
Cc: Coetzee Jacqui (CPT) <Jacqui@dwaf.gov.za>; <davidkl@nda.agric.za>; John Dini <Jdini@ozone.pwv.gov.za>; David Lindley <lindley@wetland.org.za>
Sent: Wednesday, September 25, 2002 11:53 PM
Subject: South African Wetland Action Group (WAG) : Meeting in October.

Dear All

I am writing to you on behalf of John Dini, DEAT, Pretoria.

We are planning our annual SA Wetland Action Group (WAG) meeting from 28 - 30 October 2002. The purpose of SAWAG is for field workers, administrators and scientists active in wetland conservation to maintain effective linkages, exchange ideas and experiences and to co-operate on initiatives of common interest. The focus of the group is on palustrine (marsh/floodplain) wetlands, a wetland type that has generally been overlooked in the past. A key emphasis of the Group is on actions in the field, rather than merely serving as a talk-shop.

We have identified the Western Cape as one of our focal areas in terms of supporting existing efforts by Western Cape environmental/conservation persons (such as yourself), bodies and authorities in raising wetland awareness and in wetland conservation. We have thus decided to have the WAG meeting of 28 – 30 October in the Cape Town area (the last meeting was held in Nysvlei – Limpopo Province, last year) and we would like to invite you to attend the meeting in Cape Town. It is important for us to hear from you about your experiences in dealing with wetlands, such as projects, challenges, problems, policies etc.

The Ramsar wetland theme for this year is: Wetlands - water, life, culture. It may also be an appropiate theme for the WAG meeting!

We would also appreciate it if you can be directly involved in the arrangements of this event:

- We are looking for a suitable venue that will hold about 40 - 60 people, that is appropriate for a meeting with a wetland theme, and which preferably has accommodation as well. Some of the wetlanders must pay for their own travel, accommodation and food and we would like to have venue that is not expensive – we are also not charging any fees towards WAG participants.
- Toni Belcher (DWAF regional office) have offered us the DWAF conference facilities (no cost – but accommodation close by may presents a problem) in Bellville and Dalton Gibbs (Nature Conservation Officer, City Of Cape Town) have offered us the facilities Rondevlei Nature Reserve at good rate – accommodation close by at a good rate might still present a problem. We would love to visit some wetlands/projects on Wednesday 30 October, and perhaps you have some suitable venue' s in mind.
- The agenda is not fixed yet and suggestions from you would be appreciates such as a plan for how to go about establishing a provincial wetland forum (who should take the

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lead, etc)

Could you please indicate if you are available during this time and if you could support with arrangements and in the provision of a venue and accommodation? We need to send out final invitations early next week and we would appreciate a prompt response.

We are also planning to have the annual national Working for Wetlands (WfWet) Project Management meeting at the same venue back-to-back with the WAG meeting (and you are welcome to attend this meeting as well). This meeting will mainly deal with wetland rehabilitation implementation issues. Most of the WfWet project managers will attend WAG as well. WfWet is a partnership between Working for Water (via DWAF), DEAT and the Mondi Wetland project, as well as NDA.

The topics on the Agenda for the WFWet PM Meeting are the following:

- Norms and Standards for wetlands
- Wetland Quotation Package
- Workshop Wetland Self Assessment Standards
- Introduce Wetland WIMS to PM
- Project approval process for 2003/2004

Groet'nis and I trust I will hear soon from you.

Piet-Louis

Piet-Louis Grundling
DEAT Working for Wetlands Co-ordinator
Working for Water Programme
Private Bag X352
Hartbeespoort
0216
e-mail:
tel/fax: (012) 808 5342
cell: 083 231 3489

Appendix 4: Itinerary for the preliminary field visit.

Preliminary field visit itinerary.

DATE	WETLAND	PROGRAMME
1 July 2003	Wilge River	**Departure:** Pretoria 06:00 **Arrive:** Harrismith 09:30 **Departure:** Wilge 15:00 **Arrive:** Memel 16:30
2 July 2003	Seekoeivlei	**Departure:** Seekoeivlei 15:00 **Arrive:** Piet Retief 16:30
3 July 2003	Zoar	**Departure:** Zoar 13:00 **Arrive:** Eshowe 16:00
4 July 2003	Mbongolwane	Mbongolwane
5 July 2003		**Departure:** Pretoria 07:00 **Arrive:** Harrismith 13:30
8 July 2003		**Departure:** Pretoria 06:00 **Arrive:** Harrismith 17:00
9 July 2003	Kromme River	Kromme River Wetland
10 July 2003		**Departure:** Kareedouw 06:00 **Arrive:** Pretoria 17:00

Appendix 4: Itinerary for the preliminary field visit.

Preliminary field visit itinerary.

DATE	WETLAND	PROGRAMME
1 July 2003	Wilge River	**Departure:** Pretoria 06:00 **Arrive:** Harrismith 09:30 **Departure:** Wilge 15:00 **Arrive:** Memel 16:30
2 July 2003	Seekoeivlei	**Departure:** Seekoeivlei 15:00 **Arrive:** Piet Retief 16:30
3 July 2003	Zoar	**Departure:** Zoar 13:00 **Arrive:** Eshowe 16:00
4 July 2003	Mbongolwane	Mbongolwane
5 July 2003		**Departure:** Pretoria 07:00 **Arrive:** Harrismith 13:30
8 July 2003		**Departure:** Pretoria 06:00 **Arrive:** Harrismith 17:00
9 July 2003	Kromme River	Kromme River Wetland
10 July 2003		**Departure:** Kareedouw 06:00 **Arrive:** Pretoria 17:00

Appendix 5: The Rietvlei Rehabilitation Project.

CITY OF TSHWANE
"We are the same"

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WORKING FOR
Patron in Chie
Nelson Mande

The Rietvlei Wetland Rehabilitation Project

The Rietvlei Wetland Rehabilitation project lies within the Rietvlei Nature Reserve – owned and managed by the City of Pretoria/Tswane. The Rietvlei Dam provides 15% of Pretoria's water and the area contains Bankenveld – grassland under threat in the Gauteng region.

The rehabilitation of Rietvlei is important because it:

- Promotes waste water purification through the natural systems of reeds and peat.
- Addresses the control of alien, invasive plant species
- Protects vital habitats associated with the globally important grasslands biome.
- Exemplifies innovation in combating land degradation.
- Stems the emission of carbon stored in the peat substrate, and
- Creates wetland awareness and education.

Rietvlei addresses poverty through labour intensive job creation and capacity building while the conserving water resources of a dry country. 60% of its budget is uplifts the poor. 60% of its workforce is women.

Sixty people are employed on a budget of R 1 million for 11 months of the year by WfW and an additional 20 – 30 people for an additional 3 months of the year on a Landcare budget of R 250 000 per year.

It is intended that the wetland will be rehabilitated to such as extent that only maintenance is necessary. It is also hoped that trained workers will be able to run their own businesses after funding ends.

The Rietvlei wetland rehabilitation project is part of Working for Wetlands. It is a partnership between the Working for Water Programme (Department of Water Affairs and Forestry), Department of Environmental Affairs & Tourism (DEAT), Mondi Wetland Project, as well as the Rietvlei LandCare Programme and City of Tshwane.

Contact Details:
Piet-Louis Grundling
DEAT Working for Wetlands Co-ordinator
Working for Water Programme
e-mail: peatland@mweb.co.za
Tel/Fax:+ 27 012 808 5342
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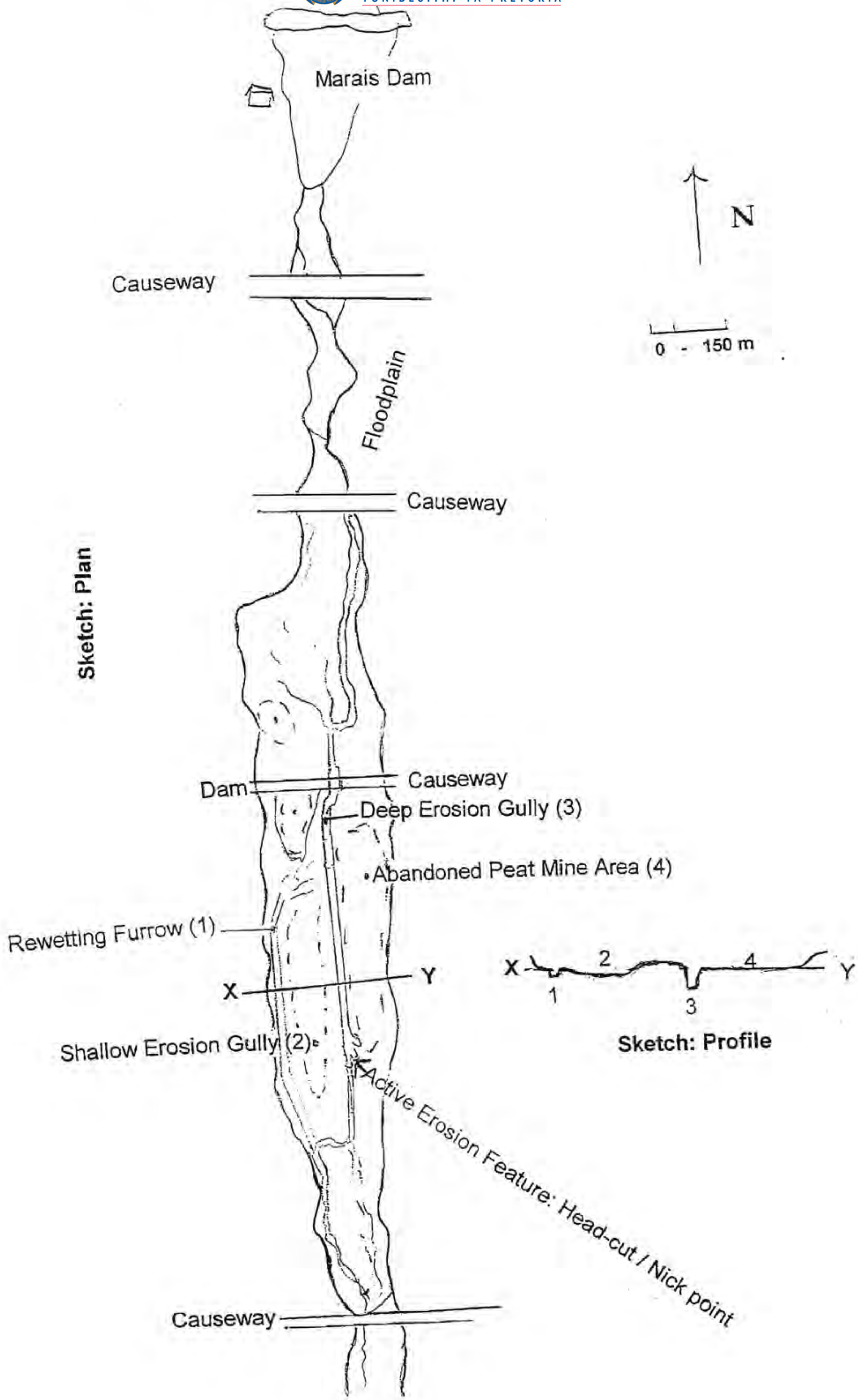
Roger Browne
Technical Advisor
Working for Water Programme
Northwest/Gauteng Region
e-mail: brownej@iafrica.com
Tel/Fax: + 2712 667 1815
Cell: + 27 83 231 3489

LANDCARE
SOUTH AFRICA

Mondi Wetlands Project

Department: Environment Affairs and Tourism
Department: Water Affairs and Forestry
Department: National Department of Agriculture

Rietvlei Wetlar ct



APPENDIX 5

INTERPRETATION OF AERIAL PHOTOGRAPHS DEPICTING LANDSCAPE CHANGES AT THE HUDSONVALE PEAT BASIN IN THE KROMME RIVER WETLAND.

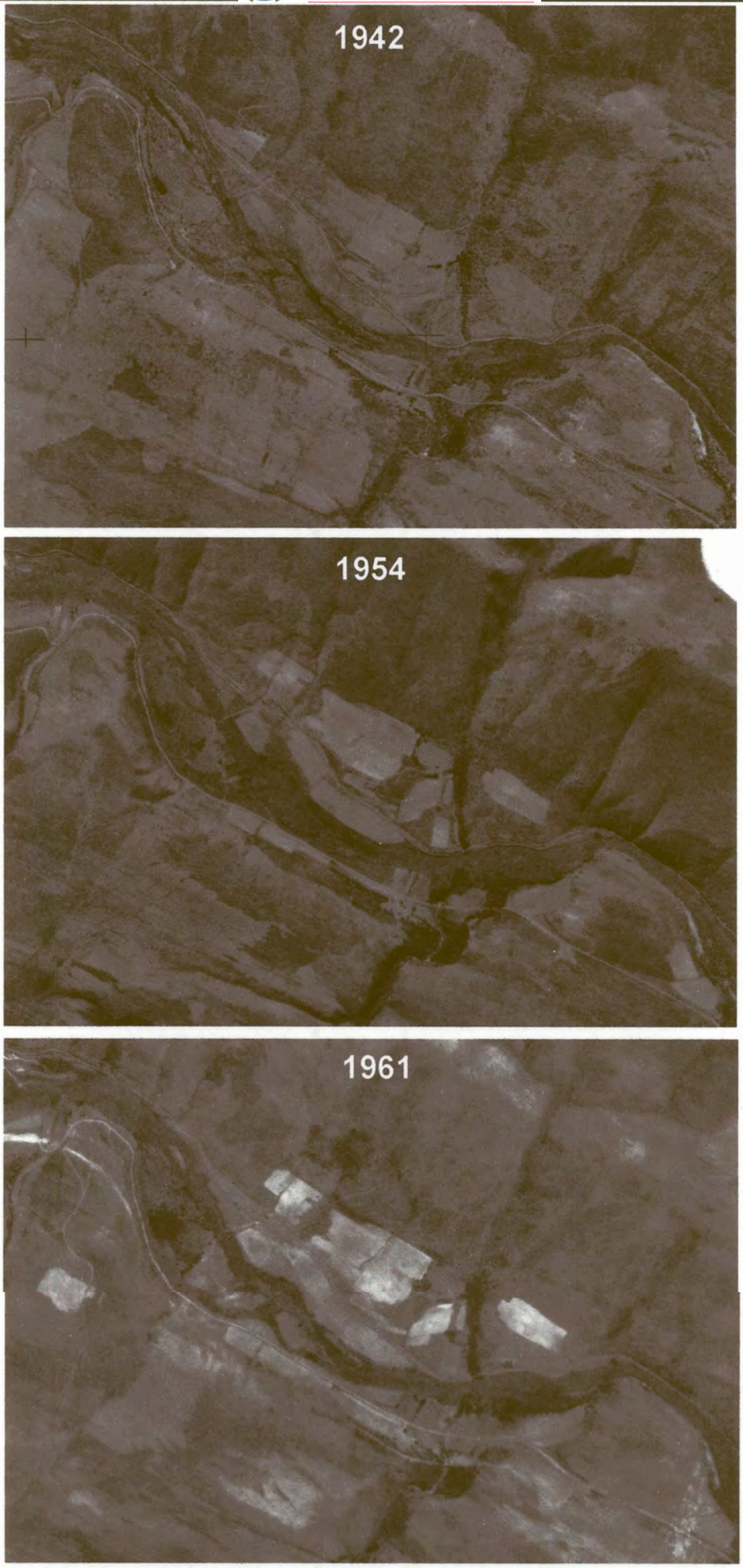


Figure 1: Landscape changes in the peat basin on the farm Hudsonvale is described from aerial photographs (1942 - 1961)(Haigh et al. 2002).

Figure 2: Landscape changes in the peat basin on the farm Hudsonvale is described from aerial photographs (1961 - 1986)(Haigh et al. 2002).

APPENDIX 6

DIFFERENT REMOTE SENSOR IMAGERY FOR THE WETLANDS STUDY AREAS (A3 SIZE MAPS).

• Kromme River Wetland	SPOT 5. Kodak DCS 420 (Near Infrared (NIR))
• Mbongolwane Wetland	DuncanTech (True colour & colour Infrared (CIR)) EROS
• Seekoeivlei Wetland	EROS
• Wilge River Wetland	DuncanTech (True colour & colour Infrared (CIR))
• Zoar Wetland	DuncanTech (True colour & colour Infrared (CIR))
• Rietvlei Wetland	DuncanTech (True colour & colour Infrared (CIR))

REMOTE SENSING IMAGERY FOR THE WETLAND STUDY AREAS ARE AVAILABLE IN Erdas.img format (Zip files) CD 1, CD 2, CD 3 and CD 4.

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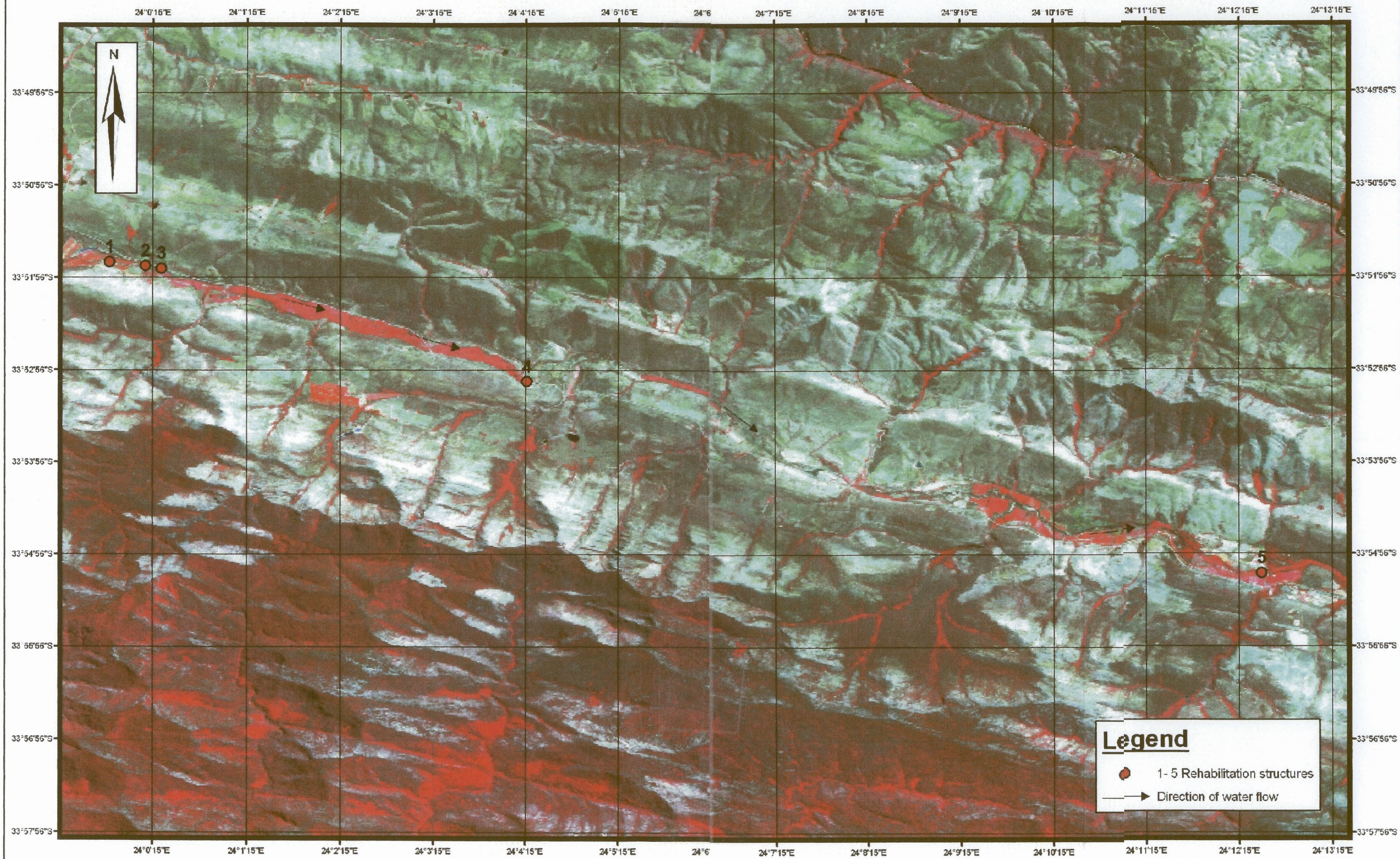
Kromme River Wetland - Spot (lse colour infrared) Imagery

Image acquisition date: 10/02/2003
Resolution: 10 m



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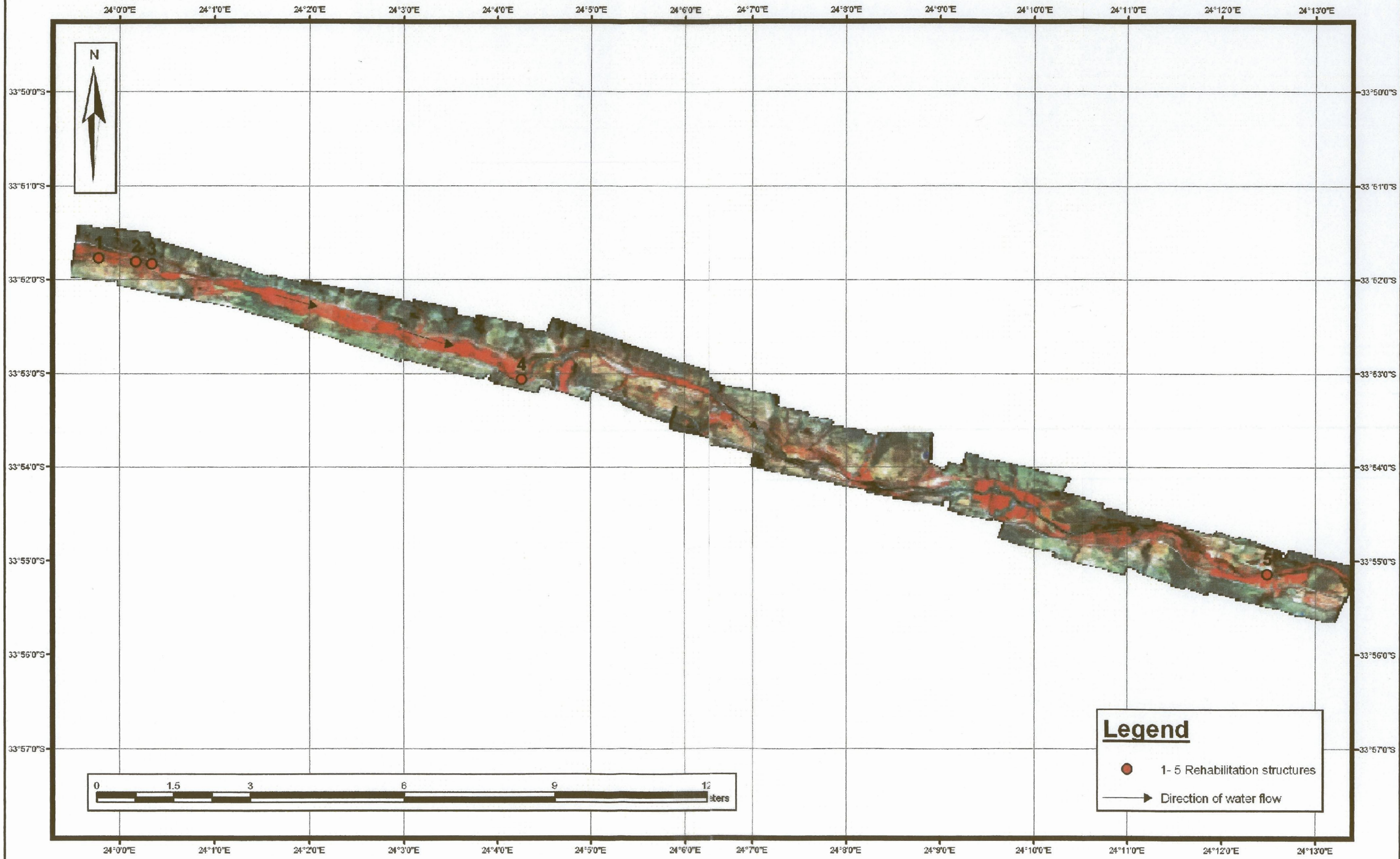
Kromme River Wetland - KodaDCS 420 (Near infrared) Imagery

Image acquisition date: 22/01/2003
Resolution: 1 m



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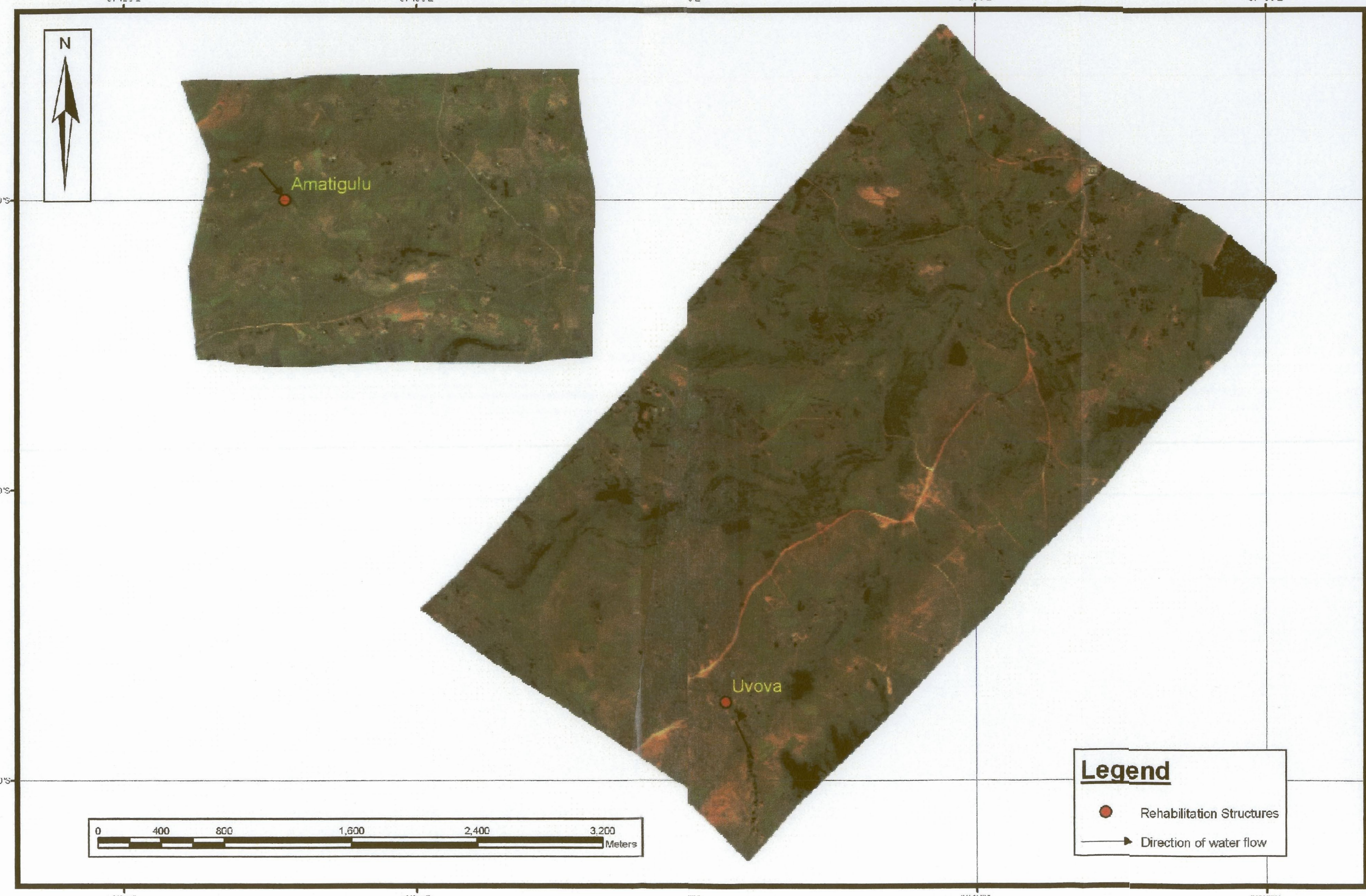
Mbongolwane Wetland - DunmTech (True colour) Imagery

Image acquisition date: 09/06/2003
Resolution: 0.25 m



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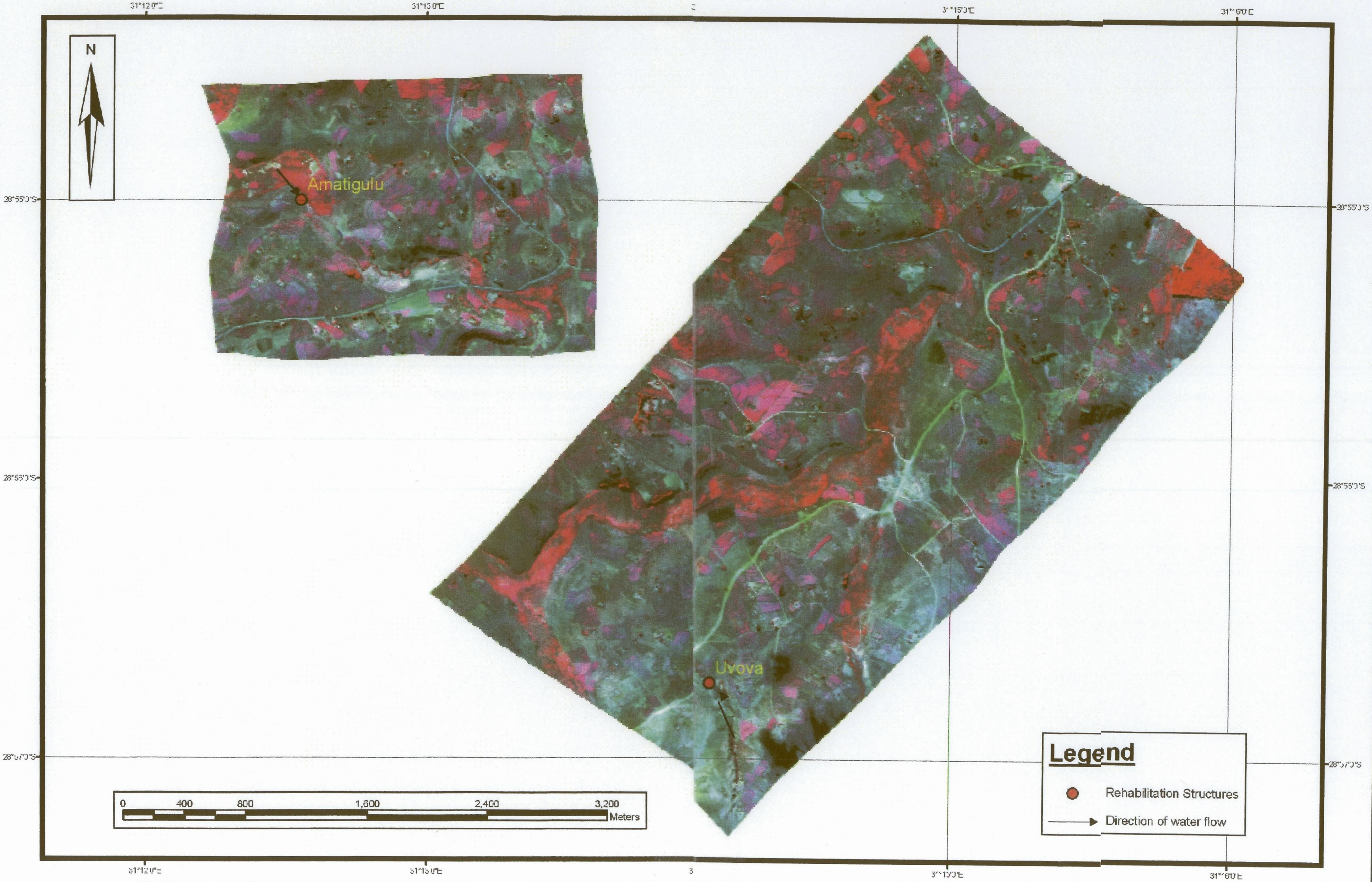
Mbongolwane Wetland - Duncaech (Colour InfraRed) Imagery

Image acquisition date: 09/06/2003
Resolution: 0.25 m



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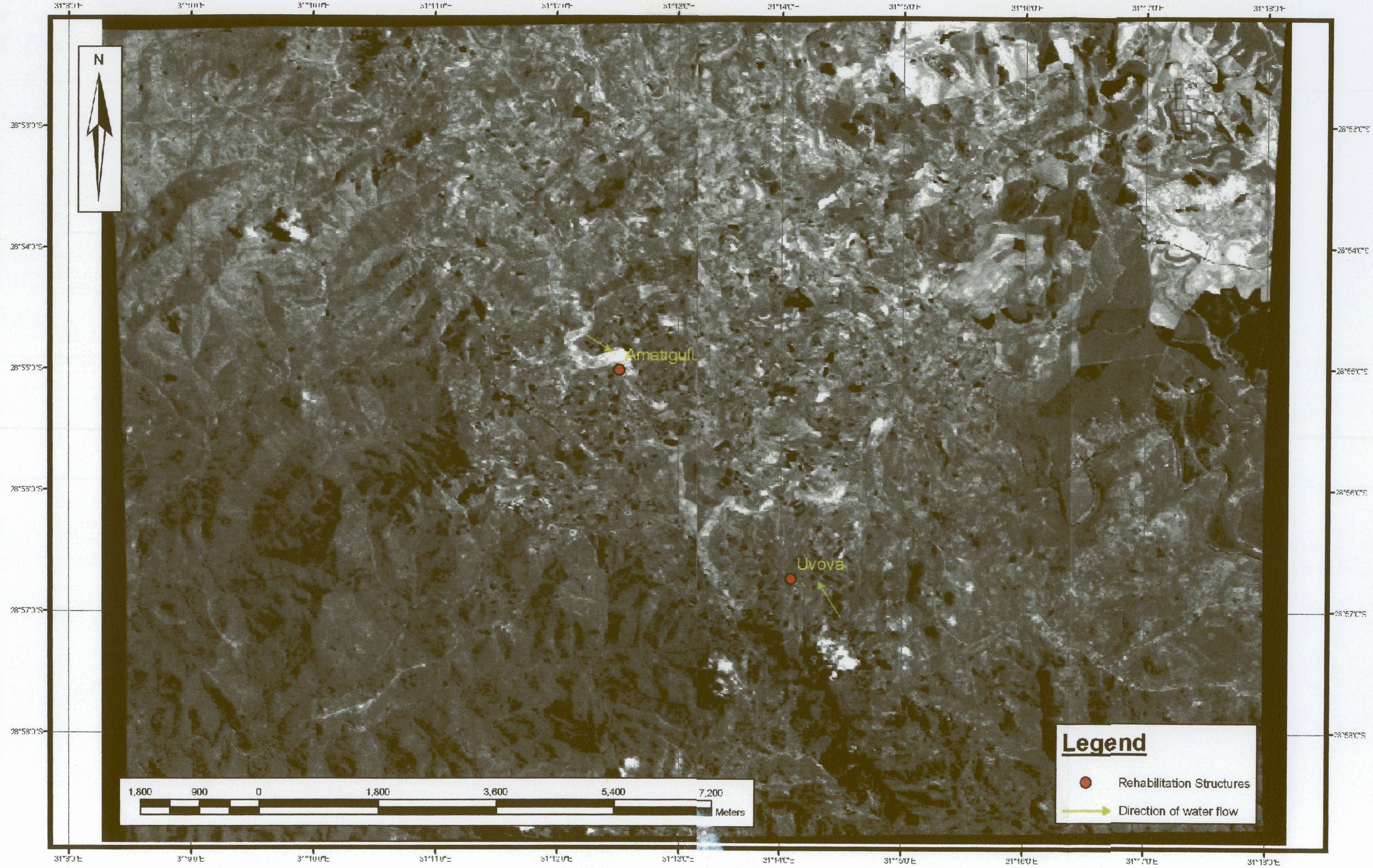
Mbongolwane Wetland Eros Imagery

Image acquisition date: 24/12/2002
Resolution: 1.8 m



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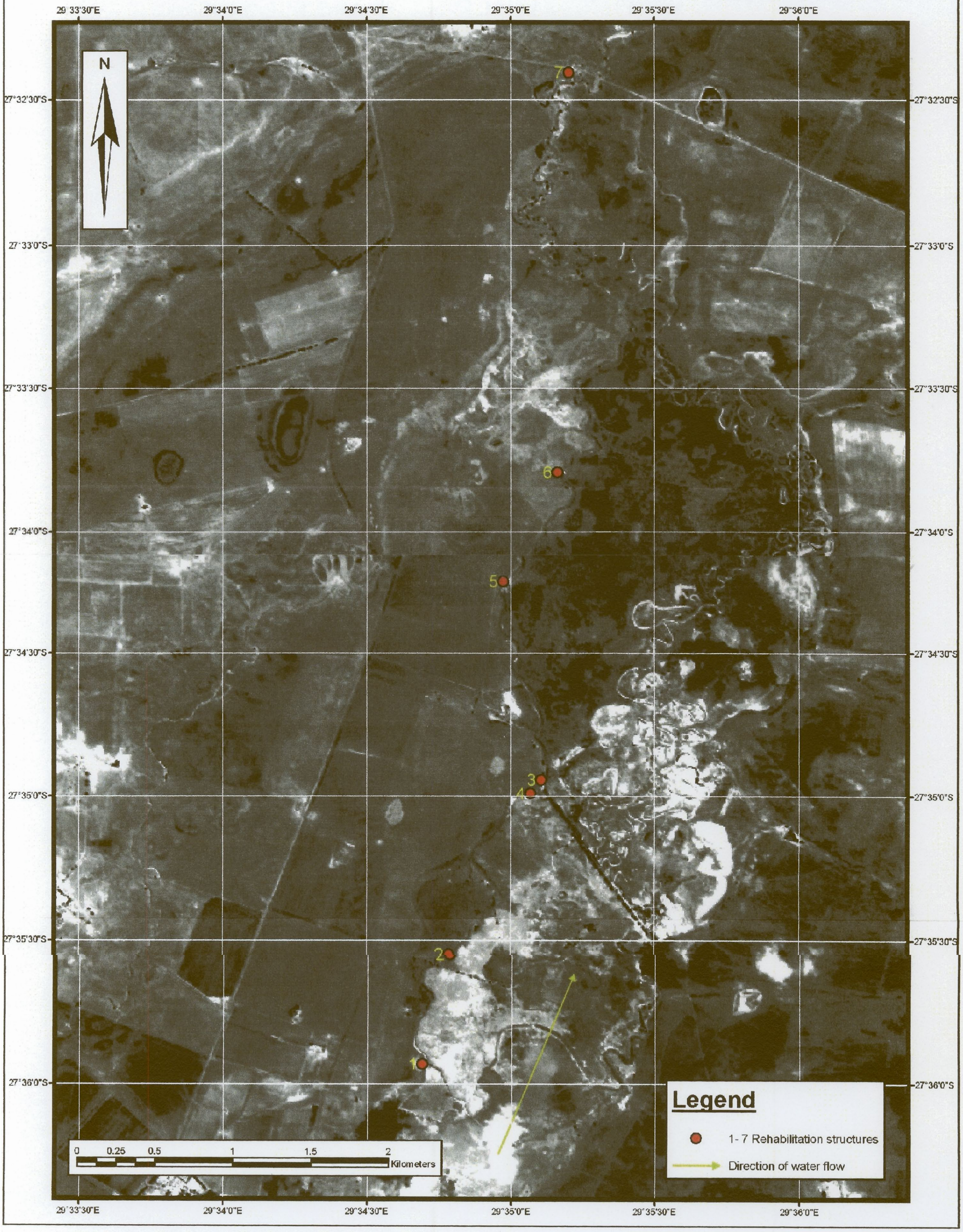
Seekoeivlei Wetland - Eros Imagery

Image acquisition date: 20/12/2003
Resolution: 1.8 m

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Zoar Wetland - DuncanTech (1e colour) Imagery
Image acquisition date: 09/06/2003
Resolution: 0.25 m
30°28'0"E
30°28'30"E
30°29'
30°29'30"E
30°30'0"E
26°50'30"S
26°51'0"S
26°51'30"S
N
1
2
3
4
5
6
7
0
0.2
0.4
0.8
1.2
1.6
Kilometers
Legend
1-7 Rehabilitation structures
Direction of water flow


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Zoar Wetland - DuncanTech (Colr InfraRed) Imagery
Image acquisition date: 09/06/2003
Resolution: 0.25 m
30°28'0"E
30°28'30"E
30°29'
30°29'30"E
30°30'0"E
26°50'30"S
26°51'0"S
26°51'30"S
N
1
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4
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0
0.2
0.4
0.8
1.2
1.6
Kilometers
Legend
1- 7 Rehabilitation structures
Direction of water flow

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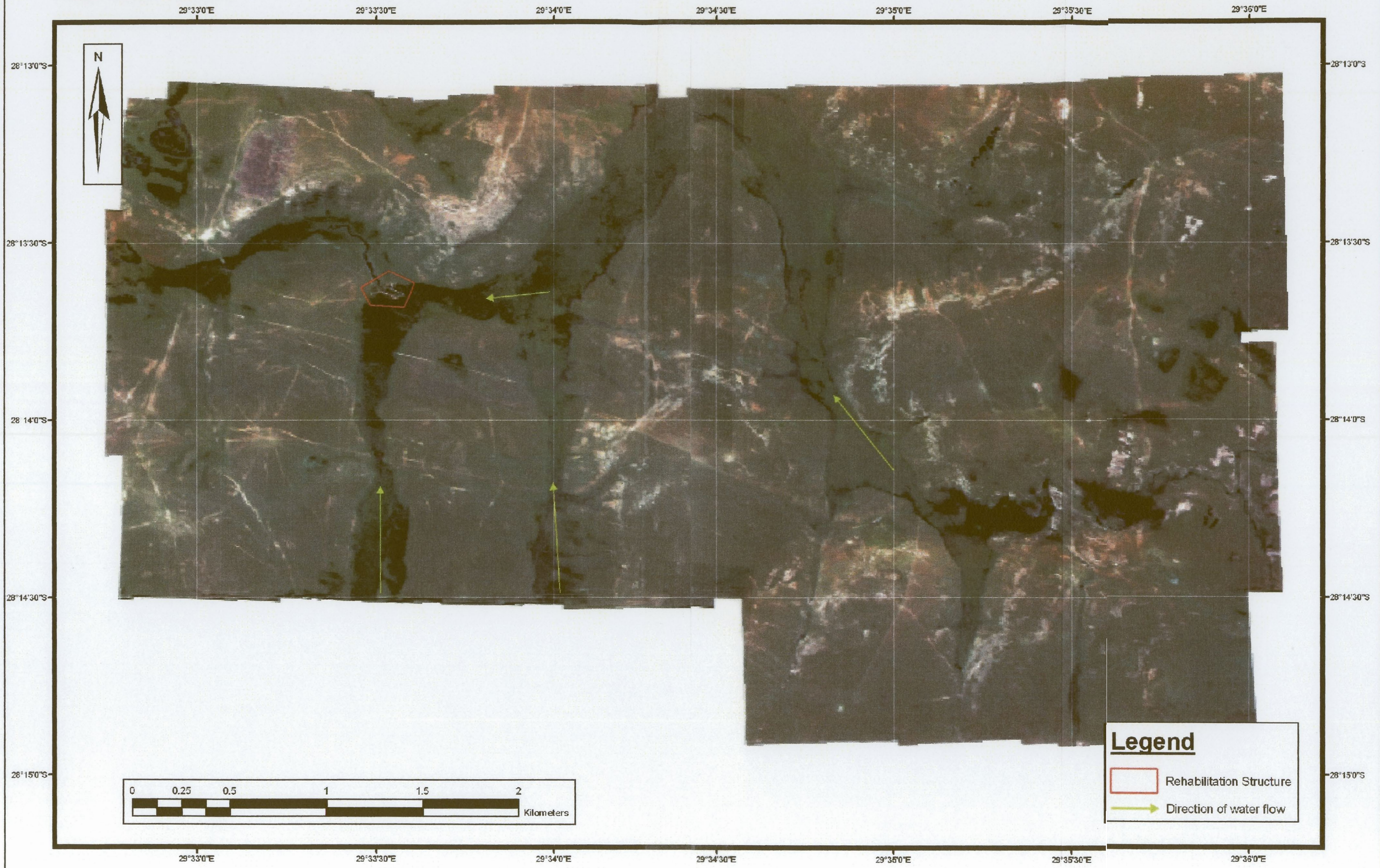
Wilge River Wetland - Duncarfech (True colour) Imagery

Image acquisition date: 08/04/2003
Resolution: 0.5 m



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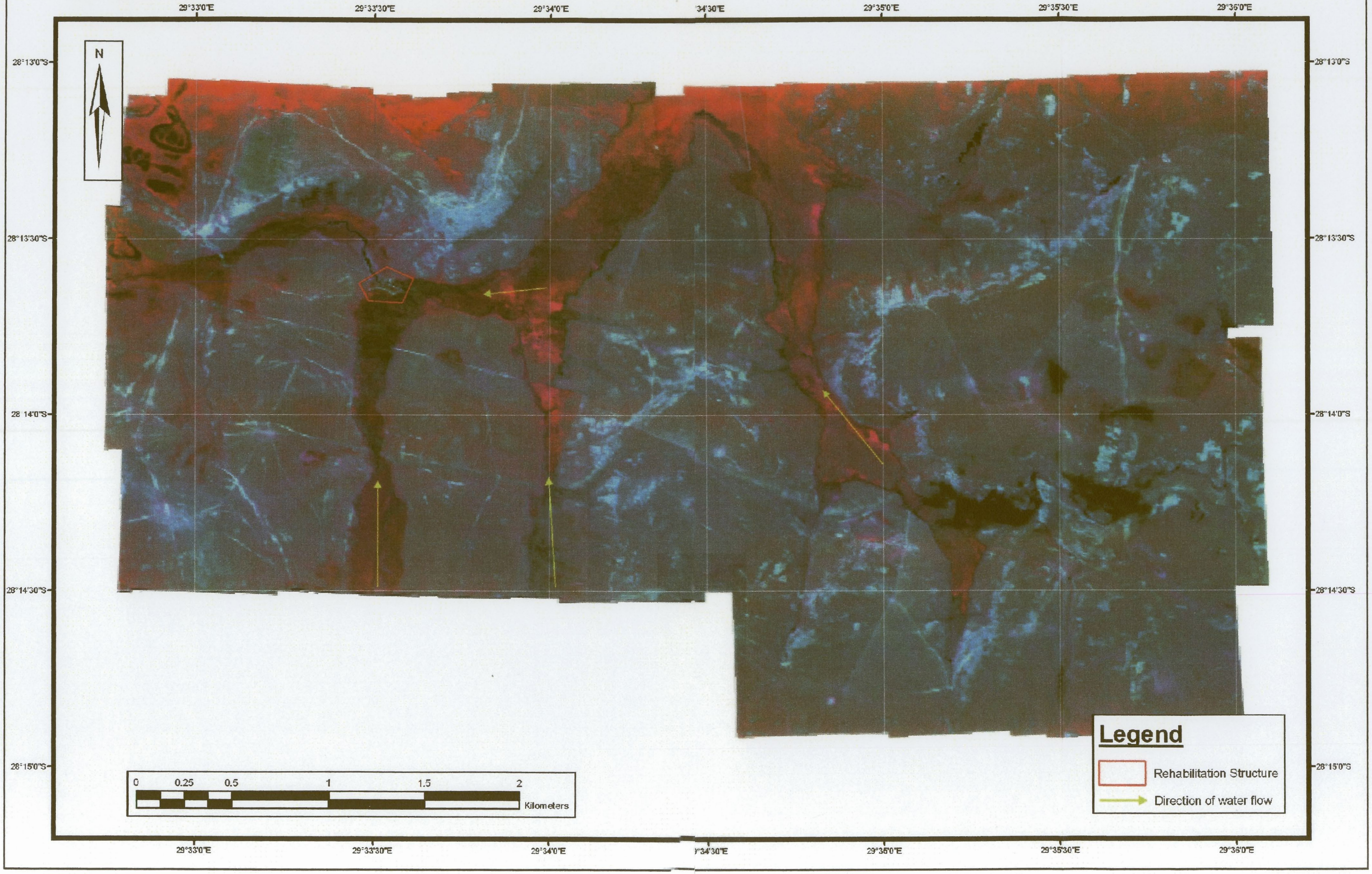
Wilge River Wetland - DuncanTer (Colour InfraRed) Imagery

Image acquisition date: 08/04/2003
Resolution: 0.5 m



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Rietvlei Wetland - DuncanTech (True colour) Imagery

Image acquisition date: 09/06/2003
Resolution: 0.5 m