A METHODOLOGY PROPOSED FOR A SOUTH AFRICAN NATIONAL WETLAND INVENTORY

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GLOSSARY OF TERMS

Anaerobic:	not having molecular oxygen (O_2) present.
Anthropogenic:	people induced.
AMSL	above Mean Sea Level
Chroma:	the relative purity of the spectral colour, which decreases with in increasing greyness.
COST	Cosine of solar zenith angle model
DEAT	Department of Environment Affairs & Tourism
Delineation (wetland):	to determine the boundary of a wetland based on soil, vegetation, and/or hydrological indicators, usually on a map.
DEM	Digital Elevation Model
DWAF	Department of Water Affairs & Forestry
Geomorphic:	(as relates to landscapes): shape or surface configuration/structure of a landscape.
GIS	Geographic Information System
Ground truthing:	to determine features by direct measurement in the field.
Heads-up digitising:	digitising directly onto a digital photo mosaic.
Hydric:	pertaining to or requiring considerable moisture.
Hydric soil:	soil that in its undrained condition is saturated or flooded long enough during the growing season to develop anaerobic conditions favouring the growth and regeneration of hydrophytic vegetation (vegetation adapted to living in anaerobic soils).
Hydrology:	the study of water, particularly the factors affecting its movement on land.
IMS	Internet Map Server - serves spatial data over the Internet.
IRVI	Infra Red Vegetation Index
LWP	Landscape Wetness Potential Model
MMU	Minimum Mapping Unit
Morphology (landscapes):	structure and form of a landscape.
Mottling/mottles (soils):	soils with variegated colour patters are described as being mottled, with the "background colour" referred to as the matrix and the spots or blotches of colour referred to as mottles.
NDVI	Normalised Difference Vegetation Index
NLC'94	1:250,000 scale SA National Land-Cover Database (1994-95)
NLC 2000	1:50,000 scale National Land-Cover Update (2000 / 01 imagery)
Orthorectified:	corrected to the actual geo-reference points on the ground.
Panchromatic:	sensitive to all colours.
PCA	Principal Component Analysis
Permanently wet soil:	soil that is flooded or waterlogged to the soil surface throughout the year, in most years.
Photo-mosaics:	photographic images.
RDBMS	relational database such as Oracle, Informix, SQL Server
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. However, some riparian areas are not wetlands (e.g. an area where alluvium is periodically deposited by a stream during floods but which is well drained).
Rhizosphere:	the soil immediately surrounding the root or rhizome system of a plant.
RMS	Root Mean Squared (Error)
Saturation (soils):	a soil is considered saturated if the water table or capillary fringe reaches the soil surface.
SPOT	Systeme Pour L'Observation de la Terre
TC	Tasseled Cap Spectral Index
Temporarily wet soil:	the soil close to the soil surface (i.e. within 50 cm) is 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. It may remain dry for more than a year.

TPI	Topographic Index
TRMI	Topographic Relative Moisture Index
Vector:	a quantity completely specified by a magnitude and a direction.
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 (Cowardin *et al.*, 1979).
Wetland signatures:	contrasting colours and shades of colour or black and white that are indicative of hydric conditions associated with wetlands.

TECHNICAL SUMMARY

In order to manage and conserve wetland resources effectively in South Africa, it is essential to have accurate information on their location and boundaries. The need for an inventory of this nature has also been accentuated through various international conventions and legislation. To this end, the Department of Environment Affairs and Tourism (DEAT) commissioned the **Wetland Inventory Consortium**, comprising the CSIR, Geospace International, Wetland Consulting Services and the Institute of Natural Resources, to execute a pilot project to develop tools and method for establishing a cost-effective, accurate and comprehensive National Wetland Inventory.

The project objectives were to determine the:

- Most cost-effective and accurate mapping methods and associated hardware and software for mapping wetlands across South Africa to the desired level of accuracy (specified in the terms of reference provided by DEA&T);
- Feasibility of utilising the MedWet wetland attribute database for the South African (SA) Inventory;
- Cost estimates and expertise requirements for compiling such a wetland inventory for SA, and
- Most appropriate and cost-effective mechanisms for making this inventory information accessible.

South Africa is characterised by a diverse landscape with many wetland types that differ in complexity, size, biodiversity, geomorphology, hydrology and levels of use and degradation. Ideally, as wide a range of wetland types from different regions should have been included in the pilot study in order to make sure that the methodology proposed is able to deal with the complexity nationally and produces the levels of accuracy required for the purpose of the inventory. Due to budgetary constraints (and with DEA&T's agreement), many wetland types and regions had to be excluded and a decision was made to focus on those systems in regions expected to pose most problems with respect to developing a suitable methodology.

Four test study sites were identified nationally to include as many different landscape, habitat and structural classes as possible, and to reflect a range of land-uses and disturbance factors since these affect the identification of signatures and wetland boundaries. The sites contain representatives of the following wetlands included in the ToR:

- Rivers and streams (with associated floodplains and riparian areas);
- Pans;
- Permanent, seasonal and temporary marshes, including hillslope seeps;
- Springs; and
- Artificial wetlands, including impoundments, excavations and wastewater treatment areas.

The four sites are:

- Highmoor (Kwa-Zulu Natal);
- Glengarry/Kamberg (Kwa-Zulu Natal);
- Walker Bay and the associated coastal flats and fold mountains (Western Cape); and
- Davel (Mpumalanga).

Two other study areas in the Western Cape were also visited during the field studies and these were the Betty's Bay/Hangklip area and an area near the Theewaterskloof Dam.

The rest of this summary will be addressed within the four key objectives set for this study.

1. Most cost-effective and accurate mapping methods and associated hardware and software for mapping wetlands across South Africa to the desired level of accuracy.

Section 1A deals with satellite mapping and section 1B deals with the use of aerial photography and ground truthing.

1A Satellite image mapping

The primary objective for identifying a suitable satellite-based remote sensing technique was to be able to facilitate the rapid collection of accurate information over large areas, and minimise the level of field-related activities with their associated higher costs. From the outset it was, however, acknowledged that satellite-based remote sensing may be more cost-efficient than other survey techniques, but in comparison to aerial and field-based surveys, may be less cost-effective in terms of achieving the required minimum wetland mapping standards.

Landsat imagery was identified as being the most suitable imagery for evaluation purposes since it offered the best combination of spatial, spectral, and costing characteristics in comparison to other medium resolution image formats. Preference was given to the use of multi-temporal datasets rather than single date imagery, in order to minimise possible effects of having to use non-optimal image acquisition dates, whilst also enhancing seasonal differences between wetland and non-wetland areas. Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper (ETM+) image datesets were acquired for the test site evaluations. Landsat 7 ETM+ imagery was specifically acquired for the Davel test site in order to evaluate the additional ultra-high resolution 15 m panchromatic band available with this dataset.

Final image selection was made based on most recent archival availability within, or closest to, the optimal seasonal windows, linked to suitability in terms of cloud-cover and optimal seasonal windows modified according to the following parameters:

- Timing and intensity of recent rainfall patterns,
- Occurrence and extent of (winter) burn scars,
- Influence of sun angle and terrain shadows (in mountainous regions), and
- Localised tidal flooding conditions at time of image overpass for coastal imagery.

During the determination of optimal data processing techniques, a range of pre-classification data preparation procedures were used to standardise all original Landsat imagery prior to subsequent wetland classification, and minimise any external factors that may influence spectral quality and thus classification accuracy. Whilst these were considered to be an essential part of the development process, some of these processes (i.e. atmospheric and topographic correction) were found to be either optional, or in some cases, unnecessary in future operational applications, thus simplifying future data preparation. All image datasets were precision ortho-corrected to standard map projections prior to further analysis and classification.

Image classification procedures were developed on the Davel data and then tested for repeatability on the Highmoor / Kamberg and Walker Bay test sites. The basic approach involved a seasonal change detection procedure, within which wetland characteristics were enhanced using biomass and wetness indicators derived from spectral ratio's and orthogonal indices. A preliminary, broad-level land-cover classification was used to identify, mask and subsequently exclude from further data processing, any land-cover categories that would not contain any wetlands, whilst also identifying areas which best represented those sections of the landscape which could *potentially* contain wetlands. Non-wetland areas were defined as cover types either within which wetlands would not occur (e.g. mines), or could not be identified, even if they existed, using Landsat-type imagery, due to the masking effects of land-use activities (i.e. cultivation). This means that Landsat equivalent imagery is, in terms of scale and resolution, unsuitable for detailed mapping of small wetland features which have been modified to such an extent by alternate land-use activities that they are no longer identifiable as a separate cover type. A re-classification of the original input spectral data within the wetland potential area was then used to determine with more accuracy, the location and spatial extent of all *spectrally definable* wetlands. However, some boundary errors were still evident due to remaining, unresolved spectral overlap between certain (vegetated) wetland and non-wetland communities. Attempts were made to minimise these by further modifying the spectrally defined wetland boundaries with data derived from a terrain-based, hydrological model.

Terrain-based hydrological modelling was used to determine areas of 'landscape potential wetness', where water (and thus wetlands), may be likely to accumulate, *irrespective of land-cover characteristics.* The objective being to compile a topographically based model which could be used to modify the spatial extent of the spectrally defined wetlands, by excluding all image-derived wetlands mistakenly identified in landscape areas not capable of containing wetlands. Modelling of 'landscape potential wetness' was completed independently from the satellite image analysis, and was not influenced by any spectrally defined parameters. All terrain modelling was based on a 50 m DEM, which had been derived from 20 m contour data. Two model formats were tested, the first being an existing model termed the Topographic Relative Moisture Index (TRMI), which was originally developed to compare the potential moisture of sites for use in the analysis of potential species habitats. The second, termed the Landscape Wetness Potential (LWP) model, was specifically developed for this study. This model is largely based on surface hydrological accumulation and terrain parameters that influence the likely occurrence and distribution of wetlands. Both the TRMI and the LWP model results were compared in order to determine the most appropriate technique for this particular wetland mapping application. Prior to integration with the satellite-derived data, the output surfaces generated from both the TRMI and the LWP model were smoothed to create more homogeneous zones by applying mean and maximum statistical focal functions using a 3 x 3 grid cell size neighbourhood, which were then tested for applicability when integrated with the image-derived wetland data.

The final wetland delineation was achieved by combining the DEM-derived LWP model with the image-derived spectral wetland classification, in order to modify the spatial distribution of the spectral wetlands according to terrain-defined wetness potential classes. Using this approach, it was possible to minimise any remaining spectral overlap between wetland and non-wetland areas with similar vegetation characteristics. The integration procedure involved constructing a 'probability' table, which combined hydrological wetness classes with the spectral wetland class(s), in order to determine those combinations of terrain and image-derived classes that best represented the true location and extent of all wetlands in the landscape. Using this integrated modelling approach it was possible to overcome the problem reported by Dely *et al* (1999), who found that unsupervised classifications *on their own* do not facilitate the identification of spectral classes in which wetlands have a high likelihood of occurring.

The use of "pan-enhanced" multi-spectral imagery was tested as a possible alternative satellite-based approach, using the 15 m panchromatic band available with Landsat 7 imagery. This type of imagery is suitable for either digital classification or manual, on-screen, photo-interpretation. Satellite-based mapping is also able to provide supplementary information on wetland status and associated landscape parameters, which could facilitate, for example, assessments of possible external threats from neighbouring land-use practices.

A three-stage classification approach, involving (a) pre-classification of basic land-cover classes to determine wetland potential areas, (b) classification of spectrally defined wetlands within the wetland potential areas, and (c) modification of these spectrally defined wetland boundaries using terrain-derived topographical models, was successfully applied at all test sites. Although a specific combination of derived image datasets were used to classify the wetlands in the final stage of the delineation process, these combinations actually represent the most suitable approach for the *specific characteristics* of the three test site. Equally useful and just as applicable alternative processing procedures are likely to be suitable for other image formats. What is key to the process, and should be regarded as the standard methodology identified in this pilot study is the use of a preliminary land-cover classification to determine wetland potential areas, classification of spectrally defined wetlands *within* these wetland potential areas, and subsequent modification of the spectrally defined wetland boundaries using terrain-derived topographical models. Due to the locally specific conditions in the Highmoor / Kamberg test site, it was also necessary to include additional level of modelling to minimise the effects of temporal burn scars, whilst in the Walker Bay site the influence of different tidal conditions at the time of satellite overpass appeared to have a greater overall influence than seasonal differences. Landsat-type imagery does, however, appear to be inappropriate in terms of scale and resolution for detailed mapping of wetland features which have been modified to such an extent by alternate land-use activities (i.e. ploughed over within cultivated areas), that they are no longer identifiable as an individual feature.

Of the two terrain-based hydrological models developed, the Landscape Wetness Potential (LWP) was chosen in preference to the Topographic Relative Moisture Index (TRMI) model was chosen since the TRMI included a strong illumination factor which over-emphasised aspect in the final landscape wetness distribution, which conflicted with the image-derived information. In the Walker Bay test site, due to the influence of local geology, the LWP model was unable, as a single dataset, to provide sufficient detail for an accurate representation of overall landscape wetness, and was therefore modified according to local geological associations.

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. No single input dataset was able to provide sufficient detail to be used on its own.

The use of pan-enhanced imagery was investigated, using the Landsat 7 imagery acquired for the Davel test site. Whilst providing obvious improvements in visual quality, the process itself is not really suitable for large area, detailed mapping applications. Nor is the pan-enhanced imagery ideally suited to digital classification techniques, other than mapping of clearly identifiable, spectrally homogenous features such as water bodies that have clearly definable boundaries

Emphasis during digital classification testing was on determining appropriate data processing technique(s) for identifying wetlands simply in terms of their spectral characteristics. However, it is also important to quantify possible improvements in accuracy provided by increasing spatial resolution, assuming that both sensor and land-cover spectral characteristics remain constant. Since the target mapping accuracies referred to in the ToR are given in terms of area-based parameters (i.e. 90% of all wetlands >1.0ha), rather than in cartographic scales, it is appropriate to use the concept of minimum mapping units (MMU's) to define the achievable levels of spatial detail that can be mapped with the raster imagery. Spatial resolution will influence the minimum object size that is detectable, assuming that sufficient spectral contrast exists between the object and its surroundings. As a general rule, spatial resolution (i.e. pixel size) of imagery should be approximately 1 order of magnitude smaller then the required theoretical MMU. For example, if 30 m resolution Landsat imagery is used, all wetlands >1 ha will be theoretically identifiable, which will only meet the "90 percent of all wetlands >1 ha", and not the 50 percent of all wetlands > 0.5 ha, which would require higher resolution imagery. The disadvantage being that higher resolution imagery typically costs more per image, despite normally covering smaller geographical area than the coarser resolution imagery. For example, a single 30 m resolution Landsat 7 ETM+ image, covering 32,400 km^2, currently costs R 7200, whereas as a 20 m resolution SPOT4 image, covering only 3600 km^2, currently costs in excess of R 17000 per image.

Classification accuracy assessment:

The objective of the verification exercise was to determine the mapping accuracy of the image classification process, based on (1) how well a given wetland can be located, and (2) how accurately are its borders delineated, in relation to the stated target objectives of being able to identify 90 percent of all wetlands >1 ha, and 50 percent of all wetlands >0.5 ha, with a 40 m boundary delineation accuracy. The field-mapped wetland boundaries were taken to be representative of true wetland location and extent, and were therefore used in all assessments as the reference dataset against which the satellite-derived classifications were compared.

In order to be able to compare data with similar formats, the field-mapped data was first rasterised to a 25 m grid format, equivalent to the image pixel size. Whilst this approach may have resulted in the loss of some very small wetland polygons, this was not seen as detrimental to the overall validation procedure, since the 25 m grid unit was smaller than both the 0.5 ha minimum wetland size (i.e. 4 x 25 m pixels) and the 40 m boundary error (i.e. ~ 2 x 25 m pixels). Mapping accuracies were then determined by comparing the spatial distribution of the image-classified wetlands with the equivalent field-mapped extents. Due to the limited geographical extent of the (field-mapped) reference wetlands, in relation to the full test site coverage mapped using the image data, *mapping accuracies could only be determined for selected portions of the test site and not the entire area*, since it was impossible to determine the accuracy of any image-classified wetlands not actually mapped in the field. No attempt was made to quantify the accuracy of any of the non-wetland cover mapping (i.e. as used in the preliminary land-cover classification), simply due to the lack of comparable field data. However, if the mapping accuracies obtained during the SA National Land-Cover Database, are used as a comparable measure, and it is assumed that these are likely to be worse due to the coarser scales and simpler methods used, then non-wetland mapping accuracies should be in the order of 80 percent.

Statistical mapping accuracies were calculated on the basis of a simplified class-legend structure, within which all (vegetated) wetlands were treated as a single entity, since it had previously been determined that it was not possible to determine actual wetland "type" from image data alone. No attempt was made to validate mapping accuracies at any higher level of wetland detail. The three categories thus used in the validation process were (a) wetland (vegetated), (b) open water, and (c) other i.e. all other non-wetland vegetated land-covers.

Table 1 lists both the overall, producers and users accuracy for the three test sites, calculated using standard 'error matrices' for comparing the reference data (i.e. field mapped wetlands) and the corresponding image-derived classifications. The overall accuracy is based on the combined "water", "wetland" and "other" image-derived categories, but cannot be seen as a true representation, since the reference field data did not actually include anything other than the individually mapped wetlands, so no reference data is available to confirm the extent of non-wetland / other areas. The wetland category "producers" accuracy does however provide a reliable indication of how well the full extent of the field mapped wetlands were in fact mapped using the image data. The wetland category "users" accuracy on the other hand provides an indication of what percentage of the image mapped wetlands were actually located within the field-mapped boundaries.

For example, 91 percent of the image-classified wetlands in the Davel site were actually located within field-mapped wetland boundaries, and that this was equal to 52 percent of the total area of field-mapped wetland. Therefore whilst the image identified wetlands were actually very accurate, they only represented 50 percent of the total (known) wetlands in the area. In comparison the Walker Bay results indicate that whilst nearly all known "wetlands" were identified (i.e. 95 percent producers accuracy), these correctly identified wetland areas only represented 65 percent of the total image-classified wetland area, indicating large over-classification. The problem is, that without additional reference material it is not possible to state whether these additional wetland areas were in fact misclassifications or additional wetlands that were not mapped in the field simply due to the significant time required for detailed field mapping.

The Walker Bay results are also further complicated because due to the nature of the field-mapped boundaries, and the inability to (field) demarcate a low water mark to the wetlands, the open water and vegetated wetland categories were combined prior to accuracy determination.

Table 1 Final wetland mapping accuracies obtained for the image-classifications, using the field-mapped wetland boundaries for reference.

Test Site	Overall Mapping Accuracy	Wetland Category Producers Accuracy	Wetland Category Users Accuracy
Davel	72	52	91
Highmoor / Kamberg	72	28	72
Walker Bay	87	95	65

A similar accuracy assessment was also made between the larger wetland extents mapped in the Upper Olifants Catchment (which contained the Davel test site) from primarily 1:50,000 scale topographic maps and reference aerial photographs, and the image-classified wetlands (Table 2).

Table 2 Final wetland mapping accuracies obtained for the Davel test site, using 1:50,000 scale map derived wetland boundaries for reference.

Test Site	Overall Mapping Accuracy	Wetland Category Producers Accuracy	Wetland Category Users Accuracy
Davel	84	41	39

Comparison to the 1:50,000 scale derived reference data indicates considerable disagreement, since only (approx) 40 percent of the image classified wetlands were located within the map derived boundaries, and that these areas of agreement only represented (approx) 40 percent of the total map-derived wetland areas. There was therefore a significant amount of map-derived wetlands not identified by the image classification, *but also* a significant amount of image-derived wetlands not identified by the map-based mapping. However, when viewed spatially rather than numerically, there is in fact significant agreement between these two datasets, especially when the non-wetland areas are taken into account, and any possible temporal changes in open-water and (vegetated) wetlands are ignored.

In evaluating classification accuracies it must be remembered that reported statistics only refer to specific sample areas, which may or may not be representative of larger area mapping accuracies (although the sample areas themselves were specifically chosen to contain representative wetlands). However, whilst these results indicate a general consistency in terms of achievable mapping accuracies, they fall short of the desired minimum target accuracies (although it should be re-emphasised that these have been developed on test-sites that represent some of the most complex wetlands to map using satellite imagery, and are as such "worst case" accuracies).

Therefore, as a guideline rule, based on the results of the validation exercise, it is possible to state that satellite-based mapping of vegetated wetlands (using Landsat type imagery) should be able to:

- Identify (as a minimum), at least 50 percent of the total wetland area (i.e. extent) in a given location, irrespective of individual wetland shape or boundaries, and

- Within the image-classified wetland areas, have identified the true location of wetlands with at least 80 percent accuracy.

Given the small size and fragmented distribution of the wetlands in the test sites (which were chosen specifically because of these difficulties), these mapping accuracies do however reflect a significant improvement on the level of wetland information contained within the only national data set available to date, namely the 1994-95 SA National Land-Cover Database, which was produced at a much coarser (1:250,000) scale, using single date, non-digital imagery.

Whilst these guidelines provide an indication of achievable *area based mapping accuracies*, they are not indicative of *linear* boundary delineation accuracies. For example, at no point in the delineation of the Viskuile (Davel) wetlands did the image-derived wetland boundary show any consistent linear agreement with the field-mapped wetland boundaries. In order for the 40 m boundary accuracy requirement to have been met, the image-mapped boundary would have had to be consistently located within 1 (Landsat) pixel of the field-mapped boundary. Assuming the Viskuile (Davel) results are representative of all sites, it can be concluded that it is not possible to achieve a 40 m wetland boundary mapping accuracy with Landsat-type satellite imagery.

The mapping accuracy of open-water wetlands is generally much higher than that of vegetated wetlands, because of the unique spectral signature associated with such features, in relation to the surrounding land-covers. As such the accuracy of these specific features will be closer the theoretical MMU described previously. Where (permanent) water bodies have been identified, their actual mapping and boundary delineation is typically within the 40 m boundary accuracy, based on the 1 x pixel difference rule defined above.

In conclusion, the results of the pilot mapping exercise suggest that satellite based mapping is not suitable for detailed wetland mapping, if Landsat-type imagery is used, and the minimum mapping standards are those specified in the original ToR. Whilst it would be possible to increase the spatial resolution of the satellite imagery by using alternative image formats to Landsat, this would be associated with significant increases in preliminary data purchase costs, and subsequent data processing costs, plus many of the alternative image data formats do not (as yet) have fully comparable spectral resolutions to Landsat TM and ETM+ imagery, which can be expected to reduce the suitability of these different image types. If higher mapping accuracies are a definite pre-requisite, then wetland mapping will have to be reliant on field and or combined field / aerial image based techniques. If however the lower spatial mapping accuracies obtainable from satellite imagery are acceptable as a preliminary national inventory, then this national dataset could be used to prioritise selected catchments (etc) for more detailed mapping using the field / aerial photo based techniques.

Satellite-based mapping using Landsat-type imagery, in terms of the definitions applied to wetlands within this study, is essentially limited to a generic "presence and absence" mapping of "core" wetland areas, where the identified wetlands are primarily defined by temporal surface vegetation characteristics rather than more permanent sub-surface soil profiles. As mentioned in the introduction to this chapter, this is an important consideration since in some years, wetlands may be much wetter than in others, such that the direct presence of water, surface vegetation conditions, or permanently saturated soils is therefore often an unreliable indicator of wetland conditions or boundaries, with the result that wetlands will not always exhibit obvious 'signatures'.

Procedure bias Testing:
A bias test procedure was used to assess the likely impact of analyst dependent decisions on final mapping accuracy, and to confirm the repeatability of recommended mapping methods. Key findings of this assessment were that significant extra time is required by first-time analysts unfamiliar to the proposed wetland mapping work-flow. This could effectively be reduced by incorporating a pre-operational training programme, under the tutorship of an analyst fully familiar with the wetland mapping techniques. Reliance on written instructions alone, even with software competent analysts is not recommended. Consideration should be given to using a single, standardising mapping application on a single software type, which although disadvantageous in terms of vendor-dependence, does have significant advantage in terms of training and quality control. Prior knowledge of the study area (in terms of expected landscape structure and associated land-cover / use characteristics) was also found to be a key factor in the speed of data processing.

Possible linkages to other initiatives:
The forthcoming implementation of the 1:50,000 scale National Land Cover 2000 (NLC 2000) project provides an ideal opportunity to kick-start a national wetland inventory, using satellite remote sensing to generate a basic national wetland inventory, using the techniques identified in this report. This can be overcome by either incorporating the enhanced image processing methods identified in this pilot study within the actual NLC 2000 data processing as an integral component, or by using the final derived land-cover dataset, at a later stage, to facilitate later re-mapping of the more detailed wetland areas.

1B: Use of aerial photography and ground truthing

Approach
A key component of the project was to evaluate and compare the mapping capabilities of a range of types of aerial photography as well as ground truthing in order to identify the most cost-effective method for delineating the wetlands at each test site. In each case the objectives were to determine the most appropriate methodology for mapping wetlands based on: (i) signature identification; and (ii) accuracy of boundary delineation. Data types used in the assessment included black and white (BW), true colour (RGB) and colour-infrared (CIR) aerial photography (in both hardcopy and digital formats). The analysis included the following data and mapping methodologies:

- Manual transfer mapping from stereo and non-stereo BW photographic prints;
- Digital mapping from ortho-rectified stereo and non-stereo BW photographic prints;
- Digital mapping from ortho-rectified digital RGB and CIR photographic imagery; and
- Mapping based on ground truthing.

For each of the four test sites (e.g. Davel, Highmoor, Glengarry/ Kamberg, and Walker Bay), complete single-date photo coverage was acquired in each of the following formats:

- Stereo and non-stereo, BW contact prints; and
- Non-stereo, ortho-corrected BW digital photo-mosaics.

For parts of the Davel site, the Betty's Bay/Hangklip site and the Theewaterskloof Dam site, 1:10000 orthophotos were purchased from the Chief Directorate Surveys and Mapping (Dept. Land Affairs) for comparison with the RGB and BW photos.

Where "off-the-shelf" digital ortho-photo mosaics were unavailable, these were created specifically for the project using the same stereo BW photography chosen for that test site.

Photographic mapping methods tested included:
- Heads-up digitising on ortho-rectified digital BW aerial photo-mosaics using Arcview 3.2;

- Digital stereo mapping on ortho-rectified digital BW aerial photo-mosaics using ERDAS Stereo Analyst;
- Manual transfer mapping from stereo pairs of BW photographic prints; and
- Manual transfer mapping from individual BW photographic prints.

Representative sets of true colour (RGB) and colour infrared (CIR) photography were acquired for the Davel site, using the in-house camera systems operated by GeoSpace International. Two sets of single-date imagery were captured over Davel, representing different seasonal conditions in order to test the suitability of these different dates for wetland mapping. Due to the actual implementation date of the project and unforeseen but unavoidable delays in the acquisition of the 2nd set of imagery as a result of unsuitable flying weather later in the season, the acquisition dates of both sets of imagery were not always 100 % optimal in terms of seasonal wetland characteristics.

Heads-up digitising on the RGB images using ArcView 3.2 proved extremely difficult due to the poor contrast of the imagery as a result of the timing of the photography and as such, this method was not used as part of the RGB assessment. Instead, RGB and imagery was visually compared with BW imagery for the Davel, Highmoor and Betty's Bay/Hangklip sites. The wetland signatures on the dataset were visually compared with those from the imagery of the other datasets in order to evaluate the suitability of using RGB at these sites and to see if it offered any advantage over BW imagery. CIR imagery was compared with BW and RGB imagery for the Davel site. The wetland signatures on the dataset were visually compared with those from the imagery of the other datasets in order to evaluate the suitability of using CIR at this site and to see if it offered any advantage over BW and RBG imagery.

Field boundary determinations were undertaken at following test sites: (i) Highmoor - plateau areas 1 and 2; (ii) Glengarry/Kamberg – Glengarry and Kamberg/Stillerust; (iii) Walker Bay – Kleinrivier Estuary and Glenhart; and (iv) Davel – Viskuile.

For each wetland complex at each site, the entire wetland boundary was walked and the soils were sampled in order to determine the boundaries. Key vegetation and other hydric indicators were also identified in order to assist with boundary delineation. The boundaries of the wetland areas were marked on ortho-rectified hard copy aerial photographs of each of the wetlands and then transferred to digital format using head-up digitizing.

Although it was not part of the project brief to modify or check on the applicability of the proposed national classification system, it came to the fore that the development of the methodology and applicability of any technique for the national inventory could not be considered independently of the classification system. A modified version of the draft national classification system of Dini and Cowan (2000) as derived from Cowardin *et al*. (1979) was used to classify the wetlands. The classification was tested on the Highmoor plateau sites, Glengarry , Kamberg/Stillerust and the Viskuile. All these wetlands were classified to sub-class level and using those modifiers that could be measured as part of the scope of the fieldwork. The implications of its application to the national inventory were considered.

In order to test which mapping methods comply with the requirement for a wetland boundary accuracy of 40m, a boundary accuracy assessment was undertaken. A procedure was developed to compare field-delineated boundaries (actual boundaries) with those captured on hardcopy and digital black BW aerial photography. The assessment was not undertaken for RGB and CIR since these did not offer any advantages (with respect to wetland identification and delineation) over BW imagery at the sites where the boundary accuracy was assessed. The details of the accuracy assessment procedure are given in Chapter 3.

Wetland maps prepared by interpreting aerial photos have inherent limitations related to many factors, including the difficulty of signature recognition, map scale (e.g. balancing minimum mapping units against map legibility), quality of imagery, conditions present when the imagery was captured (e.g., burns, wet season, dry season), the cartographic equipment used in transfer or preparation of maps, plus the skills of the photo interpreters, and image processors. Even the detailed site-specific maps prepared from on-the-ground surveys undertaken as part of this study have limitations due to scale, as well as some of the other factors listed above.

Findings

Wetlands also pose special problems for accurate mapping due to their alternating wet-dry nature and the complexity of their boundaries. While many wetlands are quite distinct due to observed wetness or unique vegetation, many others are not readily identified either on-the-ground or by interpretation of aerial photographs. Wetland identification often requires analysing subtle changes in vegetation patterns, soil properties, and signs of hydrology, especially in drier type systems and seepages. The point to remember is that the more difficult the wetland type is to identify on the ground, the more conservatively such types will be represented on maps produced by aerial photo interpretation.

Field delineation versus photo-interpretation

Maps produced by photo interpretation will never be as accurate as a detailed on-the-ground delineation, except perhaps where topographic differences are abrupt and hydrologic differences obvious. Minutes of photo interpretation time cannot hope to improve upon hours of field work examining plants, soils, and signs of hydrology and flagging the often complex boundaries of wetlands. This is not to say that photo interpretation cannot produce relatively accurate boundaries at a fraction of the cost of doing on-the-ground delineation. For some types in certain landscapes (e.g., floodplains, most pans, riparian zones, swamps, fens, lakes, dams and so on where topographic setting and vegetation and open water characteristics are easily identifiable), photo interpretation works well for locating the boundaries. For other types such as those in complex (steep slopes including convex and concave settings) or simple topographic settings (flat landscapes), those towards the dryer end of the spectrum and particularly seepage wetlands, photo interpretation will only produce generalized boundaries that may vary considerably in the field.

Wetland photo interpretation is therefore, not a simple task. Wetlands occur along a soil moisture continuum between permanently flooded to drier habitats that are not wet for long periods. This makes many wetlands, especially those subject to only brief flooding and seasonal saturation, particularly difficult to identify on the ground, let alone on aerial photographs. In general, the wettest wetlands are usually easiest to interpret, while the drier ones are most problematic. Moreover, wetlands occur over a wide range of topographic settings nationally, which further complicates their interpretation. In addition, wetlands vary widely from one region to another.

Field verification

Field verification is an extremely important requirement with respect to wetland mapping. It not only serves to calibrate one's mind to an area, but also serves to provide the baseline information necessary for calibrating all types of remote mapping from the use of satellite imagery to aerial photography. It is also the only way one can gain insight into many of the issues that should be considered when mapping in any particular region. Field verification is however the most time-consuming part of the mapping process and since this is a necessary component of any mapping, one needs to make sure it is practiced judiciously and only in those wetlands where it will add most value to the mapping of a particular region. A useful means of achieving such cost-effective ground verification would be to undertake field descriptions of a series of check-site wetlands located across all of the eco-regions in the country. Potentially useful eco-region systems (e.g. that of DWAF and the DEA&T wetlands conservation programme) already exist.

Concepts such as wetland boundary complexity and wetland complexity are important in terms of time budgets for what length of perimeter or extent of a wetland can be mapped in the field. The boundary complexity is a measure of the ease with which the boundary of the wetland can be delineated in the field, while the wetland complexity describes the relative complexity of the wetland itself, defined by the perimeter to area ratio. One can use the boundary and wetland complexity concept to get a rough estimate of the costs required to field delineate photo-interpreted checksites for any particular region or set of wetlands being mapped. One cannot expect to undertake any wetland inventory project without field delineated checksites.

The presence and intensity of anthropogenic impacts also influences the intensity of fieldwork required with respect to boundary determination. This includes the conversion of wetlands or parts of wetlands to agriculture or planted pasture, as well as draining. Sometimes, however, the impacts may be more subtle such as when the boundaries are masked by factors such as sedimentation resulting from erosion off agricultural lands. One needs to be aware of specific issues relating to boundary accuracy in the field and should give careful consideration to regional land-use practices and disturbances.

Use of stereo imagery

Stereoscopic coverage with sufficient overlap is essential to assess topographic relief and is integral to the identification, delineation and classification of wetlands and this has not only been found to apply in South Africa, but internationally as well. In particular, stereo mapping allows one insight into the three-dimensional detail on the aerial photographs. Viewing images in stereo allows one to identify those key topographic and landform features that influence the occurrence, distribution and classification of wetlands in any particular region. Changes in topography often provide clues as to the location and even boundaries of wetlands. Stereo viewing often serves to improve the confidence of mapping by allowing one to rule out or include areas that are not likely to have or have wetlands respectively, based on topography.

While three-dimensional digital image viewing (using a product like ERDAS Stereo Analyst) is a very powerful tool for assisting with wetland mapping, it nevertheless appears to have a few drawbacks when trying to map wetlands nationally. Firstly, one needs to develop the computer skills necessary for its application. There is also a requirement for data preparation. Secondly, one tends to develop a bit of eyestrain when viewing images in stereo over periods of a few hours or longer. This method also offered no benefits over-and above digital non-stereo mapping with respect to boundary accuracy of the section of the Kleinrivier estuary that was mapped, despite its ability to pick up a high level of elevational detail. This technique therefore offers little advantage over-and above digital non-stereo mapping in relatively flat terrain like that associated with the immediate boundaries of the Kleinrivier estuary. In contrast, this method did offer an visualisation advantage over-and above digital non-stereo mapping in the more mountainous terrain at Glenhart, but again this was limited by the practical problems associated with using the method and the poor quality of the digital images.

Quality of photography

In any photo interpretation project, the quality of the photography is a prerequisite for accuracy. Since emulsion is an important characteristic of aerial photographs, one might have expected that RGB and CIR imagery (which produces an array of colours and textural patterns), would be more useful for wetland mapping than BW imagery (which is panchromatic and only yields shades of grey and textural differences). This was not found to be the case, mainly due to the specific requirements of mapping using RGB and CIR imagery. These are discussed below.

Since the predominant vegetation and the hydrologic characteristics (i.e., water regime) largely determine the relative ease or difficulty with which wetlands can be interpreted, timing of the photography is also an important factor. This is a particularly important consideration with regard to RGB and CIR imagery. It appears less important in BW imagery. Antecedent weather conditions (prior to photo acquisition overflights), are also important considerations when it comes to using RGB and CIR imagery. Extreme flooding conditions as well as extreme droughts may also create problems for accurate RGB and CIR wetland photo interpretation. Despite CIR being the generally preferred imagery for wetland and vegetation mapping in the US, because this film records a wider range of colours and tones than true colour (Arnold 1997), it does not appear to offer any advantage in terms of mapping the drier end and more seasonally wet systems including seepage systems and some of the common types of floodplains found on the Highveld of South Africa. The current format and processing of the CIR aerial photography also makes it unsuitable for per-pixel based digital classification applications, and is rather more suited at present, to conventional photo-interpretation mapping techniques. For this reason, mapping off this specific CIR imagery is at present limited to conventional photo-interpretation.

Photo-image scale

Photographic scale is another important issue since it establishes limits on what can be interpreted (e.g. minimum mapping unit (MMU), degree of resolution between different wetland types, and the detail and width of wetland boundaries). The use of course-scale hard copy photography (generally 1:50000) and manual transfer methods will only be useful for national or regional inventories where less detail and low boundary accuracy (>40m) are required. With this type of photography, general wetland boundaries can be delineated for wetlands larger than one hectare in size and for even smaller conspicuous wetlands (e.g. open water areas such as dams and perennial pans).

Large scale hard copy photography (1:20 000 or larger) is best for more detailed mapping where precise boundaries of wetlands and identification of small wetlands are required. Even at large scales, the practical problems of ortho-rectification and hard copy boundary transfer to digital format still exist. BW orthophotographs at 10000 scale are already ortho-rectified and enable direct digitizing from the hard copy. However, despite the relatively large scale of the 1:10 000 orthophotos, they do not provide sufficient resolution and contrast for accurate photo interpretation and therefore wetland mapping. This imagery also does not cover the entire country.

An intermediate scale of hard copy photography such as 1: 30 000 may be the best compromise, as considerable detail can be captured in less time and therefore at lower costs than if large scale photography is used. However, the same problems exist with manual transfer methods so that even with intermediate scale photography, a wetland boundary accuracy requirement of 40m will not be met.

Transfer methods

Manual transfer methods are practically cumbersome and in some cases, highly inaccurate. The use of a zoom transfer scope and redrawing the wetland boundaries from aerial photo's onto base maps such as a 1: 50 000 topographic sheets and then digitizing these, were both ruled out as a practical means of manual transfer from hard copy to digital format. The former method was ruled out on the basis of availability of the equipment in South Africa and the other practical problems associated with mapping and boundary capture on hard copy imagery. The latter was ruled out based on accuracy and inherent human error.

The image scanning method using the remote sensing package ERDAS Imagine and a geometric correction from fiducial and ground control points and vectorization, was reasonably effective in terms of the level of accuracy achieved in the manual transfer. Similarly, the R2V vectorisation methodology also proved reasonably effective in terms of the level of accuracy achieved in the manual transfer. However, both processes required a considerable amount of manual effort in terms of scanning of individual photo prints and editing, and this renders them largely non-feasible as potential nationally applicable manual to digital transfer options

Based on the results of the accuracy assessment, it is evident that heads-up digitizing on BW photo-mosaics alone also does not provide a consistent and high level of accuracy with respect to remote wetland boundary delineation. The main reason for this is the limitations imposed by the low resolution of the digital BW images. A potential way of improving the consistent accuracy of the remotely determined wetland boundaries is to use heads-up digitizing in combination with hard copy BW stereo viewing. The BW hard copy viewing compensates for the loss of resolution on the digital images, despite the courser scale at which the image is viewed.

Proposed national classification system

The proposed classification system including the modifiers, needs further work before it will be able to be applied in South Africa. It is also important that its limitations are understood and accepted if it is to be applied to the national wetland inventory. In particular, the influence of the scale of mapping and therefore the development of minimum acceptable mapping units will be key to its application. Examples of its application are given in the main report.

Estuarine systems present a unique set of issues in terms of classification and delineation. The dynamic nature of these systems plus the high flood that extend beyond what would normally be defined as the estuary boundary in terms of the classification system, all pose unique problems with respect to photo image timing, boundary definition and classification. Careful consideration will need to be given to these systems in any national inventory project.

Skills and training

Finally, the skills of the photo interpreter also are a significant factor in the quality of the interpretation. Photo interpreters must have certain physical skills (e.g. the ability to see in stereo, to distinguish shades of grey or colours, to recognise contrast and wetland signatures, and if manual transfer is used, to accurately draw the boundaries and annotate the maps) and cognitive skills (e.g. knowledge of landscapes, the ability to interpret topography, landforms and geology, and a basic understanding of wetland ecology). They also must be able to identify wetlands and their boundaries in the field during ground truthing exercises.

Status and trend analysis
The value of any wetland inventory is considerably enhanced if it includes status and trend information. Remote mapping, no matter which technique, will not provide the sorts of information required on a wetland by wetland basis for a status or trend analysis. This will only be achieved using a strongly ground-based approach, linked to aerial photo interpretation. It will obviously be too costly to undertake this for all mapped wetlands. Thus, it is recommended that this be undertaken using a sub- or stratified sampling approach. Field checking is also required for verification during mapping of the wetlands. Since much of the time required for ground verification is taken by travelling between wetlands, it would be considerably more cost effective to undertake boundary verification and status assessment during the same operation as the main mapping exercise.

Mapping conventions
Based on the findings of this project, heads-up digitizing offers an easier alternative to manual transfer methods and, if linked to an automated classification and database management procedure, considerably reduces the need for many of the manual mapping conventions. Conventions or standards will still however be needed for this, but there would no longer be a requirement for the large number of conventions relating to pre-digitizing hard copy map symbols, classification labels and so on.

2. Feasibility of utilising the MedWet wetland attribute database for the South African (SA) Inventory

The housing and dissemination of wetland information is a vital component of the overall wetland inventory in that a well-structured, reliable, and accessible database lays the foundation for appropriate analysis, monitoring, and decision making of wetlands in South Africa.

The MedWet (Mediterranean Wetland Inventory) database has been made available to the South African Inventory. The ToR required that MedWet be examined in terms of stability, accessibility, adaptability, ability to handle the expected size of the database and compatibility with Arc/Info and other database systems used by primary stakeholders such as DWAF, DLA, and NDA.

The approach to assessing the applicability of MedWet to the South African context was to:

1) Determine the requirements for South Africa based on the required attributes, stability of the database, accessibility, size, format, speed, compatibility with Arc/Info software, and compatibility with other primary stakeholder database systems;
2) Evaluate the MedWet database against the South African requirements;
3) Determine from MedWet owners and developers usage and/or modification rights to MedWet; and
4) Make recommendations as to whether to modify the current MedWet database or to develop a new database structure that meets South Africa’s requirements.

These requirements for a South African wetland inventory database have been defined through workshops and discussions with stakeholders at various levels (governmental, provincial, NGO’s).

From the analysis in Chapter 4, it is clear that modifications to MedWet 2000 would be needed in order to meet all the listed requirements for South Africa. Some modifications would be minor, for instance adding a field to store an additional hydrological determinant; other modifications would, however, be major. Significant modifications for example are: transforming the database to capture time series information, and spatialising the database. Further, the size of the national South African inventory database is likely to be considerable, and MSAccess is known to be more suited to small-scale localised databases, rather than large-scale national databases. Speed of data retrieval becomes severely compromised if the database becomes too large.

Based on the fact that some of the modifications required for MedWet 2000 are significant, that the database has not been found to be stable enough for wide-spread use, that the size of the national database will exceed the capacity of the current MedWet database structure (MSAccess), and that third party access rights to MedWet have not yet been fully determined, a recommendation is made to develop a new wetland inventory system. Certain of the MedWet concepts should be utilised in the new database and these will be discussed below.

It is, however, suggested that the new MedWet system be assessed and more detailed discussions held with the MedWet owners to determine third party access rights before making a final decision. The newer database contains additional functionality, which may very well meet several of the South African requirements. We were not able to secure access to this database in time to evaluate if these functions do indeed fulfil what is envisaged for South Africa.

Recommendations for a new national wetland inventory database
A full user needs assessment should be conducted to determine the exact requirements of the wetland inventory database (database here refers to the capture of wetland data, the data storage facility, and the interface that interrogates that data), however general database structure and functionalities can be described at this stage and are outlined below.

Database Structure:

- At the national level, due to the volume of data that will be stored, i.e. all provincial level information, a robust relational database (RDBMS) should be used as the storage mechanism, such as Oracle, Informix, or SQL Server. The database can be easily web-enabled for data dissemination. A database such as MSAccess is not appropriate for the national database, as it tends to slow down and become unusable when populated with too many records.

- At the provincial level, the volume of data will be much less and therefore a database such as MSAccess can be used. There are obviously trade-offs in using MSAccess in terms of speed and security, and ease of use. MSAccess is not as fast and does not have the security that other RDBMS may have, however it is a database that is easy to install and maintain. An added advantage is that all the provincial organisations already have MSAccess and therefore do not have to spend money and dedicate time to purchasing and managing a database such as Oracle or SQL Server.

- A non-database dependent interface should be developed to allow the same interface to query data residing in any relational database whether that is SQL Server, Oracle at the national level or MSAccess at the provincial level.

- The national database mirrors the structure of the provincial databases, and duplicates the provincial databases. This can be useful as a backup if data is corrupted. The provinces, who will be largely responsible for the updating of wetland information once the inventory is complete, would send the national office updates at a specified interval, perhaps yearly, and the national office would collate the data into one database. The collation can be automated through routines.

- The database could be housed at any one of the existing facilities or at DEA&T if the necessary infrastructure is purchased. As developments and changes are likely to take place in organisations from now until the national inventory project commences, more detailed investigations should be conducted once the inventory has been commissioned in order to determine the best possible solution for the housing of the inventory database.

Functionality:

- Time series based;
- Fully integrated with GIS i.e. GIS be used to capture wetland boundaries and classifications, for display and query of wetland information, as well to as to automate the population of relevant attributes at the catchment level;
- Use drop-down lists wherever possible to capture data;
- Make use of pre-compiled country wide data dictionaries;

- Select or query wetlands through either spatial or attribute means;
- Generate reports;
- Make provision for the capture and storage of data relevant at both provincial and the national level;
- Different levels of data security depending on user; and
- Set-up correct tolerances depending on minimum mapping units adopted for spatial capture of wetland boundaries (mainly applicable if using the heads–up digitising method).

Certain aspects of the MedWet system can be adopted for the South African system, such as the hierarchical structure (catchment, site, habitat), but should be modified to catchment, wetland complex, site, the data dictionary concept, and the database table structure itself which can be used as a starting point for future database design.

Another important issue to consider is the derivation of a unique numbering system for all wetlands across the whole of South Africa. This unique numbering system must be implemented so that each wetland and it's associated attributes can be uniquely identified. This system must be worked out before data capture of the wetland boundaries and attributes begin. Such issues have been considered, for example the alien vegetation national database, compiled by WfW, and a similar approach could be adopted here.

3. Cost estimates and expertise requirements for compiling such a wetland inventory for SA

This section provides a summarised breakdown of the costs associated with each methodology/approach. The cost estimates are based on the extent of a 1:50,000 topographic map sheets and are the team's best estimates based on experience and the results of the study. For certain approaches, it is possible to provide accurate cost based on current prices of imagery etc, but for the field related costs, much will depend on the complexity of the wetlands to be delineated or captured. We have thus provided ***illustrative*** costs based on a hypothetical 1:50,000 sheet with a array of wetlands chosen to reflect differing complexities and a likely scenario for a typical 1:50,000 map sheet in an area of average wetland density. The density, perimeter and area of wetlands on the hypothetical 1:50,000 sheet was then compared with real data from the Steenkampsberg and the upper catchment of the Olifants River, both areas of very high wetland density and varying complexity. This was done in order to try and get an idea of the extreme ranges of densities of wetlands nationally and provide a perspective of where the hypothetical 1:50,000 sheet sits in relation to these. The percentage difference in numbers of wetlands, wetland area and perimeter, and wetland complexity was then calculated and applied to cost-benefit calculations, thereby giving a range of cost estimates for the hypothetical 1:50,000, one map sheet a quarter less complex, and one map sheet of an expected complexity close to the maximum that may be expected. This also tested the assumption that simpler wetland coverages would cost less while more complex wetland coverages would cost more.

Given the range of costs associated with the topographic sheets of differing densities of wetlands, there was simply no way that these could be accurately extrapolated to a national level. In other words, a direct extrapolation by multiplying these values by the number of 1:50 000 sheets nationally will not provide an accurate reflection of true costs. As such, the costs given below simply provide an illustrative estimate based on a range of possible 1:50 000 sheets and anyone wishing to extrapolate these to a national level should be aware of the limitations herein.

Table 3: Estimated cost breakdown for each approach based on a hypothetical 1:50 000 sheet as compared to real data from the Steenkampsberg and Upper Olifants Catchments. Note that all cost estimates exclude VAT.

Methodology	Total cost per hypothetical 1:50 000 sheet	Total cost for Steenkampsberg 1:50 000 sheet	Total cost for Upper Olifants 1:50 000 sheet
Field delineation: whole topo sheet	R 63,000	R 227,900	R 264,200
Field delineation: One check site only	R 15,000	R 15,000	R 15,000
Heads up digitising: non-stereo **Costs based on no. of wetlands** **Costs based on dividing the topo sheet**	R11,125 or R32,125 R15,400 or R37,400	R314,200 or R335,200 R116,200 or R137,200	R158,950 or R179,950 R87,400 or R108,400
Heads up digitising: stereo	R21,250 to R50,800	R231 400 to R648 400	R173 800 to R337 900
Manual Transfer: Visual non-stereo	R7,260 or R7,800	R72,360 or R72,900	R37,860 or R38,400
Manual Transfer: Visual stereo	R10,740	R75,840	R41, 340
Satellite image processing	R 22,800 (Note because of larger image data area, actual cost is likely to be lower since a component of the data preparation and processing costs will be covered in adjacent 1:50,000 map tiles.	R 22,800 (Note because of larger image data area, actual cost is likely to be lower since a component of the data preparation and processing costs will be covered in adjacent 1:50,000 map tiles.	R 22,800 (Note because of larger image data area, actual cost is likely to be lower since a component of the data preparation and processing costs will be covered in adjacent 1:50,000 map tiles.

4. Most appropriate and cost-effective mechanisms for making this inventory information accessible

The most appropriate and cost effective means of making wetland inventory data available has been investigated specifically considering three methods of data dissemination:

- Paper production of maps;
- CD-Rom; and
- Web based facilities for viewing and downloading of spatial and attribute data.

The advantages and disadvantages of each method have been analysed in terms of cost, effectiveness, labour, and long-term applicability, and can be seen in Chapter 4, Table 4.1. Wetland inventory data should be accessible to all interested parties, including governmental organisations (national government and provincial counterparts), research organisations, NGO's and the public at large. Not all information will be made available to everyone, as there is a need to protect certain information, such as rare data species locations. Any method of data dissemination must therefore take into account different levels of security, depending on the type of information as well as the user. Existing data dissemination facilities where data can be stored and made web-accessible have been investigated.

A recommendation is made to implement a web-based data dissemination method, which allows for dynamic query of both spatial and non-spatial data. Although initial labour costs may be high while implementing such a system, the long-term benefits in terms of saved labour costs are substantial.

The web based approach can also effectively facilitate all the potential dissemination methods i.e. hardcopy paper maps can be printed or downloaded from the web interface, and vector data can be downloaded from the web to a users hard drive, making the distribution of CD's unnecessary.

FINAL CONCLUSIONS

1. Most cost-effective and accurate mapping methods:

1A Satellite imagery

The results of the pilot mapping exercise suggest that satellite based mapping is not suitable for detailed wetland mapping, if Landsat-type imagery is used, and the minimum mapping standards are those specified in the original ToR. Whilst it would be possible to increase the spatial resolution of the satellite imagery by using alternative image formats to Landsat, this would be associated with significant increases in preliminary data purchase costs, and subsequent data processing costs. Furthermore, many of the alternative image data formats do not (as yet) have fully comparable spectral resolutions to Landsat TM and ETM+ imagery. In some instances, aerial mapping will be able to achieve the minimum mapping if it is supplemented by field mapping, but only field mapping will be able to consistently meet the minimum mapping standards for all wetlands. This, however, has significant implications in terms of total project costs (and time). Therefore, unless there is in effect, unlimited funding and time available for field-based mapping, it could be argued that the pre-set minimum mapping standards for wetland mapping are inappropriate for a once-off, baseline inventory. It is therefore recommended that the client consider modifying the minimum mapping standards for a national baseline inventory, but retain the original standards for local area mapping, where the sequence of local area mapping is based on a need or priority basis. The Department should consider using courser level mapping at the national scale. This must, however, be repeatable.

With this in mind and recognising the difficulties of mapping wetlands remotely, there appear to be two general ways to approach this nationally. The first is driven by a desire to map wetlands that are more or less readily photo interpreted. Following this approach means that if an area is mapped as a wetland, it should be correct or have a very high probability of being a wetland. This approach leads to more Type I errors (errors of omission), as emphasis is placed on mapping photo interpretable wetlands, so wetlands that are not, are missed. This approach is typically used in making National Wetlands Inventory maps. The other approach is based on showing all possible wetlands and accepting misclassifications and other errors in the process. This type of mapping will likely lead to more Type II errors (errors of commission) where parts of wetlands are missed or wetland areas are designated as upland and *vice versa*. Each approach has its merits, and it may actually be most desirable to have a map showing both the photo interpretable, other possible wetlands (based on landscape position, landform contiguous to interpretable wetlands etc), and a list of limitations based on a critical assessment of what types of systems were likely to have been missed or under/over-estimated in any particular region and based on what factors.

Satellite based methods are more likely to lead to Type I errors, but at least the method is repeatable given these errors. In addition, because of the errors of omission, satellite based methods may not necessarily be able to identify wetland areas that should be targeted for more detailed regional type mapping, particularly for the wetland types that are missed. Most of the smaller and drier end systems as well as seepage wetlands are not likely to be picked up and will be missed. In contrast, using aerial photo based methods is likely to result in more Type II errors where parts of wetlands are missed or wetland/dryland areas are designated incorrectly. The level of error is, however, not expected to constitute a fatal flaw since in these difficult systems; only ground truthing will resolve these problems.

Whichever option is preferred, the need for a comprehensive Decision Support System (DSS) to coordinate mapping activities then falls away, since any decision making would simply be linked to what the changes in minimum mapping standards are, and where they are to be used.

1B: Use of aerial photography and ground truthing

With respect to aerial photo based methods, the most suitable technique for general wetland mapping appears to be the use of hard copy BW photo's. For specific areas and wetland types such as for the seepage wetlands in the Western Cape, the use of RGB photography offers an advantage over BW imagery, particularly with respect to photo interpretation related to vegetation types associated with wetlands. Ground truthing and the identification and use of check sites for calibrating aerial photo interpretation are critical to the successful use of aerial photo based methods. It is also a finding of this report that heads-up digitising is the preferred transfer method from hard copy aerial photography to digital despite the time costs involved in this process. The main advantage of heads-up digitising onto digital photo-mosaics is that it provides an easy and practical way of capturing wetland boundaries accurately digitally. It gets around the problems associated with manual transfer from non-ortho-rectified hard copies and avoids the line thickness errors related to on-ground distance, thus improving boundary accuracy. It also has advantages over manual transfer methods in that it offers a standardized application requiring fewer mapping and transfer conventions if the data capture methods are automated. For those more manual aspects of the inventory that still require conventions (such as field datasheets, delineation of check sites and so on), one could tap into the wealth of experience and effort incorporated into the convention manuals already developed for the US and other wetland inventories. Using an aerial photo based method linked to heads-up digitising will however also require the development of a few new conventions in order to standardize certain aspects of the process.

Probably the most practical scale of hard copy aerial photography for national wetland mapping is 1:30000 BW stereo imagery. In all cases stereo coverage is essential and this should be backed up hard copy or digital 1:50 000 topographic sheets. Aerial photography also offers enhanced image resolution compared to the digital images used in heads up digitising.

2. Feasibility of utilising the MedWet wetland attribute database for the South African (SA) Inventory

A recommendation is made to develop a new wetland inventory system, based on the fact that some of the modifications required to MedWet are significant, that the database has not been found to be stable enough for wide-spread use, that the size of the national database will exceed the capacity of the current MedWet database structure and that third party access rights to MedWet have not yet been fully determined. It is, however, suggested that the new MedWet system be assessed and more detailed discussions held with the MedWet owners to determine third party access rights before making a final decision.

3. Cost estimates and expertise requirements for compiling such a wetland inventory for SA

A brief conclusion cannot be made of this extensive section. Please refer to the full section above for information in this regard.

4. Most appropriate and cost-effective mechanisms for making this inventory information accessible

A web-based data dissemination method for the inventory information is recommended, which allows for dynamic query of both spatial and non-spatial data. This approach can also effectively facilitate all of the other potential dissemination methods.

CHAPTER 1. BACKGROUND AND PURPOSE

In order to manage and conserve wetland resources effectively in South Africa, it is essential to have accurate information on their location and boundaries. The need for an inventory of this nature has also been accentuated through various international conventions and legislation. South Africa as a signatory and founding member of the Convention on Wetlands (Ramsar, Iran, 1971) and signatory to the Convention of Biological Diversity, has committed itself to the management, wise use and protection of it's wetland resources and as such requires the extent and localities of its wetlands to be documented (Cowan, 1999).

To this end, the Department of Environment Affairs and Tourism (DEAT) commissioned the **Wetland Inventory Consortium**, comprising the CSIR, Geospace International, Wetland Consulting Services and the Institute of Natural Resources, to execute a pilot project to develop tools and method for establishing a cost-effective, accurate and comprehensive National Wetland Inventory. This pilot project will be the forerunner of a much larger wetland inventory project where the tools and methodologies established in this pilot project will be used to establish a comprehensive national wetland inventory.

The project objectives were to determine the:

- Type of remote sensing (RS) most suitable for cost-effectively mapping wetlands across South Africa to the desired level of accuracy (using cost benefit analysis);
- Most cost-effective and accurate mapping methods and associated hardware and software for such an inventory;
- Feasibility of utilising the MedWet wetland attribute database for the South African (SA) Inventory;
- Cost estimates and expertise requirements for compiling such a wetland inventory for SA, and
- Most appropriate and cost-effective mechanisms for making this inventory information accessible.

The basic or overall approach to the project and the selection of study sites are described in Chapter 1. Chapter 2 deals with the satellite image mapping components; Chapter 3 covers the wetland mapping using aerial photography and ground truthing; Chapter 4 deals with the wetland inventory database and data dissemination, and Chapter 5 provides the cost-benefit analysis. The whole project is summarised in the technical summary.

1.1 BASIC APPROACH TO STUDY

Since most of South Africa has a very variable climate, so in some years wetlands may be much wetter than in others. The direct presence of water or permanently saturated soils is often an unreliable indicator of wetland conditions or boundaries, particularly in the arid and semi-arid regions of the country. This obviously has important implications for the development of an accurate and reliable inventory methodology. Any methods developed or recommended for use in the country must therefore not only be cost-effective, but must also be reliable enough to identify the majority of those wetlands which do not always have obvious signatures or indications of the presence of water or permanently saturated soils. In addition to this and according to the terms of reference (ToR), the methods developed should also provide a certain level of spatial accuracy (40 m on the ground) with regard to the boundary delineation of the wetland. In addition, according to the ToR, the method should, if possible, also be able to provide an indication of the main structural or habitat features of wetlands e.g. short herbaceous, tall herbaceous, forested, open water

While the methods should meet these minimum criteria, opportunities should also be explored for added benefits of the application such as, for example, whether or not the methods could be used to achieve a finer resolution of classification for some systems or provide some indication of wetland functioning. The challenge will therefore be to assess those methods which can most reliably be used not only to pick up the wetland signatures, but also aspects of the wetland structure and habitats, provide added value by allowing the collection of finer resolution information about functioning or classification, and which can accurately identify the boundaries to the equivalent of 40 m on the ground, or better.

1.2 CONSULTATION AND BACKGROUND SURVEY PROCESS

The importance of consulting as widely as possible with a variety of institutions to obtain their cooperation, buy-in and assistance with the wetland inventory was recognised during the initial stages of the project. An initial scan was completed during the first month of the project of possible information sources available to the project through a variety of identified stakeholders and other information sources. The scan included, amongst others:

- Consortium members;
- DEAT, DWAF, Surveys and Land Information and other government departments;
- The National Spatial Information Framework's Spatial Data Discovery Facility, South Africa's national spatial metadata clearinghouse;
- Commercial data suppliers;
- Satellite and aerial image suppliers; and
- The Internet and literature.

Contact was also made with a number of international institutions such as US Fish and Wildlife Services, MedWet Database providers (LuisToste Costa and Spyros Kouvelis - the MedWet Coordinator), US's Ducks Unlimited (DU) organization (possibly the largest non-governmental wetlands related body in the US) to determine their interest and possible assistance with this initiative. A Wetland Steering Committee was formed with representation of most State Departments (national and provincial) with an interest in Wetlands (Department of Water Affairs and Forestry (DWAF); National Department of Agriculture (NDA); Department of Land Affairs (DLA); Department of Environment Affairs and Tourism (DEAT); provincial conservation agencies) as well as other interested parties such as the Mondi wetlands group. Progress reports were also provided to a much broader wetlands user community through the Wetlands User group List server and comments that would benefit the project were encouraged.

1.3 SELECTION OF STUDY SITES

South Africa is characterised by a diverse landscape with many wetland types that differ in complexity, size, biodiversity, geomorphology, hydrology and levels of use and degradation. From the outset, it was therefore recognised that the inventory methodology would need to be able to deal with the inherent complexities that emerge from this diversity. The methodology does not only need to distinguish wetland from dryland areas, but also needs to, for example, be able to identify the full range of wetlands nationally, ranging from ephemeral pans to permanent marshes, as well as provide information on landform types, impacts and so on. Central to all this is a need for cost-effectiveness and due consideration of practicalities involved in acquiring and capturing the data relevant to the national inventory. Ideally, as wide a range of wetland types from different regions should have been included in the pilot study in order to make sure that the methodology proposed is able to deal with the complexity nationally and produces the levels of accuracy required for the purpose of the inventory. However, due to budgetary constraints, many wetland types and regions had to be excluded from this pilot study. As such, an alternative approach had to be considered that would at least deal with most of the key issues that one would expect nationally. It was therefore decided to focus on those systems in regions expected to pose most problems with respect to developing a suitable methodology. These also excluded those regions and/or wetland types for which there is already data on distribution and occurrence. Every effort was made to ensure that a representative sample of wetlands was included in each of the regions in which test sites were chosen.

The selection of test sites was based on a number of considerations. For example, it was considered important that the test sites included as many different landscape, habitat and structural classes as possible. The test sites also needed to reflect a range of land-uses and disturbance factors since these affect the identification of signatures and wetland boundaries. For example, besides considering the range of wetland types represented, the Davel site was also chosen based on consideration of the land-use impacts in the region. Here it was important to be able assess whether different methods could pick up wetland boundaries in areas of the wetland that had been cultivated. Similarly, it was important to be able to assess whether cultivated lands and planted pastures could be picked up within the wetlands. The full list of selection criteria for the test sites is given in the box below. In summary, the selection of the test sites was based on:

- the likelihood of there being wetlands not easily detectable using standard techniques;
- the occurrence of a variety of habitat and structural types;
- the occurrence of a range of landform types and topographic settings;
- considerations relating to regional differences in the types of wetlands in the test sites (including climatic, terrain, cultural and vegetation differences);
- the availability of data to support testing of different techniques (whether suitable information was available from other projects to add value to the pilot study);
- accessibility of the test sites; and
- consideration of factors that may be representative of similar wetland types in other regions (for example, it was assumed that techniques for identifying and delineating hillslope seepage wetlands in the Highveld may be applicable to hillslope seepage wetlands in the Kwa-Zulu Natal mist belt).

Four test study sites were identified nationally. These are believed to provide at least an overview of those inland wetland types known to be difficult in terms of remote mapping. The sites contain representatives of the following wetlands included in the ToR:

- Rivers and streams (with associated floodplains and riparian areas).
- Pans.
- Permanent, seasonal and temporary marshes, including hillslope seeps.
- Springs.
- Artificial wetlands, including impoundments, excavations and wastewater treatment areas.

Of the four sites, one (Davel) was selected for mapping analysis using all the pre-selected space, airborne and field-based survey techniques. The four sites are:

Highmoor (Kwa-Zulu Natal).
Glengarry/Kamberg (Kwa-Zulu Natal).
Walker Bay and the associated coastal flats and fold mountains (Western Cape).
Davel (Mpumalanga).

Site descriptions:

Study site 1: Highmoor (KwaZulu-Natal)

Within this study site, three wetland areas were targeted for fieldwork. These were the plateau areas 1 and 2 as described below.

Plateau area 1
This site is located north of the Highmoor station (Figure 1.1). It contains many small wetlands (some less that 10m in diameter) and others amalgamating into more extensive complexes of hundreds of hectares. In some cases, the wetlands were very small (<1 ha), making remote delineation difficult. All the wetlands in this area were relatively unimpacted. The area includes predominantly seepage wetlands. This site presented the types of challenges to mapping and classification that would be expected with small wetlands.

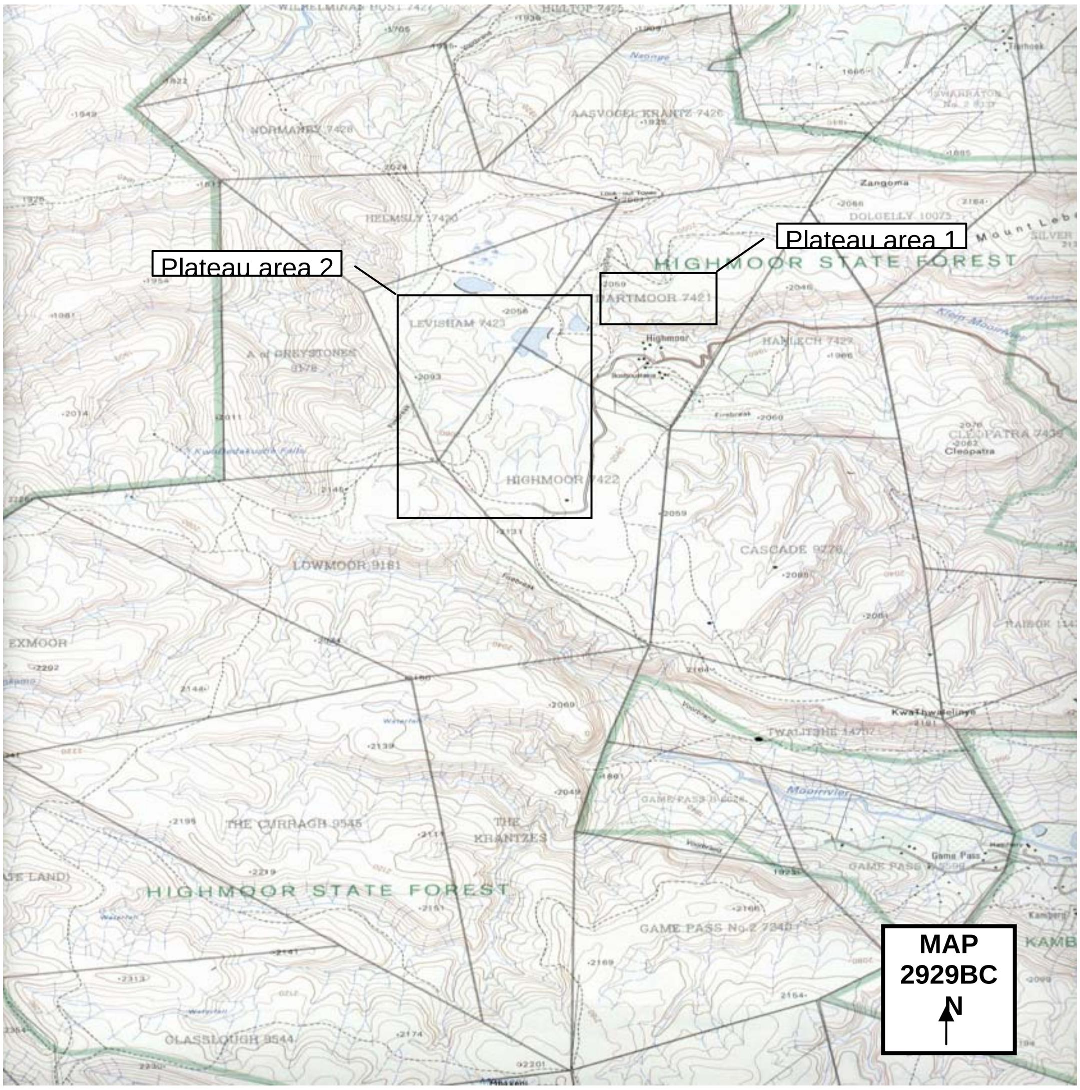


Figure 1.1: Location of the Highmoor test sites, Plateau areas 1 and 2

Plateau area 2
This site is situated to the south of the three dams that lie to the north-west of the Highmoor station (Figure 1.1). The area contained two montane wetland complexes, one impacted by dams and another that was largely unimpacted. The area includes permanent marshes and hillslope seepage wetlands as well as dams. The two wetland complexes presented the types of challenges to mapping and classification that would be expected in a natural landscape with near natural and partly modified wetlands.

Study site 2: Glengarry/Kamberg (KwaZulu-Natal)

Within this study site, two wetland areas were targeted for fieldwork. These were the Glengarry and Kamberg/Stillerust areas as described below.

Glengarry
This site is situated near and includes a section of the floodplain of the Klein Mooiriver (Figure 1.2). It contains a large floodplain in the north and large cultivated areas and dams punctuating the wetland in the south. There are many drains and furrows in the floodplain and its feeder arms and these have resulted in the degradation of the wetland complex. The area was chosen because the soils are complex and, since most of the wetland area had been converted to agriculture, boundary delineation was expected to be difficult. The area includes permanent and seasonal marshes, hillslope seepage wetlands, floodplains, riparian habitats and artificial wetlands associated with dams. This site

presented the types of challenges to mapping and classification that would be expected in a highly modified landscape.

Kamberg/Stillerust

This site is a large, near natural floodplain with many oxbows and is located within the Kamberg Nature Reserve (Figure 1.2). Seepage areas adjacent to the floodplain were expected to provide challenges with respect to boundary delineation in the field. The area was chosen because the soils are complex and, since most of the wetland area was largely natural, presented the types of challenges to mapping and classification that would be expected in a more natural grassland landscape. The area includes permanent and seasonal marshes, hillslope seepage wetlands, floodplains, riparian habitats and artificial wetlands associated with dams.

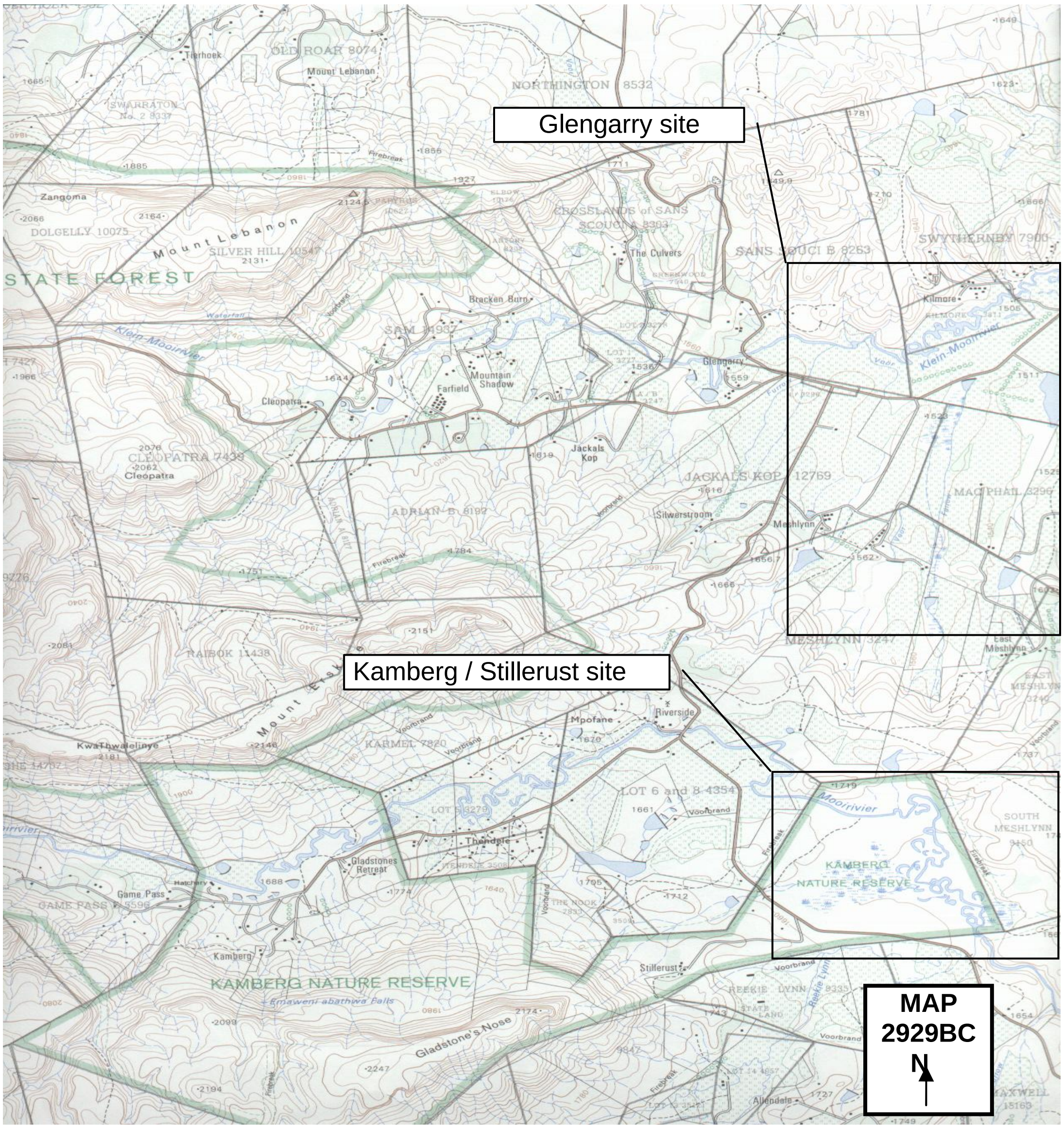


Figure 1.2: Location of the Glengarry and Kamberg/Stillerust test sites

Study site 3: Walker Bay, Betty's Bay and Theewaterskloof Dam (Western Cape)

Within this study site, four wetland areas were targeted for fieldwork. These were the Kleinrivier Estuary, an area near Glenhart, an area near Betty's Bay and Hangklip, and an area around Theewaterskloof Dam. These areas are described below.

Kleinrivier Estuary

This site included the eastern section of the Klein River estuary and a section of the Klein River itself near the town of Stanford (Figure 1.3). While the intertidal boundary of the estuary was quite distinct, the upper floodplain areas appeared more difficult to delineate. The estuary presented the types of challenges to mapping and classification that one may expect with respect to systems where the boundaries vary in space and time.

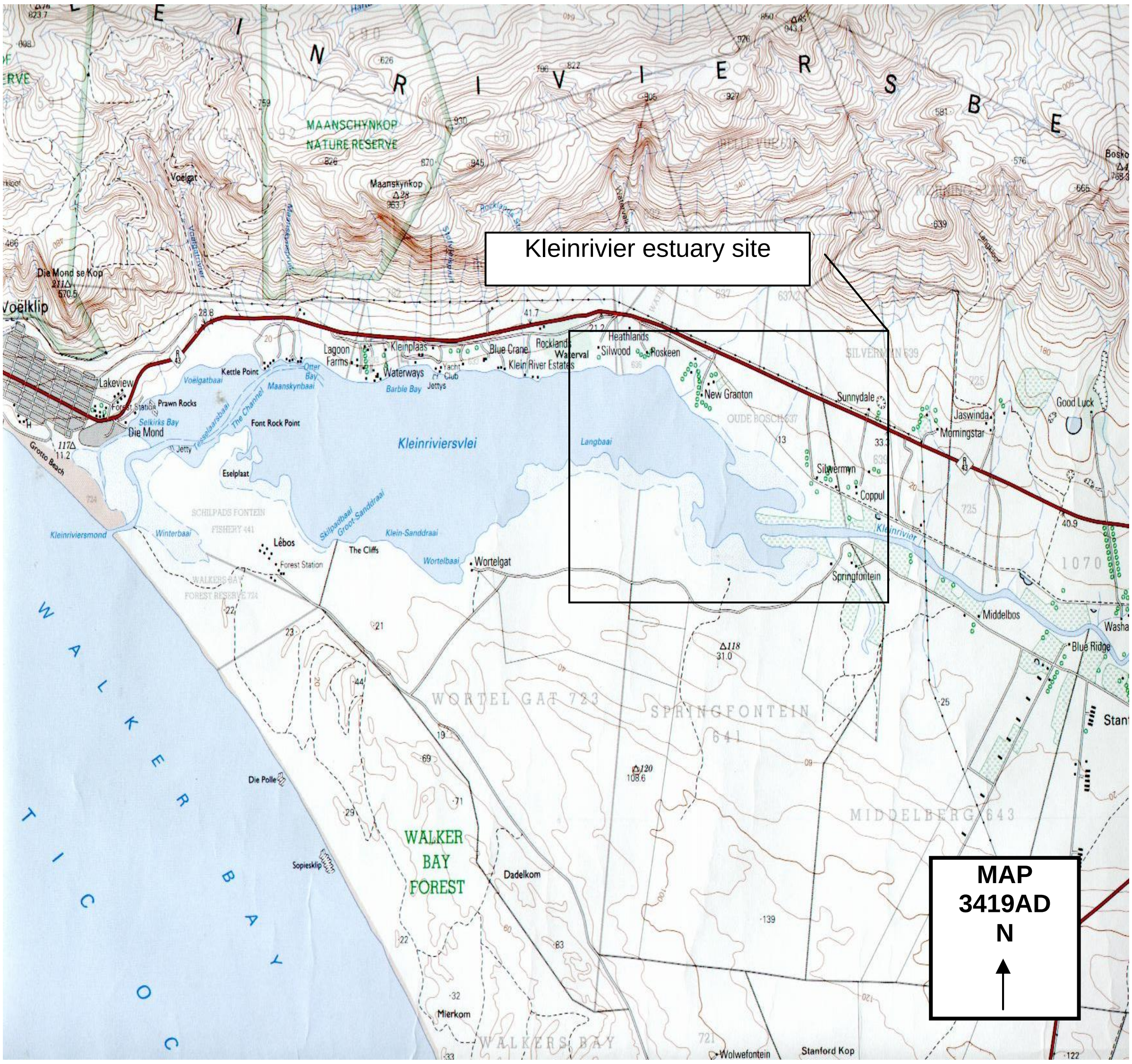


Figure 1.3: Location of the Kleinrivier estuary test site

Glenhart

This site is south-east of Shaw's Mountain Pass on the R320 from Hermanus to Caledon (Figure 1.4). It includes systems associated with drainage lines and the footslopes of the fold mountains in this part of the Western Cape. While this area is not necessarily representative of the systems in the region, it was chosen because it posed challenges with respect to landscape signatures as well as landform and topographic settings of the wetlands. The area includes seasonal and temporary marshes, hillslope seepage wetlands, floodplains, riparian habitats and artificial wetlands associated with dams. Being a highly disturbed area (due to agricultural practices), it also provided an interesting comparison with the disturbed landscapes found in the grassland sites.

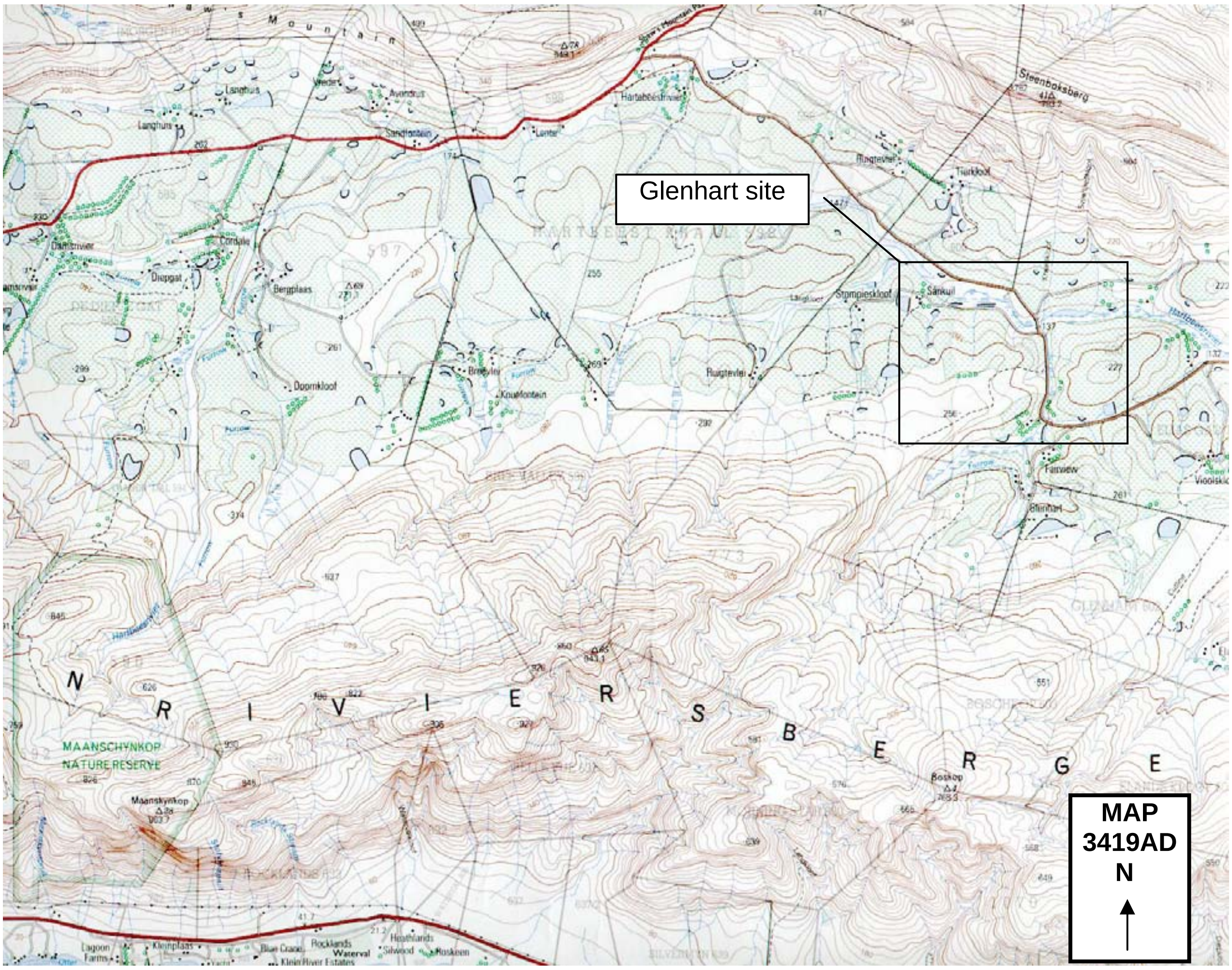


Figure 1.4: Location of the Glenhart test site

Betty's Bay and Hangklip

This site included two wetland complexes in the Betty's Bay and Hangklip area (Figure 1.5). The wetlands in this area better represented the coastal wetlands that occur in the region and exhibited many of the complex features associated with systems occurring in region. The area includes permanent and seasonal marshes and small coastal lakes. These systems therefore provided a perspective on the types of difficulties that may be encountered when trying to map the wetlands of the region.

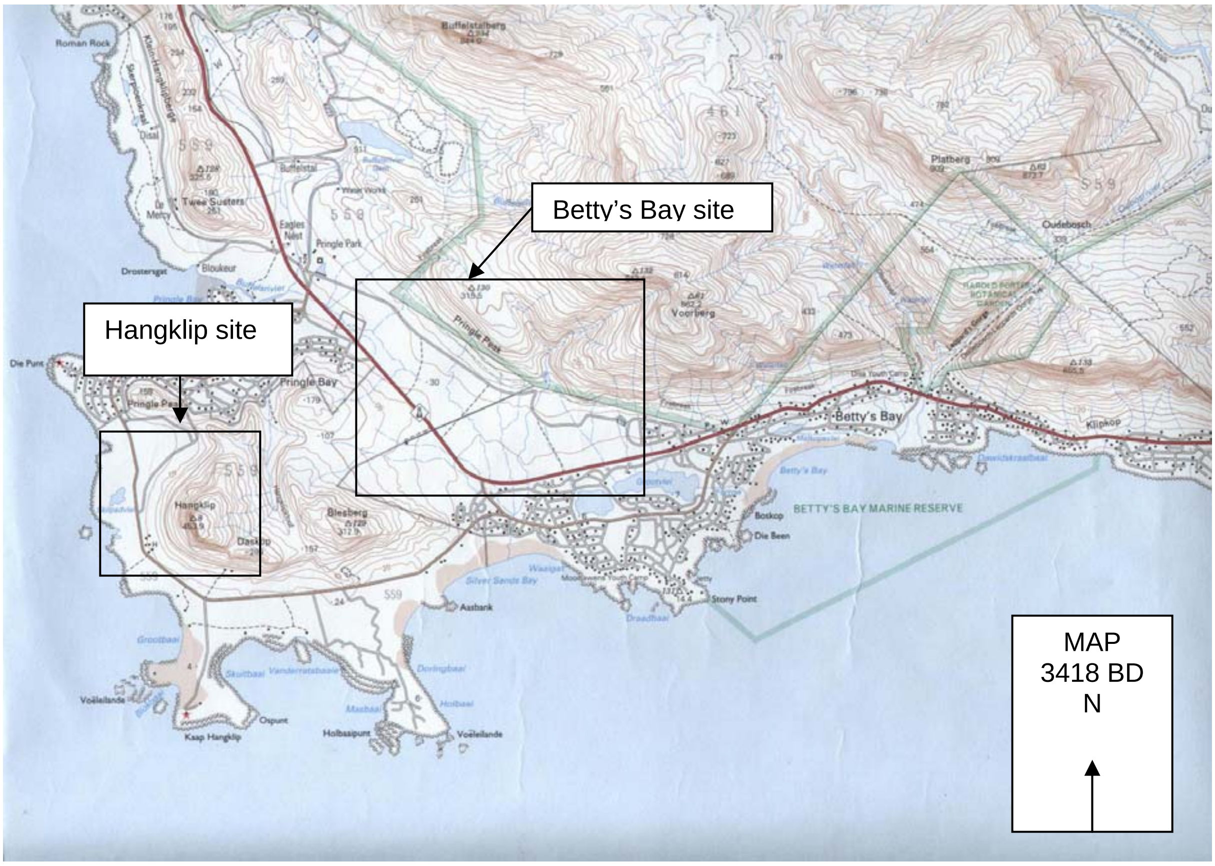


Figure 1.5: Location of the Betty's Bay and Hangklip test sites

<u>Theewaterskloof Dam</u>

This site included a large (hundreds of hectare) seepage wetland complex associated with the mountain slopes around the Theewaterskloof Dam and a riparian wetland complex associated with the Amandelrivier (Figure 1.6). The wetlands in this area highlighted the complexities and difficulties that may be encountered when trying to map the wetlands of this part of the region. The area includes seasonal and temporary seepage wetlands, and semi-permanent marshes.

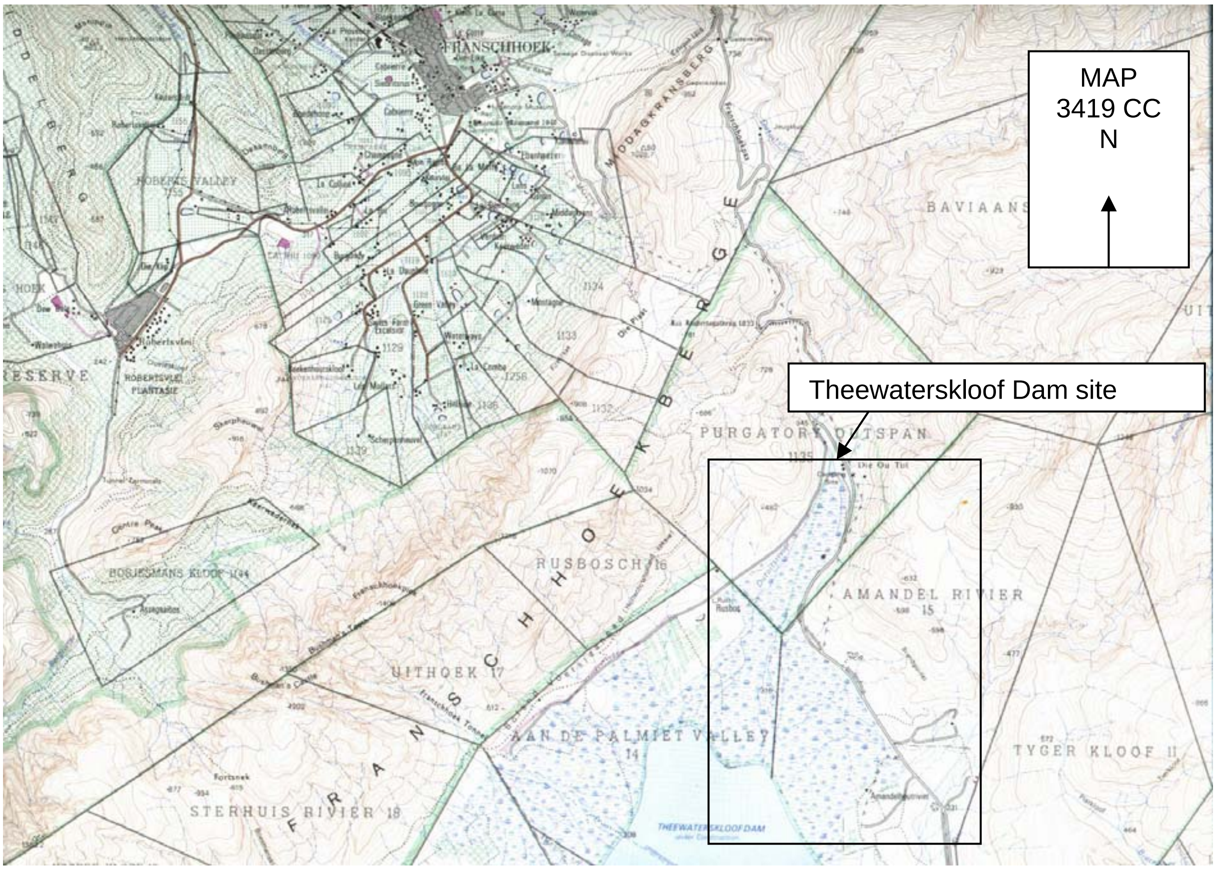


Figure 1.6. Location of the Theewaterskloof Dam test site

Study site 4: Davel (Mpumalanga)

<u>Viskuile</u>

This site is located approximately 10 km north of the town of Bethal in Mpumalanga and includes the lower reach of the floodplain of the Viskuile River and Joubertspruit (Figure 1.7). Previous work in the area showed that the majority of the hillslope seepage wetlands were not picked up using black and white aerial photography and that it was even difficult to identify and delineate these during field verification. The nature of the soils and level of landscape modification, mainly from agricultural practices also made wetland delineation very difficult. The area includes seasonal and temporary marshes, hillslope seepage wetlands, floodplains, riparian habitats, endorheic pans with and without seepage wetlands, and artificial wetlands including dams. It therefore represented an ideal site for detailed assessment. The wetlands in this area highlighted the complexities and difficulties associated with delineation in the region

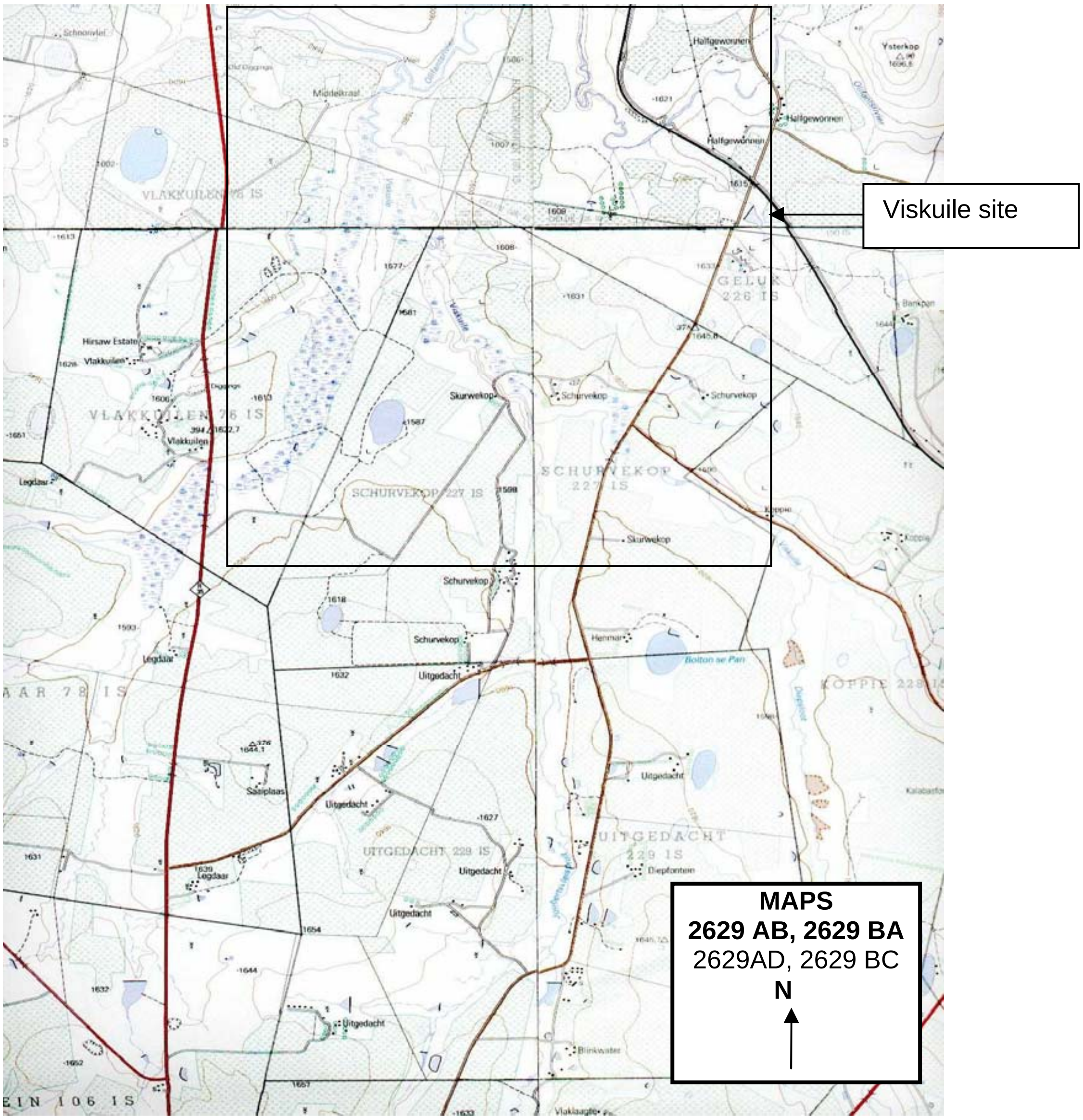


Figure 1.7: Location of the Viskuile test site

Table 1.1 provides a short summary of the study site information.

Table 1.1 Study site information.

Site Number	Province	Name	Topographic sheet	Wetland classes	Vegetation type	Motivation for testing mapping	Data already captured or available
1	Kwazulu-Natal	Highmoor	2929BC	Permanent, seasonal and temporary marshes and hillslope seepage wetlands (Palustrine). Depression and sheetrock wetlands	Montane grassland	1. Wetland area smaller than 1 ha; 2. Steep topography and signatures that complicate identification and delineation; 3. Largest mountain range in the country and many wetlands are inaccessible for ground truthing – therefore need to identify reliable mapping method; 4. Wetlands surrounded by natural grassland on steep slopes which are subject to shadow when using remote sensing techniques which complicates identification; and 5. Accessible.	No data
2	Kwazulu-Natal	Glengarry/ Kamberg	2929BC	Small to large valley bottom wetlands including permanent, seasonal and temporary marshes and hillslope seepage wetlands (Palustrine) as well as dams.	Grassland	1. Gentle topography and signatures that complicate identification and delineation; 2. A variety of severely impacted systems and near unimpacted systems in protected areas; 3. Representative of wetlands of the area; 4. Accessible; and 5. Relict wetlands make classification and delineation difficult.	1:30 000 B&W aerial photography and course delineation. SOURCE:
3	Western Cape	Walker Bay, Betty's Bay and Theewater skloof Dam	3419AD	Permanent, seasonal and temporary marshes and hillslope seepage wetlands as well as artificial wetlands around dams.	Fynbos	1. Includes coastal plain wetlands, estuary, valley bottom systems and wet areas on the slopes of associated fold mountains; 2. Sandy coastal systems with restios; 3. Seepage and riparian systems with complex soils; 4. Different vegetation type and structure;	No data for the coastal plain systems or fold mountain systems of the area. Schafer (1983) – Theewaterskloof

Site Number	Province	Name	Topographic sheet	Wetland classes	Vegetation type	Motivation for testing mapping	Data already captured or available
						and 5. Accessible.	Dam
4	Mpumalanga	Davel	2629BC	Permanent, seasonal and temporary marshes and hillslope seepage wetlands; Artificial wetlands including dams.	Highveld grassland	1. Land use impacts - cultivated wetlands; 2. Signatures very difficult to ID; 3. Includes permanently, seasonally and temporarily wet pans; 4. High diversity of hydro-geomorphic wetland types; 5. Easily accessible; 6. Non treed riparian; 7. Known strong geological influence;	Digitally mapped at 1:50000 scale. 17 wetland types already classified and mapped Vegetation well known Not accurate to 40 m level Source - WCS B&W photos GOT (1:50 000)

1.4 REFERENCES

Cowan G I, 1999. The Development of a National Policy and Strategy for Wetland Conservation in South Africa. Unpubl. PH.D Thesis, Dept of Architecture & Landscape Architecture, Univ. of Pretoria. 181p.

Ramsar, Iran, 1971. Convention on Wetlands of International Importance especially as Waterfowl Habitat

CHAPTER 2 SATELLITE IMAGE MAPPING

2.1 APPROACH

2.1.1 Background

A key objective of the wetlands project was to determine, by means of a cost-benefit analysis, which types of remote sensing are most suitable for mapping wetlands across South Africa to the desired degree of accuracy. In order to achieve this, it was first necessary to identify which remote sensing techniques were capable of meeting the pre-set minimum mapping standards, and secondly, to determine the cost-effectiveness of such techniques for national-scale implementation, which would be capable of providing strategic wetland data on a repeatable, long-term and operationally sound basis.

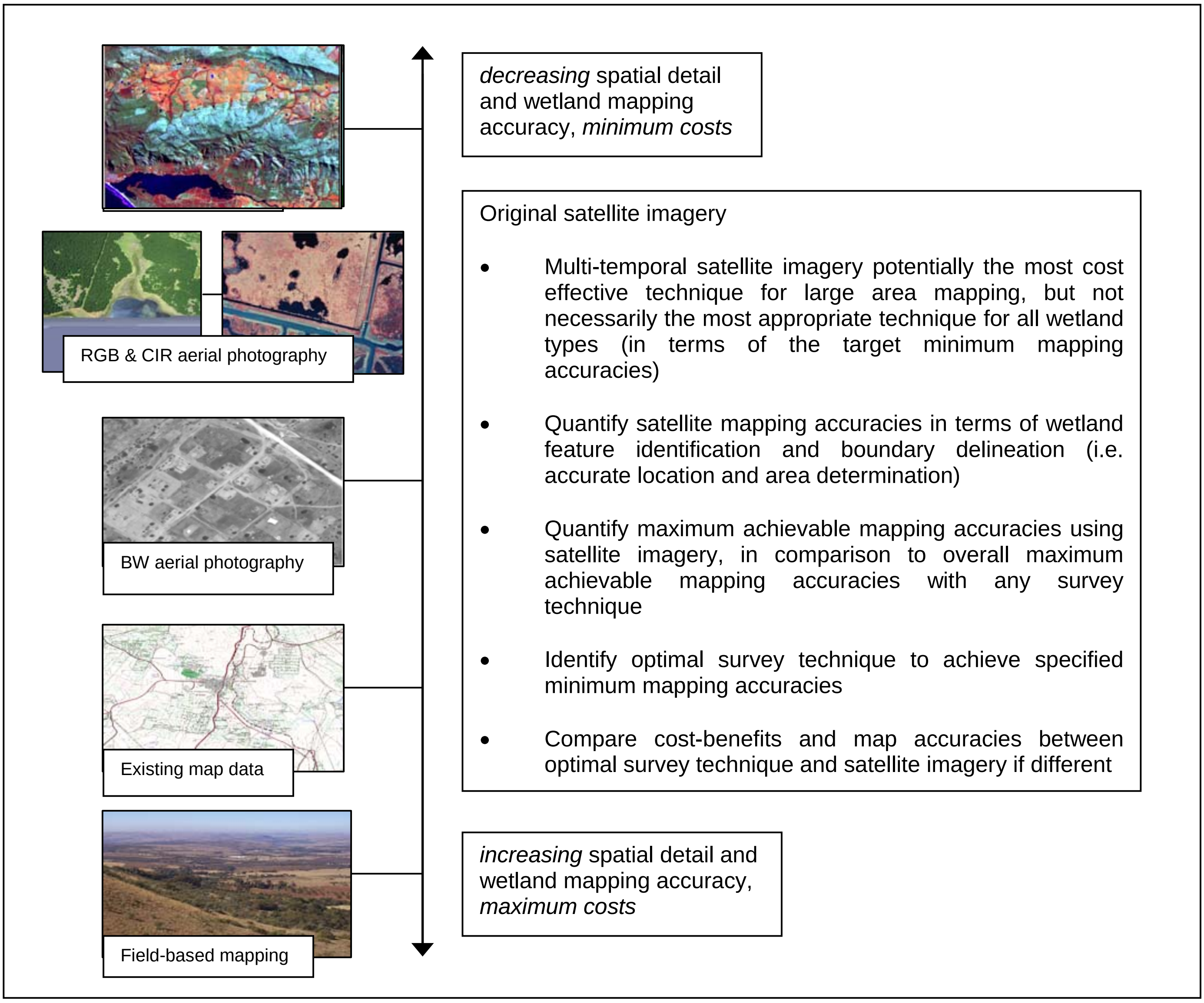
Most of South Africa has a very variable climate so that in some years wetlands may be much wetter than in others. The direct presence of water or permanently saturated soils is therefore often an unreliable indicator of wetland conditions or boundaries, particularly in the arid and semi-arid regions of the country. This has important implications for the development of an accurate and reliable inventory methodology, since any recommended technique must not only be cost-effective, but also able to consistently identify wetlands which do not always exhibit obvious 'signatures', indications of the presence of water, or permanently saturated soils. These physical characteristics are likely to increase the reliance on field mapping techniques, especially if the desired mapping accuracies are to be consistently achieved in all environments. Field surveys are, however, by their very nature, both expensive and time consuming, and thus typically limited to small areas, which obviously restricts the usefulness of the technique for large area coverage. In comparison, (airborne and / or satellite) remote sensing techniques offer large area, cost-effective surveys, but with (generally) lower mapping accuracies. Satellite-based surveys are, therefore, potentially the most cost-efficient approach, but not necessarily the most cost-effective, because of the potential inability to consistently meet the minimum wetland mapping standards.

Furthermore, those wetlands considered problematical in terms of mapping (i.e. the smaller ones), are typically characterised by steep ecological gradients within narrow vegetation units, which are often smaller than the spatial resolution of most current satellites. If, however, suitable spatial resolution imagery is available, it is typically associated with inferior spectral resolution (i.e. 10 m panchromatic imagery), which will reduce the ability to discriminate between similar wetland and non-wetland vegetation communities. In comparison the textural nature and superior spatial resolution associated with aerial photography makes it a very useful data source for detailed wetland mapping, although this method is not feasible for large area mapping because of the associated costs and logistical difficulties associated with the volume of photography required *(after* Harvey and Hill, 2001*)*. Thus, whilst the use of remote sensing for wetland mapping worldwide is well documented, in general, aerial photography is probably the most widely used tool for detailed, operational programmes (Bartlett and Klemas 1980, Cowardin and Myers 1974, Dale *et al* 1996, Dottavio and Dottavio 1984, Dottavio *et al* 1981, FGDC 1992, Jensen et al 1986,1995, Harvey and Hill 2001, Houhoulis and Michener 2000, Kennard and Lefor 1981, Lunetta and Balogh 1999, Munyati 2000, Ramsey and Laine 1997, RESAC 2001, Ringrose et al 1988, Tina 1996, Wilen and Smith 1996).

The focus of the satellite-based evaluation was therefore, to determine which, if any, of the locally accessible satellite systems were capable of meeting the required mapping standards, and to what extent the use such techniques could minimise the necessity for field-level mapping with its associated higher costs. In attempting to defining a suitable method, it has been assumed from the outset that no single remote sensing technique (i.e. airborne or satellite, or data processing methodology) will necessarily be optimal for all localities and that a range of techniques may be required, which are individually optimal for specific local conditions.

A hierarchical assessment of a range of complimentary field, aerial and satellite-based survey technologies has been used to determine the suitability of a particular remote sensing technology, and to be able to compare it to alternative survey techniques. The optimal approach at each level being the method(s) which best balances scientific rigour and defensibility with the practical constraints of cost, time and operational feasibility, whilst achieving the required spatial mapping accuracies (Figure 2.1)

Figure 2.1. Schematic diagram of hierarchical assessment framework used to compare different mapping techniques



The primary objective for identifying a suitable satellite-based remote sensing technique was to able to facilitate the rapid collection of accurate information over large areas, and minimise the level of field-related activities with their associated higher costs. From the outset it was, however, acknowledged that satellite-based remote sensing may be more cost-efficient than other survey techniques, but in comparison to aerial and field-based surveys, may be less cost-effective in terms of achieving the required minimum wetland mapping standards.

2.1.2 The Choice of Satellite Imagery

In order to determine the basic suitability of satellite remote sensing for wetland mapping, it was first necessary to determine the most appropriate imagery to use, after which the most appropriate image processing techniques should identified, and finally classification accuracies could be evaluated. Classification accuracies were evaluated, using field-mapped wetland boundaries for reference, in terms of (a) the ability to identify and locate a given wetland (irrespective of size), and (b) the accuracy of individual wetland boundary delineation. The choice of which image type to be used was based on the following parameters:

- Spatial and spectral resolution,
- Data acquisition costs in relation to large area, national coverage, and
- Data accessibility and local coverage.

Landsat imagery was identified as being the most suitable imagery for evaluation purposes. It offered the best combination of spatial and, especially spectral resolutions, very competitive costing structures in comparison to other medium resolution image formats (e.g. SPOT), and has an extensive local archive, supported by ongoing data reception, which offers multiple choice of possible image acquisition dates. Theoretical comparisons to alternative systems such as SPOT were, however, completed in order to evaluate the influence of different spatial and spectral characteristics. Multi-temporal Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper (ETM+) image datesets were acquired for the test site evaluations. Landsat 7 ETM+ imagery was specifically acquired for the Davel test site in order to evaluate the additional ultra-high resolution 15 m panchromatic band available with this dataset.

Once the optimal image type had been identified, then next consideration was the most suitable date or dates for image acquisition within selected seasonal windows, which would maximise the visibility of wetlands in relation to surrounding land-cover types.

2.1.3 Optimal Image Acquisition Date

The optimal period of any image acquisition will be at the point when wetland areas exhibit significantly different characteristics to the surrounding land-cover, especially if they are primarily vegetated as opposed to being open water features. This will vary according to local environmental characteristics, but will usually coincide with period of seasonal climatic change and associated vegetative response (Jensen *et al* 1986, Lunetta and Balogh 1999, Ramsey and Laine 1997, and Tiner 1996). In South Africa, this could potentially be either during the transitional ‘wet-up’ or ‘dry-down’ periods, but is unlikely to be within the peak wet or dry periods. Such periods, however, do not always coincide with the period of minimum cloud cover, which will significantly affect the long-term viability of any optimal period in terms of the likelihood of obtaining repetitive cloud free imagery.

In the summer rainfall areas, the optimum *wet-period* image acquisition period is likely to be spring (i.e. September – November), shortly after the onset of heavy summer rains, when the wetlands would be inundated. At this time the wetland vegetation would be exhibiting vigorous, early season growth compared to the surrounding non-wetland vegetation. The availability of suitable imagery within the optimum period would however be determined by localised cloud cover, associated annual rainfall patterns, and the occurrence and condition of any late-season burn scars (Dely *et al* 1999, Jensen *et al* 1986, Thompson 1994, Thompson *et al* 2001). Similarly, the optimal *dry-period* window for summer rainfall areas is likely to be late autumn, when the wetlands could be expected to remain wetter (and therefore greener) than the surrounding natural vegetation, and before winter burn scars become spatially dominant. A similar approach was used in the winter rainfall areas, although optimal acquisition periods were modified to accommodate the different rainfall patterns.

By using multi-temporal datasets instead of single date imagery, it is, however, possible to minimise the effects of having to use non-optimal image acquisition dates, since the seasonal differences will help to further enhance whatever differences exist between wetland and non-wetland areas (Bartlett and Klemas 1980, Cowardin and Myers 1974, Jensen *et al* 1986, 1995; Lunetta and Balogh 1999, Ramsey and Laine 1997). This can be an important contributing factor, especially if the wetlands exhibit similar structural characteristics to surrounding vegetation communities, or the timing of image acquisition dates has necessitated the inclusion within one image date of temporal burn-scar effects.

The superiority of specifically selected, multi-seasonal satellite imagery (as used in the SA wetlands mapping project), compared to single-date imagery for wetland mapping is well documented (Harvey and Hill, 2001, Jensen et al 1986, 1995, Lunetta and Balogh 1999, Ramsey and Laine 1997). In some of these reported cases, individual dates were analysed separately, whilst in others all available imagery was combined prior to classification, as within the SA test sites. For example, Lunnetta and Balogh (1999) used an initial analysis of spring leaf-on imagery to derive a basic land-cover map, followed by a second classification of spring leaf-off imagery to define seasonally saturated soils in forested and agricultural wetlands; whereas Ramsey and Laine (1997) classified a combined set of multi-season imagery for coastal wetlands.

Because of the inherent inability to guarantee the availability of optimal period imagery for all sites in all years, a multi-temporal image classification was assumed to be the best approach for the wetlands project, where preference was given as far as possible to using imagery acquired within the optimal wet / dry period windows. The final choice of image date was, however, governed by archival availability and suitability in terms of cloud cover and burn scar extent. Visual inspection of potentially suitable imagery and comparison of acquisition dates to local rainfall records (which would indicate the likely condition of wetland vegetation in comparison to non-wetland areas), were used to help identify the most suitable acquisition dates.

In some localities, it is also necessary to take account of additional factors that may influence the suitability of certain image acquisition dates. In mountainous regions (i.e. Western Cape and Drakensberg), both low winter sun illumination angles, which result in extensive shadowing in E-W trending mountains, and the possibility of masking winter snow all need to be accounted for. For coastal sites, if the choice of data permits, multi-temporal data should also be chosen to maximise the difference in tidal status at the time of overpass (approximately 0900 – 0930 local time), which can then help with coastal wetland delineation.

It may be possible to utilise only a single, wet-season image, but in such circumstances, the timing of the image acquisition date in relation to local rainfall patterns and associated wetland response pattern is critical. In most cases however, archival limitations will preclude this as a suitable option for large area coverage, operational mapping, so that the use of multi-temporal imagery becomes

Landsat imagery was identified as being the most suitable imagery for evaluation purposes since it offered the best combination of spatial, spectral, and costing characteristics in comparison to other medium resolution image formats. Preference was given to the use of multi-temporal datasets rather than single date imagery, in order to minimise possible effects of having to use non-optimal image acquisition dates, whilst also enhancing seasonal differences between wetland and non-wetland areas. Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper (ETM+) image datesets were acquired for the test site evaluations. Landsat 7 ETM+ imagery was specifically acquired for the Davel test site in order to evaluate the additional ultra-high resolution 15 m panchromatic band available with this dataset.

2.1.4 Landsat Imagery used in the Wetlands Project

Digital Landsat imagery was acquired for the different test site localities with the following acquisition dates:

•	Davel	Landsat 7 ETM+	22 August and 26 November 2000
•	Highmoor / Kamberg	Landsat 5 TM	06 April, 13 Sept 1999[1], and 30 August 2000
•	Walker Bay	Landsat 5 TM	11 October 2000 and 12 August 2001

The close proximity of the Highmoor, Glengarry, and Kamberg field study sites meant that in terms of satellite image coverage, it was possible to include them all within one sub-image area, referred to hereafter as "Highmoor / Kamberg". Similarly the Klein River Estuary and Glenharts study sites are collectively included in the Walker Bay sub-image.

As can be seen from the image dates, very few datasets were actually recorded within the theoretical optimal seasonal windows, clearly illustrating the need to use multi-temporal imagery to enhance intra-scene spectral characteristics, using inter-scene seasonal differences. A more detailed description of these data sets and associated parameters is provided in Appendix 2.1, which provides more background detail on the possible acquisition dates that were investigated, and their timing in relation to local rainfall patterns.

Final image selection was made on the basis of most recent archival availability within, or closest too, the optimal seasonal windows the, linked to suitability in terms of cloud-cover and optimal seasonal windows modified according to the following parameters:

- Timing and intensity of recent rainfall patterns,
- Occurrence and extent of (winter) burn scars,
- Influence of sun angle and terrain shadows (in mountainous regions),
- Localised tidal flooding conditions at time of image overpass for coastal imagery.

2.1.5 Defining an Optimal Satellite Survey Technique

An optimal procedure will, by necessity, be linked to currently available, easily accessible, operational remote sensing systems. However, as far as possible, the parameters that define suitability with respect to the pre-set wetland mapping requirements should be defined in terms of minimum sensor requirements rather than specific image formats, in order to reduce long-term dependency of a specific sensor, and allow potential use of new, improved technologies in the future. This is seen as important, since the local availability and exclusivity of Landsat (and SPOT) imagery in South Africa could change in the future.

Digital image classification procedures are likely to become increasingly more automated in the future with the advent of new algorithms and data processing routines, compared to more traditional, manually intensive, image and photographic interpretation methods. This is expected to place increasing emphasis on the use of multi-temporal imagery, and high-level integrated GIS modelling with non-remote sensing environmental data sets (i.e. bio-geographical parameters).

[1] A third Landsat TM image was acquired for Highmoor / Kamberg after preliminary analysis of the April and August multi-temporal dataset, in order to evaluate the influence of a slightly modified acquisition date in terms of burn scar effects and surrounding senescent winter grassland.

All of which will help to streamline data pre-processing, whilst reducing to some extent, the need for intensive expert image-analyst interaction during the mapping and classification stages. Such developments will not, however, exclude the potential application of manually assisted classification or visual interpretation techniques, with both the satellite imagery and aerial photography.

2.1.6 Satellite Mapping Methodologies

The analysis of satellite imagery consisted of the following pre-preparation, data processing and classification stages :

- Pre-classification data standardisation to (a) minimise spectral variation due to external atmospheric and topographic influences, and (b) correct all imagery to a standard map projection for precise pixel-to-pixel registration of multi-temporal datasets,
- Image classification using a combination of original and derived datasets (i.e. biomass and wetness indicators), in order to enhance seasonal differences in wetland and adjacent land-cover spectral characteristics, within each multi-temporal dataset,
- Terrain-based hydrological modelling to determine areas of ‘potential wetness’, where water, and thus wetlands, may be likely to accumulate, irrespective of land-cover,
- Spatial modelling to combine the terrain-based ‘potential wetness’ model with the image-derived wetland areas, in order to derive the final wetland distribution,
- Procedure bias testing to ensure feasibility and consistency of use of the recommended data processing techniques; and
- Wetland mapping accuracy assessment, using the field-validated wetland boundaries mapped on the aerial photography as a reference.

This is illustrated in figure 2.2 which shows in more detail, both the full compliment of data processing procedures tested, as well as the specific procedures identified as part of recommended methodology.

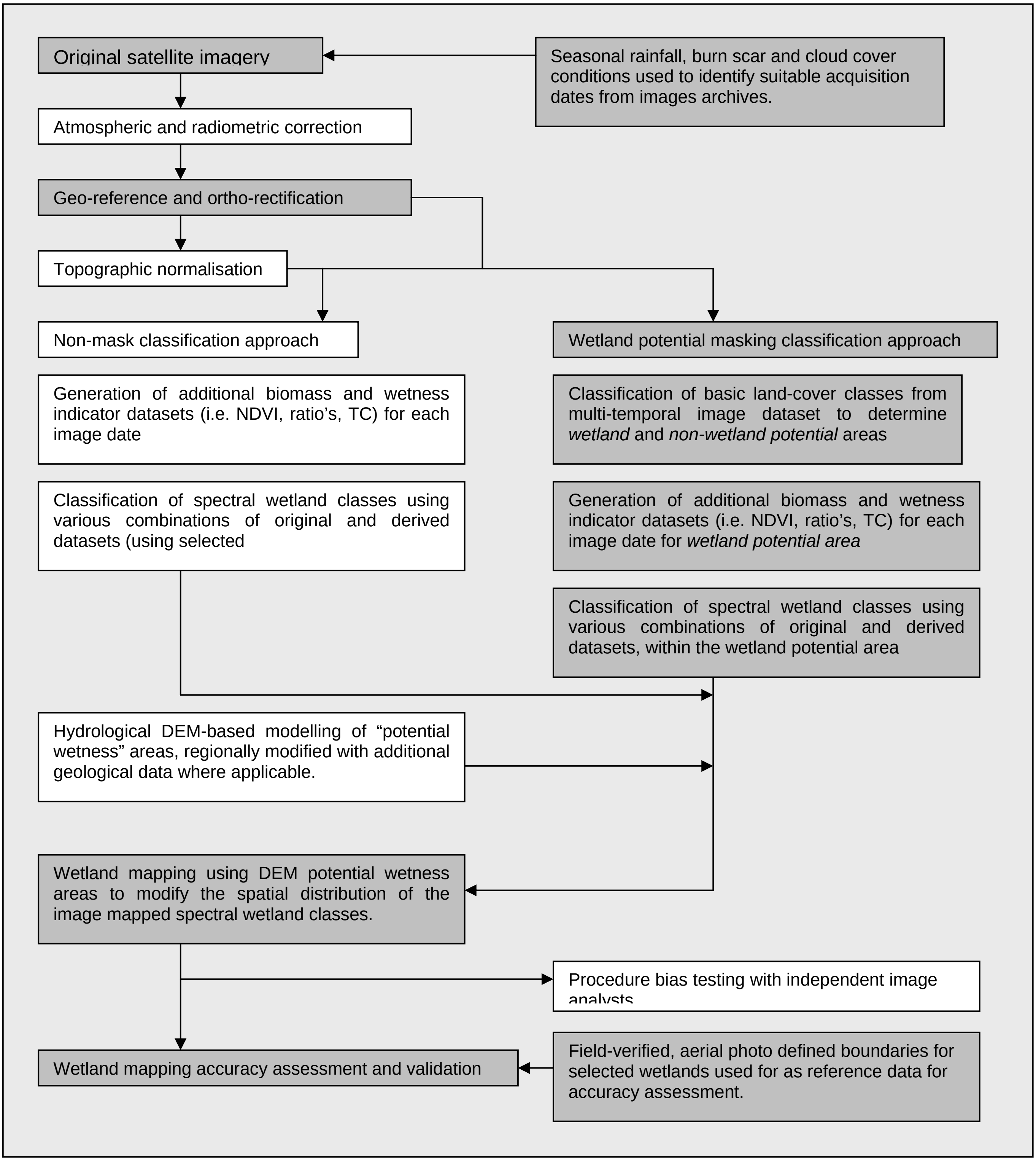
2.1.7 Pre-Classification Data Preparation

During the determination of optimal data processing techniques a range of pre-classification data preparation procedures were used to standardise all original Landsat imagery prior to subsequent wetland classification, and minimise any external factors that may influence spectral quality and thus classification accuracy. Whilst these were considered to be an essential part of the development process, some of these processes were found to be either optional, or in some cases, unnecessarily in future operational applications, thus simplifying future data preparation. These individual processes, namely (a) atmospheric and radiometric correction, (b) geo-registration and ortho-rectification, and (c) topographic normalisation are described in more detail below.

2.1.8 Atmospheric and Radiometric Correction

All imagery was atmospherically corrected using a modified version of the improved COST model (after Moran *et al* 1992 and Chavez 1996), prior to geo-correction and wetland / land-cover classification, in order to ensure that subsequent data processing was conducted on radiometrically standardised imagery, with comparable ground spectral reflectance, irrespective

Figure 2.2 Flow Diagram Illustrating the Image Processing Stages Used in the Wetlands Classification Procedure (shaded boxes represent components of recommended procedure)



of the year or season of acquisition. This method is entirely-image based, and does not require any additional *in-situ* field measurements to be acquired at the time of satellite overpass, thus making it ideally suitable for operational applications involving the comparison of historical image data[2].

Results indicate that pre-classification atmospheric correction may not be necessary during future operational implementation, *as long as cloud and haze free imagery is used*. This is because the recommended techniques do not require the comparison of *absolute* reflectance values (i.e. quantitative NDVI / biomass estimates), but rather a measure of *relative* spectral differences between seasonal image dates, for which standard radiometric calibration (supplied as standard by the Satellite Application Centre) should suffice. However, if the option exists for more comprehensive, scene-parameter specific atmospheric correction, then this should be included in the data preparation process.

2.1.9 Geometric Correction

Accurate geometric registration of multi-temporal imagery is an essential pre-requisite for the integration of multi-temporal, time-series imagery and accurate change detection. Image registration accuracies are typically between 0.5 – 2.0 pixels depending on image type and format, although an error of < 0.5 is generally preferred if the objective is to achieve ± 1 pixel absolute accuracy (Jensen 1986, Milne 1988, Mouat *et al* 1993, reported in Munyati 2000; Thompson *et al* 2001). All the atmospherically corrected wetland image datasets were geometrically corrected to a standard geo-projection format[3], with Root Mean Squared errors (RMS) in the range 0.3 – 1.0 pixels, using digital copies of the standard 1:50,000 scale topographic maps for image-to-map reference and ground control.

2.1.10 Topographic Normalisation

Digital imagery in mountainous regions often contains additional radiometric distortions caused by local variations in viewing and illumination angles, between the sun and terrain slope. Various topographic normalisation models are available to correct this effect, which effectively correct the imagery to a simulated flat surface, so that two objects with the same reflectance properties will have the same digital values (and brightness), despite different orientation to the sun's position (Colby 1991, ERDAS 1999, Jena 2001).

There are two basic models that can be used for topographic normalisation, namely the Lambertian (Cosine) model and the Non-Lambertian (Minnaert constant) model. The Lambertian

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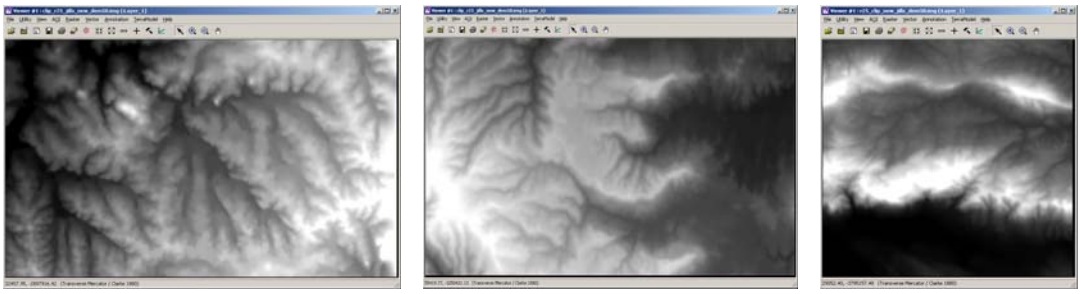
[2] The model, used in previous studies by the consultant, was sourced from NASA and implemented using the ERDAS Modeller, within preliminary scene-independent inputs derived from both a NASA sourced spreadsheet model and NASA-JPL website where sun-earth distances could be retrieved (Skirvin, 2001; Longshaw 2001). Note: the model is designed specifically for Landsat 5 TM imagery, and as such is not suitable in its present format for imagery with different spectral band characteristics, such as SPOT. Use of alternative imagery would necessitate the use of other radiometric correction procedures. In this instance however, the model was also used to atmospherically correct the comparable Landsat 7 ETM+ imagery used specifically in the Davel test site, due to the similar sensor characteristics, although it is noted that this is not an ideal application.

[3] Transverse Mercator (Gauss Conformal) projection using Clark 1880 spheroid and Cape datum. LO 29° for Davel and High Moor test sites and LO 19° for Walker Bay. All image data re-sampled to 25 m spatial resolution during geo-correction, using nearest neighbour algorithm to maintain spectral integrity during testing stage.

model is simpler, but less efficient than the Non-Lambertian model and can often result in an over-correction (i.e. disproportional brightening) of light shadow areas. Both models cannot however compensate for deep shadow regions with little or no diffuse illumination as is found in very high relief areas. The Lambertian model is often applied to flat or undulating terrain to equalise illumination differences due to different sun positions in multi-temporal datasets (Jena 2001). Both models were applied to all test sites, in order to determine the impact and necessity for such pre-classification procedures for wetland mapping in sites containing different degrees of topographical roughness. An indication of the variation in relief between the three test-sites can be found by using the standard deviation of each sites Digital Elevation Model (DEM) as a relative index of topographic roughness, as illustrated in figure 2.3

Figure 2.3 Relative topographic roughness for each wetland test based on the Standard Deviation value for each DEM[4]

	Davel	Highmoor / Kamberg	Walker Bay



std.deviation :	50.4	242.7	285.6
height :	1525-1793 m	422-3194 m	0-1133 m

note : grey tones and image scales not equivalent.

Results indicated that in high relief areas such as the Highmoor / Kamberg and Walker Bay test sites, the available correction models were ineffective in reducing the deep shadowing effects associated with the extremely rugged topography. In the in the less rugged, more undulating Davel test site, both the Non-Lambertian and Lambertian models performed well, with the former slightly outperforming the latter in terms of final visual quality[5]. However, during subsequent wetland classification it became apparent that there was no significant difference in final wetland delineation on either the topographically corrected or non-corrected Davel imagery. This was taken to be indicative that topographic pre-processing is not a definite pre-requisite for any low-relief site conditions (where it is most applicable). In more extreme relief sites, if classification *within* deep shadow areas is a problem, then it is recommended that a similar hierarchical approach to that prescribed for sites with extensive burn scars is used, (see Section 2.2.2) where shadow and non-shadow regions are classified separately.

During initial testing it was also found, as would be expected, that the single most influential factor on the performance of any topographic model was the quality of the DEM data, and its spatial resolution in relation to that of the satellite imagery. Quality factors relate to both methods used in

4 50 m grid DEMs derived from 20 m contour data (with supporting spot heights), and then re-sampled to image equivalent 25 m grid format using cubic convolution interpolation to maintain slope integrity.

5 The models are available as standard operating procedures in ERDAS Imagine software, although the non-Lambertian model (*topo_norm.gmd* located under $IMAGINE_HOME / etc / models) requires additional, scene specific parameters to be derived from non-image sources in order to generate the Minnaert constant.

the original construction of the DEM, and any subsequent re-sampling techniques used to approximate the DEM resolution to image specifications. The best topographic normalisation results were obtained (in the Davel site) using the 50m raster DEM (derived from the 20m contours with supporting spot heights), which had been re-sampled to a 25m grid, using a cubic convolution algorithm to provide contiguous gradients. The same principles applied to the generation of the terrain-based "wetness potential" model, which required a hydrologically correct DEM for maximum modelling accuracy.

During the determination of optimal data processing techniques, a range of pre-classification data preparation procedures were used to standardise all original Landsat imagery prior to subsequent wetland classification, and minimise any external factors that may influence spectral quality and thus classification accuracy. Whilst these were considered to be an essential part of the development process, some of these processes (i.e. atmospheric and topographic correction) were found to be either optional, or in some cases, unnecessarily in future operational applications, thus simplifying future data preparation. All image datasets were precision ortho-corrected to standard map projections prior to further analysis and classification.

2.1.11 Digital Image Classification

Image classification procedures were initially developed on the Davel test site, and then tested for repeatability and applicability on the Highmoor / Kamberg and Walker Bay test sites. The basic approach was to use a seasonal change detection procedure, within which wetland characteristics were initially enhanced using biomass and wetness indicators derived from spectral ratio's and orthogonal indices. These datasets were then used to identify and map likely wetland areas, based on expected differences in spectral characteristics to other, non-wetland cover types.

Initial attempts at image processing involved complete analysis of the test site, and generation of a landscape wide, land-cover classification within which *vegetated* wetlands (as opposed to areas of open water), were an integral, but separate class. However due to the limited extent of the small, highly fragmented wetland areas in comparison to the more spatially, and often spectrally dominant non-wetland cover types (i.e. natural grasslands and cultivated fields), it was not always feasible to extract a definitive wetland class.

A more viable alternative was to use a two-step approach, within which an initial broad-level land-cover classification was used to identify, mask and subsequently exclude from further data processing, any land-cover categories that would not contain any wetlands. In this manner it was possible to identify a sub-set of the test site, which best represented those sections of the landscape, which could *potentially* contain wetlands. Table 2.1 illustrates the basic land-cover legend used, and which classes were subsequently identified as non-wetland potential cover-types, and then excluded from further processing.

Non-wetland potential areas were defined as cover types either within which wetlands would not occur (i.e. urban, mines), or could not be identified, even if they existed, using Landsat-type imagery, due to the masking effects of land-use activities (i.e. cultivation). This is an important consideration which infers that satellite imagery such as Landsat, is inappropriate in terms of scale and resolution, for detailed mapping of wetland features which have been modified to such an extent by alternate land-use activities, such as cultivation, that they are no longer identifiable as a separate cover type.

A re-classification of the original input spectral data within the wetland potential area was then used to determine with more accuracy, the location and spatial extent of all *spectrally definable* wetlands. This approach works well because in most cases, the grassland biome wetlands are predominately vegetated, and have similar physiognomic and spectral characteristics to the surrounding natural vegetation. By using this two-stage masking approach it was possible to maximise the local spectral variance within the potential wetland areas, and improve the accuracy of actual wetland feature mapping. Areas of open surface water, with their unique spectral characteristics were typically mapped out during the initial land-cover generation stage.

Table 2.1. Broad-level land-cover classes mapped in the initial land-cover classification, and used to subdivide the landscape into wetland potential and non-wetland potential areas, based on the likelihood of wetland occurrence and ability to determine such wetlands using medium resolution Landsat imagery.

Class	**Definition**	**Wetland Association**
Open Water	-	YES
Plantation and Woodlots	exotic tree species ~ plus a few localised patches of dense, closed canopy natural bush	NO
Natural Vegetation	all semi-natural and / or natural vegetation communities, irrespective of structural characteristics	YES
Cultivated	all cultivated fields, irrespective of land-use practice or intensity)	NO
Urban	all urban / built-up areas, irrespective of size or land-use	NO
Mining	all mine related infrastructure, including tailings	NO
Natural Bare Rock	exposed areas of hardrock, mainly restricted to the sandstone outcrops in the little 'Berg areas in the High Moor test site	NO
Cloud / Cloud Shadow Obscured	-	POSSIBLE / NO

All land-cover classes used are based on those defined and used within the SA National Land-Cover Database (Thompson 1999).

The initial land-cover dataset was generated using a progressive sequence of unsupervised clustering routines[6], which were used to re-classify any areas containing 'mixed' spectral output classes into more specific cover types. This process was repeated until all output clusters could be associated with a single 'information class' as defined in a pre-set land-cover legend (see Table 2.1). Three iterations were generally sufficient to generate a complete land-cover classification, which did not contain any 'mixed' information classes. Post-classification editing using manually or attribute-data defined 'area-of-interest' masks were used for final class re-coding of specific cover types which were impossible to separate on a spectral basis alone (e.g. separation of deep shadow areas from permanent water bodies, or certain forest plantation). This type of procedure has been used successfully in several previous land-cover mapping projects locally (Thompson and Adam 1993, 1995, Thompson and Vink 2001 Thompson *et al* 1998, Thompson et al 2000 Thompson 2001b), and is an accepted methodology for complex landscapes (Harvey and Hill 2001).

6 ERDAS ISODATA clustering (ERDAS 1999). Approximately 80-100 classes were used in the first iteration, depending on the initial landscape complexity, with reduced output class numbers (i.e. 80, 60, 40) in each subsequent attempt, depending on the remaining degree of spectral confusion. All unsupervised classifications were completed using 99 iterations, with a threshold setting of 0.950 to ensure maximum statistical separability.

Since the objective of the satellite data analysis was to identify a technique suitable for national-scale implementation, and that this will have by association large volumes of data to process, use was made of Principal Component Analysis (PCA) during the *basic land-cover generation*. PCA is a recognised data reduction technique that increases computational efficiency and is especially useful when processing large, multi-temporal datasets (Bryne *et al* 1980, Richards 1984, Skidmore *et al* 1987). Using this technique it was possible to 'compress' all the relevant information from the 12 original TM bands and two additional NDVI's (from both image dates) into only five PC data layers. The first five components were since the corresponding eigenvalues contained >97 percent of all variance, and all components were visually informative.

Various combinations of original and derived spectral data were evaluated, including the difference-images designed to highlight seasonal changes whilst attempting to identify the most appropriate technique for re-classifying the masked wetland potential areas. The derived data consisted of a range of spectral ratio's[7] and indices with known biomass and wetness indicator characteristics, such as the NDVI and the Tasseled Cap (TC)[8]. Unsupervised classification procedures were again used because of their suitability for complex landscapes (Harvey and Hill 2001).

Depending on local wetland characteristics, the output from this stage consisted of either a series of classes representing a subjective wetland confidence gradient (i.e. "definite" to "unlikely"), or a single, amalgamated wetland class with uniform confidence. Confidence grades were subjectively allocated by the image analyst based on comparison to overlaid vectors representing the field-mapped wetland boundaries, which were used as reference data.

These output classes were taken to represent the best possible spectrally definable delineation of wetlands. However, some boundary errors were still evident due to remaining, unresolved spectral overlap between certain (vegetated) wetland and non-wetland communities. Attempts were made to minimise these by further modifying the spectrally defined wetland boundaries with data derived from a terrain-based, hydrological model.

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7 Spectral ratio's were developed to maximise the information on specific surface characteristics, such as vegetation biomass or soil moisture, whilst reducing any unwanted background effects, based on different responses from two wavelength ranges. Although ratio's can be very sensitive to, for example, biomass, changes in external environmental conditions may also have an influence, such as will occur with multi-temporal data. To a limited extent the ratio process will have a normalising effect, but this approximation is only valid if atmospheric effects are ignored (Baret 1990). For example, atmospheric moisture can have significant effect on NDVI values, with increasing atmospheric interference from haze and water vapour reducing calculated NDVI values for a given vegetation cover (Belward 1990, Diallo *et al*, 1991, Soufflet *et al* 1991). For this reason, atmospheric correction was included as part of the preliminary data preparation procedures in order to minimise, as far as possible, all external influences on final classification accuracy.

8 The TM Tassled Cap (TC) transformation (Crist and Cicone 1984) is an orthogonal index that describes image brightness, greenness and wetness, and offers an alternative method for data viewing in vegetation studies. The TM-TC transformation is an adaptation of the original TC index devised for Landsat MSS imagery by Kauth and Thomas (1976, reported in Cohen 1991). The 2nd axis describes image greenness, and is based on the contrast between NIR and VIS bands, and has been shown to be strongly related to the amount of green vegetation in a scene (ERDAS, 1999). The 3rd axes describes image wetness, and relates to canopy and soil moisture, based on the TM water absorption bands 5 and 7 (Lillesand and Kiefer, 1989, reported in ERDAS, 1999, Cohen 1991, Cohen and Spies 1992).

Image classification procedures were developed on the Davel data and then tested for repeatability on the Highmoor / Kamberg and Walker Bay test sites. The basic approach involved a seasonal change detection procedure, within which wetland characteristics were enhanced using biomass and wetness indicators derived from spectral ratio's and orthogonal indices. A preliminary, broad-level land-cover classification was used to identify, mask and subsequently exclude from further data processing, any land-cover categories that would not contain any wetlands, whilst also identifying areas which best represented those sections of the landscape which could *potentially* contain wetlands. Non-wetland areas were defined as cover types either within which wetlands would not occur (i.e. urban, mines), or could not be identified, even if they existed, using Landsat-type imagery, due to the masking effects of land-use activities (i.e. cultivation). This means that Landsat equivalent imagery is, in terms of scale and resolution, unsuitable for detailed mapping of small wetland features which have been modified to such an extent by alternate land-use activities that they are no longer identifiable as a separate cover type. A re-classification of the original input spectral data within the wetland potential area was then used to determine with more accuracy, the location and spatial extent of all *spectrally definable* wetlands. However, some boundary errors were still evident due to remaining, unresolved spectral overlap between certain (vegetated) wetland and non-wetland communities. Attempts were made to minimise these by further modifying the spectrally defined wetland boundaries with data derived from a terrain-based, hydrological model.

2.1.12 Terrain-Based Hydrological Modelling

Terrain-based hydrological modelling was used to determine areas of 'landscape potential wetness', where water (and thus wetlands), may be likely to accumulate, *irrespective of land-cover characteristics.* The objective being to compile a topographically based model which could be used to modify the spatial extent of the spectrally defined wetlands, by excluding all image-derived wetlands mistakenly identified in landscape areas not capable of containing wetlands. Modelling of 'landscape potential wetness' was completed independently from the satellite image analysis, and was not influence by any spectrally defined parameters. All terrain modelling was based on a 50 m DEM, which had been derived from 20 m contour data.

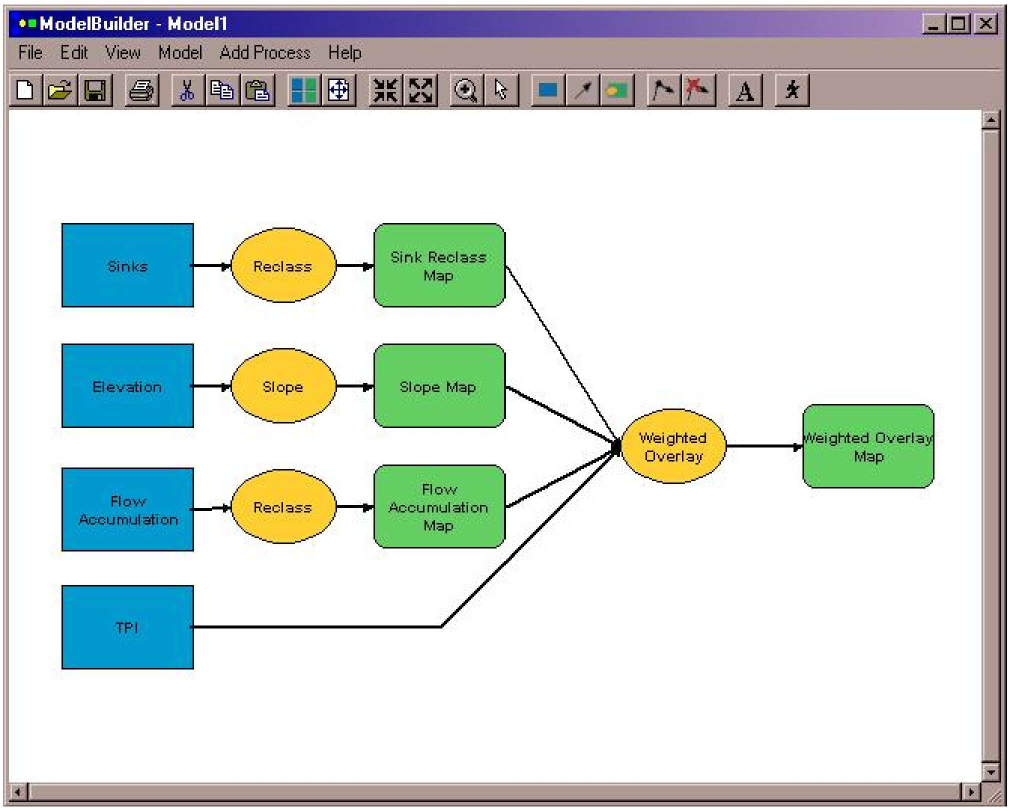
Through background research and discussions with wetland and GIS experts, it was possible to identify the key physical parameters, which influence the likelihood of wetland occurrence in the landscape. These were soil (type, structure, and texture), geology, poor drainage, rainfall exceedence of evapotranspiration, depressions, relative slope position, slope steepness, slope aspect, slope configuration or curvature, run-off and flow accumulation (Batchelor A 2001, Dely *et al* 1999, Evans *et al* 1996, Green PE 1997, Griffin, Rand Wilding L 1994, Marneweck GC 2001)). This list may not be comprehensive, but more than likely constitutes the major driving forces behind wetland creation. Based on this knowledge, various models were investigated and developed, in order to be able to delineate those sections of a landscape most likely to contain wetlands.

An existing model, devised to compare the potential moisture of sites largely for use in the analysis of potential species habitats, was applied in this study as a way to compare the relative wetness of certain area. The technique or model, termed the Topographic Relative Moisture Index (TRMI), is an index, which combines relative slope position, slope configuration, slope steepness and slope aspect into a single scalar value (accumulative range from 0 to 60). Solar radiation is included in the model relative to aspect. This index provides an explicit method to identify potentially xeric (low values) to mesic (high value) sites (Parker AJ 1982). The model uses Arc/Info software (mainly GRID) and is automated through the use of an aml (Arc macro Language) programme (see Appendix 2.2).

A second model was developed specifically for this study, taking into account that the results will be used in conjunction with remote images. The model is largely based on surface hydrological accumulation and landscape or terrain features. It makes use of a weighted overlay technique combining several physical parameters with influence factors for each parameter based on the importance of the parameter in the formation of wetlands. The weighted overlay technique is used to apply a common scale of values to diverse parameters in order to create an integrated analysis. This model, termed the Landscape Wetness Potential (LWP) Model, uses ArcView 3.2 ModelBuilder to integrate the four parameters: occurrence of sinks or depressions, slope steepness, surface hydrological or flow accumulation, and relative slope position or topographic index (TPI) (see Figure 2.4). Arc/Info GRID, automated through the use of an 'aml' programme, is used to generate depressions and topographic index, while the TARDEM model is used to generate flow accumulation. TARDEM is suite of programmes for the analysis of digital elevation data (Tarboton DG 2000). It is free software which runs on Windows 95/98/NT.

Both the TRMI and the LWP model results were compared in order to determine the most appropriate technique for this particular application. Both models are repeatable across the country i.e. can be used at a national level, since the required input data sets are available nationally at a reasonable cost. Soil information may have be a valuable addition into models of this type, but access to the national data at a reasonable cost would probably need to be negotiated through DEA&T.

Figure 2.4 Graphical representation of the components and processes of the Landscape Wetness Potential (LWP) model, used to identify those sections of a landscape most likely to contain wetlands, based solely on terrain morphology, irrespective of land-cover characteristics.



Note : Square boxes denote input layers or data themes, the oval shapes represent a specific function or procedure such as reclassification, slope calculation, buffer, data conversion, and weighted overlay, the rectangular boxes denote the derived data (as a result of the action of the previous function).

2.1.13 Derivation of Input Parameters for the Terrain Models

Surface Hydrological or Flow Accumulation. This parameter represents the movement or flow of water across a surface. For any point on a surface the upslope area contributing to that point and the down slope path water would follow is known. First the direction of flow is determined for each point or cell on the surface, and then the number of cells flowing into any given cell i.e. accumulated flow per cell, is determined. Generally this modelling technique is used to delineate stream networks through the extraction of cells with a high flow accumulation (i.e. areas of concentrated flow). For the purposes of the landscape wetness potential model the cells *not* comprising stream channels were of particular interest. All cells in the flow accumulation surface represent the amount of run-off per cell. Those cells with a high flow accumulation, but not constituting a stream or river, could be interpreted as areas wetness and therefore potential areas for wetland development or occurrence.

A digital elevation model (DEM) is used as input to the analysis. Both the TARDEM model and the Arc/Info hydrologic surface model were tested for output. The TARDEM model was found to represent flow across flatter surfaces more accurately and therefore the results of three of the TARDEM programmes (flood, d8, and aread8) were used in the landscape model to represent surface flow accumulation.

Slope Steepness. Percent slope was calculated from the DEM, and classified into slope classes based on expert knowledge of on which slopes wetlands are likely to occur (Marneweck GC 2001 and Batchelor A 2001).

Relative Slope Position. Terrain-based analysis was used to generate topographic characteristics such as ridge tops, valleys, midslopes, footslopes, upperslopes, and flat surfaces from the DEM and slope percentage surface (Fairbanks DHK 1997)). An ‘aml’ partially automates the process (see Appendix 2.3)

Depressions and Sinks. Sinks, in modelling terms, are a set of spatially connected cells, which cannot be allocated a flow direction value. This can occur when all neighbouring cells are higher than the processing cell. Sinks can be errors in the digital elevation model or they may be valid depressions in the landscape. For the landscape wetness potential model, they were assumed to be valid internal drainage areas. The Arc/Info hydrologic surface function ‘SINK’ was used to generate a surface of areas of depressions.

2.1.14 Terrain-Based Modelling: Weighted Overlay and Influencing Factors

The four parameters were combined into one integrated model through the used of a weighted overlay function. Several configurations of input parameters, reclassifications, evaluation scales, weightings and influence factors were tested before suitable model parameters were found (Table 2.2). Model configurations were compared to pre-delineated wetlands in the Davel area as a way to validate the output of the model and find the best possible model fit.

The output surfaces generated from both the TRMI and the LWP model were smoothed to create more homogeneous zones by applying mean and maximum statistical focal functions using a 3 x 3 grid cell size neighbourhood.

The mean statistic, because it produces an average value, generates smooth transitions between zones, which is visually appealing. The maximum statistic, while not generating smooth transitions, enhances the high wetland potential zones, which is advantageous for locating wetlands from remote images. All three surface; the original output surface before smoothing, the mean smoothed surface, and the maximum smoothed surface were given to the image analyst to test for applicability with the wetland delineation from remote images.

Table 2.2. Landscape Wetness Potential (LWP) model weighted overlay function parameters.

Parameter	Parameter Classification	Evaluation Scale (1 to 5)	Influence Factor (%)
Flow accumulation	1 – 20	1	40
	20 - 100	5	
	100 - 10000	4	
	10000 - 600000	3	
Relative Slope Position	Ridge	1	35
	Valley	5	
	Flat	5	
	Footslope	4	
	Midslope	3	
	Upperslope	1	
Slope steepness	0 – 3	5	20
	3 – 12	3	
	12 – 20	2	
	> 20	1	
Depressions	1	5	5

2.1.15 Digital Elevation Model Requirements for Topographical Modelling

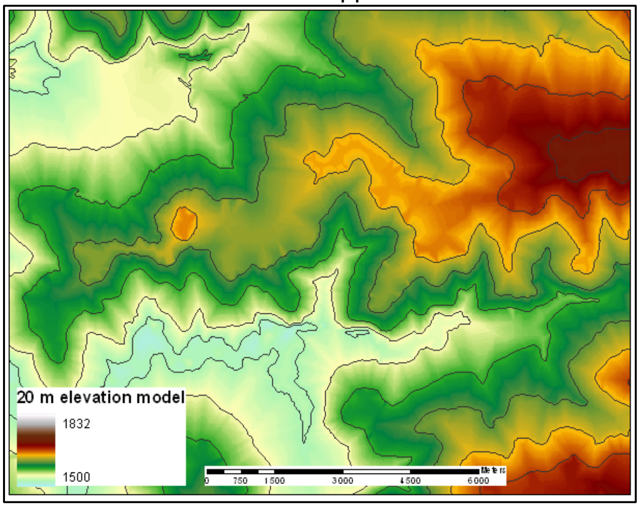
One of the major input parameters to the models is a topologically correct digital elevation model (DEM). Initially a 20 x 20 m DEM was provided to perform the GIS modelling, but it became apparent whilst developing the GIS models that the DEM was creating many terrain errors, such as an excessive amount of sinks and broken flow accumulation lines. It was established that the 20 m DEM had been derived from the 20m 1:50 000 contours provided by Surveys and Mapping. The original contours were obtained and a series of tests conducted to determine the optimum grid cell size for the models.

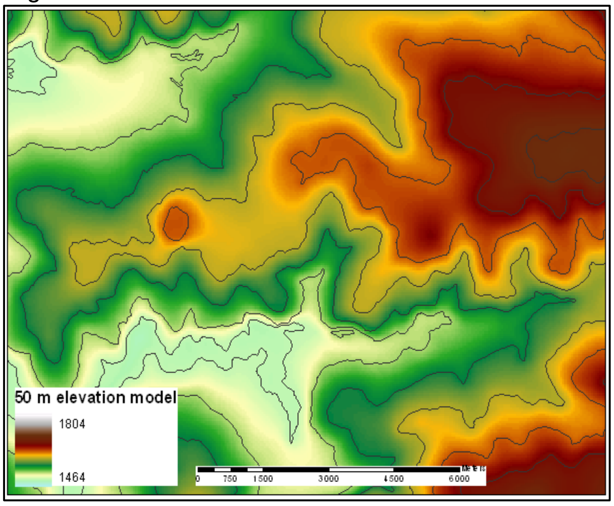
A 20 x 20 m DEM derived from 20 m contours creates artificial and potentially incorrect data between contours where the lines are more than 20 m apart. This is very often the case, particularly in flatter areas. As can be seen in Figure 2.5, many of the contours are greater than 20 m apart (note the 1 km line perpendicular to contours (middle right)), and triangulated results have been produced by the interpolation procedure.

Additional 50 m and 60 m DEM's were generated using the Arc/Info TOPOGRID command, which produces hydrologically correct elevation models. While either cell sizes would have been appropriate, the 50 m DEM seemed to produce the best elevation model in keeping with spot height values. The excessively triangulated features seen in Figure 2.5 are not evident in the 50 m DEM (Figure 2.6). Better modelling results were also experienced with the 50 m DEM in terms of continuous flow accumulation, fewer artificial depressions, and more accurate slope calculations.

The 50 x 50 m grid cell size resolution was therefore chosen as the base horizontal modelling unit for the wetness models.

Figures 2.5 and 2.6. 20 m Digital Elevation Model (DEM) derived from 20 m contours showing excessively triangulated surface. 50 m DEM derived from same 20 m contours, but which gave a smoother surface more applicable for wetland modelling.





Terrain-based hydrological modelling was used to determine areas of 'landscape potential wetness', where water (and thus wetlands), may be likely to accumulate, *irrespective of land-cover characteristics.* The objective being to compile a topographically based model which could be used to modify the spatial extent of the spectrally defined wetlands, by excluding all image-derived wetlands mistakenly identified in landscape areas not capable of containing wetlands. Modelling of 'landscape potential wetness' was completed independently from the satellite image analysis, and was not influence by any spectrally defined parameters. All terrain modelling was based on a 50 m DEM, which had been derived from 20 m contour data. Two model formats were tested, the first being an existing model termed the Topographic Relative Moisture Index (TRMI), which was originally developed to compare the potential moisture of sites for use in the analysis of potential species habitats. The second, termed the Landscape Wetness Potential (LWP) model, was specifically developed for this study. This model is largely based on surface hydrological accumulation and terrain parameters that influence the likely occurrence and distribution of wetlands Both the TRMI and the LWP model results were compared in order to determine the most appropriate technique for this particular wetland mapping application. Prior to integration with the satellite-derived data, the output surfaces generated from both the TRMI and the LWP model were smoothed to create more homogeneous zones by applying mean and maximum statistical focal functions using a 3 x 3 grid cell size neighbourhood, which were then tested for applicability when integrated with the image-derived wetland data.

2.1.16 Final Wetland Delineation using Combined DEM and Image-Derived Data

The final wetland delineation was achieved by combining the DEM-derived LWP model with the image-derived spectral wetland classification, in order to modify the spatial distribution of the spectral wetlands according to terrain-defined wetness potential classes. Using this approach it was possible to minimise any remaining spectral overlap between wetland and non-wetland areas with similar vegetation characteristics. Especially in borderline areas which did not exhibit clearly identifiable wetland spectral characteristics in terms of seasonal biomass and wetness changes, in relation to the surrounding natural vegetation. The use of integrated DEM modelling for improved image classification in ecological / landscape-type mapping applications is well document (Aspinall and Veitch 1993, Elumnoh and Shrestha 2000, Frank 1988, Lees and Ritman 1991).

The integration procedure involved constructing a 'probability' table, which combined hydrological wetness classes with the spectral wetland class(s), in order to determine those combinations of terrain and image-derived classes that best represented the true location and extent of all wetlands in the landscape. Table 2.3 illustrates the approach used to integrate these two datasets and identify final wetland areas:

Table 2.3 Probability table used to combine DEM-defined hydrological wetness with image-derived spectral wetland areas as part of the modification of image-derived wetland boundaries.

		Terrain-derived hydrological wetness classes		
		High (4,5)	Medium (3)	Low (1,2)
Image-derived wetland potential classes	definite	YES	YES	YES
	possible	YES	POSSIBLE	POSSIBLE
	maybe	POSSIBLE	NO	NO

Allocation of "POSSIBLE" confidence ratings was scene specific, and varied according to the number of spectral wetland classes that had been identified, and agreement of these with the field-mapped reference wetland boundaries. All 'definite' spectral wetland classes were however always allocated a "YES" rating at all sites. Due to the subjective nature of the data integration process, it is imperative that the image analyst has sufficient a-prior knowledge and experience in terms of image interpretation, wetland characteristics, and access to suitable reference material (such as the field mapped wetland boundaries).

Using this integrated modelling approach it was possible to overcome the problem reported by Dely *et al* (1999), who found that unsupervised classifications *on their own* do not facilitate the identification of spectral classes in which wetlands have a high likelihood of occurring.

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2.1.17 Alternative Satellite Image Formats and Classification Procedures.

As part of the evaluation of all possible mapping techniques, the use of "pan-enhanced" multi-spectral imagery was tested using the additional 15 m panchromatic band that is available as a standard with Landsat 7 imagery. Multi-resolution merging is a standard procedure for enhancing coarse resolution imagery with comparable high-resolution data, in order to generate a simulated high resolution, multi-spectral product. In order to preserve (as far as possible) the original scene radiometry and associated spectral information, a Principal Components Merge was used to derive a set of multi-temporal, pan-enhanced images for the Davel test site, with an effective 15m spatial resolution (Welch and Ehlers, 1987, reported in ERDAS 1999). The suitability of this dataset for digital classification and manual, on-screen, photo-interpretation was then investigated[9].

2.1.18 Ancillary Data Modelling (i.e. Environmental Threats)

A distinct advantage of satellite (and airborne) imagery based mapping is that supplementary information on wetland status, function and associated landscape parameters can also be derived directly from the same data source, which could facilitate, for example, assessments of possible external threats from neighbouring land-use practices and coding of specific wetland attributes, although the level of detail would be dependent on the scale and format of the imagery. An example of this is provided (see section 2.6), based on the basic land-cover data generated as part of the Davel wetland classification approach.

Depending on how and when the new national wetland inventory (i.e. NLC 2000) is implemented in the future, it should be possible to incorporate some type of land-cover / use type data into this ancillary modelling process. Where this type of external data is integrated with the wetland data, special attention will have to be given to ensuring the compatibility of independently sourced data, due to differences in scales and acquisition dates, especially if a coarser resolution dataset such as the 1:250,000 scale SA National Land-Cover Database, based on 1994-95 imagery, is linked to a more recently, smaller scale wetland database. Suitable methods for integrating different datasets in this type of modelling are documented in the recently published "Guideline Procedures for National Land-Cover Mapping and Change Monitoring" (CSIR-ARC March 2001, reference ENV/P/C 2001-006, Thompson *et al* 2001).

> The use of "pan-enhanced" multi-spectral imagery was tested as an possible alternative satellite-based approach, using the 15 m panchromatic band available with Landsat 7 imagery. This type of imagery is suitable for either digital classification or manual, on-screen, photo-interpretation. Satellite-based mapping is also able to provide supplementary information on wetland status and associated landscape parameters, which could facilitate, for example, assessments of possible external threats from neighbouring land-use practices.

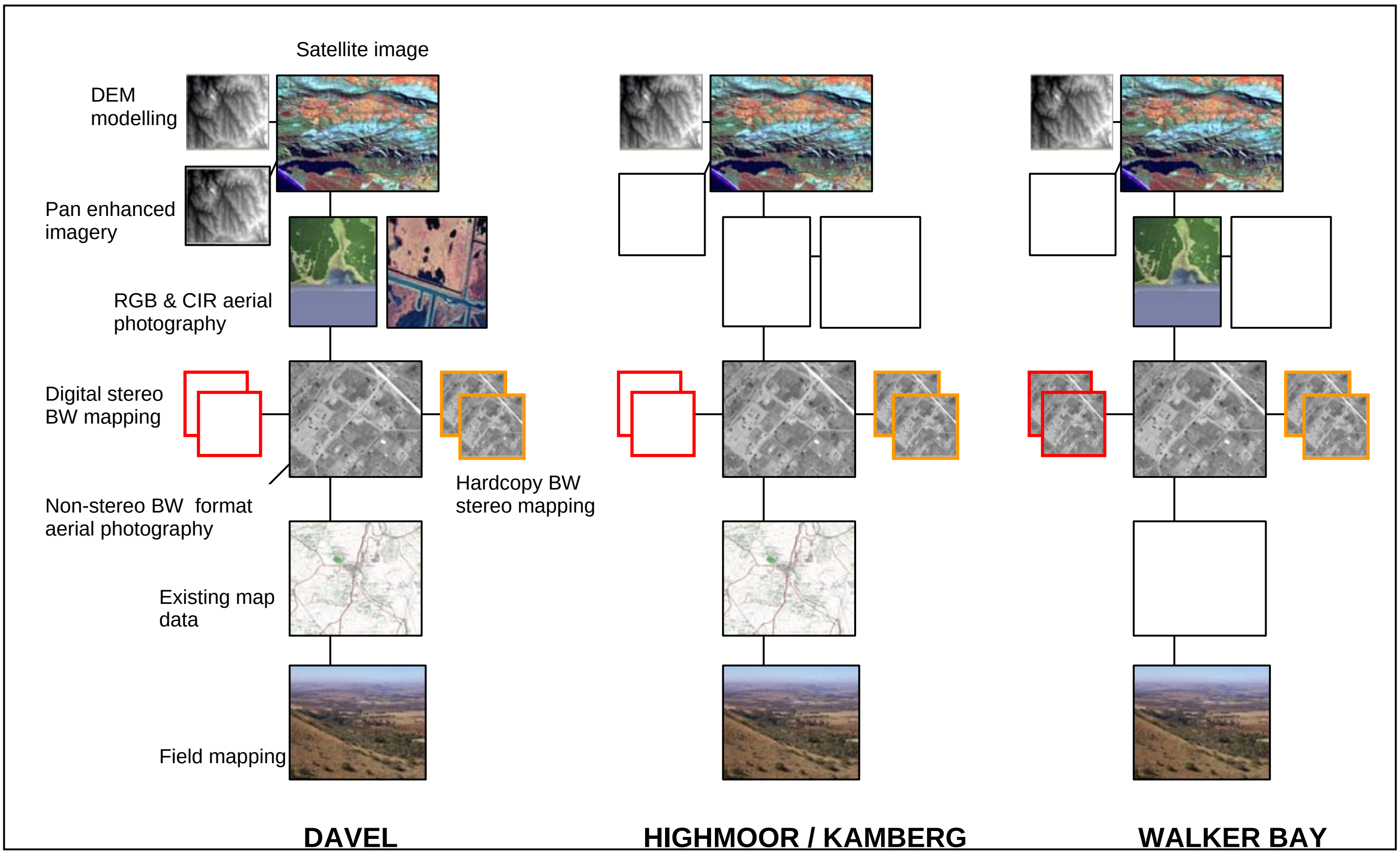
2.2 RESULTS

2.2.1 Wetland Mapping and Classification Procedures

Not all wetland mapping techniques were applied at all test sites, although collectively, a comprehensive assessment of field, aerial and satellite-based techniques was achieved, allowing a full comparison of all procedures. Figure 2.7 illustrates the basic hierarchy of mapping techniques applied at each test site.

[9] No attempt was made to test manual, photo-interpretation techniques with normal resolution Landsat imagery, since the results of the pan-enhanced mapping would indicate the viability of this technique, albeit at a coarse level of spatial detail.

Figure 2.7 Range of Hierarchical Mapping Techniques Applied at Each Test Site



2.2.2 Image Classification

The Davel, Highmoor / Kamberg and Walker Bay test sites represent some of the complicated vegetated and open water wetland communities to map using satellite imagery, due to the small size of the individual wetlands, their scattered distribution within the landscape, and similar physical appearance to surrounding non-wetland vegetation communities. By comparison, larger, more clearly definable wetlands (including open water bodies), can be classified using standard land-cover mapping procedures, often using suitably chosen, single-date imagery (e.g. Thompson and Adam 1993, Thompson et al 2000, Thompson and Vink 2001)

In presenting the results of the image classification evaluation, it should be noted that the emphasis was placed initially on determining appropriate data processing technique(s) for identifying wetland existence simply in terms of their spectral characteristics, using the superior spectral resolution provided by Landsat imagery in comparison to similar, operationally orientated sensor systems (Harvey and Hill, 2001). No attempt was made to incorporate a parallel quantification of the effect of changing spatial resolution on wetland classification accuracy at this stage, since it was assumed that spectral resolution, rather than spatial resolution was key determinant to wetland identification. As reported in the FGDC (1992) report on satellite-based wetland mapping, 'spatial resolution is often cited as the primary remote sensing shortcoming for wetland mapping, but in reality it is spectral resolution that most often results in failure to distinguish wetlands from surrounding cover types'. Increasing spatial resolution will typically decrease the size of the minimum identifiable wetland unit, *assuming that spectral imaging capabilities remain constant,* especially as spatial resolution approximates to the actual size of the smallest wetland units, decreasing the incidence mixed-cover pixels (Woodcock and Strahler

1987). The influence of increasing spatial resolution was evaluated as a separate issue, using both pan-enhanced imagery and theoretical modelling of possible minimum mapping units, linked to alternative sensor specifications.

The three-stage classification approach, involving (a) pre-classification of basic land-cover classes to determine wetland potential areas, (b) classification of spectrally defined wetlands within the wetland potential areas, and (c) modification of these spectrally defined wetland boundaries using terrain-derived topographical models, was successfully applied at all test sites. In the Davel test site, due to the near-perfect timing of the wet-period image with respect to local rainfall patterns and associated wetland vegetation response (see Appendix 2.1), it may have been possible to classify the wetlands to a similar level of accuracy using only a single-date approach, although in all other sites, due to the archive induced necessity to use sub-optimal image acquisition dates, multi-temporal imagery was a necessary pre-requisite, because of the limited spectral variance between wetlands and neighbouring land-covers available within a single-season image dataset. If more suitably timed imagery became available in the future it may be possible to use a single-image date approach, although it must be borne in mind that the image dates chosen for the test site analyses represent the best available archival data from the last two - three years, and should be indicative of expected data availability in the future.

As indicated previously, the use of a preliminary land-cover classification containing broad-level classes to define those sections of the landscape *potentially* containing wetlands, and exclude all non-wetland potential areas further data processing works well, because in many cases vegetated wetlands will have similar physiognomic (and therefore spectral) characteristics to the surrounding natural vegetation. However, a potential drawback of this approach is that it is possible for some wetlands that are located within non-natural vegetation covers (with the exception of open water bodies) to be excluded from further mapping, due to the masking effects of land-use activities (i.e. cultivation). This does not however include pans or seepage zones within field mosaics, since most of these are still actually located within open, non-cultivated spaces within the field mosaic. What will be lost are those wetlands whose physical appearance has been altered due to activities such as ploughing. This is an important consideration which infers that satellite imagery such as Landsat, is inappropriate in terms of scale and resolution, for detailed mapping of wetland features which have been modified to such an extent by alternate land-use activities, that they are no longer identifiable as a separate cover type. Whilst this is not expected to be a significant problem in terms of the likely size and extent of such features nationally, it is an important factor to note.

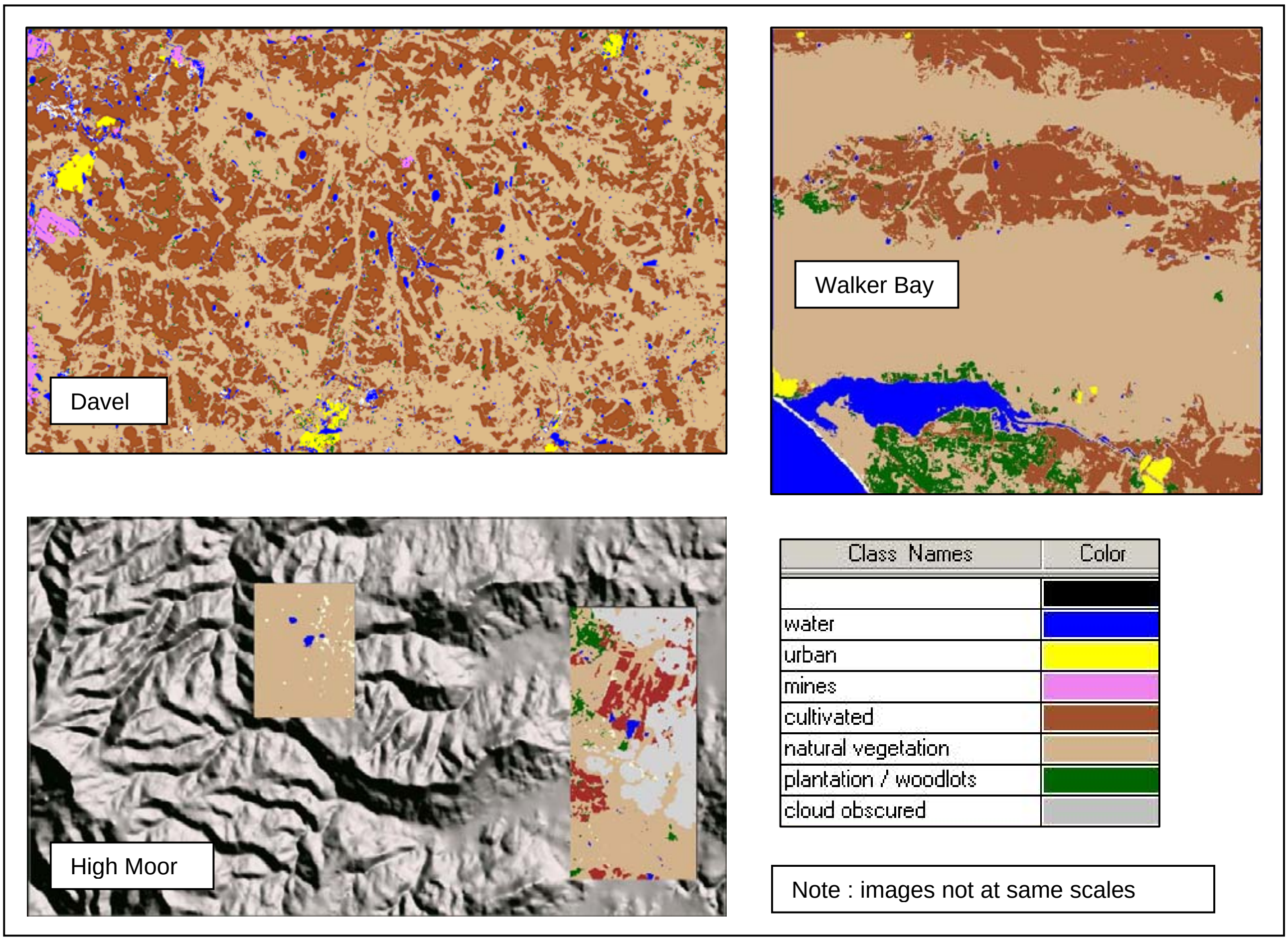
The basic land-cover classifications (which do not include a separate wetland class) for all three test sites are illustrated in Figure 2.8. The classifications were generated from non-topographically normalised imagery. Due to the influence of seasonal fire scars, and the need to additional pre-processing to minimise these temporal effects during final wetland mapping, only two sub-areas were finally classified in the HighMoor / Kamberg test site, compared to the full test site classifications completed on both the Davel and Walker Bay sites. The shaded relief background used in the Highmoor / Kamberg image illustrated the full test site area.

Unsupervised classification procedures were found to be the most suitable method for generating the preliminary land-cover map due to their suitability in complex landscapes. Whilst the progressive sequence of clustering routines is universally applicable to all sites, this is not necessarily the only suitable method for generation of the initial land-cover classification. A more simplified, single-iteration approach, when combined with user-defined spatial masks for localised image editing, also gave similar results in the Highmoor / Kamberg site, possibly as a result of the simpler landscape structure, which is dominated by natural montane grassland, rather than a mix of natural and man-made cover types found in the other test sites.

Although based on broad-level class definitions, the level of *spatial detail* associated with preliminary land-cover classification is still expected to be high, as a result of the improved per-pixel level discrimination possible with multi-temporal datasets. Because of this, the basic land-cover datasets were spatially filtered to generalise class distributions prior to generation of the wetland potential mask, in order to simplify the mask format. Filtering parameters were pre-set to ensure that potential wetland areas were never reduced, but rather enlarged in relation to adjacent non-wetland potential areas[10], so that any marginal wetland zones were not lost.

A multi-temporal dataset consisting of an NDVI and components two and three from the TC algorithm (representing 'greenness' and 'wetness'), from each image date, were found to be the best combination for identification of spectrally defined wetlands. As with previous stages, the method was determined on the Davel test site imagery and then tested for repeatability and suitability on the Highmoor / Kamberg and Walker Bay data. This approach was used since it was assumed that it would be more preferable for future applications to develop a uniformly applicable methodology, rather than individual, location-specific methods.

Figure 2.8 Preliminary Land-Cover Classifications for Davel, Highmoor / Kamberg and Walker Bay test sites (which do not contain a wetland specific class)



The linear rotations used in the TC transformation are sensor-dependent, but once defined for a particular sensor, can be applied to any scene taken by that particular sensor. Whilst this has the advantage of wide area applicability, it also means that it is difficult to apply *exactly* the same procedure to alternative image formats, such as SPOT (Longshaw *pers com* 2002). The TC transformation was originally developed for Landsat MSS data (Kauth and Thomas 1976), but

[10] 3 x 3 pixel majority neighbourhood filter (ERDAS 1999), applied to only non-wetland cover classes, after initial removal of all isolated, non-wetland potential class clusters <0.5 ha

was later adapted for the increased spatial dimensionality of TM imagery (Crist and Cicone 1984), who extended the concept to include a third dimension: wetness, relating to canopy and soil moisture (Kauth and Thomas 1976; and Crist and Cicone 1984, both reported in Lillesand and Kiefer 2000). In order to derive TC-equivalent data from non-Landsat imagery would first require the re-calculation of the original algorithm, although in most cases the end-product would not be an identical product to the Landsat derived TC data.

It should be remembered, however, that the NDVI / TC combination only represents the most suitable approach identified for the *specific characteristics* found within imagery used for the three test sites. Equally useful and just as applicable alternative data processing procedures will be available for other image formats (or acquisition dates). What is key to the process, and should be regarded as the standard methodology identified in this pilot study is the use of a preliminary land-cover classification to determine wetland potential areas, classification of spectrally defined wetlands *within* these wetland potential areas, and subsequent modification of the spectrally defined wetland boundaries using terrain-derived topographical models.

Alternative data combinations could include either individual bands with known biomass or moisture relationships, or alternative ratio's, several of which were tested during initial evaluations. For example, Harvey and Hill (2001) used a combination of TM bands 2,3,4,5 because of the documented suitability for wetland mapping, which can be duplicated with SPOT 5 Xi imagery. Similarly, the TC wetness component could be replaced by 'Infrared Vegetation Index' (IRVI), which shows a strong relationship to changes in plant biomass and water stress (Hardisnky *et al*, 1983, reported in Cohen 1991)[11]. The choice of which is the most suitable data combination for classification of the 'wetland potential areas', will be to a large extent, determined by the format of the imagery used, and the experience of the analyst.

The actual allocation of the spectral classes generated during the unsupervised classification of the wetland potential areas into final wetland classes, was a subjective procedure, whose overall accuracy was directly related to the experience of the image analyst, and the accuracy of any reference material (in this case the field mapped wetland boundaries). Whilst an good estimate of final wetland extent could be made by an experienced analyst using just the 3D model of the terrain as a basic reference, the availability of more precise, example wetland boundary vectors was found to be critical in identifying marginal spectral classes that had to be included in the final wetland delineation. What is important in such cases is not so much the spatial coverage provided by the reference wetland boundaries (since this is accounted for during digital extrapolation on the imagery), but more the choice of representative wetlands and the accuracy of their boundary mapping.

Due to the extent of fire scars on the sub-optimally timed imagery[12] used in the Highmoor / Kamberg test site, it was necessary to include an additional level of spatial masking prior to the classification of spectrally defined wetlands (see Appendix 2.1). This burn-index mask was used to sub-divide the 'wetland potential area' into units containing uniform multi-temporal burn patterns, within which any spectral variance is more likely to be representative of non-burn related seasonal differences, both between and within wetland and non-wetland areas. The uniform burn units were then classified as independent datasets using the prescribed NDVI / TC classification procedures, after which the spectral wetland classes were re-combined to generate the final spectral wetland classification for the full area. Figure 2.9 illustrates the burn-index mask generated from the combined fire scars in both the 03-08-2000 and 13-09-1999 images.

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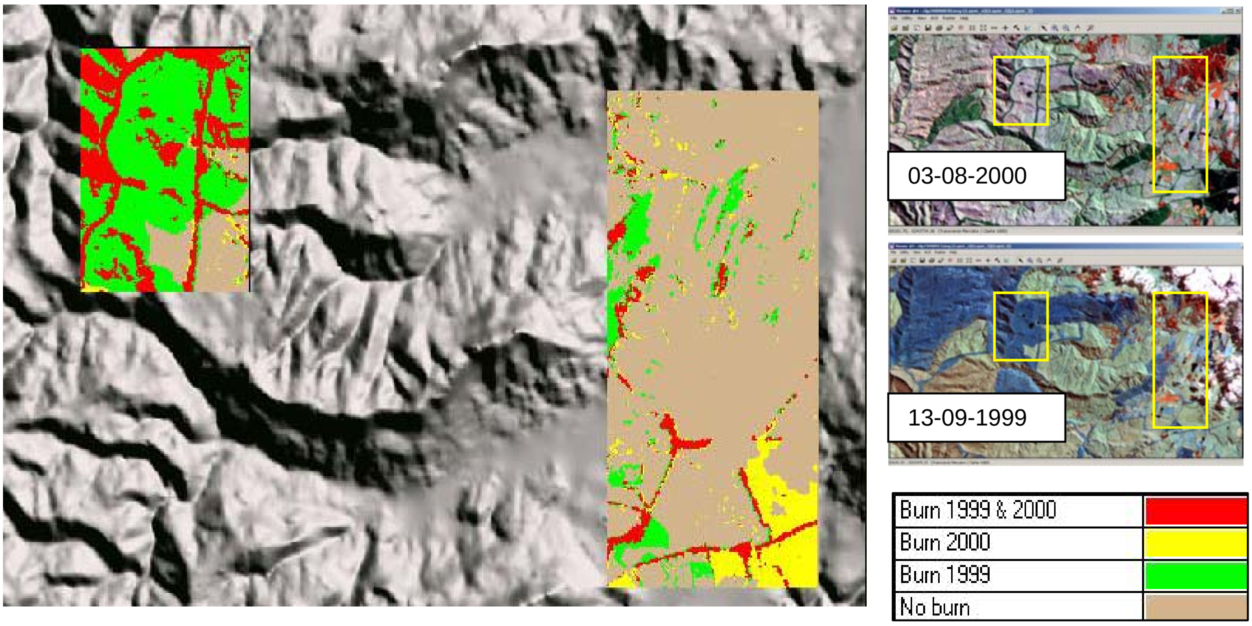
[11] The IRVI: (TM4-TM5) / (TM4+TM5), was tested in the wetlands project as one of several possible indices and ratio's, but was in terms of the specific characteristics of the test sites, found to be less suitable than the TC wetness indicator.

[12] The 06-04-1999 Highmoor / Kamberg image was found to contain insufficient wetland detail because of the uniformly high levels of montane grassland at the end of the summer, despite the lack of masking fire scars.

Figure 2.9 Burn-index masks generated for the Highmoor / Kamberg test site to enable sub-division into uniform burn conditions, prior to spectral wetland classification.



In both the Davel and Highmoor / Kamberg sites, the wetland vegetation is very similar to the surrounding natural grassland communities, *in terms of spectral image representation*. In contrast, many of the non-coastal wetlands in the Walker Bay test site are characterised by very different vegetation communities (e.g. tall fynbos / riparian bush communities) compared to surrounding natural / semi-natural conditions. This meant that many of the (field-mapped) seepage zones and riparian communities could actually be identified successfully off a single image in the Walker Bay test site (i.e. image date 2000-10-11). However, since this was not known to be uniformly applicable to all non-coastal wetlands in the southern Cape mountains, final mapping was still based on the use of multi-temporal imagery. The estuarine wetlands in the Walker Bay site posed a slightly different problem, since initial image processing indicated that although the use of multi-temporal imagery was preferential to single date imagery, the influence of different tidal conditions at the time of satellite overpass had a greater overall influence than seasonal differences.

A three-stage classification approach, involving (a) pre-classification of basic land-cover classes to determine wetland potential areas, (b) classification of spectrally defined wetlands within the wetland potential areas, and (c) modification of these spectrally defined wetland boundaries using terrain-derived topographical models, was successfully applied at all test sites. Although a specific combination of derived image datasets were used to classify the wetlands in the final stage of the delineation process, these combinations actually represent the most suitable approach for the *specific characteristics* of the three test site. Equally useful and just as applicable alternative processing procedures are likely to be suitable for other image formats. What is key to the process, and should be regarded as the standard methodology identified in this pilot study is the use of a preliminary land-cover classification to determine wetland potential areas, classification of spectrally defined wetlands *within* these wetland potential areas, and subsequent modification of the spectrally defined wetland boundaries using terrain-derived topographical models. Due to the locally specific conditions in the Highmoor / Kamberg test site, it was also necessary to include additional level of modelling to minimise the effects of temporal burn scars, whilst in the Walker Bay site the influence of different tidal conditions at the time of satellite overpass appeared to have a greater overall influence than seasonal differences. Landsat-type imagery does however appear to be inappropriate in terms of scale and resolution for detailed mapping of wetland features which have been modified to such an extent by alternate land-use activities (i.e. ploughed over within cultivated areas), that they are no longer identifiable as an individual feature.

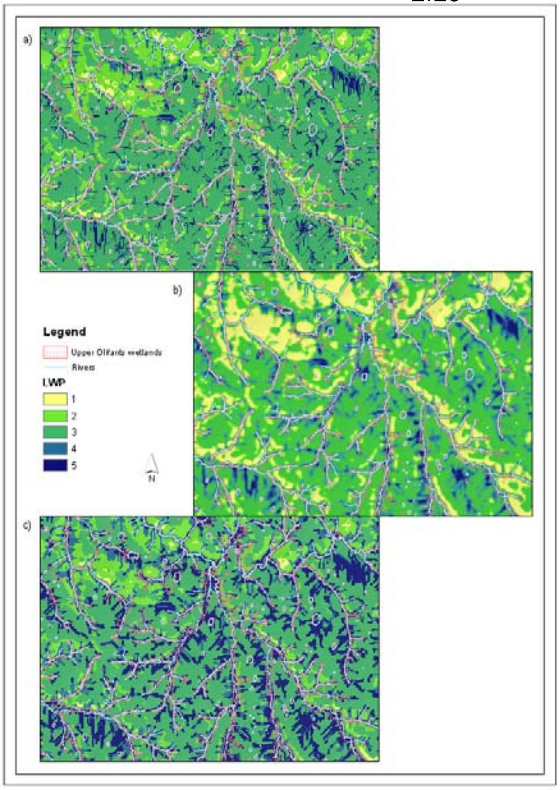
2.2.3 Terrain-Based Hydrological Modelling

Two versions of terrain-based hydrological modelling were evaluated, in order to determine the best approach for identifying potential areas of landscape wetness, where water (and thus wetlands), may be likely to accumulate, *irrespective of land-cover characteristics.* Figures 2.10 – 2.14 illustrate both the TRMI and the LWP models calculated for each test site.

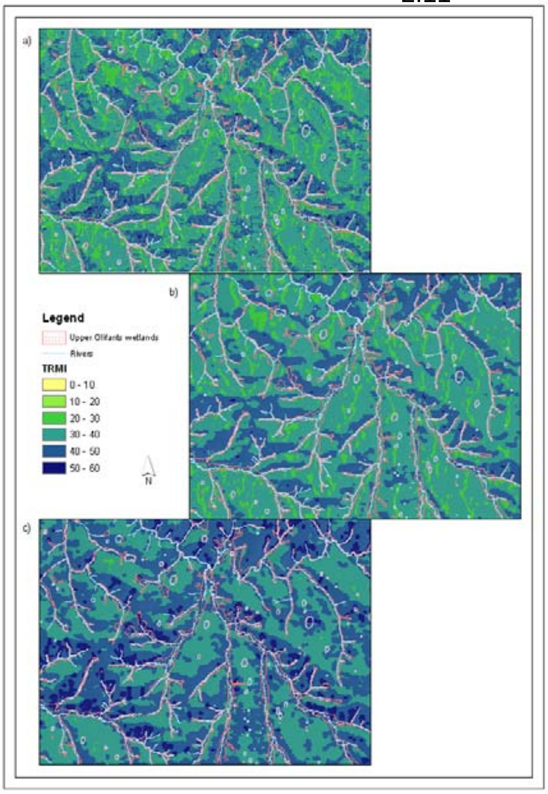
Figure 2.10. Landscape Potential Wetness model results for Davel, the Viskuile study site (a) no smoothing (b) mean smoothed surface and (c) maximum smoothed surface.

Figure 2.11. TRMI model results for Davel, the Viskuile study site, (a) no smoothing (b) mean smoothed surface and (c) maximum smoothed surface

2.10



2.11



Each model has been overlaid with 1:50,000 scale river lines to aid in visual orientation. The TRMI data ranges between 0 – 60, with 0 being the driest, and 60 very wet. Yellow zones indicated areas with a low moisture index (and therefore low wetland potential), increasing to areas of high moisture content in dark blue (and likewise, high wetland potential). The LWP model data is based on a 5-class scale, where classes 1 and 2 represent high wetland occurrence potential, class 3 represents possible wetland occurrence, and classes 4 and 5 low wetland occurrence potential (i.e. exclusion zones when used in combination with image-derived wetland data).

Figure 2.12 TRMI model results with the mean smoothed surface option for the Highmoor / Kamberg test site.

Figure 2.13. Landscape Wetness Potential (LWP) Model results with the maximum smoothed surface option for the Highmoor / Kamberg test site.

Fig 2.12

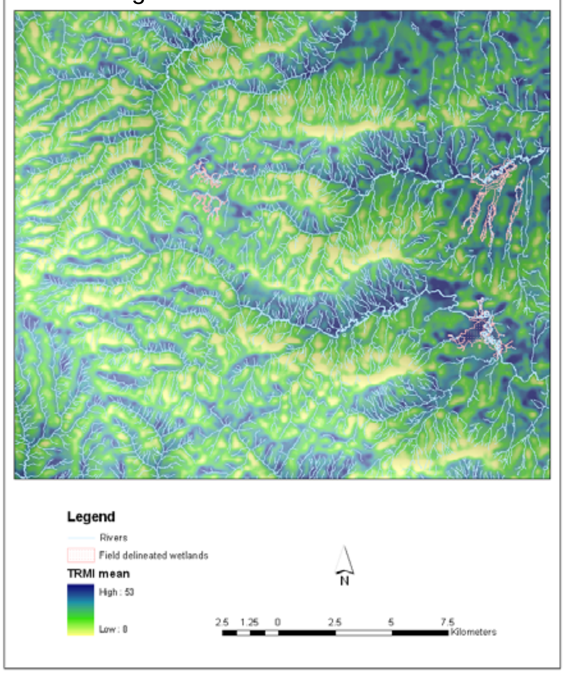
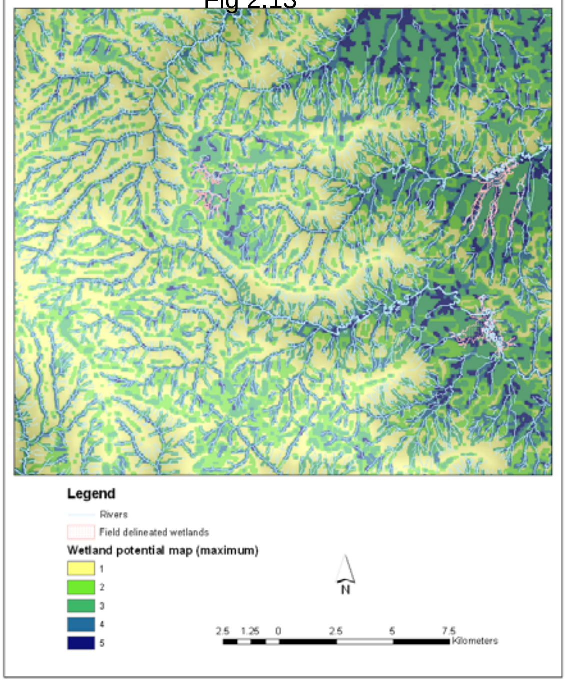


Fig 2.13



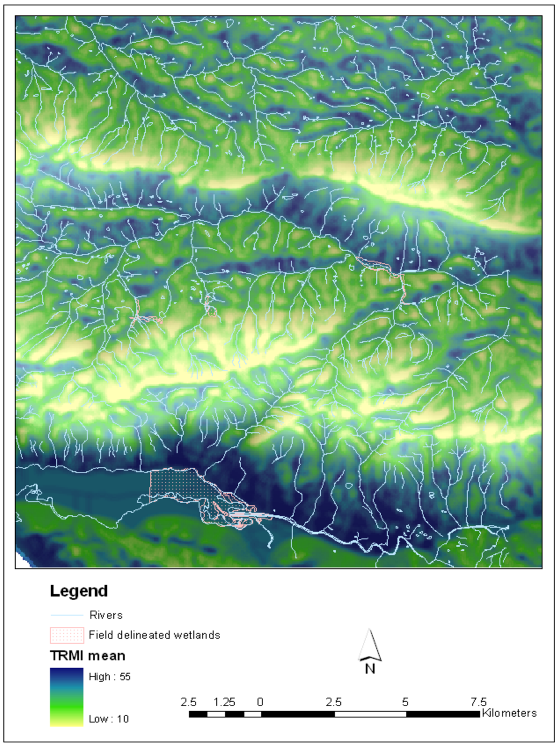


Figure 2.14 TRMI model results with the mean smoothed option for the Walker Bay site.

For the Davel test site, for both the TRMI and LWP models, both the original models results as well as smoothed surfaces, based on the mean and maximum statistics are illustrated (Figures 2.10 and 2.11). Only the TRMI mean and the LWP model maximum surfaces are shown for the Highmoor / Kamberg and Walker Bay sites, since these two versions were found to be the most appropriate surfaces from each model in terms of subsequent integration with the image-based classification.

2.2.3.1 Landscape Wetness Potential (LWP) Model Accuracy

A zonal statistical analysis was performed on the maximum smoothed surface, calculating statistics for the wetness potential values found within delineated and non-delineated wetland boundaries (Table 2.4). The statistics generated show that for wetland delineated areas, while the range and variety of classes per wetland type are high, the majority of cells have a value of 5 (high wetness potential). The median value reflects the same result; values 4 and 5 are most commonly found. In non-wetland delineated areas, while again the range and variety are high, the majority of cells have a value of 3 (mid to low wetness potential). This would seem to indicate that a reasonable model fit has been achieved.

Table 2.4 Zonal statistics on the landscape wetness potential maximum smoothed model results for the Davel site for wetland types and non-wetland areas.

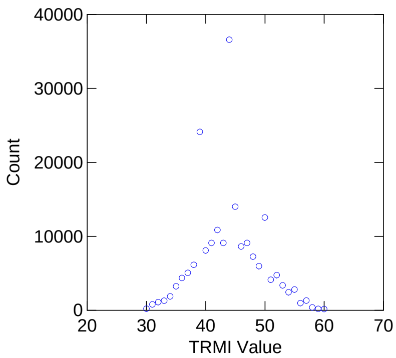
Wetland Description	Range	Variety	Majority	Median
Non wetland delineated areas	4	5	3	3
Wetland Delineated Types				
Valleyhead seepage wetlands	3	4	5	4
Dams	3	4	5	5
Drainage lines with riparian zone	3	4	5	5
Non-permanently wet pans	4	5	3	3
Footslope seepage wetlands	4	5	5	5
Midslope seepage wetlands	3	4	5	4
Artificial wetlands	2	3	5	5
Permanently wet pans	3	4	3	3
Seepage wetlands associated with pans	2	3	3	3
Seasonally inundated channelled valley bottom floodplain wetlands with footslope seepage wetlands	4	5	5	5
Channelled riparian wetlands	3	4	5	5
Wet grasslands	2	3	5	5
Seasonally inundated valley bottom floodplain without footslope seepage wetlands	4	5	5	4
Temporarily to seasonally inundated channelled valley bottom foodplain	3	4	5	5
Seasonally inundated non-channelled valley bottom floodplain	3	4	5	5
Non-channelled riparian wetlands	2	3	5	5

2.2.3.2 TRMI Accuracy

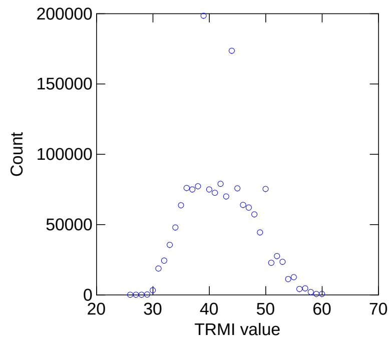
A different approach was used to compare the TRMI results, as the surface is continuous, and not categorical as is the case with the LWP model, which would make a zonal statistical analysis inappropriate. Instead the maximum smoothed TRMI model results were masked to the wetland boundaries and a scatterplot analysis was performed (Figure 2.15). The scatterplot shows that the range of values falls between 30 and 60, peaking at around 45 for wetland areas. A similar analysis was carried out using the non-wetland delineated areas, and again values were found to range from around 30 to 60, although occurred slightly earlier at about 43.

Figure 2.15. Scatterplots of the TRMI maximum smoothed surface values for (a) delineated wetland areas and (b) non-delineated wetland areas, in the Davel test site.

(a) mean = 45; std deviation = 9.1



(b) mean = 43; std deviation = 10.2



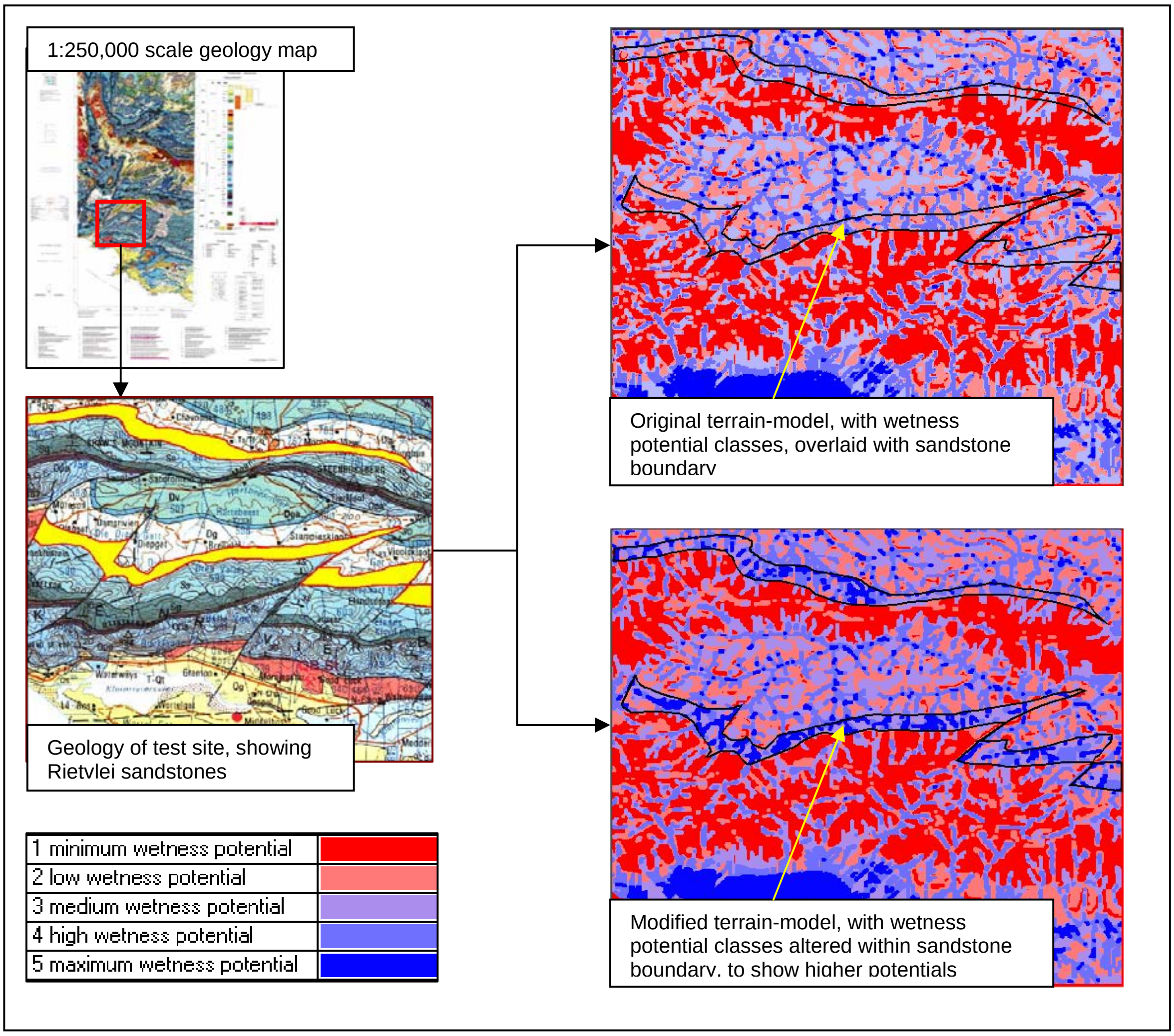
The LWP model was finally chosen in preference to the TRMI model, since the latter included a strong illumination factor, which over-emphasised aspect in the final landscape wetness distribution, whereas the LWP model was primarily based on slope morphology with respect to hydrological flow accumulation, with minimal aspect influence. Since the objective of the terrain-based model was to modify the final boundaries of the image-defined wetlands, rather than delineate actual wetland boundaries, the TRMI model was found to be too spatially restrictive since it effectively included an internal modifier (based on aspect induced wetness), prior to integration with image-defined wetland areas. Any aspect related influence on overall wetland distribution being identified during the image-based mapping of actual wetland areas.

Maximum value modelling was taken to be the most appropriate procedure for re-sampling the terrain-derived model prior to image integration, since this ensured that in any given grid unit, the highest probability was automatically allocated to the wetness class with the highest likelihood of wetland occurrence.

2.2.3.3 Localised Modification of LWP Model with Geology

In the Walker Bay test site, due to the influence of local geology, the terrain-defined, LWP model was unable, as a single dataset, to provide sufficient detail for an accurate representation of overall landscape wetness, and was modified according to local geological association, prior to integration with the image data. Figure 2.16 illustrates how the spatial extent of the Rietvlei sandstone (Gresse and Theron 1992), was used to modify the probability weighting of the terrain-derived landscape wetness classes. This specific zone, which defines the abrupt change in slope at the base of the north-facing escarpments, had been identified during field-mapping as the primary source of many wetlands due to changes in local relief and soil types. The actual modification process involved simply increasing the wetness potential rating of each terrain class by one unit within the area defined by the sandstone layer, e.g. "*medium* wetness potential" became "*high* wetness potential".

Figure 2.16. Geological modification of LWP model in the Walker Bay test site.



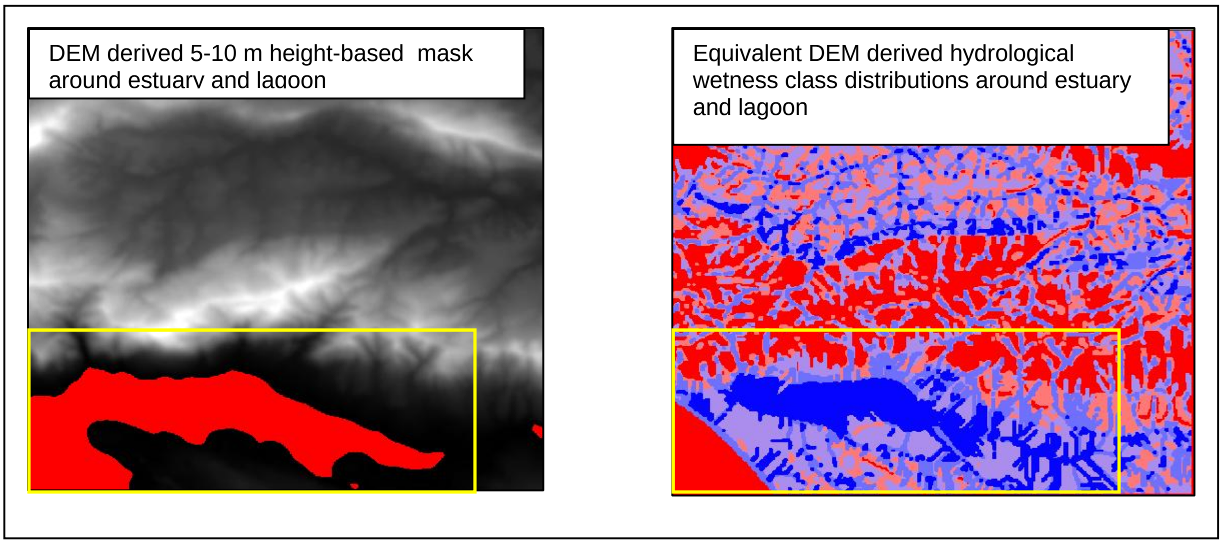
Two different terrain-based hydrological models were evaluated, in order to determine the best approach for identifying potential areas of landscape wetness, where water (and thus wetlands), may be likely to accumulate, irrespective of land-cover characteristics. The Landscape Wetness Potential (LWP) was chosen in preference to the Topographic Relative Moisture Index (TRMI) model was since the TRMI included a strong illumination factor which over-emphasised aspect in the final landscape wetness distribution, which conflicted with the image-derived information. In the Walker Bay test site, due to the influence of local geology, the LWP model was unable, as a single dataset, to provide sufficient detail for an accurate representation of overall landscape wetness, and was therefore modified according to local geological associations.

2.2.4 Final Wetland Mapping using integrated LWP Model and Image-Derived Classification

An integrated modelling approach that combines the image-derived spectral classification with the terrain-derived hydrological model provides the most reliable method for consistently mapping wetlands with the same degree of reliability, since satellite imagery on its own does not appear to be able to provide sufficient detail, even if multi-temporal imagery is used, in terms of the prescribed wetland mapping accuracies and the characteristics of the three test sites. This agrees with Dely *et al* (1999), who concluded that (Landsat) satellite imagery on its own was unable to provide sufficient detail for accurate mapping of small wetland areas, since it was not possible to identify spectral classes within which wetlands have a high likelihood of occurrence. Given that the test sites used in the study represent some of the most complicated wetland communities to map using satellite imagery, this approach can be assumed to be suitable for all similar environments elsewhere. Whilst larger more easily definable wetlands (including open water bodies) can in most cases be mapped using only satellite imagery, the inclusion of terrain-based modelling will certainly increase the accuracy of boundary delineations, especially in marginal zones where actual wetland boundaries cannot be clearly defined in terms of vegetation cover changes.

A modified approach to terrain modelling was used in the estuarine areas of the Walker Bay site, based on contour (i.e. height) rather than hydrological flow accumulation modelling, because the hydrological modelling was found to be unsuitable in the low lying areas bordering the estuary / lagoon, where it became too abstract, possibly due to the extremely low variation in relief (Figure 2.17). This alternative approach was based on defining an approximate 3 – 5 m AMSL height threshold[13], which effectively defines the mouth breaching flood level (Marnweck pers com, after consultation with CSIR Stellenbosch). This height threshold was then used to modify the boundaries of the spectrally defined estuarine wetlands in the same manner as the normal terrain-defined hydrological wetness class boundaries.

Figure 2.17 Difference in Height and Hydrological Flow topographic-based masks, used to modify estuarine wetland boundaries in the Walker Bay test site.



[13] The approximate 5 – 10 m AMSL contour threshold was derived from the same 25m raster DEM model used in the pre-classification, topographic normalisation process, which was originally based on 20m contours. The cubic convolution re-sampling process used to generate the final 25m grid from the initial 50m grid produced a linear interpolation of heights within the finer grid structure, from which it was possible to approximate a value close to 5m, although in reality this is likely to be closer to 10m AMSL.

Due to the unique spectral characteristics associated with the different landscape structures in each test site, it was not possible to generate a generic ‘probability table’ that could be used at all sites (see Table 2.3), for the merging of the spectral wetland classes with landscape wetness classes in order to derive the final wetland classification. This meant that separate ‘probability table’ had to be developed for each test site, based on subjective decision by the analyst, which again emphasises the reliance on experienced image analysts with a detailed understanding of wetland occurrence in a given landscape, and access to detailed reference data for accurate decision making. The actual format of the ‘probability table’ used to model the final wetland distribution also varied according to the format of the spectral wetland classes, since in some cases a series of classes representing a wetland confidence gradient were generated, where as in other cases, a single, amalgamated wetland class with uniform confidence was generated.

The final (unverified) wetland classification results for all three test sites are shown in Figure 2.18. The classifications have been background ‘terrain-shaded’ using the 25 m DEM to help illustrate the location of the classified wetlands in relation to test site topography.

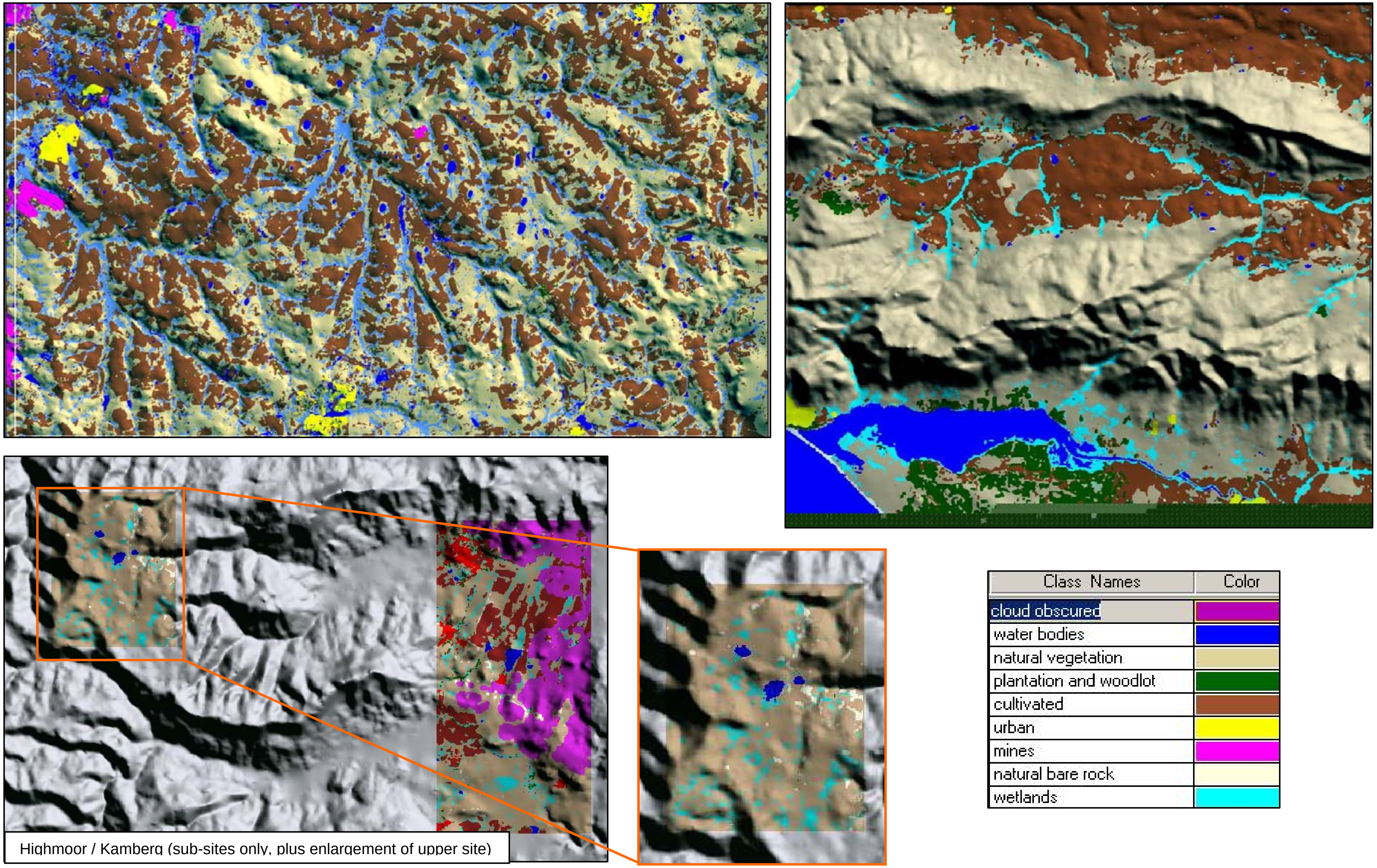
> Wetlands were finally mapped using an integrated modeling approach that combined spectrally-defined, potential wetland areas mapped from the satellite imagery, with a DEM-defined landscape wetness potential model, in order to determine final wetland boundaries. No single input dataset was able to provide sufficient detail to be used on its own.

2.2.5 Visual Image Interpretation and ‘Pan-Enhanced’ Imagery

Depending on specific mapping objectives, and the type and format of imagery that is used, manual photo-interpretation can be a viable option for image-based mapping. For example, it has been used successfully in many national land-cover mapping programmes (using Landsat image prints at 1:250,000 scale), where the scale, coverage and level of detail required are compatible with this mapping technique (Thompson 1999). The method is also applicable to smaller mapping scales (e.g. 1:50,000 scale Gauteng Urban Land-Cover (Thompson 2000), but in such cases it is more suited to smaller geographical areas, because of the acknowledged time inefficiency of this method, in comparison to automated, digital classification procedures.

The most significant factor influencing the accuracy of photo-interpretation is the amount of information visible on the imagery. The use of multi-resolution data merging allows very high quality, visual products to be generated, which combine the spatial characteristics of high-resolution panchromatic imagery with the multi-spectral characteristics of lower resolution imagery. Since Landsat 7 simultaneously records both 15 m panchromatic and 30 m multi-spectral data, the potential application of pan-enhanced multi-spectral imagery was tested on the Davel site. Whilst the process of multi-resolution data merging is an accepted technique for generating simulated, high-resolution multi-spectral imagery, the product is more suitable for visually based image interpretation rather than digital classifiers, since the data value modification effects can result in problems during subsequent pixel-level classifications. Despite the reported ability of the Principal Components Merge (ERDAS 1999), to preserve (as far as possible) the original scene radiometry and associated spectral information, some variation in final data values will still be found. As can be seen from the pan-enhanced example (Figure 2.19), the process does however produce significant improvements in visual image quality.

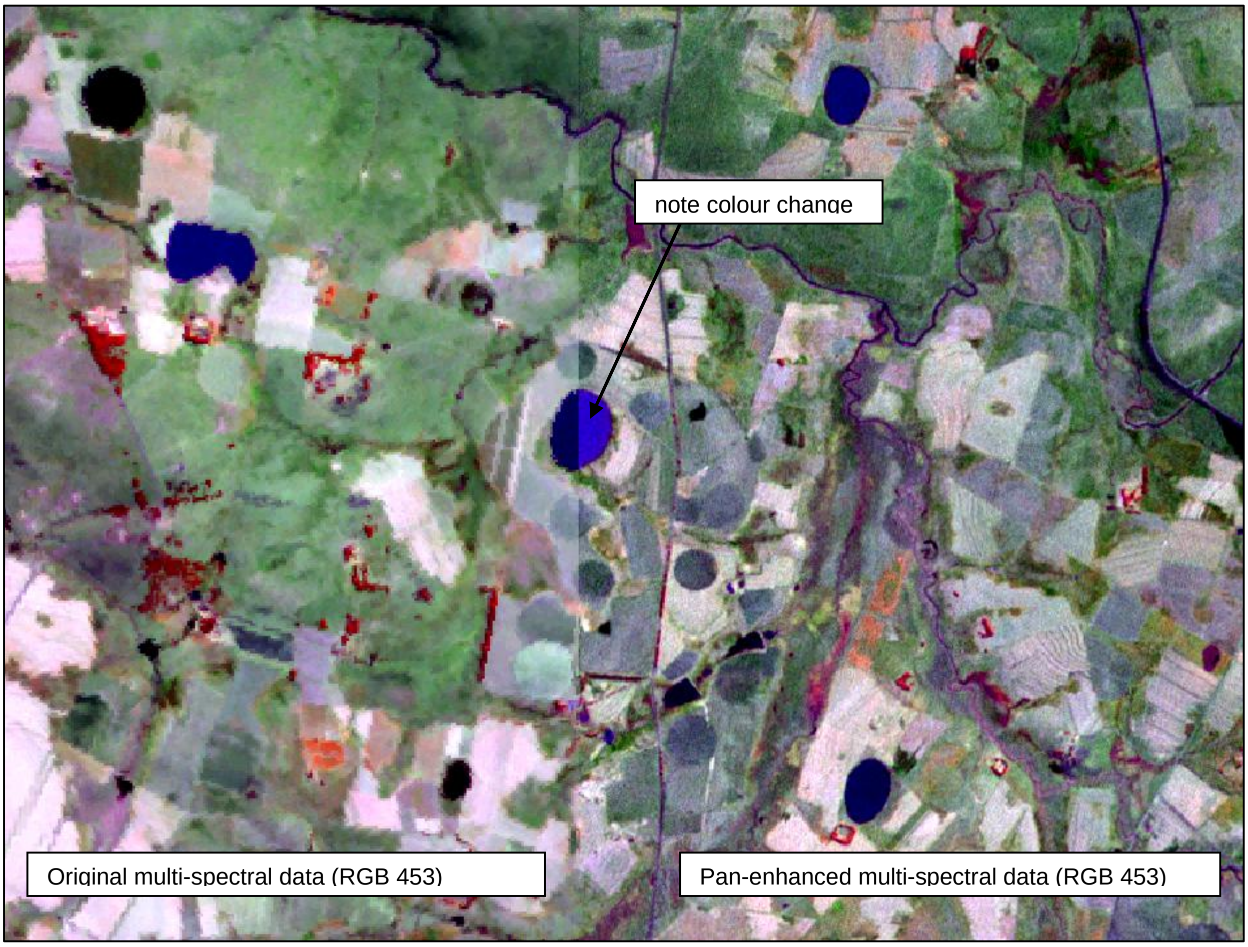
Figure 2.18 Final wetland classifications for Davel, Highmoor / Kamberg and Walker Bay test sites, generated using image-derived spectral classifications, modified with terrain-derived hydrological flow accumulation models.



Unfortunately, in terms of the specific mapping objectives of the wetland study, visual interpretation methods are not suitable for national wetland mapping due to the significant amount of digitally base, data preparation and modelling procedures that are necessary during pre-classification stages. As reported by the FDGC (1992), visual interpretation of pan-enhanced TM imagery is not really a practical alternative, and as an ancillary dataset was only found to offer limited improvement to post classification editing decisions (although the identification of smaller features improved with the higher resolution).

Pan-enhanced imagery could however be feasibly used in smaller study areas, where the time-inefficiency associated with extensive, high-detail photo-interpretation mapping is unlikely to be a problem, assuming of course that the wetland features to be mapped are clearly definable in terms of spectral characteristics, and that images do not require the level of digital pre-processing and integrated modelling used in the test sites. Full digital classification of pan-enhanced imagery could possibly be used to improve boundary delineation accuracies for clearly definable features, such as water bodies, due to smaller minimum mapping units (MMU's), associated with the finer spatial resolution. The concept of MMU's is explained in the next section.

Figure 2.19 Improved visual detail associated with Pan-Enhanced Imagery (Davel 22-08-2000)



The use of pan-enhanced imagery was investigated, using the Landsat 7 imagery acquired for the Davel test site. Whilst providing obvious improvements in visual quality, the process itself is not really suitable for large area, detailed mapping applications. Nor is the pan-enhanced imagery ideally suited to digital classification techniques, other than mapping of clearly identifiable, spectrally homogenous features such as water bodies, that have clearly definable boundaries

2.2.6 Mapping Accuracy, Spatial Resolution and Minimum Mapping Units [14]

As indicated previously, emphasis during digital classification testing was on determining appropriate data processing technique(s) for identifying wetlands simply in terms of their spectral characteristics, using the broad range of spectral data provided by Landsat 7. It is however important to theoretically quantify as well the possible improvements in spatial mapping accuracy provided by increasing spatial resolution, assuming that both sensor and land-cover spectral characteristics remain constant.

Since the target mapping accuracies referred to in the terms of reference are stated in terms of area-based parameters (i.e. 90% of all wetlands >1.0ha), rather than in terms of precise cartographic scales[15], with their associated positional accuracies, it is more appropriate to apply the alternative concept of minimum mapping units (MMU's) to define achievable levels of spatial detail that can be mapped. This is a well established and widely used approach to defining spatial mapping accuracies, which allows direct linkage with image spatial resolution. However the relationship between satellite imagery, scale and minimum mapping units is complex, not least due the fact that scale dependency is an inherent characteristic of all geographic phenomena, and that the term 'scale' has a variety of meanings and can be used in different contexts in various situations (after Cao and Lam 1997).

Spatial resolution is a fundamental characteristic of all remotely sensed imagery. The problem exists however that the spatial resolution is typically pre-determined by sensors characteristics, which may or may not be optimal for a viewed landscape, since the appropriate scale for observations is a function of the spatial structure of the environment, and the kind of information needed (Lunetta 1999; Woodcock and Strahler 1987). Spatial resolution will therefore influence the minimum object size that is detectable, assuming that sufficient spectral contrast exists between the object and its surroundings. For example, Wilson (1988, reported in Townshend and Justice 1988) showed that for 30 m resolution Landsat TM imagery, an object must be 54 m across before its central recorded radiance is within 10 percent of the original, thus indicating that the minimum size of a detectable object is larger than the spatial resolution of the imagery. Similar effects were reported by Smith and Thompson (1994, in Thompson 1999) when mapping newly established (exotic) forest plantations, which could only be identified as a "plantation", when canopy closure rates exceed (in general) 50 – 60 %, due to confusion with background cover radiance. Minimum mapping units are thus defined as the spatial resolution at which the dominant land-cover can be consistently and repetitively mapped, such that only landscape elements that exceed a given MMU will be classified (after Thompson 2000; Lunetta 1999, and Stuckens 2000).

Normally a MMU is defined in terms of specific spatial resolution, linked to particular sensor, such as Landsat 7. Since the terms of reference for the wetland project define a pre-set MMU, it is also necessary to identify the satellite system that best approximates to these targets. For digital, raster-based imagery where classifications are conducted on a per-pixel basis, Lunetta (1999) provides a general rule for MMU's, which states that the spatial resolution (i.e. pixel size) of imagery should be approximately 1 order of magnitude smaller then the required theoretical MMU.

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[14] The information used in this section was extracted primarily from Thompson MW, Berg van den HM, Newby TS and Hoare D, 2001. Guideline Procedures for National Land-Cover Mapping and Change Monitoring. CSIR / ARC contract report ENV/P/C 2001-006 (section 6.2).

[15] A cartographic (or map) scale refers to the ratio between a given distance on the ground and the corresponding distance on a map, and is typically associated with pre-set horizontal positional accuracies. For example, the US National Map Accuracy Standards require an positional accuracy of 12.2 metres (or 1/50 inch) for 1:24,000 (or smaller) scale maps (NMPS, 2000). Similarly, 0.5 mm at the scale of the map can be used as a guideline for accepted cartographic positional accuracy errors, due to factors such as digitising, paper stretch, map drafting etc (Goodchild 2000 and Fowler 1997).

Table 2.5 illustrates this for a range of MMU's, in relation to current earth observation satellite sensor characteristics.

Table 2.5 Minimum Mapping Units and Pixel Size (after Lunetta 1999)

Minimum Mapping Unit	Theoretical pixel size (m)	Equivalent satellite / sensor
1000 ha	1000 x 1000	SPOT Vegetation, NOAA-AVHRR
50 ha	224 x 224	TERRA-MODIS
5 ha	71 x 71	Landsat MSS
1 ha	32 x 32	Landsat 5 TM / Landsat 7 ETM
0.5 ha	22 x 22	SPOT 2 XS / 4 Xi
0.25 ha	16 x 16	Landsat 7 Pan
0.1 ha	10 x 10	SPOT Pan
0.025 ha	5 x 5	IKONOS Multispectral
0.001 ha	1 x 1	IKONOS Pan

As can be seen from Table 2.5, if 30 m resolution Landsat imagery is used all wetlands larger than 1 ha will be theoretically identifiable, which will only meet the "90 percent of all wetlands >1 ha", and not the "50 percent of all wetlands >0.5 ha" mapping standards prescribed in the ToR. In order to meet the 0.5 ha requirement, it would be necessary to use higher resolution multi-spectral imagery such as SPOT. Pan-enhanced (Landsat) imagery, despite its higher spatial resolution is not considered a viable alternative to physically higher resolution multi-spectral sensors because of the inherent modification to pixel values, and the negative implications of this effect during digital, per-pixel classification. The drawback to this conclusion is that higher resolution imagery typically costs more per image, despite normally covering smaller geographical area than the coarser resolution imagery. For example, a single 30 m resolution Landsat 7 ETM+ image, covering 32,400 km^2, currently costs R 7200, whereas as a 20 m resolution SPOT4 image, covering only 3600 km^2,(i.e. one ninth of a Landsat scene), currently costs in excess of R 17000 per image.

The guideline figures presented in Table 2.5 are not dissimilar from an associated rule of thumb for the classification of digital imagery, which indicates that the smallest feature that can be easily and repetitively mapped will be (approximately) 3x the spatial resolution, due to the effect of boundary pixels. For example, using this approach, the recommended MMU for 30 m Landsat TM (or ETM+) imagery would be 0.8 ha, and for SPOT Panchromatic imagery 0.09 ha. Both these estimates are similar to the 1 ha and 0.1 ha MMU values for Landsat and SPOT provided by Lunetta (1999).

It is possible to find published examples with higher (and lower) MMU's for equivalent map scales and / or spatial resolutions, due to differences in image format, data processing techniques, mapping objectives, and landscape complexity and heterogeneity. For example, the 'National Land-Cover Map of Great Britain', based on 25 m, digital, geo-rectified Landsat TM imagery reportedly managed to achieve a 0.125 ha MMU for features with strong spectral signatures (Fuller et al 1994).

2.2.6.1 How Does This Compare To Reported Wetland Mapping Accuracies ?

The theoretical guidelines presented in Table 2.5 are not always similar to those reported for wetland specific mapping applications, which implies that spectral characteristics of a given wetland, in comparison to the surrounding area, may be more important than pixel size in determining the accuracy and success of wetland identification. This is supported by the FGDC (1992) report on the application of remotely sensed imagery for wetland mapping, which concluded that spectral resolution was more influential than spatial resolution. For example reported, whilst Lunetta and Balogh (1999) report a 0.8 ha MMU for Landsat-based wetland mapping, and a potential 0.4 ha MMU from SPOT imagery, Tiner (1996) reports a 90 percent (Landsat) mapping accuracy only for water bodies > 8 ha, and only 25 percent for emergent, or seasonally wet vegetation communities. These studies were however completed in very different wetland environments, and may therefore be indicative of the influence of local wetland characteristics on mapping accuracies. Alternatively, Ducks Unlimited (one of the largest wetland monitoring groups in the US) state that 20 % of wetlands <0.8 ha (i.e. 9 x TM pixels), 70 % of wetlands between 0.8 - 2.0 ha (i.e. 25 x TM pixels), 91 % of wetlands between 2 - 4 ha (i.e. 45 x TM pixels), and 100% wetlands > 4 ha can be mapped using Landsat TM imagery (FGDC 1992). Locally, the Department of Water Affairs and Forestry (DWAF) is considering implementing a project to update the national forest database using a 2 ha MMU (1:50,000 scale applicable) approach, based on semi-automated classification combined with photo-interpretation of digital Landsat 7 imagery (Wannenburgh *pers comm* 2000, reported in Thompson *et al* 2001)[16].

For comparative purposes, the MMU typically reported for wetlands mapped from aerial photography, using conventional photo-interpretation techniques are significantly smaller as would be expected when using a more detailed data source. For example, the US National Wetlands Inventory assume >0.4 ha MMU with 1:58,000 scale photography, and 0.2 – 0.4 ha MMU with 1:40,000 scale photography, although mapping and interpretation time, data volumes and associated costs will increase with smaller mapping scales (Tiner 1996). Similarly, the USGS-NPS Vegetation Mapping programme is using a 0.5 ha MMU with 1:24,000 scale photography (USGS-NPS 2000).

> Emphasis during digital classification testing was on determining appropriate data processing technique(s) for identifying wetlands simply in terms of their spectral characteristics. However it is also important to quantify possible improvements in accuracy provided by increasing spatial resolution, assuming that both sensor and land-cover spectral characteristics remain constant. Since the target mapping accuracies referred to in the ToR are given in terms of area-based parameters (i.e. 90% of all wetlands >1.0ha), rather than in cartographic scales, it is appropriate to use the concept of minimum mapping units (MMU's) to define the achievable levels of spatial detail that can be mapped with the raster imagery. Spatial resolution will influence the minimum object size that is detectable, assuming that sufficient spectral contrast exists between the object and its surroundings. As a general rule, spatial resolution (i.e. pixel size) of imagery should be approximately 1 order of magnitude smaller then the required theoretical MMU. For example, if 30 m resolution Landsat imagery is used, all wetlands >1 ha will be theoretically identifiable, which will only meet the "90 percent of all wetlands >1 ha", and not the 50 percent of all wetlands > 0.5 ha, which would require higher resolution imagery. The disadvantage being that higher resolution imagery typically costs more per image, despite normally covering smaller geographical area than the coarser resolution imagery. For example, a single 30 m resolution Landsat 7 ETM+ image, covering 32,400 km^2, currently costs R 7200, whereas as a 20 m resolution SPOT4 image, covering only 3600 km^2, currently costs in excess of R 17000 per image.

[16] It is worth noting that the a 1 ha and 2 ha MMU is approximately equivalent to the a 3 x 3 pixel framework, and a 5 x 5 pixel framework for 30m Landsat imagery, indicating that the pixel equivalent difference between small MMU's is not that significant with medium resolution imagery.

2.3 CLASSIFICATION ACCURACY ASSESSMENT

The objective of the verification exercise was to determine the mapping accuracy of the image classification process, based on (1) **how well a given wetland can be located**, and (2) **how accurately are its borders can delineated,** in relation to the stated target objectives of being able to identify 90 percent of all wetlands >1 ha, and 50 percent of all wetlands >0.5 ha, with a 40m boundary delineation accuracy. The field-mapped wetland boundaries were taken to be representative of true wetland location and extent, and were therefore used in all assessments as the reference dataset against which the satellite-derived classifications were compared.

In order to be able to compare data with similar formats, the field-mapped data was first rasterised to a 25 m grid format, equivalent to the image pixel size. Whilst this approach may have resulted in the loss of some very small wetland polygons, this was not seen as detrimental to the overall validation procedure, since the 25 m grid unit was smaller than both the 0.5 ha minimum wetland size (i.e. 4 x 25 m pixels) and the 40 m boundary error (i.e. ~ 2 x 25 m pixels). Mapping accuracies were then determined by comparing the spatial distribution of the image-classified wetlands with the equivalent field-mapped extents. Due to the limited geographical extent of the (field-mapped) reference wetlands, in relation to the full test site coverage mapped using the image data, *mapping accuracies could only be determined for selected portions of the test site and not the entire area*, since it was impossible to determine the accuracy of any image-classified wetlands not actually mapped in the field. No attempt was made to quantify the accuracy of any of the non-wetland cover mapping (i.e. as used in the preliminary land-cover classification), simply due to the lack of comparable field data. However, if the mapping accuracies obtained during the SA National Land-Cover Database (Thompson 2000), are used as a comparable measure, and it is assumed that these are likely to be worse due to the coarser scales and simpler methods used, then non-wetland mapping accuracies should be in the order of 80 percent.

Statistical mapping accuracies were calculated on the basis of a simplified class-legend structure, within which all (vegetated) wetlands were treated as a single entity, since it had previously been determined that it was not possible to determine actual wetland “type” from image data alone. No attempt was made to validate mapping accuracies at any higher level of wetland detail. The three categories thus used in the validation process were (a) wetland (vegetated), (b) open water, and (c) other i.e. all other non-wetland vegetated land-covers (Figure 2.20).

Table 2.6 lists both the overall, producers and users accuracy for the three test sites, calculated using standard ‘error matrices’ for comparing the reference data (i.e. field mapped wetlands) and the corresponding image-derived classifications (Lillesand and Kiefer 2000). The overall accuracy is based on the combined “water”, “wetland” and “other” image-derived categories, but cannot be seen as a true representation, since the reference field data did not actually include anything other than the individually mapped wetlands, so no reference data is available to confirm the extent of non-wetland / other areas. The wetland category “producers” accuracy does, however, provide a reliable indication of how well the full extent of the field mapped wetlands were in fact mapped using the image data. The wetland category “users" accuracy, on the other hand, provides an indication of what percentage of the image mapped wetlands were actually located within the field-mapped boundaries.

For example, 91 percent of the image-classified wetlands in the Davel site were actually located within field-mapped wetland boundaries, and that this was equal to 52 percent of the total area of field-mapped wetland. Therefore, whilst the image identified wetlands were actually very accurate, they only represented 50 percent of the total (known) wetlands in the area. In comparison, the Walker Bay results indicate that whilst nearly all known “wetlands” were identified (i.e. 95 percent producers accuracy), these correctly identified wetland areas only represented 65 percent of the total image-classified wetland area, indicating large over-classification. The problem is, that without additional reference material it is not possible to state whether these additional wetland areas were in fact misclassifications or additional wetlands that were not mapped in the field simply due to the significant time required for detailed field mapping.

The Walker Bay results are also further complicated because due to the nature of the field-mapped boundaries, and the inability to (field) demarcate a low water mark to the wetlands, the open water and vegetated wetland categories were combined prior to accuracy determination.

Table 2.6 Final wetland mapping accuracies obtained for the image-classifications, using the field-mapped wetland boundaries for reference.

Test Site	Overall Mapping Accuracy	Wetland Category Producers Accuracy	Wetland Category Users Accuracy
Davel	72	52	91
Highmoor / Kamberg	72	28	72
Walker Bay	87	95	65

A similar accuracy assessment was also made between the larger wetland extents mapped in the Upper Olifants Catchment (which contained the Davel test site) from primarily 1:50,000 scale topographic maps and reference aerial photographs (Marneweck and Batchelor 2001), and the image-classified wetlands (Table 2.7).

Table 2.7 Final wetland mapping accuracies obtained for the Davel test site, using 1:50,000 scale map derived wetland boundaries for reference.

Test Site	Overall Mapping Accuracy	Wetland Category Producers Accuracy	Wetland Category Users Accuracy
Davel	84	41	39

Comparison to the 1:50,000 scale derived reference data indicates considerable disagreement, since only (approx) 40 percent of the image classified wetlands were located within the map derived boundaries, and that these areas of agreement only represented (approx) 40 percent of the total map-derived wetland areas. There was therefore a significant amount of map-derived wetlands not identified by the image classification, *but also* a significant amount of image-derived wetlands not identified by the map-based mapping. However, when viewed spatially rather than numerically, there is in fact significant agreement between these two datasets, especially when the non-wetland areas are taken into account, and any possible temporal changes in open-water and (vegetated) wetlands are ignored (see Figure 2.21)

In evaluating classification accuracies it must be remembered that reported statistics only refer to specific sample areas, which may or may not be representative of larger area mapping accuracies (although the sample areas themselves were specifically chosen to contain representative wetlands). However, whilst these results indicate a general **consistency** in terms of **achievable** mapping accuracies, they fall short of the desired minimum target accuracies (although it should be re-emphasised that these have been developed on test-sites that represent some of the most complex wetlands to map using satellite imagery, and are as such “worst case” accuracies).

Therefore, as a guideline rule, based on the results of the validation exercise, it is possible to state that satellite-based mapping of **vegetated wetlands** (using Landsat type imagery) **should be** able to:

- Identify (as a minimum), at least **50 percent** of the **total wetland area** (i.e. extent) in a given location, irrespective of individual wetland shape or boundaries;
- 90 percent of all wetlands >1 ha, and
- Within the image-classified wetland areas, have identified the **true location of wetlands** with at least **80 percent** accuracy.

Given the small size and fragmented distribution of the wetlands in the test sites (which were chosen specifically because of these difficulties), these mapping accuracies do, however, reflect a significant improvement on the level of wetland information contained within the only national data set available to date, namely the 1994-95 SA National Land-Cover Database, which was produced at a much coarser (1:250,000) scale, using single date, non-digital imagery.

Whilst these guidelines provide an indication of achievable *area based mapping accuracies*, they are not indicative of *linear* boundary delineation accuracies. For example, as shown in Figure 2.22, at no point in the delineation of the Viskuile (Davel) wetlands did the image-derived wetland boundary show any consistent linear agreement with the field-mapped wetland boundaries. In order for the 40 m boundary accuracy requirement to have been met, the image-mapped boundary would have had be consistently be located within 1 (Landsat) pixel of the field-mapped boundary. Assuming the Viskuile (Davel) results are representative of all sites, it can be concluded that it is not possible to achieve a 40 m wetland boundary mapping accuracy with Landsat-type satellite imagery.[17]

The mapping accuracy of open-water wetlands is generally much higher than that of vegetated wetlands, because of the unique spectral signature associated with such features, in relation to the surrounding land-covers. As such the accuracy of these specific features will be closer the theoretical MMU described previously (see section 2.2.6). Where (permanent) water bodies have been identified, their actual mapping and boundary delineation is typically within the 40 m boundary accuracy, based on the 1 x pixel difference rule defined above.

In conclusion, the results of the pilot mapping exercise suggest that satellite based mapping is not suitable for detailed wetland mapping, if Landsat-type imagery is used, and the minimum mapping standards are those specified in the original ToR. Whilst it would be possible to increase the spatial resolution of the satellite imagery by using alternative image formats to Landsat, this would be associated with significant increases in preliminary data purchase costs, and subsequent data processing costs, plus many of the alternative image data formats do not (as yet) have fully comparable spectral resolutions to Landsat TM and ETM+ imagery, which can be expected to reduce the suitability of these different image types. If higher mapping accuracies are a definite pre-requisite, then wetland mapping will have to be reliant on field and or combined field / aerial image based techniques. If however the lower spatial mapping accuracies obtainable from satellite imagery are acceptable as a preliminary national inventory, then this national dataset could be used to prioritise selected catchments (etc) for more detailed mapping using the field / aerial photo based techniques (described in Chapter 3).

Satellite-based mapping using Landsat-type imagery, in terms of the definitions applied to wetlands within this study, is essentially limited to a generic “presence and absence” mapping of

[17] This is unrelated to the theoretical MMU, which is based on the relationship between image pixel resolution and feature size, and assumes all features are spectrally unique. Boundary delineation inaccuracies illustrated in the Viskuile (Davel) wetland example are primarily a result of spectral overlap between wetland and non-wetland grassland communities. The classification accuracies of spectrally unique features such as open water bodies, is more likely to be influenced by the MMU, since spectral overlap with other land-covers is not usually an issue.

“core” wetland areas, where the identified wetlands are primarily defined by temporal surface vegetation characteristics rather than more permanent sub-surface soil profiles. As mentioned in the introduction to this chapter, this is an important consideration since the in some years wetlands may be much wetter than in others, such that the direct presence of water, surface vegetation conditions, or permanently saturated soils is therefore often an unreliable indicator of wetland conditions or boundaries, with the result that wetlands will not always exhibit obvious ‘signatures’.

2.4 PROCEDURE BIAS TESTING

In order to confirm the repeatability of the prescribed wetland mapping method(s) and the ability to generate consistent mapping results, a bias test procedure was used to assess the likely impact of analyst dependent decisions on final mapping accuracy. Of primary concern were the qualitative inputs regarding spectral class allocation to (wetland) information classes, and potential variability of the subjective-decision making component.

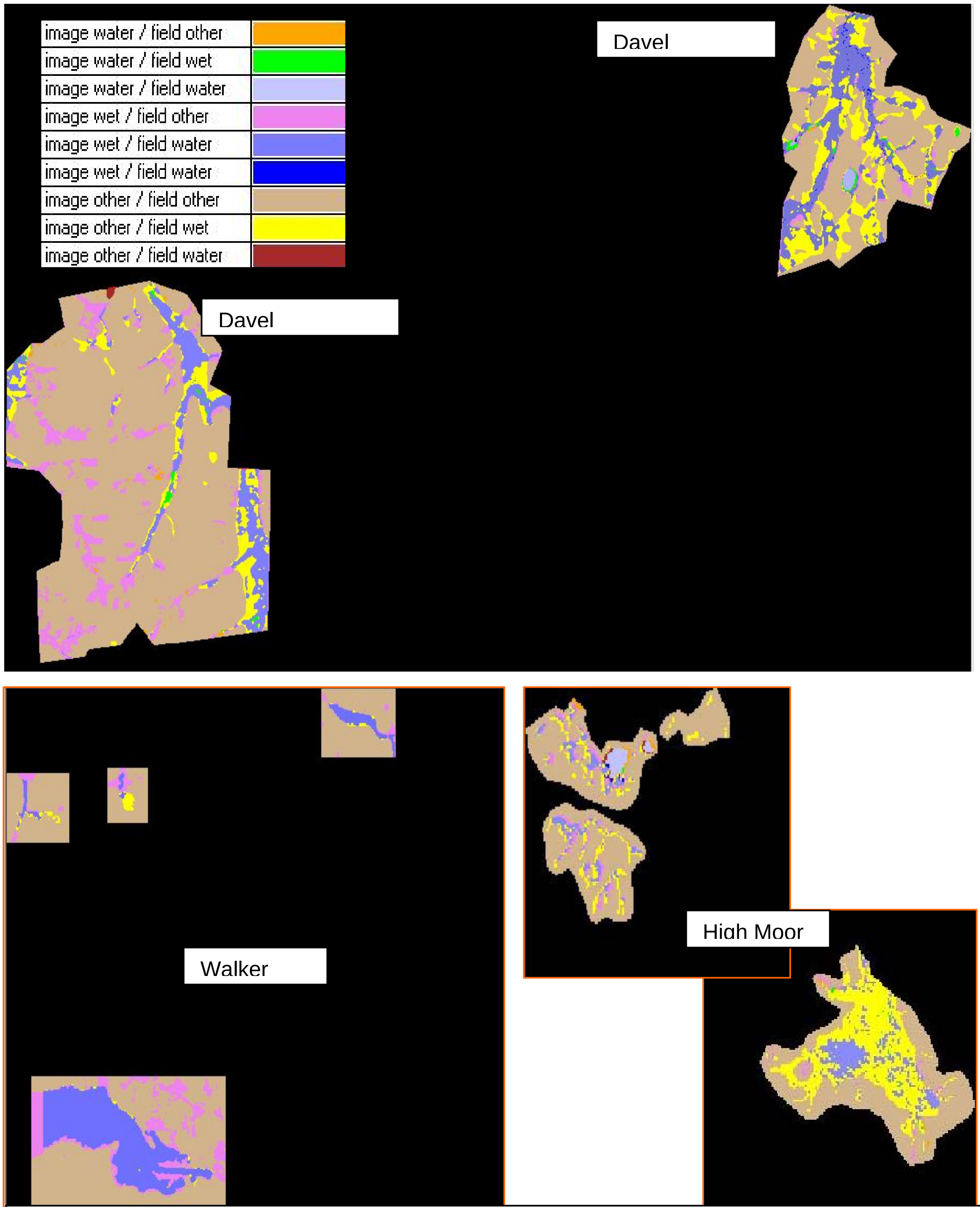
Bias testing involved requested two independent image analysts, with no previous knowledge of the recommended wetlands image processing techniques, to attempt duplicate re-classifications of the Davel test site data, by following a set a standard classification instructions. The results of this process were then used to gauge both the repeatability of the proposed techniques, estimate the level of analysts experience necessary, and confirm the consistency of mapped results. Whilst both analysis were conducted, albeit independently, on ERDAS Imagine © software, the standard set of wetland mapping instructions were specifically written in a software independent manner, so that it was also possible to estimate the minimum level of software competency required.

The two independent image analysts used in the testing were located in physically separate institutions (i.e. CSIR Environmentek, and INR), had variable levels of software competency, and worked independently.

2.4.1 Results of Bias Testing

The results of the bias testing exercise indicated several key factors that need careful consideration prior to possible implementation of the prescribed image processing techniques in a future national wetlands inventory. First and foremost, neither of the image analysts were able to fully complete the full wetland classification in the allotted time-span, with the level of progress appearing to be closely linked to the amount of (ERDAS specific) software experience. This indicates that the time requirements associated with the complexity of 1st time mapping are possibly close to double that of an analyst familiar with the proposed wetland mapping work-flow. This could effectively be reduced by incorporating a pre-operational training programme, under the tutorship of an analyst fully familiar with the wetlands mapping techniques. This reliance on written instructions alone, even with software competent analysts is not recommended. Because of this, it would be preferential to try and standardise mapping applications on a single software type, which although disadvantageous in terms of vendor-dependence, does have significant advantages in allowing standard, function-specific command sequences. Comments received during feedback from both analysts indicated that more ERDAS specific command-linked instructions would have been appreciated, rather than the emphasis towards generic, software-independent instructions, although several key ERDAS specific tips were included (see Appendix 2.4). Note however that all the ***image-classification*** procedures used in the recommended wetland mapping methodology, can be completed on ERDAS Imagine (Advantage).

Figure 2.20 Spatial agreement between image-derived and field-mapped wetlands for selected sub-areas within each test site. Sub-areas correspond to individual field-mapped wetlands.



Note : image sub-areas not to scale between different test sites.

Figure 2.21 Spatial agreement between image-derived and 1:50,000 scale map-defined wetlands for the whole of the Davel test site (after Marneweck and Batchelor 2001)..

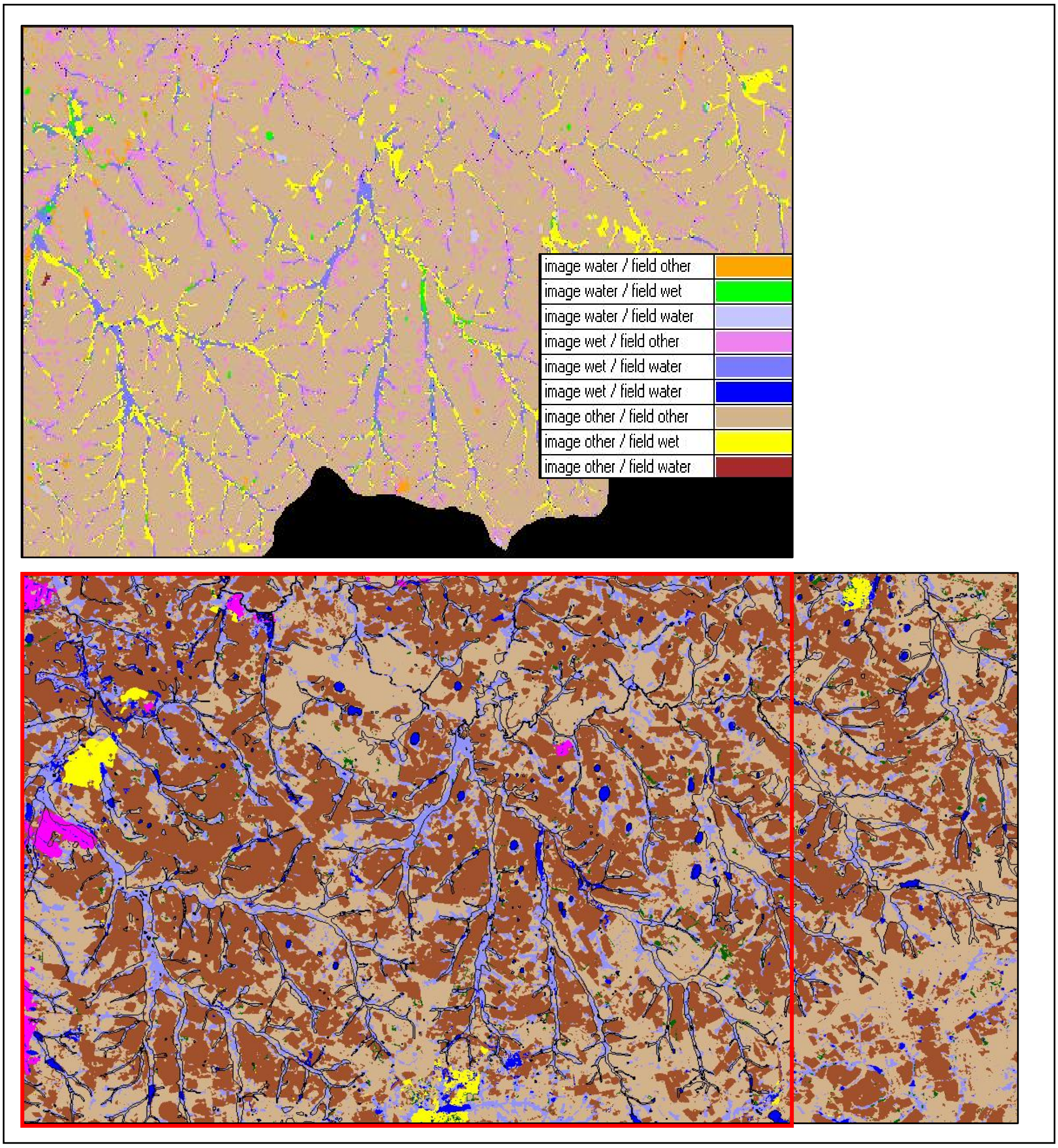
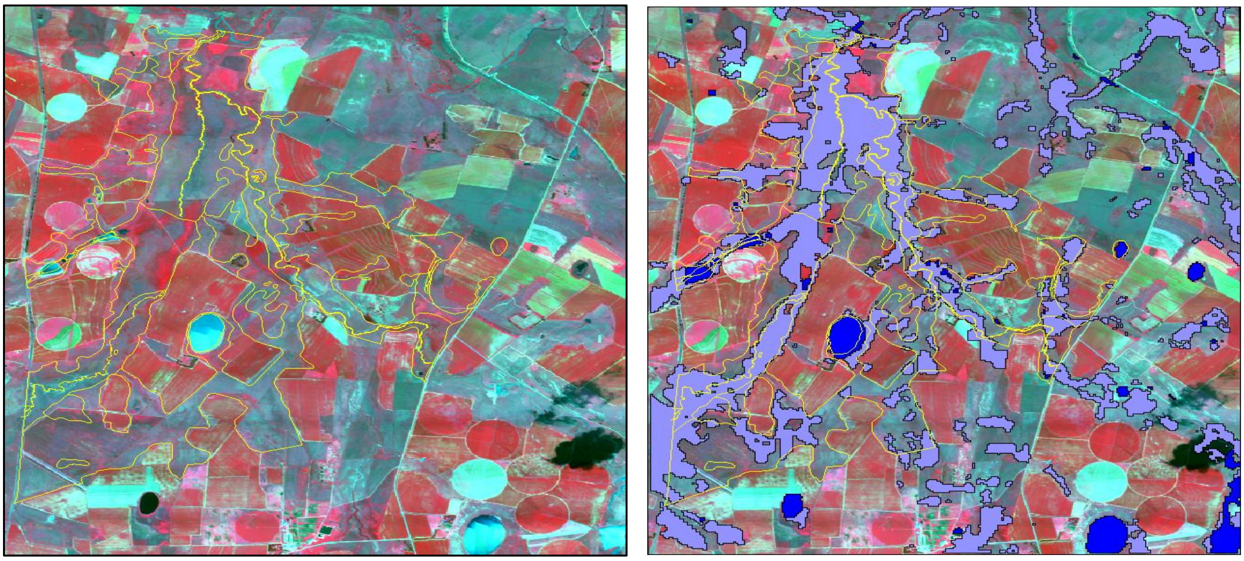


Figure 2.22 Field and image mapped wetland boundaries, overlain on the colour-infrared image of the Viskuile wetland complex (Davel).



*Background image is the CIR 0.75m resolution digital airborne image (Jan 2002). **Yellow** vectors show field-mapped wetland boundaries, and **purple** area shows equivalent image-mapped wetlands*

Prior knowledge of the study area (in terms of expected landscape structure and associated land-cover / use characteristics) was also found to be a key factor in the speed of data processing, especially in terms of decision making related to allocation of spectral classes to information classes. This could be incorporated into a training programme to ensure a uniform, minimum level of landscape understanding. Neither of the independent analysts for this study had much prior knowledge of the sites.

Since neither of the bias testing attempts actually managed to complete the full mapping exercise in the allotted time, it was not possible to calculate a statistical comparison between the test datasets and original Davel classification. Because of this, no statement (or conclusion) can be made with respect to achievable mapping accuracies or suitability of the techniques used for wetland delineation. Bias testing results are essentially guidelines on the ability of other image analysts to use these techniques in a consistent manner, with comparable output qualities.

The time-estimates provided in the final cost-benefit analysis (Chapter 5) are based on the processing times expected to be required by a project-knowledgeable, software competent image analyst, and do not include preliminary training or preparation times.

A bias test procedure was used to assess the likely impact of analyst dependent decisions on final mapping accuracy, and to confirm the repeatability of recommended mapping methods. Key findings of this assessment were the significant extra time required by first-time analysts unfamiliar the proposed wetland mapping work-flow. This could effectively be reduced by incorporating a pre-operational training programme, under the tutorship of an analyst fully familiar with the wetlands mapping techniques. Reliance on written instructions alone, even with software competent analysts is not recommended. Consideration should be to using a single, standardising mapping applications on a single software type, which although disadvantageous in terms of vendor-dependence, does have significant advantage in terms of training and quality control. Prior knowledge of the study area (in terms of expected landscape structure and associated land-cover / use characteristics) was also found to be a key factor in the speed of data processing.

2.5 LINK TO NATIONAL LAND-COVER 2000 INITIATIVE (NLC 2000)

The forthcoming implementation of the 1:50,000 scale NLC 2000 project (Thompson 2001) provides an ideal opportunity to kick-start a national wetland inventory, using satellite remote sensing to generate a basic national wetland inventory, using the techniques identified in this report. The NLC 2000 proposes to use multi-temporal Landsat ETM+ imagery for detailed 1:50,000 scale suitable land-cover mapping, in exactly the same manner as described for the preliminary land-cover generation described in terms of the wetland mapping procedures. Although "wetlands" are an integral component of the proposed legend / land-cover classification scheme to be used in the NLC 2000 project, the level of detail at which they are likely to be mapped is expected to be less than that identified as being possible within this wetlands project, since the image processing techniques (and legend structure[18]) are geared to more generalised land-cover for all possible categories, rather than emphasis on wetlands alone. This can be overcome by either incorporating the enhanced image processing methods identified in this pilot study within the actual NLC 2000 data processing as an integral component, or by using the final derived land-cover dataset, at a later stage, to facilitate later re-mapping of the more detailed wetland areas. The former approach would necessitate rapid involvement in the wetland project in order to incorporate these additional mapping requirements into the prescribed NLC 2000 methodology, whereas the latter approach, which is not so time dependent, could be initiated at any time in the future once the basic land-cover data is available, and access to the original image-data.

The actual image dates currently being identified from archival Landsat 7 ETM imagery appear to be in synchronisation with the wetlands image acquisition date requirements, and link to the recommended wet and dry period optimal windows. Whether the final choice of imagery used in the NLC 2000 project will meet both recommended seasonal windows still has to be confirmed, but it is expected that at least one image per multi-seasonal pair will coincide with at least one of the wet or dry period optimum wetland mapping windows.

> The forthcoming implementation of the 1:50,000 scale NLC 2000 project provides an ideal opportunity to kick-start a national wetland inventory, using satellite remote sensing to generate a basic national wetland inventory, using the techniques identified in this report. This can be overcome by either incorporating the enhanced image processing methods identified in this pilot study within the actual NLC 2000 data processing as an integral component, or by using the final derived land-cover dataset, at a later stage, to facilitate later re-mapping of the more detailed wetland areas.

2.6 MODELLING SUPPLEMENTARY INFORMATION

The interpretation of remote satellite images can provide information as to the location of wetlands, but it is difficult to derive detailed attribute information about the wetland through this method. With the aid of GIS-based modelling, it is possible generate additional, high level information which can supplement, or act as an interim measure, until detailed field surveys or aerial photograph analysis are conducted, and associated database attributes are populated with detailed information.

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[18] The legend structure proposed for the NLC2000 project is based on that used in the original 1:250,000 scale SA National Land-Cover Database (Thompson 1999), within which "wetlands" are defined as a single, all encompassing category, that includes both permanent and temporarily wet areas, including dry salt pans.

While it would be difficult to automate the collation of wetland classification parameters such as system, subsystem, class, and subclass, it is possible to provide information on some of the possible classification *modifiers*. For example, the "Landscape modifier" which records information on the relative position of a wetland in the landscape, such as a valley bottom, flat, or hill slope (etc), could be determined using the modelled topographic index described in sections 2.1.12 - 15. Figure 2.23 shows, for a portion of the Davel site, the results of the topographic modelling, the land-cover derived from remote satellite image interpretation, and the resulting landscape modifier classification of the delineated wetlands. In this procedure the image-derived wetlands are selected from within the land-cover coverage and used as a mask for the topographic index coverage. The resulting coverage contains Landscape modifier information for only the wetland areas.

Similarly, the same land-cover coverage can be used to determine possible land use threats to wetlands. These threats could also be recorded in the "Landuse modifier". The accuracy of the threat evaluation, in terms of both class- and spatial-detail, is a function of both the format of the original imagery used to derived the land-cover classification, and the class-specific characteristics that were actually mapped. For example, the impact of donga formation on wetland condition could only be determined if the original imagery was of suitable spatial / spectral resolution to facilitate identification of dongas in the first place, and that the classification legend structure actually includes these as a separate class. By way of example, this type of information is included is expected to be included in the classification legend to be used in the forthcoming 1:50,000 scale NLC 2000 project (Thompson 2001), and has been included in similar mapping projects (Thompson, Scheepers and Meyer 2000).

Threats to wetlands are largely related to the human activities, which alter the landscape from its natural state. Activities such as agriculture, mining, forestry, urbanisation, and dams can cause either total devastation of the wetland, or partial wetland area loss, as well as associated changes wetland functionality. Land use threats can be calculated at the catchment level, e.g. quaternary catchments, as well as at more detailed levels, i.e. threats to a specific wetland.

Catchment level threats can be simply obtained by calculating the area and percentage for each land use within the specified area. For example, Table 2.8 lists the land-cover class statistics for quaternary catchment B11A in the Upper Olifants catchment, which were extracted from the Davel test site land-cover classification (Figure 2.24). Note : since the Davel test site classification did not cover the full quaternary catchment, a proportion of the catchment (approximately 3000 ha), was coded as 'undefined'. Calculations exclude these undefined areas, so that whilst the actual values in listed in Table 2.8 are not correct, however the methodology and conclusions made are valid.

Table 2.8. Threats to wetlands for quaternary catchment B11A in the Upper Olifants area.

Code	Description	# of Polygons	Area (ha)	% of Area
1	Urban Areas	93	69.15	0.08
2	Mines	2	61.37	0.07
3	Forest Plantations	1095	733.86	0.80
4	Cultivated	2173	37934.10	41.47
5	Natural Grass	2531	39843.41	43.56
6	Wetlands	2750	11397.18	12.46
7	Waterbodies	800	1434.88	1.57
Total		9444	91473.96	100.00

In quaternary catchment B11A, the greatest threat to wetlands is cultivation, which represents a loss of 41 percent of natural grasslands to agriculture. In total 44 percent of the area has been altered from natural grassland due to human land uses such as housing, mining, forestry, agriculture, and dams.

The land-cover / use types directly adjacent to each wetland can also be a useful indicator of more pressing threats to wetlands. Adjacent land use is determined by buffering each (image-derived) wetland by a certain radius. In this test case the wetlands were buffered by 100 m, and then intersected with the image-mapped land use data (Figure 2.25). Area and percentages per land cover type can then be derived for the buffered areas or areas adjacent to each wetland (Table 2.9).

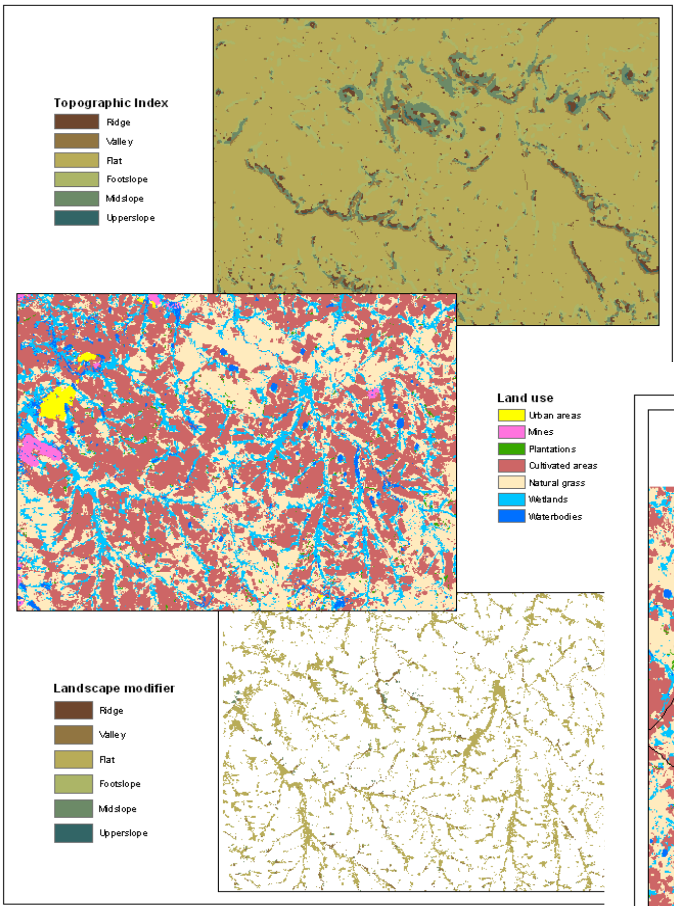

Figure 2.23. Illustration of how the modelled relative slope position or topographic index can used to derive a Landscape modifier index for coding of image-classified wetlands (based on the Davel test site).

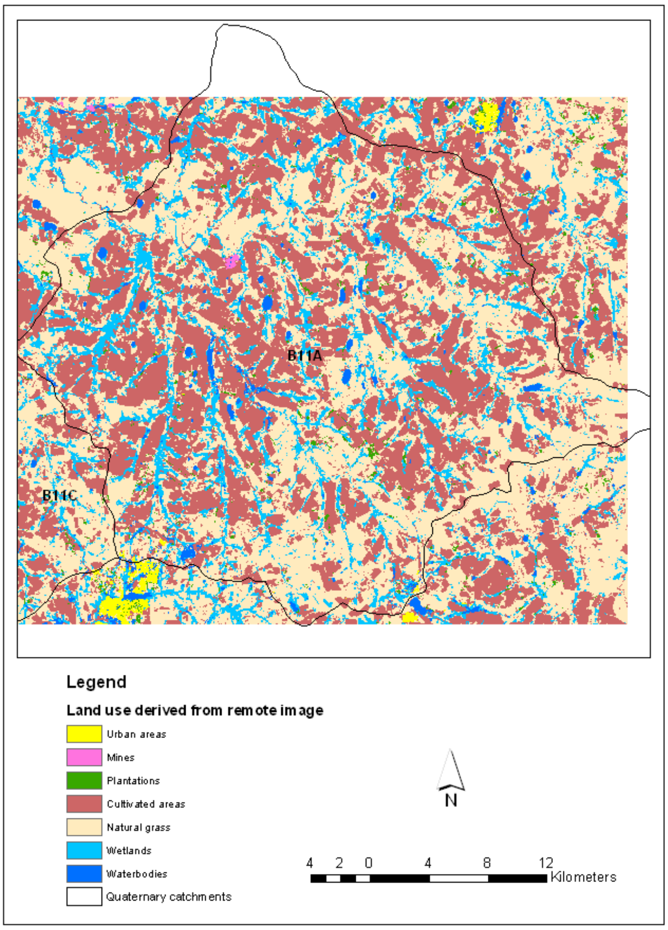

Figure 2.24. Land use derived from satellite images for the Upper Olifants area within which the Davel study site is located.

Table 2.9. Threats to wetlands determined by land-cover / use directly adjacent to wetlands, calculated for quaternary catchment B11A, using the Davel test site land-cover classification.

Code	Description	# of Polygons	Area (ha)	% of Area
1	Urban areas	46	20.29	0.09
2	Mines	3	8.34	0.04
3	Forest Plantations	686	326.92	1.37
4	Cultivated	3128	6735.38	28.31
5	Natural Grass	4514	15892.06	66.80
7	Waterbodies	750	808.43	3.40
Total		9127	23791.42	100.00

What can be deduced from Table 2.9 is that agriculture is not as direct a threat to wetlands as might have been assumed from the previous total quaternary catchment calculation (Table 2.8), since only 28 percent, as opposed to 41 percent of wetlands are directly affected by agriculture along their borders (Figure 2.26). The interpretation of these results must be used with care however, for a number of reasons:

- The calculations do not take into account *previous* total wetland loss due to agriculture, and only show the present wetland situation and associated potential land use pressures.
- Choosing a different buffer width in the analysis will produce different results, which means that buffer widths should be chosen with care in order to be appropriate for the spatial characteristics of the area and the associated wetlands. For example, the use of insecticide and pesticide in agriculture could have a much greater influence than 100m due to downslope transport of pollutants, plus, most of the wetlands themselves are actually located in grassland corridors between the cultivated areas

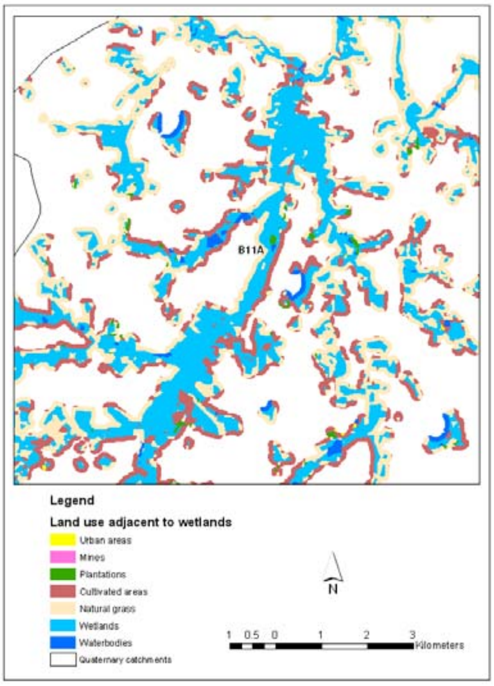

Figure 2.25. Land cover / use directly adjacent to wetlands, identified using a 100 m buffer.

2.7 ALTERNATIVE DATA SOURCES: EMERGING TECHNOLOGIES

As indicated in the introductory sections, it is quite feasible that alternative image formats will become available in the future, which may either compliment or replace current systems. Although the pilot study concentrated on satellite remote sensing systems that are essentially commercially orientated, operational programs, rather than research or developmental projects, several of these alternate systems have been successfully used for wetland mapping. They are not however that useful (at present) for developing a national inventory in South Africa, either due to unavailable or limited local data availability, or are unsuitability for detailed surveys covering extremely large areas. For example, Synthetic Aperture Radar (SAR) is able to provide very fine resolution DEM's, but at present such data (or sensors) are available locally. SAR has also proven very adept at wetland mapping in areas where standing water is covered by vegetation (i.e. swamp forest). Passive microwave can also be used to identify wet soils, as can thermal imagery. All these techniques are however still in their infancy compared to optical-based sensor techniques (such as Landsat and SPOT), in terms of mapping wetlands with the range of characteristics likely to be found within a national survey in South Africa.

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APPENDIX 2.1 SATELLITE IMAGERY

Davel
2 x Landsat 7 ETM+ images acquired for scene reference 169-078, on 22 August and 26 November 2000. The 26-11-2000 image represented the most suitable cloud free *wet period* image after onset of the heavy summer rains, which should show inundated wetlands where the 'greener' wetland areas were clearly discernable from the slower growth stages in the surrounding natural grasslands, and cultivated (maize) areas were still visible as predominantly bare soil areas (i.e. germination and seedling development, after Thompson *et al* 2001 *Appendix 6: Defining Suitable Acquisition Dates for Multi-temporal Imagery*). The 22-08-2000 image represented the most suitable cloud free *dry period* image with minimum burn scar effects, which showed maximum variation with the *wet period* image in both the wetland, non-wetland and cultivated areas (i.e. maize fields would be typically non-prepared fallow / stubble).

Highmoor / Kamberg
3 x Landsat 5 TM sub-images acquired for scene reference 169-080, on 06 April, 13 September 1999[19], and 30 August 2000. The three images were chosen to represent the most suitable dataset <u>from within the last 2 – 3 years</u> in terms of the prescribed optimum seasonal windows, but are not necessarily the most ideal in terms of actual rainfall and burn scar patterns, compared to if a longer period of data choice was allowed[20]. This approach was followed in order to investigate what possible problems may be encountered if, during future operational implementation, a maximum image age is specified in order to ensure that the final output is relatively current. The Highmoor / Kamberg test site consisted primarily of open natural montane grasslands, with only a small amount of cultivated fields in the valley bottoms, which had minimal influence on wetland identification.

The 13-09-1999 was the only *recent* cloud free image available within the prescribed late spring / early summer *wet period* (after the onset of summer rains), but was sub-optimal due to the extent of late winter / early spring burn scars 1999. The 06-04-1999 and 30-08-2000 images both represent alternative choices for the 2nd image dataset, with the April image representing end-of-autumn, pre-burn conditions, and the August image representing a mid-winter, burnt period. Given the sub-optimal conditions associated with all Highmoor / Kamberg imagery, the two non-wet period images were chosen to see which, if any, provided the most appropriate (spectral) variation to the September wet-period image. Due to the high relief in the test area, and the low sun elevation angles associated with the image dates, terrain shadowing was an unavoidable problem on south facing slopes.

Walker Bay
2 x Landsat 5 TM sub-images acquired for scene reference 175-084, on 11 October 2000 and 12 August 2001. In the winter rainfall areas it was assumed that the most important ability was to identify a suitable multi-temporal dataset that maximised the basic difference in fynbos vegetation (and wetland) conditions between the wet and dry periods, with minimal cloud cover and terrain shadowing (which is especially problematical with the E-W trending mountains and the low winter sun elevation angles at the time of early morning satellite overpass). The two images chosen represent the assumed best possible combination for these factors, but also provided additional differences in terms of local tidal flood conditions in the Walker Bay estuary at the time of

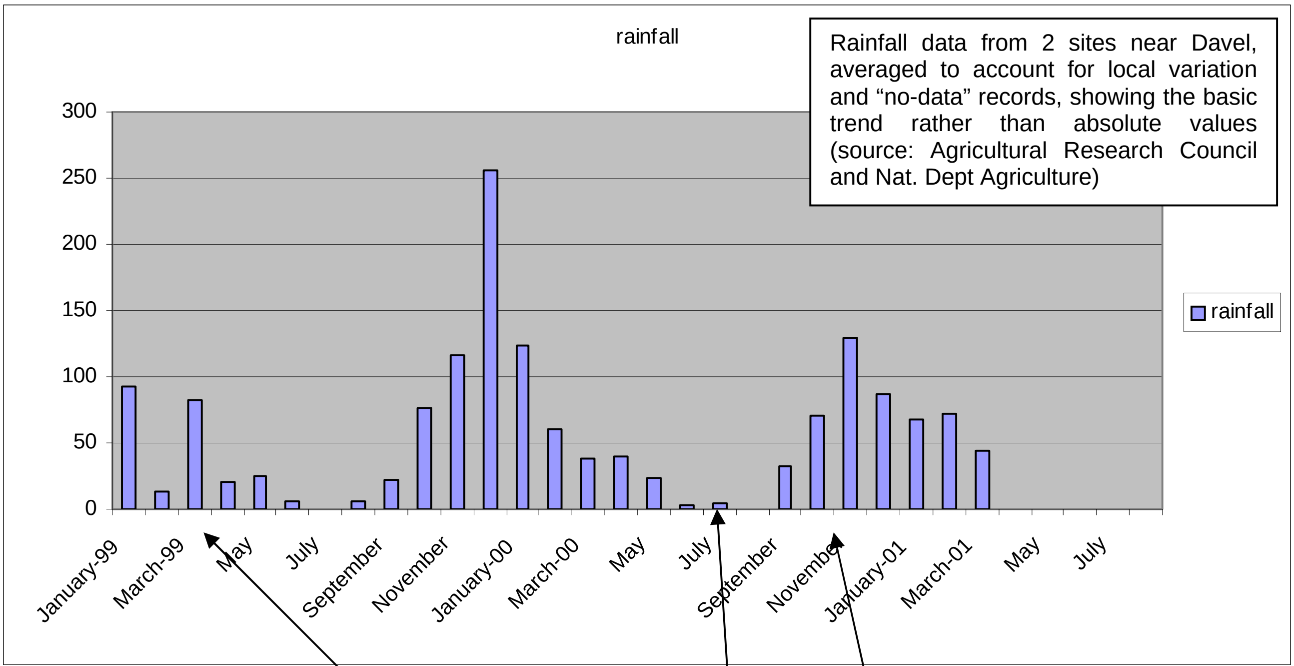
---

19 A third Landsat TM image was acquired for Highmoor / Kamberg after preliminary results were obtaining from the original multi-temporal dataset, in order to evaluate the influence of a slightly modified acquisition date in terms of burn scar effects and senescent winter grassland.

20 Previous land-cover mapping exercises in similar upland environments have shown the suitability of alternative archival image dates for the delineation of larger upland wetland areas using single-date wet period imagery, i.e. 07 September 1991 (Dely et al 1999), 10 May 1999 (Thompson *et al* 2000).

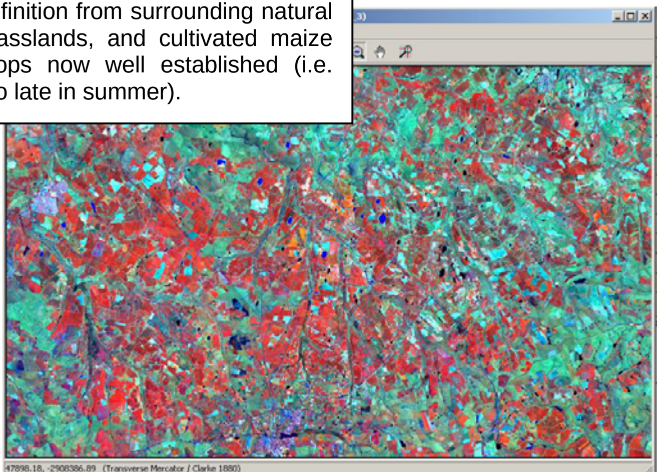
overpass, thus enhancing the ability to determine coastal wetland communities. The two image dates represent near maximum tidal differences with the 11-11-2000 image representing low tide conditions (i.e. tide height about 0.4m at 0900 local time, with spring low tide at 0834 local time). The 12-08-2001 image is representative of high tide conditions (i.e. tide height about 1.35m at 0900 local time, with high tide at 0912 local time). The condition of the cultivated fields (i.e. wheat) in the two images would similar, exhibiting late-senescent / early harvesting stages in October and near-maximum / ripening stages in August.

DAVEL

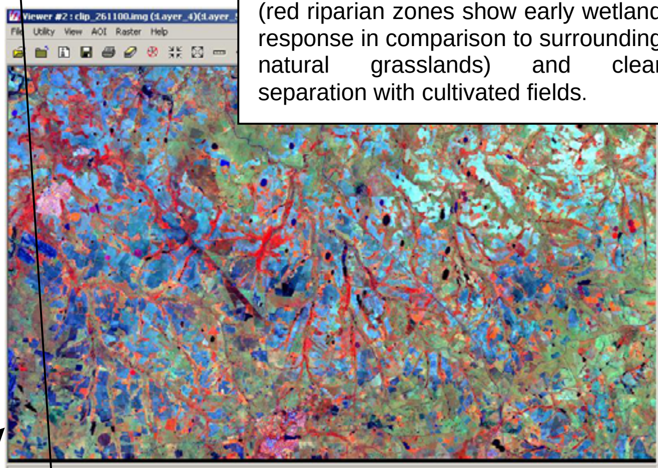


Rainfall data from 2 sites near Davel, averaged to account for local variation and "no-data" records, showing the basic trend rather than absolute values (source: Agricultural Research Council and Nat. Dept Agriculture)

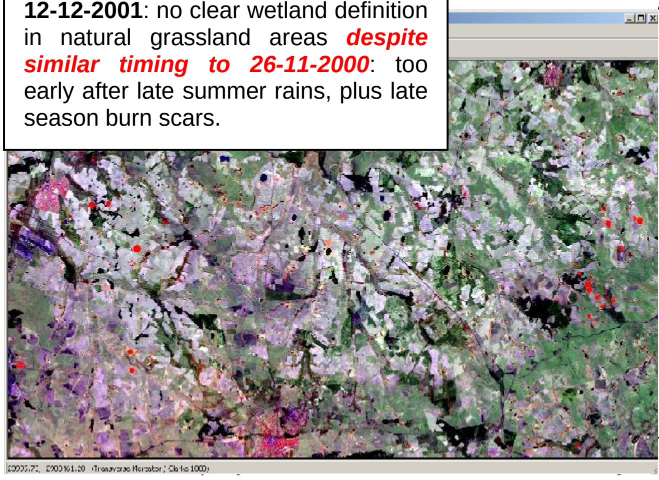
09-03-1999 no clear wetland definition from surrounding natural grasslands, and cultivated maize crops now well established (i.e. too late in summer).



26-11-2000 good wetland distinction (red riparian zones show early wetland response in comparison to surrounding natural grasslands) and clear separation with cultivated fields.

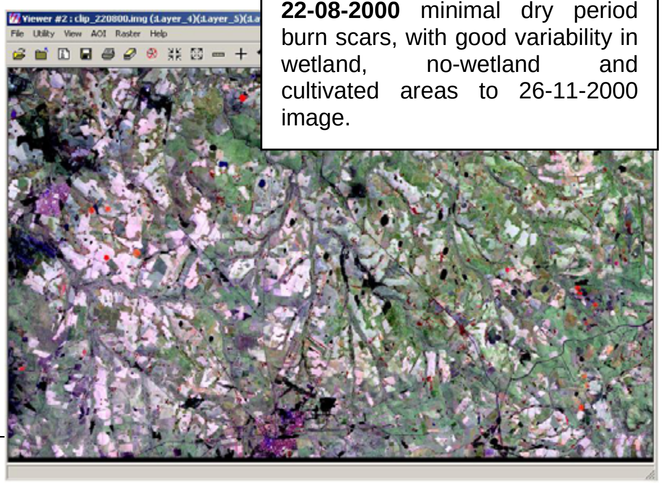


12-12-2001: no clear wetland definition in natural grassland areas ***despite similar timing to 26-11-2000***: too early after late summer rains, plus late season burn scars.

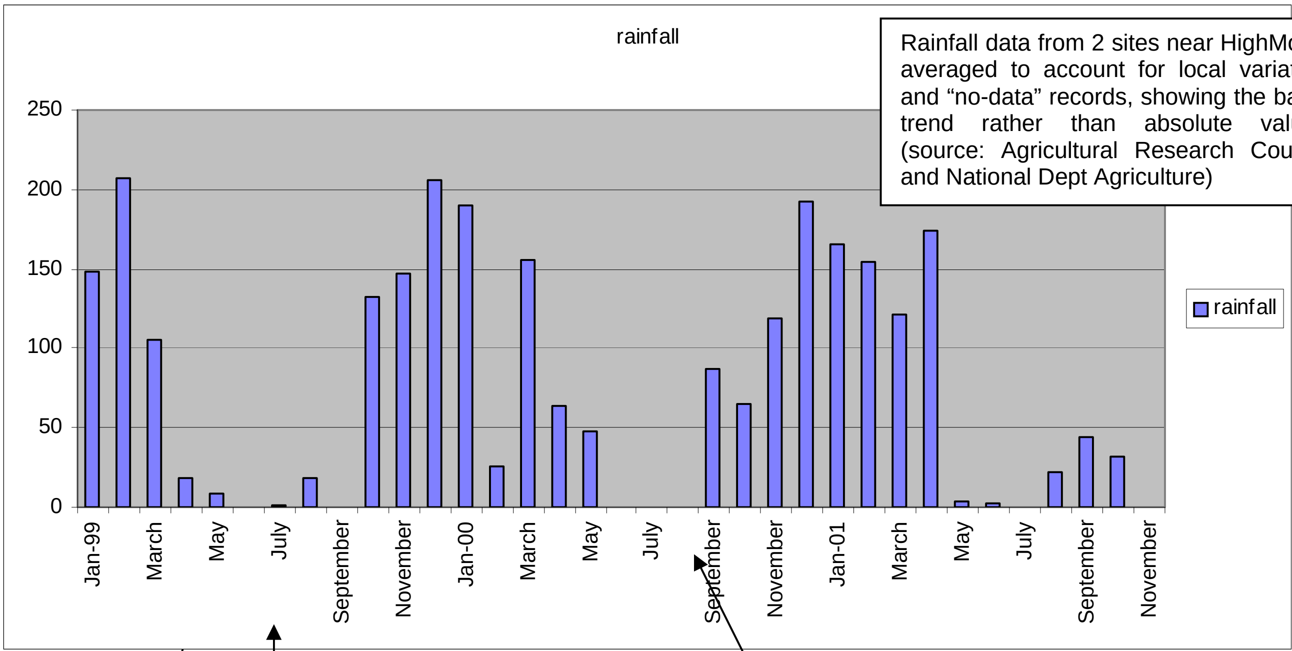


2002

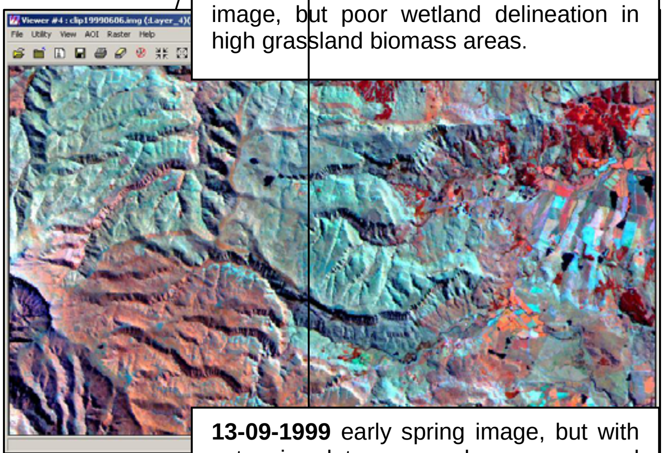
22-08-2000 minimal dry period burn scars, with good variability in wetland, no-wetland and cultivated areas to 26-11-2000 image.



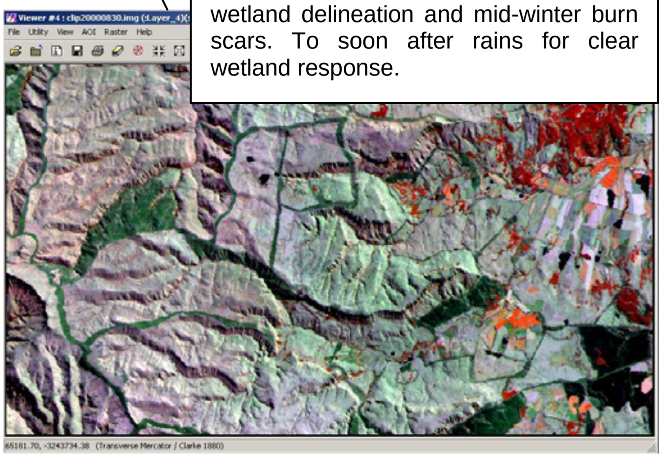
HIGHMOOR / KAMBERG



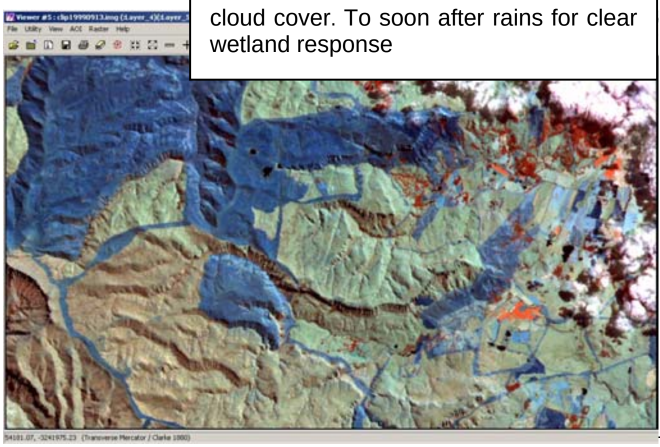
Rainfall data from 2 sites near HighMoor, averaged to account for local variation and "no-data" records, showing the basic trend rather than absolute values (source: Agricultural Research Council and National Dept Agriculture)



04-06-1999 late autumn, pre-winter burn image, but poor wetland delineation in high grassland biomass areas.

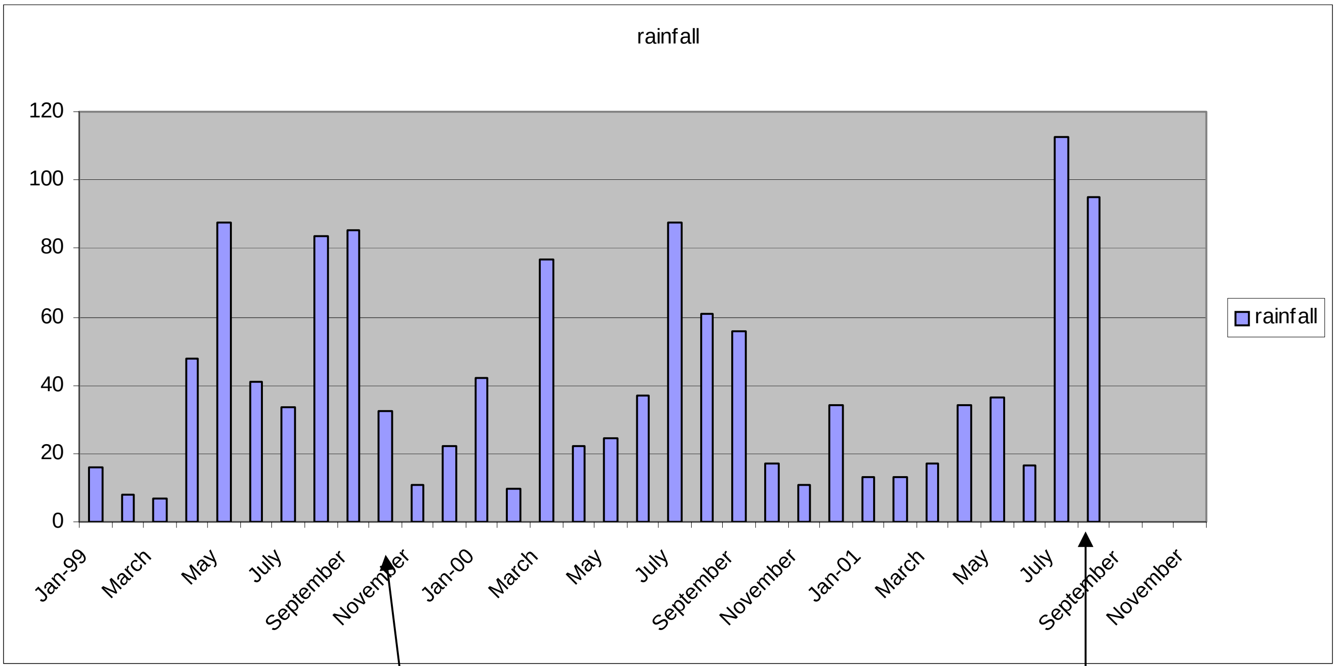


30-08-2000 late winter image, with poor wetland delineation and mid-winter burn scars. To soon after rains for clear wetland response.



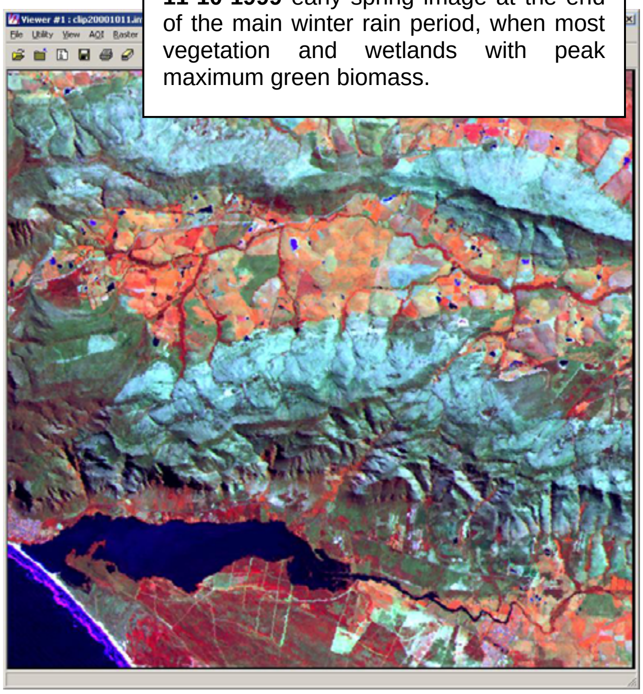
13-09-1999 early spring image, but with extensive late-season burn scars and cloud cover. To soon after rains for clear wetland response

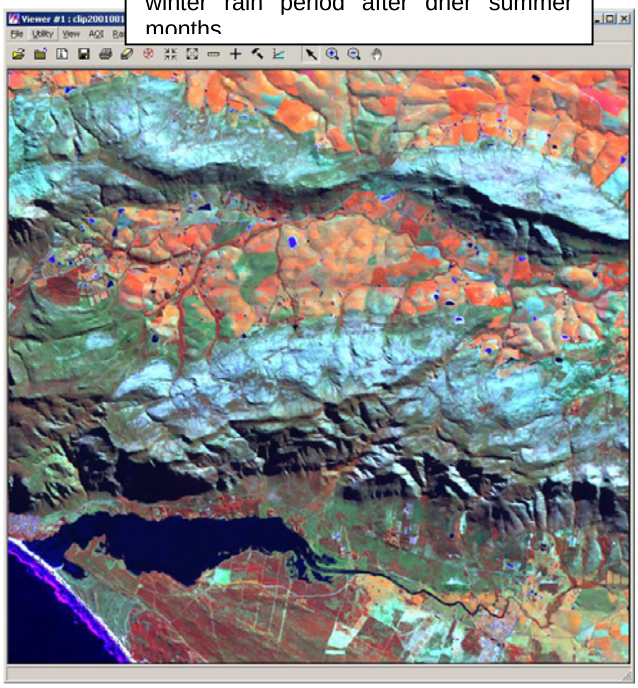
WALKER BAY



11-10-1999 early spring image at the end of the main winter rain period, when most vegetation and wetlands with peak maximum green biomass.

12-08-2001 mid-winter image, at start of winter rain period after drier summer months





Appendix 2.2: AML used to automate the generation of the Topographic Relative Moisture Index (TRMI) results

```
/* Program: trmi.aml
/*
/* Purpose: Calculates a topographic relative moisture index from a DEM
/*
/* Background:
/* Topography mediates the local climatic and edaphic conditions on the landscape. Vegetation
/* structure and composition are often related to topographic variables for use in the analysis
/* of potential species habitats.
/*
/* History: coding based on Parker (1982) and refinements by Moore et al. (1990).
/*
/* AML coding refined by Dean Fairbanks 2001, Percy FitzPatrick Institute, University of Cape Town.
/*
/* Input:
/*
/*      Required layers: elevation (must be in meters)
/*      Look up tables: rsp.rmt, slope.rmt, aspect.rmt, config.rmt
/*
/* Output: slope, aspect, rsp, topographic relative moisture index (TRMI)
/*
/* Slope is one of the most common topographic indices calculated for environmental analysis.
/* Slope strongly affects the flow and residence time of moisture on a landscape.
/* Aspect (the Azimuth direction of a hillslope facet) is generally calculated to estimate
/* differences in solar incidence, thermal conditions and exposure between sites (e.g. south vs
/* north facing slopes).
/*
/* Topographic Relative Moisture Index (TRMI) (Parker 1982) is an index which combines
/* relative slope position, slope configuration, slope steepness and slope aspect into a single
/* scalar value ( accumulative range 0 - 60). This index provides an explicit method to identify
/* potentially xeric (low values) to mesic (high value) sites. The TRMI index was devised as a
/* field-based technique to compare the potential moisture of sites. The GRID version of TRMI
/* calculation presented here is a rapid "first approximation" approach to identifying potential
/* moisture differences within an entire landscape (Method modified after Wilds 1996).
/*
/* This index is constructed from four different topographic variables:relative slope position,
/* slope configuration, slope steepness and slope aspect.
/*
/* Relative slope position is calculated by evaluating the relative position along a slope and
/* classifying that position into one of five possible classes (table 1). Relative postion
/* along a slope affects both the general thermal and hydrologic regime of a site.
/*
&args ele trmi

 &if [null %ele%] or [null %trmi%] &then
  &return &warning Usage: TRMI <elevation> <trmi>
 &describe %ele%

setwindow %ele%
setcell %GRD$DX%

/* Initial processing to create a filled DEM

fill %ele% fill_dem # # flow_dir
flow_accu = flowaccumulation(flow_dir)

/* Calcluate the slope and aspect grids
```

```
slope_ = int(slope(fill_dem))
aspect_ = int(aspect(fill_dem))
/*asp1 = setnull(aspect_ < 0, aspect_)

/* Finding the bottom

streams = con(flow_accu < 25, 1)
streams_flip1 = con(isnull(streams),1,0)
streams_thin1 = thin(streams_flip1)
streams2 = setnull(streams_thin1 > 0, 1)
setmask streams2
flow_dir2 = flow_dir
setmask off
flow_down = (flowlength(flow_dir2,#,downstream)) + 1

/* Finding the top

mean = focalmean(fill_dem, rectangle, 10, 10)
differ = mean - fill_dem
top = con(differ < -10, 1, 0)
thin_top = thin(top, #, #, #, 15)
ridges = setnull(thin_top > 0, 1)
setmask ridges
flow_dir3 = flow_dir
setmask off
flow_up = (flowlength(flow_dir3, #, upstream)) + 1

/* Relative Slope Position final calculation

rsp_float = flow_down / (flow_up + flow_down)
rsp = int(rsp_float * 100)

/* Calculating the topographic relative moisture index
/* Reclassify commands require the following LUT's aspect.rmt, slope.rmt, rsp.rmt
/* If  requiring aspect of -1 to be NULL then set aspect_ to asp1.

asp_reclass = reclass(aspect_, aspect.rmt)
slope_reclass = reclass(slope_, slope.rmt)
rsp_reclass = reclass(rsp, rsp.rmt)

/* Force Min & Max RSP values for ridge tops and streams

rsp_reclass1 = con(isnull(ridges), 0, rsp_reclass)
rsp_reclass2 = con(isnull(streams2), 20, rsp_reclass1)

/* Slope configuration calculation
/* Relcassify commands require the following LUT config.rmt

curve_grid = curvature(fill_dem, prof_curve, plan_curve)
plan_100 = int(plan_curve * 100)
prof_100 = int(prof_curve * 100)
config_a = reclass(plan_100, config.rmt)
config_b = reclass(prof_100, config.rmt)
config_1 = con(config_a < 0 & config_b < 0 , 10, 0)
config_2 = con(config_a == 0 & config_b < 0 , 8, 0)
config_3 = con(config_a < 0 & config_b == 0 , 7, 0)
config_4 = con(config_a == 0 & config_b == 0 , 5, 0)
config_5 = con(config_a > 0 & config_b == 0 , 3, 0)
config_6 = con(config_a == 0 & config_b > 0 , 2, 0)
config = config_1 + config_2 + config_3 + config_4 + config_5 + config_6

/* Final TRMI calculation
```

```
%trmi% = asp_reclass + slope_reclass + rsp_reclass2 + config

/* Clean up of temporary grids

kill (! slope_ all aspect_ all !) all
/*kill asp1 all
kill (! fill_dem flow_dir flow_accu streams streams_flip1 streams_thin1 !) all
kill (! streams2 flow_dir2 flow_down !) all
kill (! Mean differ top thin_top ridges flow_dir3 flow_up rsp_float rsp rsp_reclass !) all
kill (! rsp_reclass1 rsp_reclass2 asp_reclass slope_reclass curve_grid plan_curve !) all
kill (! prof_curve plan_100 prof_100 !) all
kill (! config_a config_b config_1 config_2 config_3 config_4 config_5 config_6 config !) all
```

Appendix 2.3: AML to automate the generation of topographic index (TPI) surface.

```
&args grid
setwindow %grid%

/* This equation creates the position index, i.e. ridge/crest, valley, or flat.
/* The data is then scaled from 0 to 1.

&if [exists pindex -grid] &then kill pindex all
pindex = %grid% - focalmean(%grid%,circle,3,DATA)
&describe pindex
&if [exists pindex_s -grid] &then kill pindex_s all
pindex_s = (pindex - %GRD$ZMIN%) / (%GRD$ZMAX% - %GRD$ZMIN%)
kill pindex all

/* This section reselects out the ridge/crest, valley and flat areas into two
/* separate coverages.

/* 3rd std deviations are .2019 and .4056
&if [exists flat -grid] &then kill flat all
flat = con(select(pindex_s,'value >= .2019 and value <= .4056'),1)
&if [exists ridge -grid] &then kill ridge all
ridge = con(select(pindex_s,'value > 0.4056'),2)
&if [exists valley -grid] &then kill valley all
valley = con(select(pindex_s,'value < 0.2019'),3)
rv = int(merge(ridge,valley))
kill ridge all
kill valley all

/* This section calculates and reclassifies a slope percentage surface.
/* The reclassification is based on the National Terrain Classification Sys.

&if [exists slp -grid] &then kill slp all
slp = slope(%grid%,1,percentrise)
cls1 = con(select(slp,'value <= 4.0'),4)
cls2 = con(select(slp,'value > 4.0 and value <= 6.0'),5)
cls3 = con(select(slp,'value > 6.0 and value <= 12.0'),6)
cls4 = con(select(slp,'value > 12.0'),7)

&if [exists slp_cls -grid] &then kill slp_cls all
slp_cls = int(merge(cls1,cls2,cls3,cls4))

kill ( ! cls1 cls2 cls3 cls4 !) all

/* This section masks the slope/terrain classification by the flat surface.
&if [exists slpcls_msk -grid] &then kill slpcls_msk all
slpcls_msk = selectmask(slp_cls,flat)

/* Now merge together the data sets to produce a terrain position index.

&if [exists tpi -grid] &then kill tpi all
tpi = int(merge(rv,slpcls_msk))
kill ( ! slp_cls rv_all !) all

&return
```

APPENDIX 2.4 INSTRUCTIONS FOR WETLAND MAPPING

Objective: delineate all the wetlands in the test site using the recommended methodology devised within the DEAT Wetlands project in order to test and confirm the operational suitability of the process in terms of repeatability by other image analysts.

Data: each analyst will be supplied with the following digital datasets, which are in the same geo-projection format (Transverse Mercator, LO29, Clarke 1880, Cape datum), in ERDAS Imagine *.img format, clipped according to the test site (i.e. Davel, Mpumalanga):

- Atmospherically corrected, ortho-rectified Landsat ETM imagery (25m resolution, bands 1-5,7) for two acquisitions dates, representing the optimum wet and dry periods for wetland mapping

- Digital terrain model for the test site, derived from 20 m contour intervals, and reproduced as a 25m grid

- Wetland terrain model (womax), derived from slope and hydrological modelling parameters, which illustrates the likelihood or potential for wetland existing in the landscape, where class 5 indicates maximum likelihood and 1 zero possibility

For reference purposes, the following will be supplied:

- Digital topographic maps of the test area

- Shape files showing the location and extent of selected wetlands as defined in the field and captured on small scale digital ortho-rectified aerial photography

The analyst should attempt to identify and digitally classify all areas of wetlands in the test site, using as a reference the supplied topographic maps and any additional vector data as seen fit, in order to produce a comprehensive digital thematic map of land-cover, that includes a detailed inventory of all wetlands.

Procedures

STEP 1: **Generate basic land-cover map using the multi-temporal imagery** that shows all land-cover classes that could potentially include wetlands, and all those that don't, in order to be able to generate a geographical mask of wetland potential cover types (i.e. natural veld and water bodies). It is expected that the analyst uses his / her intuitive understanding of the landscape and the various seasonal activities (i.e. cultivation practices) to produce the most accurate landcover classification possible, using the different spectral characteristics associated with the different seasonal cover conditions.

Approach: Use **principal component analysis** to generate a composite dataset that contains a summary of all the original L7 bands from both dates, as well as an NDVI dataset for both image dates, and use this as the input into an **unsupervised iso-classification** to generate the basic land-cover map.

- Generate NDVI for each date, and "layerstack" bands1-5/7 and NDVI for all dates

- Generate PC's for "stacked" dataset

- Evaluate which PC's contain most useful info, normally PC's 1 - 5 and possibly 6

- Extract useful PC's into separate data "stack" and iso-classify

- Hint: choose suitable RGB image output format for visual clarity, and use 99 iterations, 0.990 threshold and 80 class output

- ID all spectral classes which define specific cover classes (based on the legends below), and all those spectral classes that contain mixed land-cover classes

- Extract new geographically masked dataset from same optimum PC dataset for only those spectral classes that were found to be mixed units in the first iso-classification, **and repeat classification procedures** for this masked dataset in order to further "un-mix" the confused classes into specific land-cover types. Use only 40 - 60 class outputs for the 2nd iteration, assuming that there are approximately 12 - 20 "mixed" classes that need to be re-classified

- Repeat classification for a third iteration *if deemed necessary*, in order to end up with a basic land-cover classification of the test site, based on the multi-temporal wet / dry imagery.

- Spatially filter (3x3 majority filter) the final basic land-cover map in order to generate a final land-cover coverage that will allow clear separation of wetland and non-wetland potential areas (according to class legend content)

The following legends is to be used (where applicable)

• Natural veld (i.e. grassland) ~ ***wetland potential class***	tan
• Open water ~ ***wetland potential class***	blue
• Exotic Plantation / Woodlots	d.green
• Cultivated fields	brown
• Urban / Built-Up	yellow
• Mines, Quarries, Tailings	mauve
• Natural Bare Rock / Sand	white

Remember - the aim is not to spend too much time on the generation of a detailed landcover classification, but rather to generate an accurate representation of the basic landcover classes that can be used to help identify any wetland potential cover types as well as any possible 'threats' (i.e. fragmentation due to cultivation, mining activities etc).

STEP 2 : **generate wetland map** using combination of **spectral classification modified by terrain modelling,** based on the expected seasonal differences in biomass and wetness within wetland areas in comparison to the surrounding natural veld.

Approach : Generate "NDVI" and "Tassled Cap" indices for both image dates for only the area contained within the natural veld and open water land-cover classes, which are indicative of the areas that are likely to contain wetlands. Classify a combined NDVI-TC dataset into wetland and non-wetland classes using the same iso-classification process as used previously, and then further modify the "classified" wetlands using the supplied terrain model layer to adjust the localised wetland boundaries.

Hint, ensure that after and / or during all processes, **image statistics** should be continually updated using a 1x1 sampling rate, and **masking "aoi's"** are used to ensure that all masked (zero) areas are a excluded from the processing routine in order to maximise 8bit processing of actual data areas.

- generate masked NDVI for only the wetland potential areas for each date (i.e. natural veld and open water)

- generate masked TC for only the wetland potential areas for each date (i.e. natural veld and open water), and extract components 2 (greenness) and 3 (wetness)

- stack all multi-temporal NDVI and TC (2 & 3) datasets into a single file and classify using the same iso-clustering approach as used previously (but with only 20 – 40 output classes)

- ID all spectral classes which are thought to define wetlands

- Merge ***assumed*** wetland classes with the 5-class terrain wetland model dataset to define final wetland extent, by integrating all high potential spectrally-defined wetland classes with comparable high wetland potential terrain-defined classes (hint : use ERDAS 'index" function after first defining matrix codes manually …)

- Visually ID which *combination* of output classes from the merged spectral and terrain modelling datasets best represent the extent of wetlands in the test site (using the reference vectors to guide the final choice of classes)

- Create final composite from both the final mapped wetlands and the original general land-cover dataset to show all classes together as a final land-cover classification

Note in all cases, the recommended output format for data is unsigned 8bit.

The above notes are intended as basic guidelines that are intended to be sufficient for an image analyst familiar with both ERDAS software and basic classification processes to follow ~ **but please fell free to phone / email me for more specific information as and when it is required** since I need to find out how much of the process is intuitive to me based on my own experience as opposed to being something that is easy to follow and replicate …

CHAPTER 3: WETLAND MAPPING: AERIAL PHOTOGRAPHY AND GROUND TRUTHING

3.1 APPROACH

A key component of the project was to evaluate and compare the mapping capabilities and levels of accuracy (relative to the standards stipulated in the ToR) of a range of types of aerial photography as well as ground truthing in order to identify the most cost-effective method for delineating the wetlands at each test site. In each case the objectives were to determine the most appropriate methodology for mapping wetlands based on: (i) signature identification; and (ii) accuracy of boundary delineation. Data types used in the assessment included black and white (BW), true colour (RGB) and colour-infrared (CIR) aerial photography (in both hardcopy and digital formats). The analysis included the following data and mapping methodologies:

- Manual transfer mapping from stereo and non-stereo BW photographic prints;
- Digital mapping from ortho-rectified stereo and non-stereo BW photographic prints;
- Digital mapping from ortho-rectified digital RGB and CIR photographic imagery; and
- Mapping based on ground truthing.

3.1.1 Black and White (BW) Aerial Photography and Orthophotos

Conventional format, BW photography represents potentially the largest source of historical airborne imagery with national coverage, based on the archival data available from the Chief Directorate Surveys and Mapping (Dept. Land Affairs)[1]. For each of the four test sites (e.g. Davel, Highmoor, Glengarry/ Kamberg, and Walker Bay) complete single-date photo coverage was acquired in each of the following formats:

- Stereo and non-stereo, BW contact prints; and
- Non-stereo, ortho-corrected BW digital photo-mosaics.

For parts of the Davel site, the Betty’s Bay/Hangklip area and the Theewaterskloof Dam area of the Walker Bay Site, 1:10000 orthophotos were purchased from the Chief Directorate Surveys and Mapping (Dept. Land Affairs) for comparison with the RGB and BW photos.

The choice of aerial photo data acquisition date was governed primarily by the date of the most recently acquired photography, since there is typically insufficient multi-date photography available for a specific season or year to be chosen. The varying dates (and scales) of the final choice of photography are indicative of the limited choice of data available, and the necessity to be able to incorporate a range of photographic data formats in the mapping procedures. Where “off-the-shelf” digital ortho-photo mosaics were unavailable, these were created specifically for the project using the same stereo BW photography chosen for that test site. Complete specifications for the conventional and ortho-rectified BW photography are listed in Appendix 3A.

[1] In addition to this State archival source, several parastatals such as Telkom and CSIR also have internal air photo databases for specific regional and coastal areas, which may be of use, although access and cost may be an issue.

3.1.1.1 *Heads-up digitising on ortho-rectified digital BW aerial photo-mosaics*

Desktop delineation from orthorectified digital black and white photographs was performed at all the wetland sites using ArcView GIS 3.2 prior to, and after, undertaking the field visits. The pre-delineation helped to assess the accuracy that could be achieved with respect to mapping without experience of an area or having seen the wetland types being mapped. As was the case with all the mapping, the time spent on the desktop mapping using this method was recorded on a time sheet.

3.1.1.2 *Digital stereo mapping on ortho-rectified digital BW aerial photo-mosaics*

A trial mapping exercise using digital stereo mapping was undertaken using the computer programme Stereo Analyst at GIMS. With assistance from Adolf Vosloo at GIMS, a section of the Kleinrivier Estuary was mapped using this method. The method was also tried at Glenhart to at least get a comparison of its use in more mountainous terrain. This was equivalent to precision-level photogrammetric mapping (namely 3-D modelling on ortho-rectified imagery).

3.1.1.3 *Manual transfer mapping from stereo pairs of BW photographic prints*

Stereo pairs of black and white aerial photographic prints at a scale of 1:50 000 and 1:30 000 were purchased from the Chief Directorate: Surveys and Mapping for the purpose of manual stereo-pair mapping of the Viskuile and plateau area 2 wetland complexes. The photographs were taken in July 1991 (Job no. 952, photo no. 5068, 1991) and April 1996 (Job no. 22W, photo no. 2654, 1996) respectively. Photo overlays were made from clear mylar and fastened onto the hard copy aerial photographs with drafting tape. Landmark or fiducial features were marked on the photos and precisely transferred to the overlay. The overlays were correctly aligned to these prior to the photo interpretation. All the delineations were made with waterproof ink using a 0.3mm pen. The delineated wetland boundaries were then scanned in using an A3 scanner at 800dpi.

The scanned image was rotated and imported into a remote sensing package (ERDAS Imagine). A camera geometric correction was applied to the image which involved using a 20 m DEM, the camera statistics i.e. fiducial coordinates and focal length. Rectification was performed on the image using fiducial and eight ground control points. The image was then resampled, converted to GeoTIFF format, and imported into a vectorisation package (R2V) where lines were generated, smoothed and splined. Minimal editing had to be performed to ensure a correct product. The line or vector file was then imported into a GIS package, polygon topology was built and attributes added. An alternative method to the R2V vectorisation package was tested using a methodology which involves converting the image to an Arc/Info grid, applying GRID operations of THIN, EXPAND, and GRIDLINE. ArcScan vectorisation package is used to reduce the amount of post-editing. The process up to but excluding the ArcScan element was tested. It was therefore found that quite a lot of manual editing was necessary afterwards to produce a viable product. Another transfer method using a zoom transfer scope was also investigated.

3.1.1.4 *Manual transfer mapping from individual BW photographic prints*

Black and white aerial photographic prints at a scale of 1:50 000 and in non-stereo format were purchased from the Chief Directorate: Surveys and Mapping for the purpose of desktop delineation of the Viskuile wetland complex. The photographs were taken in July 1991 (Job no. 952, photo no. 5068, 1991). The boundaries of the wetlands were delineated on transparent film overlays on the aerial photographic prints. The delineated wetland boundaries were then manually transferred from the overlays onto the relevant 1:50 000 topographic map sheets. This information was then digitised using ArcInfo.

3.1.2 True Colour (RGB) and Colour Infrared (CIR) Aerial Photography

Whilst (State) archival BW photography represents potentially the largest source of historical data with a national coverage, the decision to include RGB and CIR photography was based on the reported improved mapping capabilities that are possible with these alternative formats (especially structural vegetation discrimination with CIR), and their established use worldwide (FWS/NWI, 1975; Tiner 1977; Brown 1978; Tiner 1990; Lee 1991; Dale *et al*. 1996; FGDC 1992; Tiner 1996; and Wilen and Smith 1996).

Representative sets of RGB and CIR photography were acquired for the Davel site, using the in-house camera systems operated by GeoSpace International. Two sets of single-date imagery were captured over Davel, representing different seasonal conditions in order to test the suitability of these different dates for wetland mapping. The first set consisted of an RGB dataset captured in August 2001 with a 2nd RGB – CIR combination being flown in January 2002. Both datasets were flown to provide coverage of only selected sub-areas within the Davel site. Due to the actual implementation date of the project and unforeseen but unavoidable delays in the acquisition of the 2nd set of imagery as a result of unsuitable flying weather later in the season (which is in itself is an indication of future operational suitability for wetland mapping), the acquisition dates of both sets of imagery were not always 100 % optimal in terms of seasonal wetland characteristics. Specifications for the Davel digital photography are listed in Appendix 3B.

3.1.2.1 *Heads-up digitising on ortho-rectified digital RGB and CIR aerial photo-mosaics*

Desktop delineation on orthorectified RGB digital photographs was attempted for the imagery taken in August from the Davel site. This imagery did not provide suitable contrast for the delineation of the wetlands and as such no heads up digitising could be performed. This result nevertheless provided information on the suitability of this type of imagery at the Davel site, which is largely representative of grassland areas. Due to the late availability of the CIR, no heads up digitising was undertaken with this dataset.

3.1.2.2 *Comparisons of RGB with BW and CIR aerial photos*

RGB aerial photos were compared with BW aerial photos for the Davel, Highmoor and Betty's Bay/Hangklip sites. The wetland signatures on the dataset were visually compared with those from the imagery of the other datasets in order to evaluate the suitability of using RGB at these sites and to see if it offered any advantage over BW imagery.

CIR aerial photos were compared with BW and RGB aerial photos for the Davel site. The wetland signatures on the dataset were visually compared with those from the imagery of the other datasets in order to evaluate the suitability of using CIR at this site and to see if it offered any advantage over RGB and BW imagery.

3.1.3 Ground Truthing

Because the hydrology, soils and vegetation generally change gradually along a continuum of increasing wetness laterally, the nonwetland-wetland boundary is often not clearly apparent in the field. The boundary may also be temporally variable, further confounding delineation. For the purposes of mapping, however, the boundary must be identified and placed at a point in this continuum. While it is recognized that this boundary is largely a human construct, it is necessary from a management, and in this case inventory point of view, that delineation is undertaken based on scientifically defensible criteria. Although data are often not available to describe the boundary directly, this can be reliably done in an indirect way using soil morphology, other indicators of wetting and/or vegetation. Where soils have not been heavily disturbed, soil criteria are probably the most reliable long-term indicators since prolonged saturation of soil has a characteristic effect on soil morphology, affecting soil matrix chroma and mottling in particular. From experience however, using a combination of soil and vegetation characteristics generally provides the highest accuracy or at least the highest confidence in terms of the assessment of where the boundaries lie.

Field boundary determinations were undertaken at the following test sites: (i) Highmoor - plateau areas 1 and 2; (ii) Glengarry/Kamberg – Glengarry and Kamberg/Stillerust; (iii) Walker Bay – Kleinrivier Estuary and Glenhart; and (iv) Davel – Viskuile.

For each wetland complex at each site, the entire wetland boundary was walked and the soils were sampled in order to determine the boundaries, with sampling intensity varying according to complexity (see Section 3.2.3). Vegetation, in particular, and landform were used together for interpolating the wetland boundary between soil sample points. For each soil sample, notes were made on chroma of the soil matrix, the degree of soil mottling and rhizosphere oxidation conditions. The combined criteria for wetland boundary determination as specified by Kotze and Marneweck (1999) was applied in the delineation. The boundaries of the wetland areas were marked on ortho-rectified hard copy aerial photographs of each of the wetlands and then transferred to digital format using heads-up digitising.

3.1.4 Wetland Classification

Although it was not part of the project brief to modify or check on the applicability of the proposed national classification system, it came to the fore that the development of the methodology and applicability of any technique for the national inventory cannot be considered independently of the classification system. A modified version of the draft national classification system of Dini and Cowan (2000) as derived from Cowardin *et al*. (1979) was used to classify the wetlands in this study. A summary of the modified classification system is presented in the Results under Section 3.2.4 and used to assist in providing context to some of the issues arising from this pilot project. The classification was tested on the Highmoor plateau sites, Glengarry, Kamberg/Stillerust and the Viskuile. All these wetlands were classified to sub-class level and using those modifiers that could be measured within the scope of the fieldwork. The implications of its application to the national inventory were considered. While the application, and further development, of the national classification system was not part of the ToR of this project, it was nevertheless felt that the classification system is central to the whole inventory methodology and therefore forms an integral aspect to the assessment of an appropriate inventory methodology.

Prior to the implementation phase, the proposed classification system will need to be re-visited and modified somewhat in order to ensure that certain aspects unique to South Africa are included in the systems.

3.1.5 Accuracy Assessment

In order to test which methods comply with the requirement for a wetland boundary accuracy of 40m, a boundary accuracy assessment was undertaken. A procedure was developed to compare field-delineated boundaries (actual boundaries) with those captured on hardcopy and digital black BW aerial photography. The assessment was not undertaken for RGB and CIR since these did not offer any advantages (with respect to wetland identification and delineation) over BW imagery at the sites where the boundary accuracy was assessed. The steps used in the accuracy assessment procedure are outlined below. The same procedure was followed for each site tested.

- The vector boundaries were dissolved using the *system* field as the dissolve item. The system field is the highest order in the Cowardin classification system. The result is such that only the outer polygon boundary is left for comparison;

- A point coverage was then created from the vertices defining the outer polygon of the aerial technique (not the field delineated boundary);

- The Arc/Info NEAR command was used to compute the distance in meters from each point to the nearest arc of the field delineated boundary.

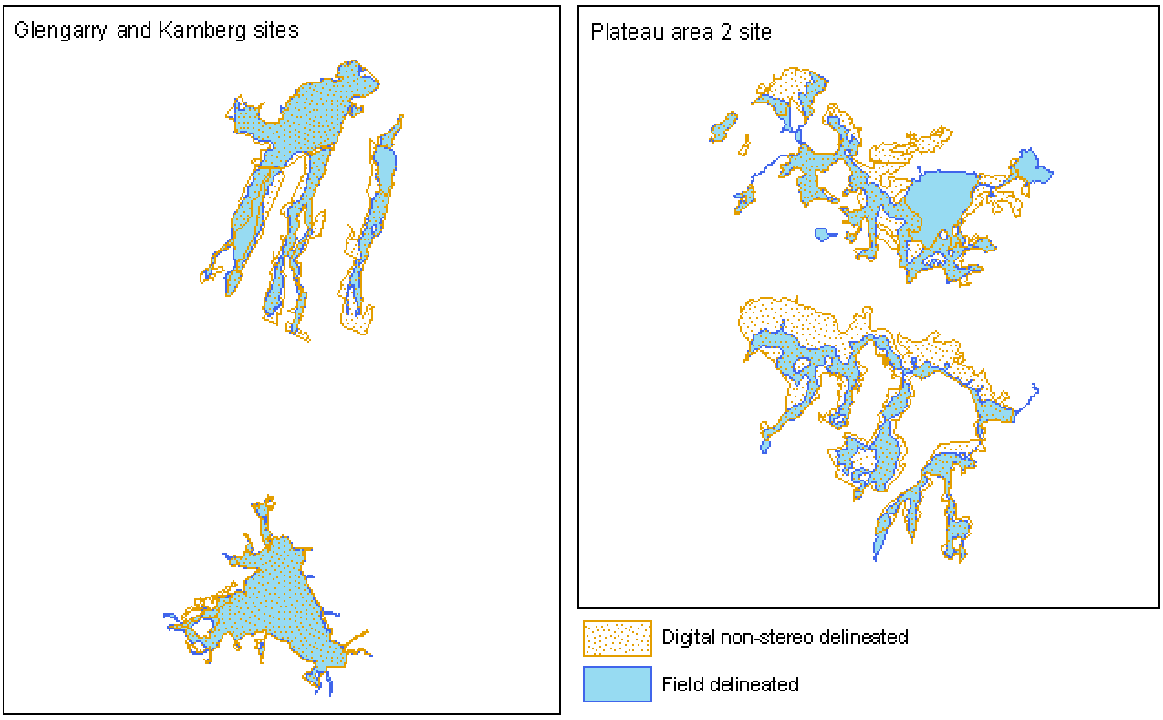
It was not calculated on which side of the boundary the difference is found i.e. on the inside or outside of the field delineated polygon; only an absolute value is returned. This is however good enough to determine if the remote aerial technique fulfils the ToR specifications that boundary accuracy be within 40 m. Maximum, range, mean and median statistics are used to assess the accuracy of each technique.

3.2 RESULTS

3.2.1 Black and White (BW) Aerial Photography

3.2.1.1 *Heads-up digitising on ortho-rectified digital BW aerial photo-mosaics*

Heads-up digitising onto ortho-rectified digital BW aerial photo-mosaics without complimentary use of hard copy BW photographs and stereo produced poor boundary accuracy. This is despite the method being the easiest way of capturing wetland boundaries in digital format. This is illustrated in the accuracy assessment shown in Figures 3.1 and 3.2.



	Digital non-stereo mapping for Glengarry	Digital non-stereo mapping for Kamberg	Digital non-stereo mapping for Plateau area 2
Field Delineated Area (m^2)	2735455	2024246	645810
Screen Delineated Area (m^2)	3293802	2092737	1047787
Difference from field delineated area (m^2)	-558347	-68491	-401977

Distance Statistics			
Minimum	0.01	0.00	0.00
Maximum	272.42	150.83	232.30
Range	272.41	150.83	232.30
Median	17.88	3.59	15.71
Mean	38.83	18.77	36.05
Standard Dev	49.55	30.61	48.27
Variance	2454.78	937.02	2330.12

Figure 3.1. Accuracy assessment for Highmoor: Glengarry, Kamberg and Pleateau area 2 sites indicating area and distance differences between the field delineated wetland boundaries and the digital non-stereo delineated boundaries.

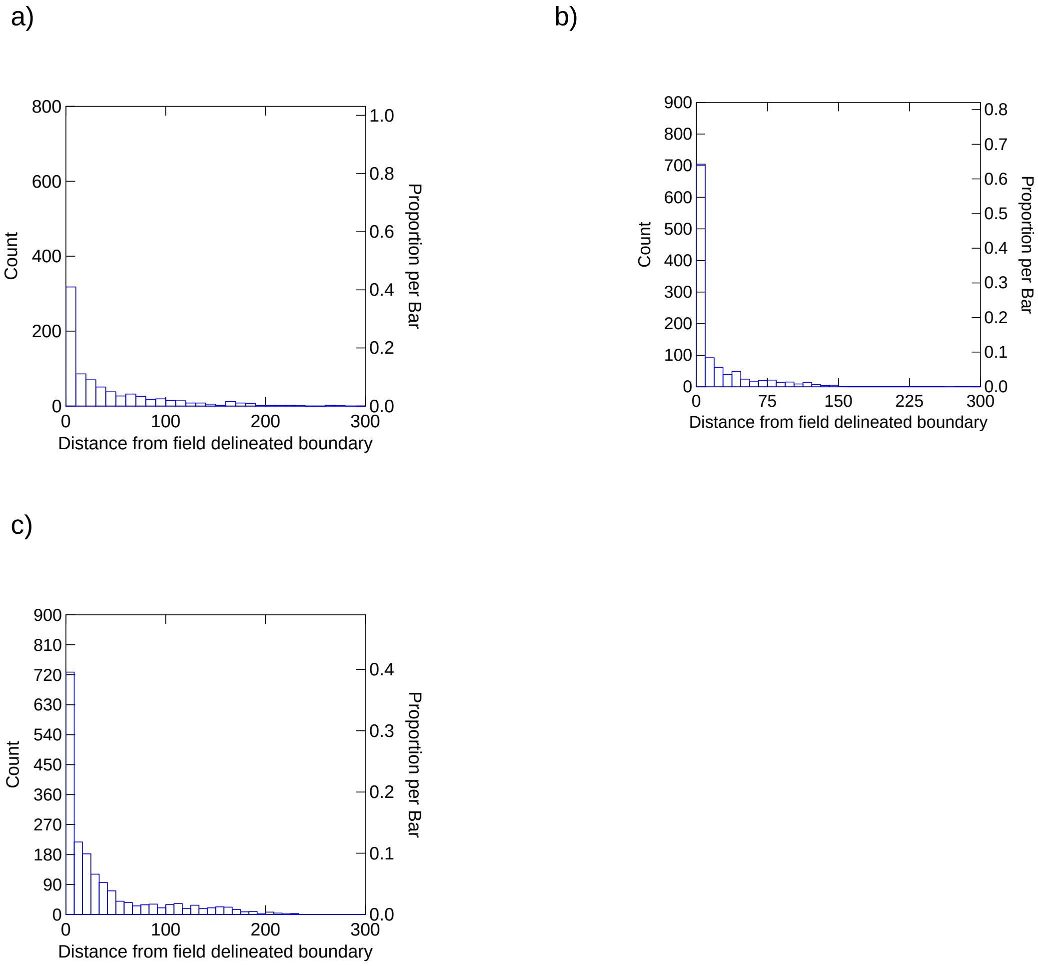


Figure 3.2. Frequency analysis for distance from field delineated boundaries to digital non-stereo captured data for a) Glengarry site, b) Kamberg site, and c) Plateau area 2 site.

Delineation using heads-up digitising alone overestimated the size of the Glengarry wetland by 20%, the Kamberg/Stillerust wetland by 3.4%, and the Highmoor plateau area 2 wetlands by 62% (see table in Figure 3.1). Heads-up digitising alone resulted in the boundary being, on average, within 40 m of the field-delineated boundary around the whole perimeter of each of the wetlands. However, the range showed that in places in each of the wetlands (Glengarry, Kamberg/Stillerust and Highmoor Plateau area 2), heads-up digitising alone resulted in the boundaries being 272m, 150m, and 232 m out respectively. The standard deviation was higher than 40m at the Glengarry (50m) and Highmoor (48m) wetlands and lower than 40m at Kamberg/Stillerust wetland (31m).

Of relevance is the range, which showed that when used alone, heads-up digitising on BW photo-mosaics is fairly inaccurate with respect to determining the wetland boundaries in parts of the wetland. The higher levels of accuracy achieved at the Kamberg/Stillerust wetland were a result of this wetland have a fairly well defined signature on the BW photo-mosaics reflecting a fairly simple boundary complexity on the ground. In contrast, the very low levels of accuracy achieved at Highmoor plateau area 2 were as a result of the complex wetland boundaries that were further complicated by the presence of the grass *Festuca costata*. The effects of vegetation on remote boundary accuracy determination are discussed later in Section 3.3.1.3. An important factor that also contributed to this was the lack of local knowledge of the area prior to the pre-delineation.

Figure 3.2 shows that for most of the digitised points on the perimeter of the Kamberg/Stillerust wetland, the boundary captured using heads-up digitising alone fell within 10m of the field delineated boundary. In contrast, while Figure 3.2 showed a similar distribution of digitised boundary points at the Glengarry and Highmoor plateau area 2 wetlands, these were more skewed showing that a greater proportion of the points fell further from the field delineated boundary.

Based on the results of the accuracy assessment, it is evident that heads-up digitising on BW photo-mosaics alone does not provide a consistent and high level of accuracy with respect to remote wetland boundary delineation. The main reason for this is the limitation imposed by the low resolution of the digital BW images and a lack of a stereo-view of the topography. This is discussed further under Section 3.3.2 Photo-image resolution. A potential way of improving the consistent accuracy of the remotely determined wetland boundaries is to use heads-up digitising in combination with hard copy BW stereo viewing. The BW hard copy viewing compensates for the loss of resolution on the digital images, despite the courser scale at which the image is viewed (see Section 3.3.2). A major advantage of heads-up digitising is that it offers an easy way of capturing the boundary digitally and because it allows one to change scale by zooming in and out, and it allows for more accurate line placing along the boundary on the ortho-rectified digital image.

Once one has developed a basic understanding of the use of ARCVIEW, heads-up digitising is not too time consuming. The times spent doing heads-up digitising tasks for the different wetlands where this was undertaken are given in Table 3.1.

Table 3.1. The number of hours spent on heads-up digitising at each of the wetland sites. The letters represent the following tasks:

A) Pre-delineation onto digital orthorectified black and white aerial photographs;
B) Delineation onto digital ortho-rectified black and white aerial photographs following the field visit (including the polygon splits for the classification of the wetlands);
C) Filling in of the data tables for the classification in ArcView.

Wetland	Time (hours)		
	A	B	C
Plateau area 1	4	0.5	0.5
Plateau area 2 W1 and W2	5	4.25	1.5
Glengarry	3.5	3.25	1
Stillerust / Kamberg	2.5	5	1
Kleinrivier estuary	1	0.5	0.5
Glenhart	2.5	0.5	0.25
Viskuile	-	4	2

Based on Table 3.1, and excluding pre-delineation (which was only performed for the purposes of this project) and filling in of the data tables, the time taken to digitise a wetland complex may vary from 30 minutes to 5 hours depending on the complexity of the wetland and the number of classes that are identified. One of the recommendations of this report is that the classification procedure (filling in of the data tables) is automated in order to make this process more cost-effective.

3.2.1.2 *Digital stereo mapping on ortho-rectified digital BW aerial photo-mosaics*

The use of stereo mapping is integral to the identification, delineation and classification of wetlands and this has not only been found to apply in South Africa, but internationally as well (Tiner 1999). In particular, stereo mapping allows one insight into the three-dimensional detail on the aerial photographs. Viewing images in stereo allows one to identify those key topographic and landform features that influence the occurrence, distribution and classification of wetlands in any particular region. Changes in topography often provide clues as to the location and even boundaries of wetlands. Stereo viewing often serves to improve the confidence of mapping by allowing one to rule out or include areas that are likely not to have or have wetlands respectively based on topography.

While digital three-dimensional digital image viewing (using a product like ERDAS Stereo Analyst) is a very powerful tool for assisting with wetland mapping, it nevertheless appears to have a few drawbacks when trying to map wetlands nationally. Firstly, one needs to develop the computer skills necessary for its application. There is also a requirement for data preparation. Secondly, one tends to develop eyestrain when viewing images in stereo over periods of a few hours or longer. Perhaps one could get over this by resting frequently or mapping in shifts. Mapping in shifts also has its own inherent risks, in that continually changing people who are mapping may increase the chance of errors through interpretive differences based on lack of continuation.

The value and power of digital stereo mapping is highlighted in the delineation that was undertaken for the Kleinrivier estuary. Digital stereo mapping allowed one to identify areas within the estuary that were elevated as little as 1 m above the surrounding wetland area. Figure 3.3 which shows the section of the Kleinrivier estuary that was mapped illustrates this. Higher-lying areas originally considered as wetland in the non-stereo mapping were excluded using stereo viewing.

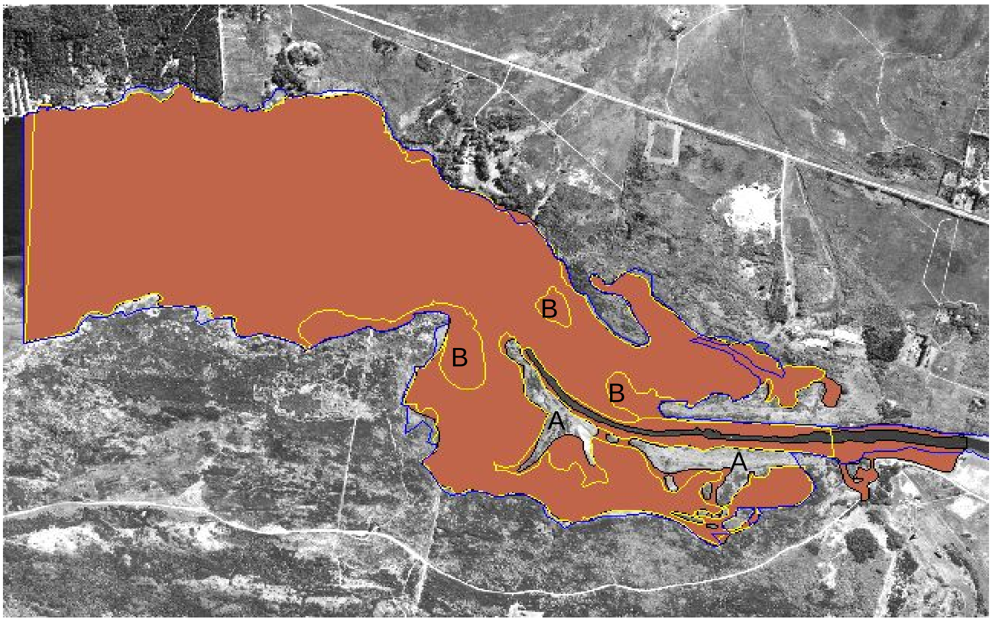
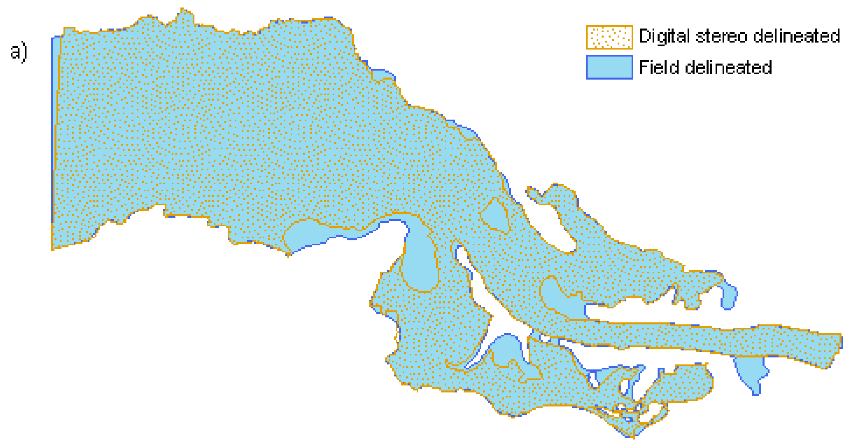


Figure 3.3. The digital non stereo (blue line) compared to digital stereo (yellow line) mapping (using ERDAS Stereo Analyst) of the wetland boundaries of a section of the Kleinriveir estuary compared to the actual wetland boundaries (brown shaded area) as mapped in the field. Notice how the higher lying areas (B) are not picked up in the non stereo mapping. While some of these areas fall within the wetland boundaries, the stereo mapping picked up elevation changes as small as 0.5 – 1 m.

However, despite this, the accuracy assessment showed that the level of boundary accuracy achievable using digital stereo was not increased (Figure 3.4). In fact, digital stereo delineation underestimated the size of the wetland by 9% while digital non-stereo delineation overestimated the size of the wetland by only 5%. The reasons for this are shown in Figure 3.3. The power of the digital stereo view allowed one to easily exclude raised areas as non wetland, thus excluding too much, and therefore underestimating the extent of the wetland. The raised areas marked B in Figure 3.4, for example, were in fact wetland. Despite the high level of accuracy gained by being able to view even small height differences in stereo, it was not always easy to decide whether these areas were wetland.

Both techniques however were on average within 20 m of the field delineated boundary around the whole perimeter of the wetland. The range however showed that in places the digital stereo and non-stereo methods were between 200m and 100m out respectively. The standard deviation however was lower than 40m at 39m for digital stereo mapping and 18 m for non-stereo mapping (Figure 3.4).



	Technique		
	Field	Digital stereo BW	Digital screen BW
Area (m2)	3749140	3413273	3923371
Difference from field (m2)		335867	-174231

Distance Statistic			
Minimum	-	0.00	0.04
Maximum	-	219.90	113.97
Range	-	219.90	113.93
Median	-	2.90	6.39
Mean	-	19.29	14.01
Standard Dev	-	38.48	17.72
Variance	-	1480.74	314.03

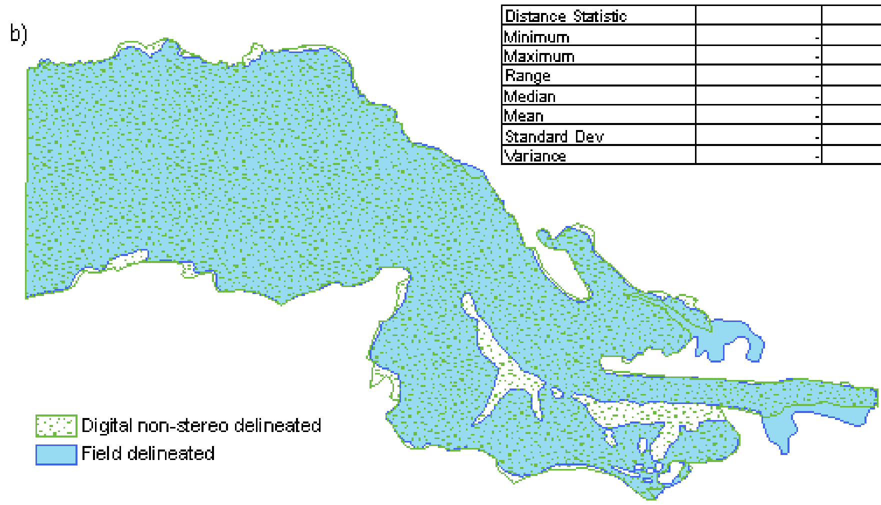
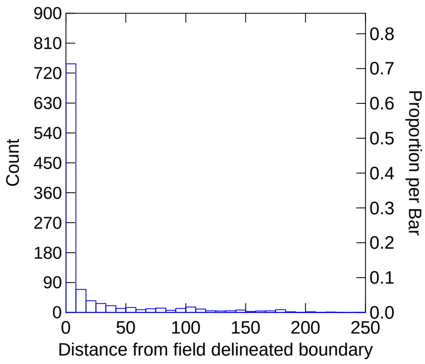


Figure 3.4. Accuracy assessment for the Walker Bay, estuary site indicating area and distance differences between the field delineated wetland boundaries and the a) digital stereo and b) digital non-stereo delineated boundaries.

a) b)



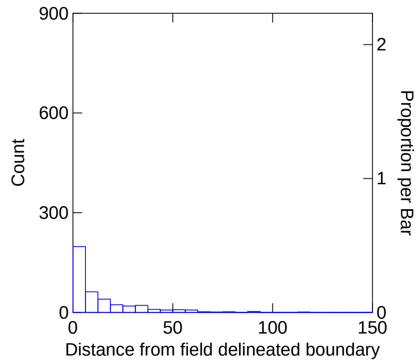


Figure 3.5. Frequency analysis for distance from field delineated boundaries to a) digital stereo captured data and b) digital non-stereo captured data.

Figure 3.5 shows that for most of the digitised points on the perimeter of the estuary (>720 points), the boundary captured using digital stereo mapping fell within 10m of the field delineated boundary. Similarly, for the boundary captured using digital non-stereo mapping, the majority of digitised points also fell within 10m of the field delineated boundary despite there being fewer points captured relative to the stereo method. The larger number of points captured in the stereo digitising accounted for the longer time period spent digitising in stereo as opposed to non-stereo (3 hours as opposed to 1 hour respectively).

Based on the results for the estuary, it is apparent that the digital stereo method of wetland boundary delineation offers little advantage over-and above digital non-stereo mapping in relatively flat terrain like that associated with the immediate boundaries of the Kleinrivier estuary. In contrast, this method did offer a visualisation advantage over-and above digital non-stereo mapping in the more mountainous terrain at Glenhart, but again this was limited by the practical problems associated with using the method and the poor quality of the digital images.

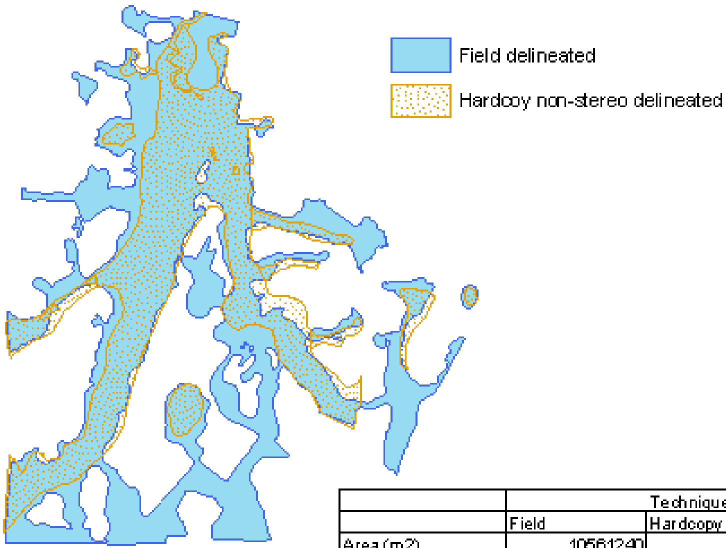
3.2.1.3 *Manual transfer mapping from stereo pairs and individual BW photographic prints*

The use of a zoom transfer scope was ruled out as a practical means of manual transfer from hard copy to digital format on the basis of availability of zoom transfer scopes nationally. There are very few of these scopes operational in the country with one at the Council for GeoSciences, one at the CSIR (not operational) and one at the University of Cape Town. None are apparently available at the Department of Water Affairs and Forestry or the Chief Directorate: Surveys and Mapping. The zoom transfer scope effectively operates as a manual ortho-rectification process by including an elevation component through the use of stereo pair black and white photographic prints and mirrors.

Redrawing the wetland boundaries from aerial photo's onto base maps such as a 1: 50 000 topographic sheets and then digitising these was also ruled out as a possible suitable method for manual transfer of hard copy to digital format. Even when using 1:50 000 scale imagery and transferring the boundaries to 1:50 000 topographic sheets, one runs the risk of considerable errors in terms of accuracy since the hard copy photo's are not ortho-rectified and line placement often requires best judgement. In areas where there are few contours to assist with orientation and line placement (particularly in flat terrain), errors become more pronounced and the level of accuracy that can be achieved is low, particularly with respect to the 40m boundary criterion. BW orthophotographs at 10 000 scale are already ortho-rectified and enable direct digitising from the hard copy. However, despite the relatively large scale of the 1:10 000 orthophotos, they do not provide sufficient resolution and contrast for accurate photo interpretation and therefore wetland mapping. This imagery also does not cover the entire country.

The image scanning method using the remote sensing package ERDAS Imagine and a geometric correction from fiducial and ground control points and vectorization was reasonably effective in terms of the level of accuracy achieved in the manual transfer. Similarly, the R2V vectorisation methodology which involved converting the image to an Arc/Info grid and applying GRID operations also proved reasonably effective in terms of the level of accuracy achieved in the manual transfer. However both processes required a considerable amount of manual effort in terms of scanning of individual photo prints, editing and so on and this renders them largely non-feasible as potential nationally applicable manual to digital transfer options.

The results of the accuracy assessment for the manual transfer mapping from stereo pairs and individual BW photos are given in Figures 3.6 and 3.7. Delineation using BW hard copy individual and stereo pairs of photos both underestimated the size of the Viskuile wetland. The former technique resulted in an underestimation of 43% while the latter only underestimated the size of the wetland by 3.2%.



	Technique		
	Field	Hardcopy non-stereo	Hardcopy stereo
Area (m2)	10561240	6025755	10222439
Difference from field		4535485	338801

Distance Statistics			
Minimum	-	0.22	0.06
Maximum	-	455.67	374.43
Range	-	455.45	374.37
Median	-	48.52	23.67
Mean	-	81.88	50.02
Standard Dev	-	92.55	64.95
Variance	-	8564.71	4218.47

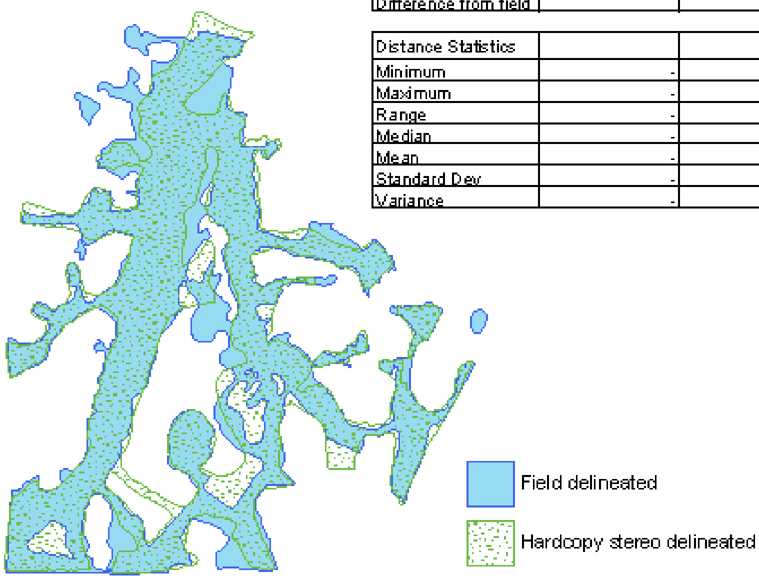
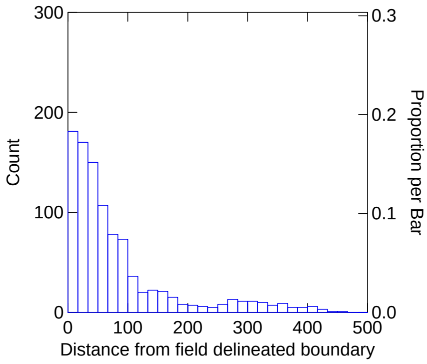


Figure 3.6. Accuracy assessment for Davel, Viskuile site indicating area and distance differences between the field delineated wetland boundaries and the hardcopy non-stereo and hardcopy stereo delineated boundaries.

a)



b)

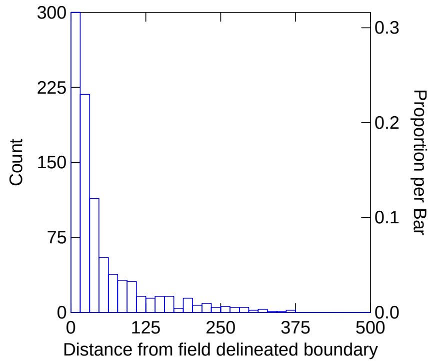


Figure 3.7. Frequency analysis for distance from field delineated boundaries to a) hardcopy non-stereo captured data and b) hardcopy stereo captured data for the Davel, Viskuile site.

Both methods resulted in the boundary being, on average, more than 40 m of the field delineated boundary around the whole perimeter of the wetland (non-stereo with an average of 81m and stereo with an average of 50m). The range showed that in places, manual non-stereo and stereo mapping resulted in the boundaries being 455m and 374m out respectively. The standard deviation was 92m and 64m for each method respectively.

Figure 3.7 shows that for most of the digitised points on the perimeter of the Viskuile wetland, the boundary captured using manual non-stereo and stereo transfer mapping had similar distributions with a skewed proportion of points falling further from the actual field delineated boundary i.e. large numbers of points fell outside of the 40m boundary accuracy range

Based on the results of the accuracy assessment, it is evident that both methods do not provide a consistent and high level of accuracy with respect to remote wetland boundary delineation. While the size estimate of the wetland using the stereo method was only 3.2% out, the boundaries were on average not accurate to 40m and the extent to which some were out were as high as 370m. The key issue is therefore not the level of accuracy achieved with respect to the size of the wetland, but rather the boundary accuracy. The problems experienced with boundary accuracy using these techniques were mainly due to the limitations imposed by scale of the photography. The boundaries were manually captured on 1:50 000 scale photographs and with 0.5mm pen points which meant that even small shifts of the pen on the image resulted in large shifts (tens of metres) in terms of metres on the ground. Examples of on-ground width changes per pen line width and photo scale are given in Table 3.2. The lower accuracy of the non-stereo method is further exacerbated by not viewing the photo's in stereo and thus losing the landform perspective.

Table 3.2. On ground width in metres relative to pen line width (for point sizes 0.5, 0.25, 0.18 and 0.13mm) and photo scale.

Photo Scale	On ground width (m) relative to pen line width			
	Pen line width (0.5mm)	Pen line width (0.25mm)	Pen line width (0.18mm)	Pen line width (0.13mm)
1:5 000	2.50	1.25	0.90	0.50
1:7 500	3.75	1.88	1.35	0.98
1:10 000	5.00	2.50	1.80	1.30
1:15 000	7.50	3.75	2.70	1.95
1:30 000	15.00	7.50	5.40	3.90
1:40 000	20.00	10.00	7.20	5.20
1:50 000	25.00	12.50	9.00	6.50

A potential way of improving the accuracy of the wetland boundary is to move away from manual transfer to digital transfer. By using heads-up digitising, one is able to compensate for the scale limitations by zooming in and out on the digital images once the approximate boundary is established on the hard copy images. The issue of a combined technique is discussed further in Section 3.3.8. In comparison to the computer software technology currently available (such as ARCVIEW), manual transfer methods alone also prove to be cumbersome and operationally impractical.

3.2.2 True Colour (RGB) and Colour Infrared (CIR) Aerial Photography

3.2.2.1 *Use of Digital RGB and CIR Aerial Photography for Computer-Based Classification*

The current format and processing of the CIR aerial photography makes it unsuitable for per-pixel based digital classification applications, and is rather more suited at present to conventional photo-interpretation mapping techniques. The digital camera system used to generate both the true colour (RGB) and colour-infrared (CIR) aerial photography is similar to conventional aerial surveys, in that a series of individual images are captured along a given flight-line. The individual images are then digitally merged into a single mosaic, using a combination of on-board GPS and ground references for control.

Each image is originally recorded as an independent digital dataset, which exhibits slightly different spectral characteristics in comparison to its immediate neighbour, due to changing sun-angle illumination effects, as a result of plane orientation at the exact moment of capture. Although these differences are visually corrected during final colour balancing of the image mosaic, these differences are still represented within the actual image data values. Digital, per-pixel, multi-spectral classification routines may enhance these image-image differences to the detriment of any land-cover information, since these algorithms typically utilise the original image data values, and not the modified display values.

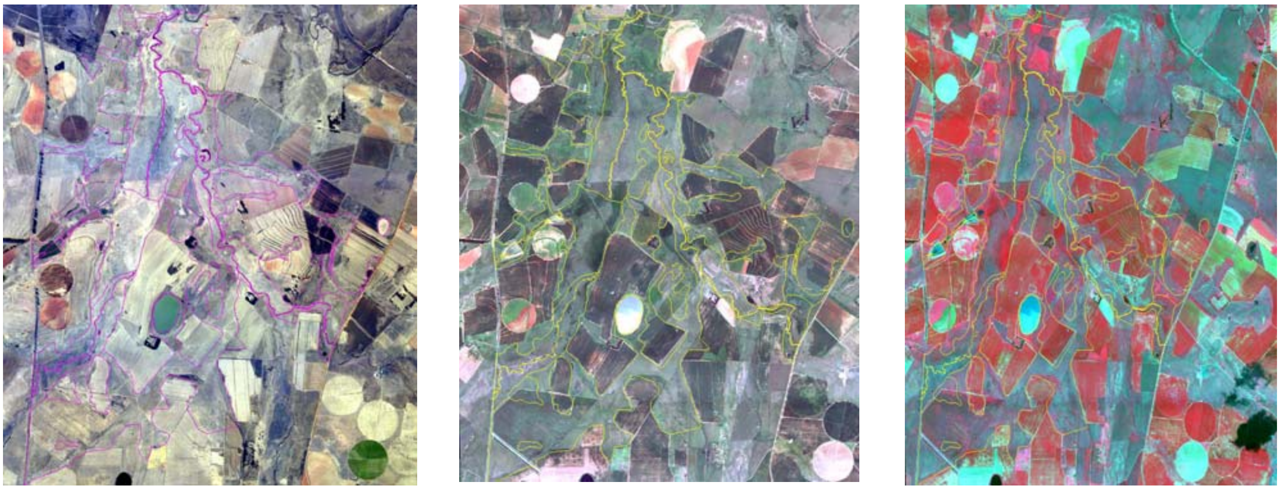
For this reason, it is recommended that mapping off this specific digital airborne imagery is limited to conventional photo-interpretation, unless it is possible to make use of pre-classification normalisation procedures such as spectral vegetation indices (i.e. NDVI). In terms of the wetland mapping project, since the use of an NDVI dataset on its own is insufficient for detailed wetland mapping, the preferred mapping technique is conventional photo-interpretation.

Note: work is currently been undertaken to develop suitable algorithms / procedures for accurate colour-contrast matching between individual input images to facilitate per-pixel based multi-spectral classifications.

3.2.2.2 *Comparisons of RGB and CIR with BW aerial photos*

The results of the examination of the true colour (RGB) imagery show that the timing of the photography is critical. Wetland signatures were very difficult to distinguish on the true colour imagery (RGB) from the Davel area taken in August (end of winter) (Figure 3.8). Winter die-back of grasses and sedges made it difficult to distinguish wetland grassland or grass/sedge plant communities on the digital true colour imagery. Remote boundary delineation was therefore not possible using these images. In contrast, the wetland signatures were easily identified on the BW photography for the same area taken in July (middle of winter). For certain areas therefore, BW photography provides a more reliable source for identifying wetland signatures no matter the time of year. The added value of true colour photography lies in the identification of vegetation types within wetlands. However, implicit in this is that the vegetation types have sufficient colour variation to reflect different signatures.

What is important to point out is that despite the extra costs involved in acquiring RBG imagery, it does not provide a more accurate means of picking up the wetlands or wetland boundaries than BW imagery. This is highlighted in Figure 3.8 which shows that even with ultra high resolution CIR imagery, the field mapped wetland boundaries are not accurately picked up. It can be argued that even if the CIR imagery had been taken at the optimal time for this type of imagery (early to mid-summer as opposed to mid to late summer), it is unlikely to have been able to pick up the wetland boundaries any better than the other two methods. It is also limited by surface based visual image interpretation factors and thus does not necessarily offer any advantage over the other methods in systems that fall on the drier end of the wetland spectrum. In support of this argument, many of the cited wetland mapping reports are associated with easily identifiable surface characteristics, such as open water bodies, or wetland vegetation communities that are significantly different from the surrounding communities (Tiner, 1999).



(a) (b) (c)

Figure 3.8. Early spring (a) and mid summer (b) RGB photographic images of the Davel Viskuile site compared to the colour infrared image (c). Note that the actual wetland boundary is shown on the images in order to highlight that none of the images provided a good (accurate) representation of the actual wetland boundaries.

There is however a distinct advantage of the higher detail CIR airborne imagery for identification of localised wetland threats that are not as easily visible using RGB and BW imagery e.g. the clearly defined grazing effects between the fence lines in the central Viskuile wetland (Figure 3.9).

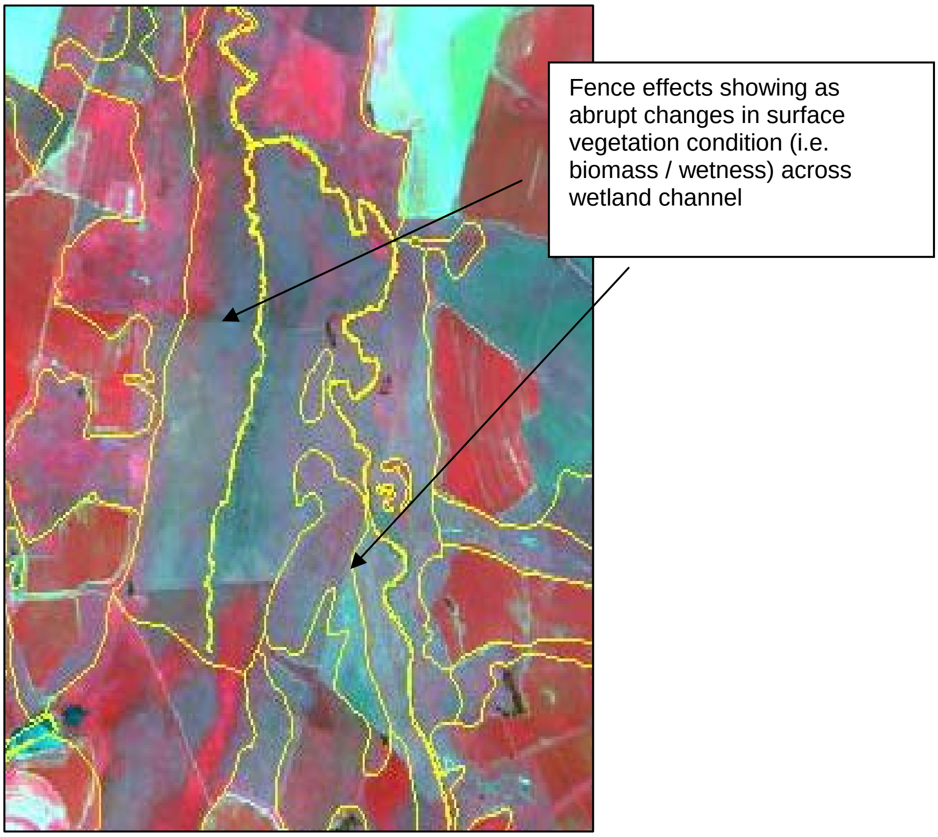


Figure 3.9. Fence-line effects visible on Viskuile (Davel) CIR aerial photography

In contrast to the findings for the Davel area, true colour imagery proved to be of value for boundary delineation in cases where the land comprised a mosaic of wetland and non wetland areas such as in places in the Western Cape. The signatures of certain plants such as a small orange *Elegia* species and the tall dark green *Berzelia lanuginosa*, *Psoralea pinnata* and *Osmotopsis asteriscoides* from the Betty's Bay area were easily distinguishable on true colour imagery thereby providing a reasonably accurate indication of the boundaries of the drier edge, and more permanently wet, plant communities of these wetlands respectively (Figure 3.10). The wetland boundary could be interpolated from the distribution of these communities. The only other means of accurately mapping these complex boundaries would be through field verification using grid transects.

Figure 3.10. Example of how RGB photographs (right) compared to black and white (left - in this case a 1:10 000 orthophotograph) may help with the identification of vegetation zones in complex type-type wetlands such as those found near Betty's Bay in the Western Cape.

3.2.3 Ground Truthing

Field verification is an extremely important requirement with respect to wetland mapping. It not only serves to calibrate one's mind to an area, but also serves to provide the baseline information necessary for calibrating all types of remote mapping from the use of satellite imagery to aerial photography. It is also the only way one can gain insight into many of the issues that should be considered when mapping in any particular region. For example, field verification allows one to get a better understanding of local conditions that may affect image interpretation such as whether wetland boundaries are likely to extend into adjacent fields, whether certain vegetation types are likely to be problematic with respect to signatures and so on. It also allows one to determine the accuracy of remote delineation as well as get an idea of the functional status and levels of degradation in the systems of a particular region.

Field verification is however the most time-consuming part of the mapping process and since this is a necessary component of any mapping, one needs to make sure it is practiced judiciously and only in those wetlands where it will add most value to the mapping of a particular region. There are a two concepts in particular around field verification and the costs involved in this that require explanation. These are:

- boundary complexity; and
- wetland complexity.

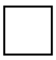
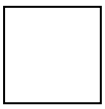
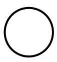
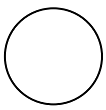
The *boundary complexity* is measured in terms of the ease with which the boundary of the wetland can be delineated. For example, if there are clear vegetation or soil indicators of hydric conditions, the boundary is easier to determine than when the soils are complex or the vegetation has been transformed. Where field delineation conditions are difficult, one needs to spend more time in determining the wetland boundary and as such the costs per km delineated increase. The boundary complexity is represented here as the length of perimeter of a wetland that can be walked and mapped in an 8-hour day. In order to depict this, a few general rules were developed based on the findings of the fieldwork component of this study.

These are as follows:

- In a system with a low boundary complexity, about 15km of perimeter can be mapped in an 8 hour day by one person;
- In a system with a medium boundary complexity, about 10km of perimeter can be mapped in an 8 hour day by one person;
- In a system with a high boundary complexity, only about 5km can be mapped in an 8 hour day by one person;

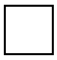
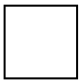
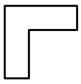
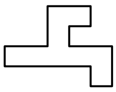
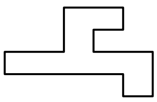
Similarly, the length of perimeter that can be mapped in a day directly affects the area of wetland that can be mapped in a day and this is dependent on the *wetland complexity*. The wetland complexity is defined here as the ratio of perimeter to area (P:A) ratio. The P:A ratio is, however, affected by the size of the wetland. For example, a smaller wetland of the same shape will have a larger P:A ratio compared to a larger wetland of the same shape (Table 3.3). In order to overcome the inherent decrease of P:A ratio with increase of wetland size, a complexity value was determined. The complexity value is determined by dividing the square of the perimeter by the area (i.e. P^2/A). The units used for the perimeter and the area must be comparable (e.g. km and km^2 or m and m^2). While the complexity value is an arbitrary value, it provides an indication of the relative complexity of different systems.

Table 3.3. Table showing how the perimeter to area ratio is affected by the size of the wetland.

Shape	**Segment length**	**Perimeter**	**Area**	**P:A ratio**	**Complexity (P^2/A)**
	1m	4m	$1m^2$	4	16.00
	2m	8m	$4m^2$	2	16.00
	4m	16m	$16m^2$	1	16.00
Shape	**Diameter**	**Perimeter**	**Area**	**P:A ratio**	**Complexity (P^2/A)**
	1m	3.14m	$0.78m^2$	4	12.57
	2m	6.28m	$3.14m^2$	2	12.57
	4m	12.57m	$12.57m^2$	1	12.57

Similarly, a wetland that is simple (round or square, with very few arms) will have a smaller P:A ratio than one of similar size with many arms (Table 3.4).

Table 3.4. Comparison of P:A and complexity values of wetlands with different configurations

	Shape	**Dimensions**	**Perimeter**	**Area**	**P:A ratio**	**Complexity (P^2/A)**
a)		2m x 2m	8m	$4m^2$	2.00	16.00
b)		1m x 4m	10m	$4m^2$	2.50	25.00
c)		3m x 3m	12m	$9m^2$	1.33	16.00
d)		3m	12m	$5m^2$	2.40	28.80
e)		-	20m	$9m^2$	2.22	44.44
f)		-	40m	36m	1.11	44.44

Consider the examples given in Table 3.4. Wetland (a) has the same area as wetland (b), but the perimeter of (b) is greater, giving a greater complexity value. Similarly, wetland (c) and (d) have the same perimeter length, but the area which they cover differs and hence the complexity of (d) is greater. Wetland (c) and (e) have the same area, but (e) has a greater perimeter and hence a greater complexity value.

The following examples from the fieldwork undertaken as part of this study highlight some of these issues (Figure 3.11).

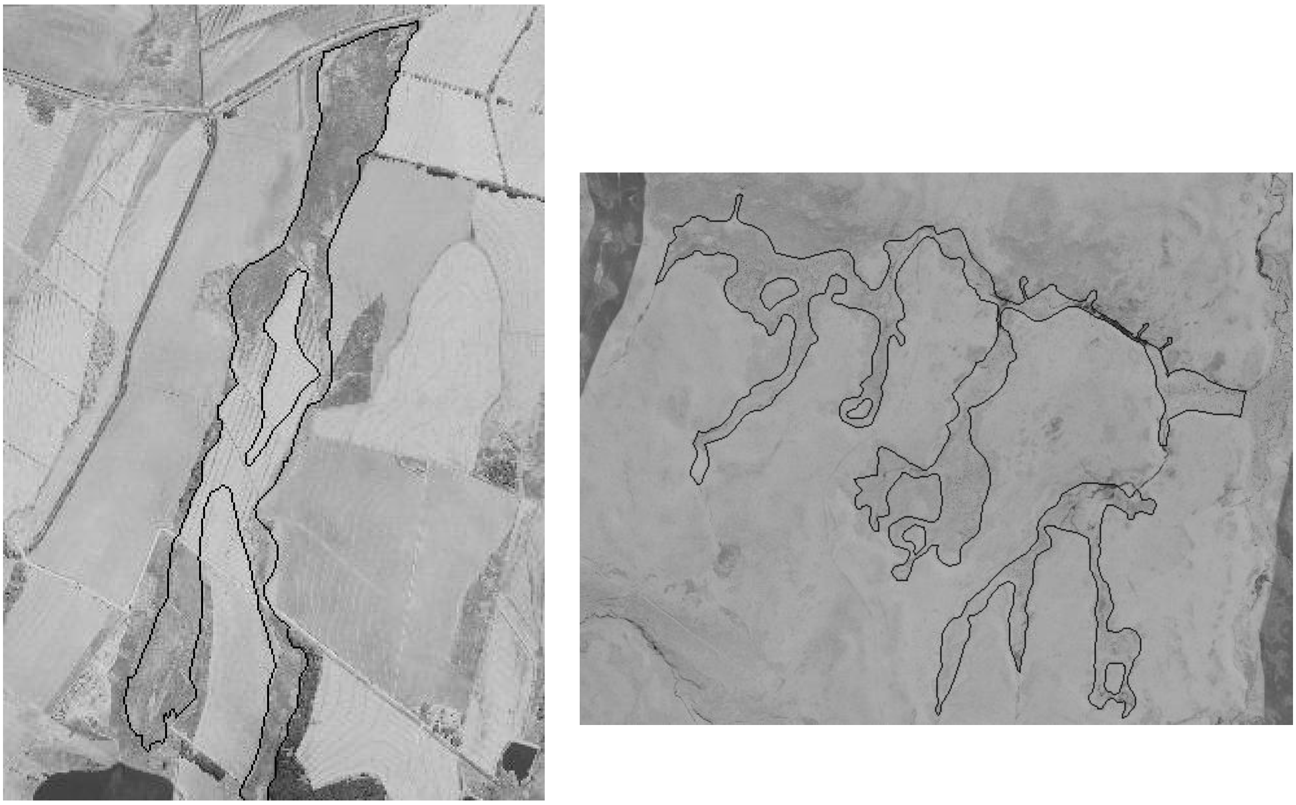


Figure 3.11. Differences in wetland boundary complexity as illustrated in a comparison of an arm of the Glengarry wetland on the left and one of the wetlands from the Highmoor plateau on the right.

The arm of the Glengarry wetland in Figure 3.12 (a) has a perimeter of 9600m, an area of 498000m^2, a P:A ratio of 0.02 and a complexity value of 185. It took one person approximately 8 hours to map the boundary of this wetland on the ground. The Highmoor plateau wetland in figure 3.12 (b) has a longer perimeter (13800m), a smaller area (286000m^2), a higher P:A ratio (0.48) and a higher complexity value (666) and yet also took 8 hours to map on the ground. The reason for being able to map 30% more boundary in the same amount of time in the more complex wetland at Highmoor compared to the simpler wetland at Glengarry was that the boundary was less complex at Highmoor. Thus despite the wetland being more complex at Highmoor, the difficulty experienced in terms of boundary delineation at Glengarry, meant that a smaller perimeter of wetland was mapped. This is in spite of the larger area of wetland covered. Thus the relationship between perimeter of wetland mapped, area of wetland mapped and time or costs to do so using fieldwork is therefore not linear nor is it simple. A simplified depiction of the relationship between these parameters is given in Table 3.4.

The complexity value for simple wetlands is approximately 200, 400 for medium wetlands and above 600 for complex wetlands. (Table 3.5). The entries in italics are taken from those calculated for the two field measured examples given above respectively. The other entries were calibrated based on complexity values, area and perimeter values measured at all the sites.

Table 3.5. Approximate areas that can be mapped in an 8-hour day for systems with different boundary and system complexity.

	Wetland system complexity					
Boundary complexity*	Simple ha	Simple km^2	Medium Ha	Medium km^2	Complex ha	Complex km^2
5km/day	12.5	0.125	6.3	0.063	4.2	0.042
10km/day	49.8	0.498	25.0	0.250	16.7	0.167
15km/day	112.5	1.125	56.3	0.563	28.6	0.286

Note: The boundary complexity is measured in terms of the length of perimeter mapped on the ground in an 8hour day.

The wetland system complexity and boundary complexity are therefore, important components to consider when determining time budgets for mapping and delineating wetlands in the field. One can get a rough estimate of the perimeter and area of a wetland from aerial photography, and then determine the complexity value and based on an understanding of the boundary complexity, prioritise representative wetlands for detailed ground truthing

3.2.4 Wetland Classification

An example and summary of the modified system is given in Figure 3.12 below. It still needs some modification as well as verification with respect to implementation. The modified version makes provision for four hydrological components (inflow, outflow, throughflow channelled and throughflow unchannelled) at the sub-system level for palustrine systems. This links in with the hydrological components at sub-system level for all the other systems. In order to include other important landscape and wetland type issues, an attempt was made to bring these in as modifiers. Wetland type modifiers are also introduced as are land-use modifiers and two additional artificial modifiers (Afforested and alien invasive encroachment). While it seemed to work well for these sites, problems were encountered with interpretation and consistency, and it proved very intensive and time consuming to capture all wetland complexes to class level detail. The classification system is also scale dependent and thus it follows that mapping conventions (rules) will be need to be established and set in place prior to the main implementation phase in order to deal with this problem.

The proposed classification system is hierarchical in nature proceeding from general to specific as seen in Figure 3.12. At the highest level, wetlands are defined by the system. The term system represents "a complex of wetlands that share the influence of similar hydrologic, geomorphologic, chemical, or biological factors" (Cowardin *et al*. 1979). Five systems are defined: marine, estuarine, riverine, lacustrine, and palustrine. The marine system generally consists of the open ocean and its associated high-energy coastline, while the estuarine system encompasses salt and brackish marshes, mangrove swamps, non vegetated tidal shores, and brackish waters of coastal rivers, estuaries and bays. Freshwater wetlands fall into one of the other three systems: riverine (rivers and streams), lacustrine (lakes and dams), or palustrine (e.g. marshes, bogs, swamps, seepage systems, springs and so on).

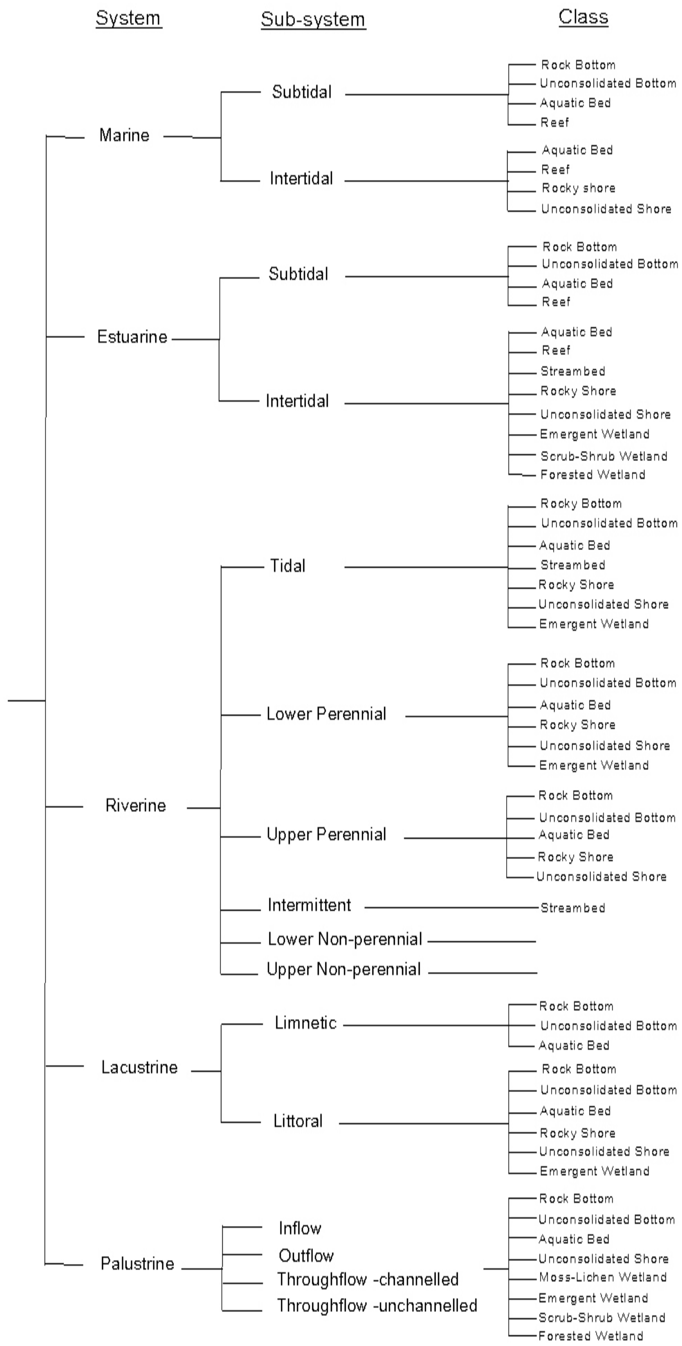
Each system, with the exception of the palustrine, is further subdivided into subsystems. The marine and estuarine systems both have the same two subsystems, which are defined by tidal water levels: subtidal (continuously submerged areas) and intertidal (areas alternately flooded by tides and exposed to air). Similarly, the lacustrine system is separated into two systems based on water depth: littoral (wetlands extending from the lake shore to a depth of 2m below low water or to the extent of non persistent emergent plants if they grow beyond that depth), and limnetic (deepwater areas lying beyond the 2m depth limit at low water). By contrast, the riverine system is further defined by four subsystems that represent different reaches of a flowing freshwater or lotic system: tidal (water levels subject to tidal fluctuations for at least part of the growing season); lower perennial (permanent, flowing waters with a well-developed floodplain); upper perennial (permanent, flowing water with very little or no floodplain development); and intermittent (channel containing non tidal flowing water for only part of the year). In terms of the Cowardin *et al.* (1979) system, there is no sub-system for Palustrine wetlands. For the system proposed for South Africa, a provisional four subsystems have been added to Palustrine. These are simply unchannelled throughflow, channelled throughflow, outflow and inflow and serve to describe the hydrological (flow related) differences between Palustrine wetlands at the sub-system level.

The next level - class - describes the general appearance of the wetland or deepwater habitat in terms of the dominant vegetative life form or the nature and composition of the substrate. Of the 11 classes, five refer to areas where vegetation covers 30% or more of the surface: aquatic bed, moss-lichen wetland, emergent wetland, scrub-shrub wetland, and forested wetland. The remaining six classes represent areas generally lacking vegetation, where the composition of the substrate and degree of flooding distinguish classes: rock bottom, unconsolidated bottom, reef (sedentary invertebrate colony), streambed, rocky shore, and unconsolidated shore. Permanently flooded non vegetated areas are classified as either rock bottom or unconsolidated bottom, while exposed areas are referred to as streambed, rocky shore, or unconsolidated shore. Invertebrate reefs are found in both permanently flooded and exposed areas.

Each class is further divided into subclasses to better define the type of substrate in non-vegetated areas (e.g. bedrock, rubble, cobble-gravel, mud, sand, and organic) or the type of dominant vegetation. The sub-classes would also need to be modified for South African conditions with categories such as moss and lichen as well as needle-leaved deciduous and evergreen being changed or modified. Below the subclass level, dominance types can be applied to specify the predominant plant or animal in the wetland community.

To describe the hydrologic, chemical, the soil characteristics of wetlands and human impacts, the proposed classification system contains the four types of specific modifiers described by Cowardin *et al*., (1979): water regime, water chemistry, soil, and special, plus three additional modifier categories. These additional modifier categories include landform, wetland type and land-use modifiers that together with the other modifiers, may be applied to class and lower levels of the classification hierarchy.

It is important to point out that since the system was developed primarily for mapping purposes, the various levels do not necessarily reflect functionality or processes in the systems they describe. One therefore needs to look carefully at the definitions of these prior to working with the classification. It also only describes a state of a system at any one time and therefore is dynamic (or accounts for the dynamic nature of a wetland) in as far as it allows one to pick up changes visible on maps if and when the classification repeated at another time. These are important considerations with respect to its application or usefulness. The proposed classification system including the modifiers need further work before it will be able to be applied in South Africa. It will also be important that its limitations are understood and accepted, if it is to be applied to the national wetland inventory. In particular, the influence of the scale of mapping and therefore the development of minimum acceptable mapping units will be key to its application (see Section 3.3.3). A draft of a revised version (Dini and Cowan 2000) of the original proposed classification system for South Africa is available from John Dini (Department of Environmental Affairs and Tourism).



DRAFT PROPOSED WETLAND CLASSIFICATION FOR THE WETLAND INVENTORY

Figure 3.12. Draft proposed wetland classification system for the national wetland inventory.

3.2.4.1 *Examples of the application of the classification system*

Below in Figures 3.13 and 3.14 are examples of the classification of the Highmoor plateau area 2, wetland 1 and the Glengarry wetland respectively from system to sub-class level. These serve to highlight the level of detail that is required in terms of the classification systems and illustrates that in terms of remote techniques, only aerial photos offer the level of detail necessary for classification to this level. The example also illustrates how this information can be captured using the software package ARCVIEW.

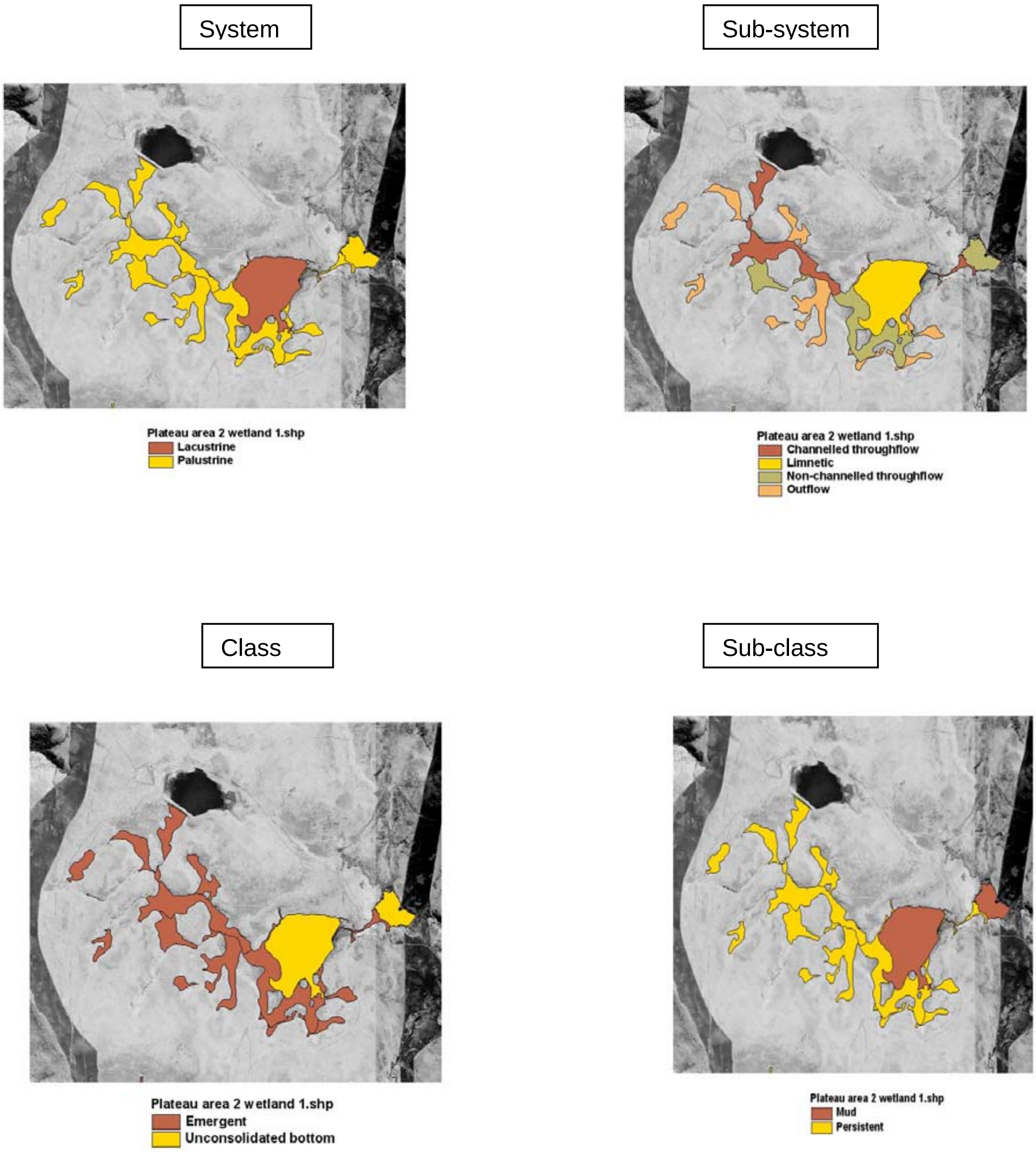


Figure 3.13. Example of the application of the classification system showing the breakdown from system to sub-class level for the Highmoor plateau area 2, wetland 1.

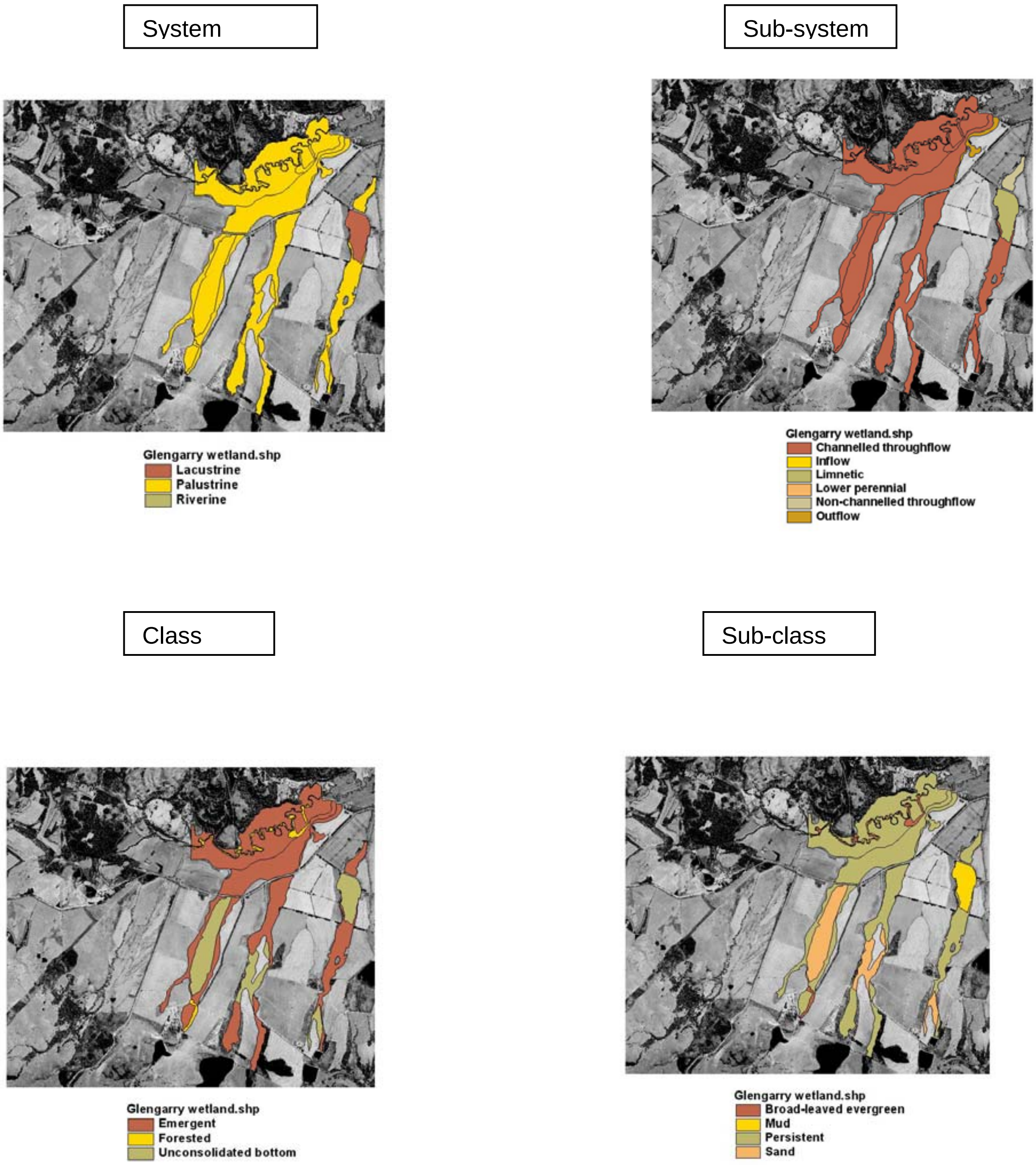


Figure 3.14. Example of the application of the classification system showing the breakdown from system to sub-class level for the Glengarry wetland.

3.3 DISCUSSION

3.3.1 Wetland Signatures

The correct interpretation of aerial photography is based fundamentally on the recognition of the signatures in the image. That is, the recognition of pattern and contrast (lightness or darkness) in the image that represent certain features on the ground. The same feature may give a different signature, depending on the position of the sun, shadows, reflection off water bodies etc.

Wetlands are generally associated with characteristic spectral signatures (including tone, texture etc.) and the greater the contrast between these signatures and that of the surrounding non-wetland area, the more reliably the wetlands will be able to be delineated using remote means. One would expect wetland signatures to vary according to the particular region (through the influence of regional differences in climate, topography, geology, etc.), and indeed this is so. Thus, it is important that a sound understanding of these regional influences be gained.

Still further complicating interpretation of remote images is the variation encountered within a region. Several factors influence the distinctness of the wetland's signature and its boundary, as seen in remote imagery, particularly black and white aerial photography. These are:

- Position of the wetland in relation to landform;
- Water regime;
- Vegetation type, species composition, cover, texture and tone;
- Fire; and
- Disturbance including anthropogenic disturbance and land-use practices.

3.3.1.1 *Position of the wetland in relation to landform*

As a very general rule, wetlands occur predominantly in landforms favouring the retention of water (i.e. those gently sloped or depressional). For a given landform, the higher the rainfall relative to potential evaporation, the greater the likelihood that a given landform will support a wetland. (The "rainfall deficit" is a useful term used to describe the extent to which rainfall falls short of potential evaporation.) The influence of landform may, however, be moderated strongly by sub-surface features (e.g. porosity of the soil and near surface rock strata). Landform settings (e.g. depressions), which are inherently conducive to the collection and retention of water based on the shape of the land surface, may be rendered ineffective for supporting wetland conditions if the water drains away rapidly through porous soil. Conversely a landform surface which rapidly sheds surface water (e.g. a steep concave slope) may support wetland conditions under specific sub-surface conditions (e.g. where impervious underlying rock strata force a consistent supply of subsurface water flow very close or onto the soil surface).

3.3.1.2 *Water regime*

Wetlands vary from areas that are temporarily saturated/flooded to areas permanently saturated/flooded, and the more permanent areas generally appear darker than temporarily wet areas, provided that these tones are not obscured by the vegetation. It is generally easier to distinguish the wetter areas (permanent and seasonal) from the less wet areas (temporary) from surrounding non-wetland areas. Wetland vegetation may, however, obscure (see following Section).

3.3.1.3 *Vegetation type, species composition, cover, texture and tone*

Vegetation is an expression of soil moisture and, in turn, the cover offered by the vegetation modifies the direct spectral influence of the moisture. Thus, an area having an inherently dark spectral signature owing to the high soil moisture may be rendered light by a dense cover of highly reflective vegetation cover (e.g. from a dense stand of *Carex acutifiormis* following winter die-back). Wetland signatures are therefore strongly influenced by the vegetation and this includes the extent to which die-back of the vegetation has taken place.

The extent to which particular vegetation types or clearly visible species are consistently associated or not with wetlands varies. An understanding of this may aid considerably in the delineation of wetlands. Specific vegetation features encountered in the test sites are described below.

Marginal (edge) communities within certain types of wetlands do not always give wetland signatures despite the presence of some wetland plant species. The wetland boundary may thus lie beyond the outer extent of the wetland signature, and in many cases this makes accurate remote delineation very difficult. This can be dealt with by ensuring that representative test sites are ground truthed in order to facilitate interpolation to those wetlands that are only mapped remotely.

In other cases, certain vegetation types, plant communities or species may mask the wetland boundary simply by way of their distribution across the boundary . The grass *Festuca costata*, in the high rainfall area of the Highmoor plateau, is a case in point. *Festuca costata* dominated grassland occurs widely across the Drakensberg and has a characteristically dark spectral signature. It is associated predominantly with moist but reasonably well drained soils. It is predominantly absent from wetland areas, where soils are less well drained. However, where *Festuca costata* grasslands occur adjacent to wetlands, the wetland margin may extend a short distance into the *F. costata* grassland (Figure 3.15). As a general rule, if the wetland margin occurs on a change of slope from a gently sloped wetland to steeper upslopes surrounding the wetland, the *F. costata* grassland will not extend more than about 1-3 meters into the wetland.

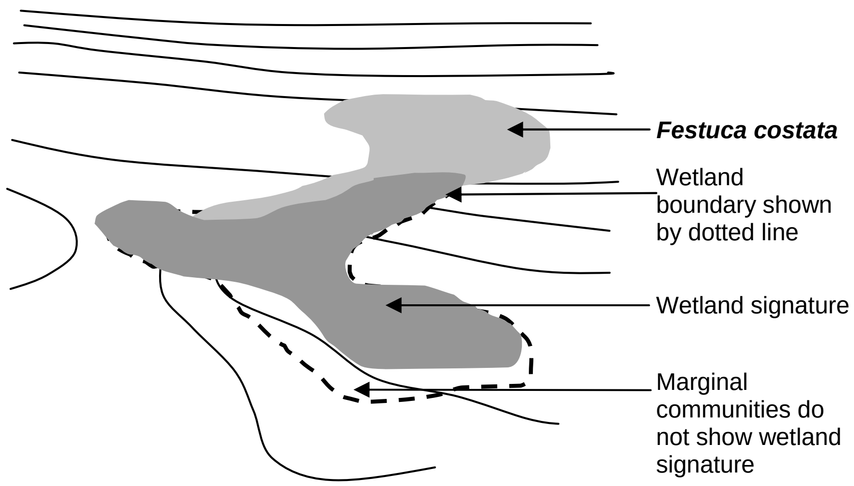


Figure 3.15. Schematic diagram of how the actual wetland boundary can be hidden by the vegetation

Vegetation boundaries may therefore, not always provide an indication of the boundaries of wetlands. This is also applicable where plant species that are normally in an obligate wetland indicator category in low rainfall areas for example, shift to a facultative wetland indicator category in higher rainfall areas.

Regional differences in vegetation types may also affect signature interpretation. For example, images from the Glenhart (Walker Bay study site) showed that what appeared to be wetland areas within areas of non-wetland, were actually natural fynbos and renosterveld vegetation within areas of planted pasture. The wetland areas could not easily be distinguished from natural vegetation in non-wetland areas on these images.

Specific conditions relating to vegetation signatures may also occur regionally or even locally. A few examples of these are given below. In the KwaZulu Natal grassland area, for example, the following may apply:

- *Carex* sp. occurs as uniform stands which appear usually as very uniform dark areas but may appear as uniformly light after winter die-back and the stand is very dense;
- *Merxmuellera* sp are consistently very dark because of almost no winter die-back;
- Wet grasslands often resemble adjacent upland grasslands, but the differences lie in subtle changes in tone which is often darker in wetter grassland;
- Dwarf sheetrock wetlands have a characteristic patchy/mosaic appearance;
- *Scirpus ficiniodes* characteristically occurs on the outer margins of wetlands and following winter die-back is highly reflective.

The past or current disturbance of a wetland, wetland boundary or area adjacent to a wetland may also influence vegetation signatures. For example, *Paspalum dilitatum* and *P. urvellei* occur in abundance in both previously disturbed wetlands and in disturbed moist well-drained soils adjacent to the wetland and the presence of stands of these species also tends to affect the accuracy of boundary delineation.

3.3.1.4 *Fire*

Burnt areas on remote imagery, particularly aerial photographs also affects the recognition of wetland signatures, complicating the separation of wetland from non-wetland areas (Figure 3.16). This may also affect remote boundary identification. Where extensive areas are burnt, it may be necessary to source other sets or dates of photographs that show the unburnt state. Similarly, overgrazing can affect signatures of the vegetation. Again, the only way of dealing with this is by making sure that there is a representative suite of checksites at which this type of affect is recorded. In most cases, it is therefore necessary to make sure that the checksites include farmed and grazed areas for any particular region.

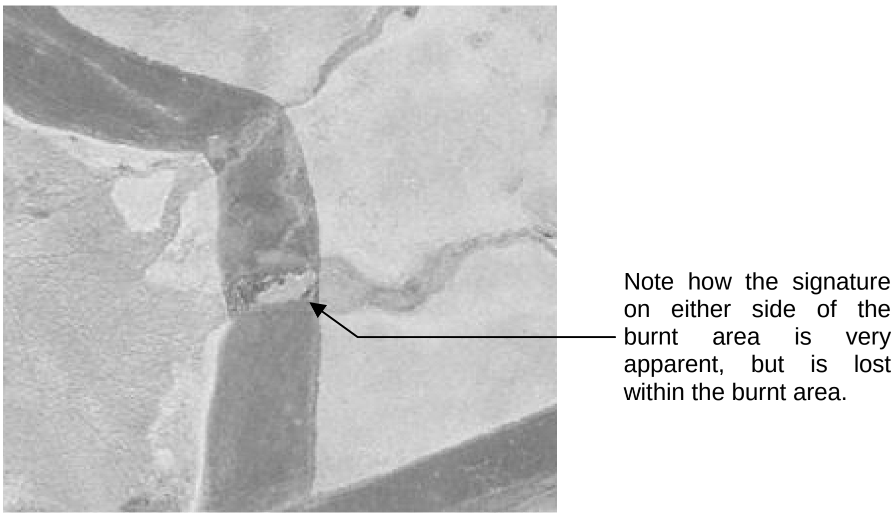


Figure 3.16. Aerial photograph showing masking effects of a burn (in this case a firebreak) on wetland signatures

3.3.1.5 *Disturbance including anthropogenic disturbance and land-use practices*

Further complicating the influence of vegetation on the spectral signature of a wetland and the delineation of the wetland boundary, is the effect of human activities. Anthropogenic factors, such as the planting of pastures or agricultural crops, removes the natural vegetation (and alters hydrology through drainage, depending on the particular activity), which result in change in the associated signatures, affecting the accuracy of remote boundary delineation and in many cases, simply of identifying wetland and non-wetland areas (Figure 3.17).

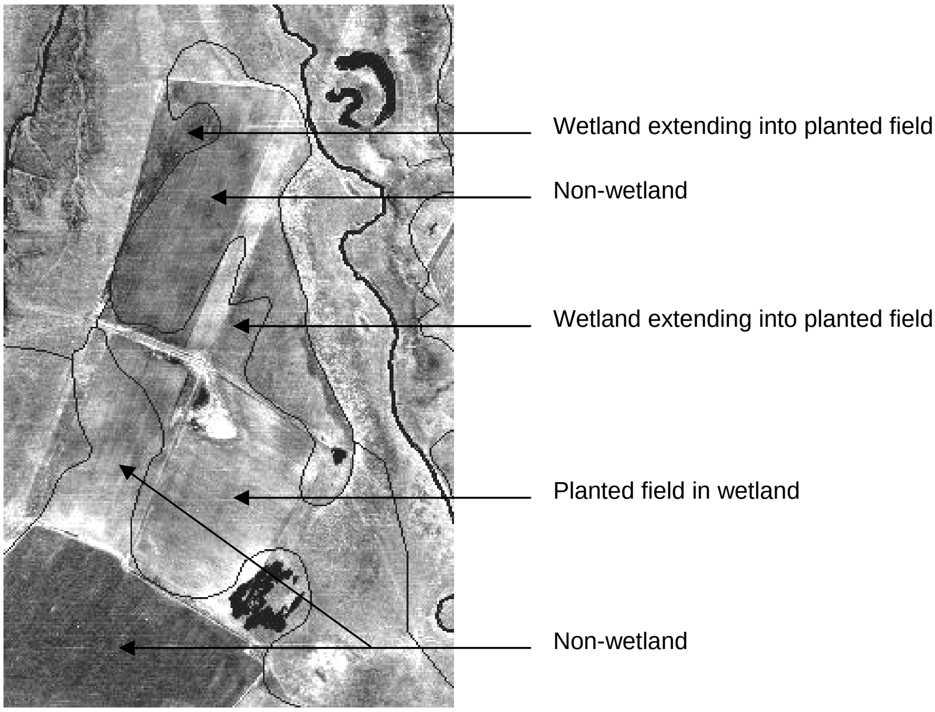


Figure 3.17. Aerial photograph showing agricultural effects on wetland boundary identification

At times, wetland soils may be recognised in agricultural lands. For example, at the Glengarry site, wetland boundaries could be easily recognised remotely and without auguring in those fields that were ploughed but not yet planted. If the photographs had been taken once the field were planted, this would not have been possible to do remotely. The only means of delineation would be through groundwork that would involve soil auguring.

Within particular areas or districts, farmers will often follow similar practices with regard to the modification of wetlands for agricultural purposes. The study sites varied considerably in terms of the level to which wetlands have been converted to annual crops. In the Viskuile wetland, for example, annual cropping is confined to the narrow margins of only a few wetland areas. In contrast, extensive areas of the Glengarry site are annually cultivated, which has been facilitated through drainage and ridge and furrowing. Local knowledge of agricultural practices helps in the interpretation of aerial photographs, especially when sub-surface drains are used. These are impossible to identify from a remote source.

3.3.2 Digital Photo-image Resolution

Digital orthorectified photographs do not provide as good a resolution of wetland boundaries as do hard copy aerial photographs. This may result in some wetlands being overlooked, despite their size and this also affects the accuracy of boundary delineation remotely when trying to delineate using digital images alone. This is mainly due to digital images not having the same clarity as aerial photographs. This project has shown that even when viewing at much smaller scales (1:50 000 compared to 1:5000), the quality of the hard copy images is generally far superior to the digital images. Stereoscopes with magnifying lenses can also be used to enlarge the viewing scale of the hard copy images up to eight times without losing much clarity. Thus, the use of high-resolution digital imagery does not guarantee that all wetlands will be identified or that the boundaries will be picked up. This necessitates the use of hard copy imagery in conjunction with digital imagery.

3.3.3 Scale of Photo-imagery

Photo-imagery scale is an important issue. All aerial photographs have a minimum mapping unit (MMU), which is related to image legibility. Examples of minimum mapping units (MMU's) for different scales of aerial photography according to a pre-defined minimum unit are given in Table 3.6.

Table 3.6. Examples of minimum mapping unit sizes for different scales of aerial photography based on a minimum visible mapping unit of 1mm x 1mm.

Map scale	Minimum size of delineation (m^2)	Minimum size of delineation (Hectares)
1:500	0.25	-
1:2 500	6.25	-
1:5 000	25.00	0.0025
1:7 500	56.25	0.0056
1:10 000	100.00	0.0100
1:15 000	225.00	0.0225
1:20 000	400.00	0.0400
1:30 000	900.00	0.0900
1:40 000	1600.00	0.1600
1:50 000	2500.00	0.2500

Note: The minimum-size of delineation is based on a 1mm x 1mm (0.01cm^2) square, which is probably the smallest area that can visibly identified and mapped at any scale. Small farm dams for example, that are approximately 0,01cm^2 in extent, can be seen on 1:50 000 BW aerial photo's.

The MMU may not however always be related to the target mapping unit (TMU) which in this case relate to those signatures that reflect the presence of wetlands. For a wetland map, a TMU is therefore an estimate of the minimum sized wetland that will be consistently mapped. It is therefore, not necessarily the smallest wetland that appears on the map, but rather the size class of the smallest group of wetlands that are consistently shown. While knowledge of the TMU may be important to the users, accurately determining the TMU is another matter (Tiner 1999). For wetlands, some types are conspicuous (e.g. floodplains and open water areas) allowing smaller ones to be mapped. Other types such as hillslope seepage systems and the drier-end wetlands (including those that have been drained) may be more difficult to map (photo interpret) and larger ones may be missed as is shown for the sheetrock-type system in Figure 3.18. This 4ha wetland at the Highmoor plateau site 1 could not be identified remotely despite the large scale (1:5 000) imagery that was used in the mapping. Setting a TMU for different wetland types is therefore extremely difficult. Despite the benefits of using aerial photographs for wetland mapping, one needs to recognise the limitations of this method as well especially when setting TMU's for the national wetland inventory.

Instead of trying to set a TMU as per the ToR of this project, it may therefore be more suitable to take an approach that involves setting a national mapping scale (NMS) that represents a compromise between minimum and target mapping units, map scale legibility and practicality, especially given the limitations of trying to map to a specific TMU. This means the acceptance that certain wetlands of various types and sizes will be missed in the remote mapping exercise, no matter what technique is used.

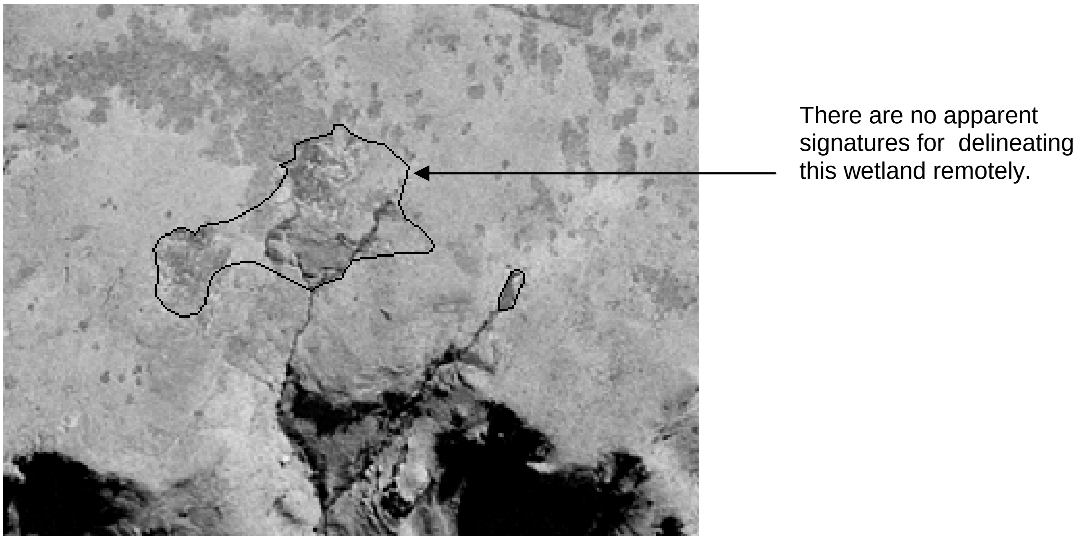


Figure 3.18. Some wetland types such as this sheetrock system (4 ha in extent) are very difficult to identify remotely as can be seen from the lack of a wetland signature in this image.

The setting of a NMS has important consequences for classification. By using a course NMS such as 1:30 000, for example, in smaller wetlands (0-50 ha) fewer units will be distinguishable at any given level in the classification. This may for example, result in fewer numbers of classes and sub-classes being picked up on the courser scale image compared to the what might have been picked up on a finer scale image. For example, a stream channel that may not be distinguishable at a 1:30 000 in a smaller wetland may be easily distinguishable at a scale of 1:10 000. This obviously has implications for how the wetland is classified at the different levels at each of the scales. In contrast, in a larger wetland, the stream channel may be easily visible at both these scales, thereby not affecting the classification. This is illustrated in the images shown in Figure 3.19 (a) and (b). At the scale given, the distinguishable levels of classification clearly differ between the top and bottom image in relation to what can be seen in the un-classified images (a: top and bottom) compared to the classified image (b: top and bottom).

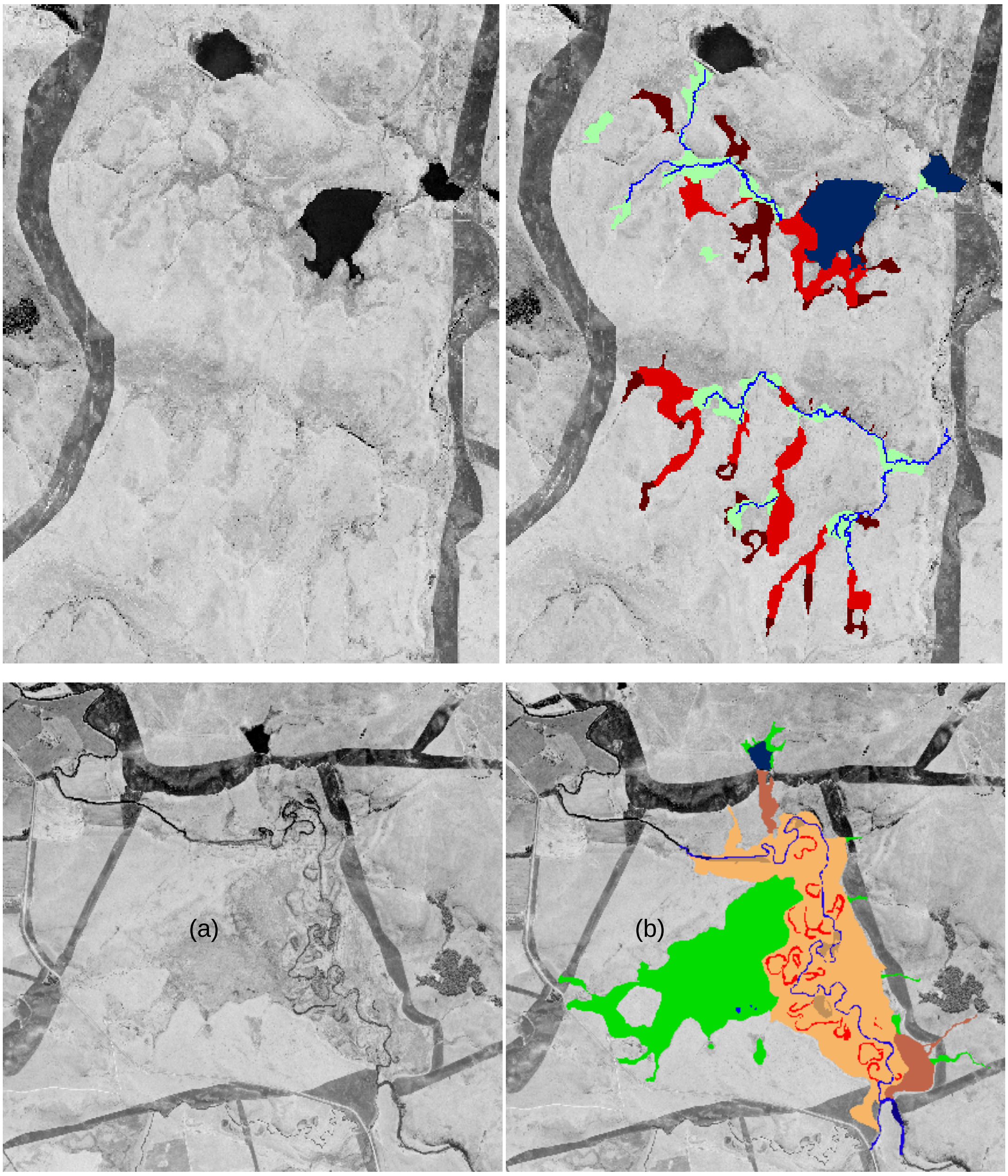


Figure 3.19. Aerial photographs illustrating the scale dependence effects related to mapping units. Actual mapping units are given in the images on the right while the legibility at this scale is given in the left image. If both these systems are mapped at the scale depicted here, more mapping (classification) units are evident in the lower wetland complex (Kamberg/Stillerust site) as opposed to the wetland complex occurring in the Highmoor plateau site above.

As long as this limitations relating to scale dependence are recognised, this issue can be dealt with by developing mapping conventions for ensuring that any inherent error or scale dependence factors are kept consistent and thus reflected throughout all the mapping. One will therefore need to understand the limitations of the dataset prior to undertaking any analytical or interpretative studies.

3.3.4 Wetland boundary accuracy

In many cases, particularly in complex systems with difficult boundaries, a 40m-boundary accuracy around an entire wetland will only be achieved with intensive fieldwork. However, once one has developed an understanding of the wetlands in a particular area, it may be possible to achieve very high accuracy for a large portion of boundary of the wetland using aerial photography. The remaining portion may not only have a low boundary accuracy, but in many cases, may be missed completely due to masking of signatures by some or other factor. For example, it was estimated that for 80% of the Viskuile wetland complex, the boundaries could have been mapped accurately (well within 40 m) using aerial photography. However, the remaining 20% of the area would have been missed completely simply because there was no wetland signature distinguishable on the aerial photographs due to conversion of these areas to planted pastures and crops (Figure 3.20). Thus, one would end up with 80% of the wetland boundary being accurate to within 40 m on the ground and 20% of the wetland not having being recognised at all. Without extensive ground truthing (soil auguring) there is no solution to this problem. A possible solution is to determine these degrees of error for each region or for a particular suite of wetlands in particular regions and then go ahead and map recognising that this type of error is likely to occur throughout. How one deals with this in the analysis of the data can then be decided as long as the rationale is made explicit and any conclusions are qualified by consideration of the degree of error expected for any particular area or suite of wetlands.

Figure 3.20. Photographs showing a section of the Viskuile wetland that has been converted to planted pasture.

Thus, the presence and intensity of anthropogenic impacts also influences the intensity of fieldwork required with respect to boundary determination. As discussed above, this has obvious implications for the accuracy of remote boundary determination. Conversion of wetlands or parts of wetlands to agriculture or planted pasture is a case in point. Sometimes however, the impacts may be more subtle such as when the boundaries are masked by factors such as sedimentation resulting from erosion off agricultural lands. At the Viskuile wetland for example, high chroma soil washed down from adjacent non-wetland cultivated areas covers sections of the wetland boundary. In some areas, the boundary may be covered with over 60 cm deep high chroma soil. One needs to be aware of such features in the field and should give careful consideration to this type of effect in regions with certain agricultural practices.

The level of accuracy that can be achieved using aerial photography or ground mapping is also region and type dependent. If the wetland margin occurs on a change of slope from a gently sloped wetland to steeper up-slopes surrounding the wetland, the boundary is usually very clear. This is particularly so where the boundary lies between the backmarsh area of a high stream order valley bottom/floodplain wetland and a steep convex slope adjacent to the wetland. However, where the wetland boundary lies where there is no clear change in slope then the transition from wetland to non-wetland conditions is usually much more gradual and often not clearly distinguishable on the image. For example, the more linear boundary of the plateau wetland at Highmoor (KwaZulu-Natal) is far easier to pick up on the ground compared to the complex mosaic boundary of the wetland at Theewaterskloof Dam (Western Cape) [Figure 3.21]. The differences between the two systems in terms of their geomorphic setting, soil characteristics, hydrology and so on all reflect regional factors, despite them both being predominantly seepage systems.


(a) (b)

Figure 3.21. Photographs showing differences in wetland boundary complexity between the plateau wetland at Highmoor (a) and a wetland complex from the Theewaterskloof Dam in the Western Cape (b). Note the relatively easily identifiable linear boundary in the former site as opposed to complex mosaic in the latter site.

In systems where there are no clear-cut hydric indicators in the soils, boundary delineation needs to be based on vegetation and other indicators such as wetness in the soil profile, presence of organic material in the soil, and so on. Often in these cases, the boundary can only at best be determined through professional judgment since the more traditional hydric guides are largely absent. This is further complicated by wet and dry cycles and may be biased by timing of field visits. These types of difficulties are common in the systems visited in the Western Cape in particular, where soil profiles comprise deep-leeched sands with no hydric indicators. We speculate that vegetation indicators are key in these types of systems, and this is discussed further later in this report.

Sometimes boundaries are also masked by sedimentation resulting from erosion off agricultural lands. At the Viskuile wetland for example, high chroma soil have washed down from the adjacent non-wetland area, covering the wetland margin with, in some areas, over 60 cm deep of high chroma soil. This can affect the delineation of the boundary if one is not careful.

3.3.5 Issues for Consideration in Estuarine systems

Estuarine systems present a unique set of issues over and above those mentioned above. According to the proposed national classification system, estuaries contain two subsystems, namely subtidal (areas permanently submerged by tidal water) and intertidal (areas where the substrate is exposed and inundated by tides – subject to daily/seasonal tidal fluctuations). The two subsystems represent the area inundated at spring low and high tide levels respectively. One would require at least two sets of imagery to pick up the extent of these zones. For example, consider Figure 3.22. At the time when this aerial photograph was taken, the extent of inundation represents a state somewhere between high and low tide, and neither the subtidal or intertidal zone can be picked up from the imagery. The subtidal zone lies somewhere within area A and the intertidal zone would extend from A to beyond this in places. Furthermore, these systems are also generally quite dynamic and the position of these zones may change over time as a result of sediment movement and so on. This has implications with respect to trying to delineate areas within an estuary that represent different systems and subsystems. Aerial photography that is a few years old therefore not always resemble what exists on the ground at present.

Figure 3.22. Aerial photograph of a section of the Kleinrivier estuary

In systems where the mouth closes, flood events responsible for mouth breaching will cause water levels to rise above the spring high tide level and fringe palustrine area levels of these types of systems. This may only happen for short periods (a few days) immediately prior to mouth breaching. The area inundated during this time therefore extends beyond what would normally be defined as the estuary boundary in terms of the classification system. The extent of these floods are unlikely to be picked up by standard mapping or boundary determination methods (Figure 3.23), yet these are important events for maintaining the functioning and dynamics of these types of systems. The reality is that this boundary is unlikely to be picked up by using either aerial photography or ground truthing. Morant and van Niekerk (Pers. Comm. 2001) suggest a simpler way of dealing with this issue and this is by using the 3-5m contour level (above mean sea level) as an indication of the mouth breaching level and thus actual upper boundary of these types of estuaries.

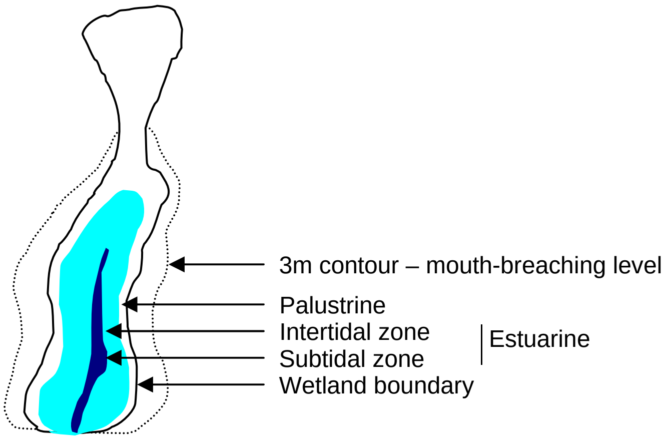


Figure 3.23. Schematic representation of an estuary depicting how the wetland boundary may lie within the critical mouth breaching contour level and how this would not be reflected in the classification of the system

Palustrine systems may also occur on the fringe of estuaries, depending on the influence of freshwater seepage on the edges as well as inputs from tributaries and so on. These systems, while predominantly maintained by freshwater, may be exposed to saline conditions at certain times such as during flooding. By definition, the classification of these areas would theoretically change during these periods when salinity increases to levels similar to that of the estuary. Considering all of the above, the suitability of the proposed classification system to all types of estuaries will need to be critically assessed and evaluated by relevant experts in the estuarine field.

3.3.6 Aerial photography and trend analysis

3.3.6.1 *Implications relating to the date of aerial photography*

In general, the optimal time for an image is when wetland areas exhibit significantly different (spectral) characteristics to surrounding areas. A common problem experienced with the conventional format BW aerial photographs in South Africa, is that they do not offer the opportunity for multi-temporal mapping. As such, they may only be available for a particular date and this date may not be the best for remote wetland identification. Older photos may also not represent what presently exists on the ground. Any data derived from these may therefore, also not necessarily represent the present extent or status of any particular wetland system or number of systems. This may also affect the classification of a wetland. For example, the removal of vegetation adjacent to a river system may change the Class from scrub-shrub or forested to emergent. Large flood events may alter entire areas and even change the position of channels, levees and so on. Thus, it is important to understand that the data captured from aerial photographs represents what was present at the time of the photography. It is assumed that a national dataset based on aerial photography would be made up of images from numerous dates. Analysis and interpretation of the data would need to take this into account. This would also therefore have important implications with respect to trend-type analyses.

3.3.6.2 *Trend analysis*

A wetland inventory should provide baseline of information against which the success of management actions can be judged. Many inventories have been no more than a catalogue of attributes of a set of wetland sites. While such information is useful, this approach does not go far enough in today's climate of rapid wetland change. Whether local, national or regional in scale, a wetland inventory should include those data that benefit conservation and sustainable use (Frazier 1998). In order to provide "State of the Environment" information or information that can be used in a trend-type analysis, it is essential that the condition of individual wetlands be determined, even if this is only at a rapid assessment level. For larger wetlands, airphoto-interpretation is effective for revealing certain land-use impacts within wetlands and other on site factors that may be negatively affecting a wetland. These include, for example:

- Surface drainage channels. In airphoto interpretation one must be careful not to confuse these with fence lines and/or the edges of cultivated lands;
- Cultivated lands, especially those that are associated with surface drainage channels. This however is limited to those wetlands that have relatively distinct boundary signatures;
- Erosion dongas, especially major dongas;
- Road, railway and bridge crossings;
- Power lines and fences;
- Afforestation; and
- Settlement ….

Other impacts may be very difficult or impossible to identify using airphoto-interpretation. These impacts include for example:

- Incision of natural channels. This usually cannot easily be detected in a "plan view" of the steam channel:

- Planted pastures lacking surface drainage channels. These are often impossible to distinguish remotely from natural wet grasslands. In addition, planted pastures such as *E. curvula* pastures often occur well across the transition from wetland to non-wetland, as it was found at the Davel site. In some cases, this may be associated with a darkening of the tone into the wetland. However, in other cases it is not associated with a discernable change in tone. Such pastures also make field verification very difficult in that vegetation cannot be used for interpolation, therefore requiring a high level of soil sampling;

- Invasion by alien plants. This applies particularly to herbaceous alien plants such as American bramble or chromelina, which are often not possible to detect from airphotos unless they have reached very dense levels of infestation. Woody plants (e.g. black wattles) may be clearly discernable on airphotos. However, these trees often invade both wetlands and non-wetlands and the dense canopy of the trees generally obscures indications of whether the area is wetland or not. In some areas as well, the invasive species cannot be distinguished from indigenous riparian trees using airphoto interpretation;

- Infilling may be revealed on airphotos (could be detected using supplementary older photo-sets), but generally requires closer inspection and historical information;

- Level of current erosion activity. Although major dongas are generally visible, it is generally not possible to determine how active the erosion is, and hence the threat that the erosion is posing. Minor dongas and rill and sheet erosion are also generally not clear on airphotos; and

- Unprotected stormwater outflows.

Thus, a strongly ground-based approach will be required for this component of the inventory. It will obviously be too costly to undertake this for all mapped wetlands. Thus, field checking will need to be undertaken using a sub-sampling approach. Field checking is also required for verification during mapping of the wetlands. Since much of the time required for ground verification is taken by travelling between wetlands, it would be considerably more cost effective to undertake boundary verification and status assessment during *the same operation* rather than first completing mapping and then undertaking the status assessments afterwards.

A standardized datasheet (which should preferably be no more than 2 pages) for undertaking a rapid status assessment needs to be finalized for use at a national level. A draft datasheet has been compiled based on the data needs expressed in the national inventory workshop (DEAT 1997) and the database workshop convened at the beginning of 2002 for this project as well as by modifying components of existing datasheets. Table 3.7 provides an example sheet indicating the sorts of information that should be included in a status and trend assessment.

Table 3.7. Example of the types of information required in a field datasheet for a wetland status and trend analysis

EXAMPLE: FIELD DATASHEET – WETLAND STATUS AND TREND ANALYSIS

General information
Location, unique identity number for wetland, compiler, date

Classification
According to the national system including importantly the landform setting and type modifiers

Key biophysical features
Notes on geology, key points, slope and general topography
Presence of habitat types subject to particularly high levels of loss (e.g. swamp forest) or that are particularly rare (e.g. dolomitic eyes).
Presence of Red Data or other notable species).

Land ownership
Land owner details:
Land tenure: private, government, communal, etc.

Land-uses in the wetland

	%cover	*Impact on wetland functioning*
Commercial crops		
Subsistence crops		
Timber plantations		
Planted pastures		
Etc.		

Land-uses surrounding the wetland and in the catchment
Catchment activities (e.g. feedlots) causing a reduction in water quality
Catchment activities (e.g. irrigation) causing a reduction in quantity of water input
Extent to which a natural buffer exists around the wetland
Note: Some of the more general catchment-based land use information will be automatically available from the national land cover dataset that will already be part of the mapping and database process.

Overall state of the wetland
Based on an assessment of the combined effects of all land-use impacts described above, complete assessment of the wetland's overall status using, for example, the categories below, which relate to reserve determination:

A Natural/unmodified
B Largely unmodified
C Moderately modified/impacted
D Largely modified

The use of other rankings and scoring systems will need careful consideration since, in many cases, they require careful interpretation and can introduce bias if not thoroughly tested.

Threats to the Wetland e.g. proposed afforestation or urban development

3.3.7 Mapping Conventions

As part of the US National Wetlands Inventory, mapping conventions were developed in order to ensure consistency in mapping efforts on a nationwide basis (National wetlands inventory, US Fish and Wildlife Service 1994). These conventions relate to aspects such as: the use of mapping equipment; map sheet preparation; transfer methods; map sheet production; information capture; lettering and labelling guides for datasheets and maps; digitising guides; classification; and correction and revision guidelines. An example of the type of display used for lettering relating to the classification conventions on a pre-transfer map is given for the Viskuile wetland in Figure 3.24.

The conventions are particularly necessary when applying the manual transfer methods, since these are fairly complex operational procedures that require standardised procedures in order to ensure consistency. The US cartographic convention manuals are available in South Africa and offer considerable insight into the practical and other experience-related issues pertaining their manual mapping and transfer methods. It is important to point out that the manuals have been developed for application in the US wetland inventory and therefore relate specifically to the methodology being used in the US.

Based on the findings of this project, heads-up digitising offers an easier alternative to manual transfer methods and, if linked to an automated classification and database management procedure, considerably reduces the need for many of the manual mapping conventions. Conventions or standards will still however, be needed for this but there would no longer be a requirement for the large number of conventions relating to pre-digitising hard copy map symbols, classification labels and so on. The heads-up digitising procedure linked to an automated classification and database management procedure therefore potentially offers a standardized application requiring fewer conventions. For those aspects of the inventory that will still require conventions (such as field datasheets and delineation of checksites), one could tap into the wealth of experience and effort incorporated into the convention manuals already developed for the US and other wetland inventories. It is also likely that some new conventions will be required in order to standardize certain aspects of an automated transfer process such as heads-up digitising.

Figure 3.24. An example of the classification to class level of the Viskuile wetland using mapping conventions. The letters correspond to the symbols as per the mapping conventions as given in the cartographic conventions for the US National Wetlands Inventory (1994) plus a few additions for the palustrine sub-systems proposed for the SA system.

3.3.8 Potential advantages of using a combination of techniques

3.3.8.1 *Using heads-up digitising on ortho-rectified digital images in combination with hard copy BW stereo pair photography*

Since the main advantage of heads-up digitising onto BW photo-mosaics is that it provides an easy way of capturing wetland boundaries digitally, it seems sensible to consider this in combination with other methods that provide enhanced signature and boundary identification. In addition, by being able to change the scale of the view, one can also get around the problems associated with hard copy line thickness in relation to on-ground distance.

When heads-up digitising is used in combination with stereo hard copy BW photo pairs and/or fieldwork, the delineated wetland boundaries can be more accurately captured digitally since one gets around the need for manual transfer. This was the method used for accurately capturing the field-delineated boundaries in digital format. A schematic of the combined technique is presented below based on what has been discussed in depicted schematically in the diagram shown in Figure 3.25.

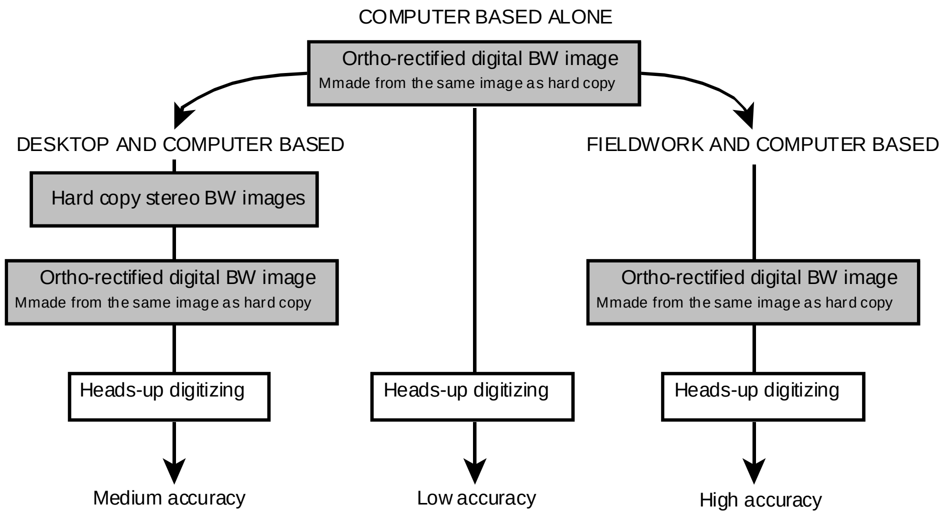


Figure 3.25. Schematic representation of the level of wetland boundary accuracy achievable using heads-up digitising on ortho-rectified BW images alone, and in combination with stereo hard copy imagery and fieldwork.

SUMMARY TABLE

Wetland maps prepared by interpreting aerial photos, have inherent limitations related to many factors, including the difficulty of signature recognition, map scale (e.g. balancing minimum mapping units against map legibility), quality of imagery, conditions present when the imagery was captured (e.g. burns, wet season and dry season), the cartographic equipment used in transfer or preparation of maps, plus the skills of the photo interpreters, and image processors. Even the detailed site-specific maps prepared from on-the-ground surveys undertaken as part of this study have limitations due to scale as well as some of the other factors listed above.

Wetlands also pose special problems for accurate mapping due to their alternating wet-dry nature and the complexity of their boundaries. While many wetlands are quite distinct due to observed wetness or unique vegetation, many others are not readily identified either on the ground or by interpretation of aerial photographs. Wetland identification often requires analysing subtle changes in vegetation patterns, soil properties, and signs of hydrology, especially in drier type systems and seepages. The point to remember is that the more difficult the wetland type is to identify on the ground, the more conservatively such types will be represented on maps produced by aerial photo interpretation.

Field delineation versus photo-interpretation
Maps produced by photo interpretation will never be as accurate as a detailed on-the-ground delineation, except perhaps where topographic differences are abrupt and hydrologic differences obvious. Minutes of photo interpretation time cannot hope to improve upon hours of fieldwork examining plants, soils, and signs of hydrology and flagging the often complex boundaries of wetlands. This is not to say that photo interpretation cannot produce relatively accurate boundaries at a fraction of the cost of doing on-the-ground delineation. For some types in certain landscapes (e.g. floodplains, most pans, riparian zones, swamps, fens, lakes and dams where topographic setting and vegetation and open water characteristics are easily identifiable) photo interpretation works well for locating the boundaries. For other types such as those in complex (steep slopes including convex and concave settings) or simple topographic settings (flat landscapes), those towards the dryer end of the spectrum and particularly seepage wetlands, photo interpretation will only produce generalized boundaries that may vary considerably in the field.

Wetland photo interpretation is therefore, not a simple task. Wetlands occur along a soil moisture continuum between permanently flooded to drier habitats that are not wet for long periods. This makes many wetlands, especially those subject to only brief flooding and seasonal saturation, particularly difficult to identify on the ground, let alone on aerial photographs. In general, the wettest wetlands are usually easiest to interpret, while the drier ones are most problematic. Moreover, wetlands occur over a wide range of topographic settings nationally, which further complicates their interpretation. In addition, wetlands vary widely from one region to another.

Field verification
Field verification is an extremely important requirement with respect to wetland mapping. It not only serves to calibrate one's mind to an area, but also serves to provide the baseline information necessary for calibrating all types of remote mapping from the use of satellite imagery to aerial photography. It is also the only way one can gain insight into many of the issues that should be considered when mapping in any particular region. Field verification is, however, the most time-consuming part of the mapping process and since this is a necessary component of any mapping, one needs to make sure it is practiced judiciously and only in those wetlands where it will add most value to the mapping of a particular region.

Concepts such as wetland boundary complexity and wetland complexity are important in terms of time budgets for what length of perimeter or extent of a wetland can be mapped in the field. The boundary complexity is a measure of the ease with which the boundary of the wetland can be delineated in the field, while the wetland complexity describes the relative

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complexity of the wetland itself, defined by the perimeter to area ratio. One can use the boundary and wetland complexity concept to get a rough estimate of the costs required to field delineate photo-interpreted checksites for any particular region or set of wetlands being mapped. One cannot expect to undertake any wetland inventory project without field delineated checksites. The presence and intensity of anthropogenic impacts also influences the intensity of fieldwork required with respect to boundary determination. This includes the conversion of wetlands or parts of wetlands to agriculture or planted pasture as well as draining and so on. Sometimes however, the impacts may be more subtle such as when the boundaries are masked by factors such as sedimentation resulting from erosion off agricultural lands. One needs to be aware of specific issues relating to boundary accuracy in the field and should give careful consideration regional land-use practices and disturbances. *Use of stereo imagery* Stereoscopic coverage with sufficient overlap is essential to assess topographic relief and is integral to the identification, delineation and classification of wetlands and this has not only been found to apply in South Africa, but internationally as well (Tiner 1999). In particular, stereo mapping allows one insight into the three-dimensional detail on the aerial photographs. Viewing images in stereo allows one to identify those key topographic and landform features that influence the occurrence, distribution and classification of wetlands in any particular region. Changes in topography often provide clues as to the location and even boundaries of wetlands. Stereo viewing often serves to improve the confidence of mapping by allowing one to rule out or include areas that are likely not to have or have wetlands respectively based on topography. While digital three-dimensional digital image viewing (using a product like ERDAS Stereo Analyst) is a very powerful tool for assisting with wetland mapping, it nevertheless appears to have a few drawbacks when trying to map wetlands nationally. Firstly, one needs to develop the computer skills necessary for its application. There is also a requirement for data preparation. Secondly, one tends to develop eyestrain when viewing images in stereo over periods of a few hours or longer. This method also offered no benefits over-and above digital non-stereo mapping, with respect to boundary accuracy of the section of the Kleinrivier estuary that was mapped, despite its ability pick up a high level of elevational detail. *Quality of photography* In any photo interpretation project, the quality of the photography is a prerequisite for accuracy. Since emulsion is an important characteristic of aerial photographs, one might have expected that RGB and CIR imagery (which produces and array of colours and textural patterns) would be more useful for wetland mapping than BW imagery (which is panchromatic and only yields shades of grey and textural differences). This was found not to be the case, mainly due to the specific requirements of mapping using RGB and CIR imagery. These are discussed below. Since the predominant vegetation and the hydrologic characteristics (i.e. water regime) largely determine the relative ease or difficulty with which wetlands can be interpreted, timing of the photography is also an important factor. This is a particularly important consideration with regard to RGB and CIR imagery. It appears less important in BW imagery. Antecedent weather conditions (prior to photo acquisition over flights) are also important considerations when it comes to using RGB ABD CIR imagery. Extreme flooding conditions as well as extreme droughts may also create problems for accurate RGB and CIR wetland photo interpretation. Despite CIR being the generally preferred imagery for wetland and vegetation mapping in the US because this film records a wider range of colours and tones than true colour (Arnold 1997), it does not appear to offer any advantage in terms of mapping the drier end and more seasonally wet systems including seepage systems and some of the common types of floodplains found on the Highveld of South Africa. The current format and processing of the CIR aerial photography also makes it unsuitable for per-pixel based digital classification applications, and is rather more suited at

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present to conventional photo-interpretation mapping techniques. For this reason, mapping off this specific CIR imagery is at present limited to conventional photo-interpretation. *Photo-image scale* Photographic scale is another important issues since it establishes limits on what can be interpreted (e.g. minimum mapping unit (MMU), degree of resolution between different wetland types, and the detail and width of wetland boundaries). The use of course-scale hard copy photography (generally 1:50000) and manual transfer methods will only be useful for national or regional inventories where less detail and low boundary accuracy (>40m) is required. With this type of photography, general wetland boundaries can be delineated for wetlands larger than one hectare in size and for even smaller conspicuous wetlands (e.g., open water areas such as dams and perennial pans). Large scale hard copy photography (1:20 000 or larger) is best for more detailed mapping where precise boundaries of wetlands and identification of small wetlands are required. Even at large scales, the practical problems of ortho-rectification and hard copy boundary transfer to digital format still exist. BW orthophotographs at 10000 scale are already ortho-rectified and enable direct digitising from the hard copy. However, despite the relatively large scale of the 1:10 000 orthophotos, they do not provide sufficient resolution and contrast for accurate photo interpretation and therefore wetland mapping. This imagery also does not cover the entire country. An intermediate scale of hard copy photography such as 1: 30 000 may be the best compromise, as considerable detail can be captured in less time and therefore for lower costs than if large-scale photography is used. However the same problems exist with manual transfer methods so that even with intermediate scale photography, a wetland boundary accuracy requirement of 40m will not be met. *Transfer methods* Manual transfer methods are practically cumbersome and in some cases are highly inaccurate. The use of a zoom transfer scope and redrawing the wetland boundaries from aerial photo's onto base maps such as a 1: 50 000 topographic sheets and then digitising these, were both ruled out as a practical means of manual transfer from hard copy to digital format. The former method was ruled out on the basis of availability of the equipment in South Africa and the other practical problems associated with mapping and boundary capture on hard copy imagery. The latter was ruled out on the basis of accuracy and inherent human error. The image scanning method using the remote sensing package ERDAS Imagine and a geometric correction from fiducial and ground control points and vectorization was reasonably effective in terms of the level of accuracy achieved in the manual transfer. Similarly, the R2V vectorisation methodology also proved reasonably effective in terms of the level of accuracy achieved in the manual transfer. However both processes required a considerable amount of manual effort in terms of scanning of individual photo prints, editing and so on and this renders them largely non-feasible as potential nationally applicable manual to digital transfer options Based on the results of the accuracy assessment, it is evident that heads-up digitising on BW photo-mosaics alone also does not provide a consistent and high level of accuracy with respect to remote wetland boundary delineation. The main reason for this is the limitations imposed by the low resolution of the digital BW images. A potential way of improving the consistent accuracy of the remotely determined wetland boundaries is to use heads-up digitising in combination with hard copy BW stereo viewing. The BW hard copy viewing compensates for the loss of resolution on the digital images, despite the courser scale at which the image is viewed. *Proposed national classification system* The proposed classification system including the modifiers needs further work before it will be able to be applied in South Africa. It is also important that its limitations are understood

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and accepted if it is to be applied to the national wetland inventory. In particular, the influence of the scale of mapping and therefore the development of minimum acceptable mapping units will be key to its application. Examples of its application are given in the main report.

Estuarine systems present a unique set of issues in terms of classification and delineation. The dynamic nature of these systems plus the high flood that extend beyond what would normally be defined as the estuary boundary in terms of the classification system all pose unique problems with respect to photo image timing, boundary definition and classification. Careful consideration will need to be given to these systems in any national inventory project.

Skills and training

Finally, skills of the photo interpreter also are a significant factor in the quality of the interpretation. Photo interpreters must have certain physical skills (e.g. the ability to see in stereo, to distinguish shades of grey or colours, to recognise contrast and wetland signatures, and if manual transfer is used, to accurately draw the boundaries and annotate the maps) and cognitive skills (e.g. knowledge of landscapes, the ability to interpret topography, landforms and geology, and a basic understanding of wetland ecology) (MacConnel *et al*. 1992). They also must be able to identify wetlands and their boundaries in the field during ground truthing exercises.

Status and trend analysis

Remote mapping, no matter the technique will not provide the sorts of information required on a wetland by wetland basis for a status or trend analysis. This will only be achieved using a strongly ground-based approach linked to aerial photo interpretation. It will obviously be too costly to undertake this for all mapped wetlands. Thus, it is recommended that this is undertaken using a sub or stratified sampling approach. Field checking is also required for verification during mapping of the wetlands. Since much of the time required for ground verification is taken by travelling between wetlands, it would be considerably more cost effective to undertake boundary verification and status assessment during the same operation as the main mapping exercise.

Mapping conventions

Based on the findings of this project, heads-up digitising offers an easier alternative to manual transfer methods and, if linked to an automated classification and database management procedure, considerably reduces the need for many of the manual mapping conventions. Conventions or standards will still however be needed for this but there would no longer be a requirement for the large number of conventions relating to pre-digitising hard copy map symbols, classification labels and so on.

The way forward

Based on the findings of the report and recognising the difficulties of mapping wetlands remotely, there appear to be two general ways to approach wetland mapping. The first is driven by a desire to map wetlands that are more or less readily photo interpreted (Tiner 1999). Following this approach means that if an area is mapped as a wetland, it should be correct or have a very high probability of being a wetland. This approach leads to more Type I errors (errors of omission), as emphasis is placed on mapping photo interpretable wetlands, so wetlands that are not, are missed. This approach is typically used in making National Wetlands Inventory maps (Tiner 1999). The other approach is based on showing all possible wetlands and accepting misclassifications in the process. This type of mapping will lead to more Type II errors (errors of commission) where parts of wetlands are missed or wetland areas are designated as upland and *vice versa*. Each approach has its merits, and it may be most desirable to have a map showing both the photo interpretable, other possible wetlands (based on landscape position, landform contiguous to interpretable wetlands etc), and a list of limitations based on a critical assessment of what types of systems were likely to have been missed or under/over-estimated in any particular region and based on what factors.

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The potential also exists to use a combination of mapping techniques. Since the main advantage of heads-up digitising onto BW photo-mosaics is that it provides an easy way of capturing wetland boundaries digitally, it seems sensible to consider using this in combination with other methods that provide enhanced signature and boundary identification. Probably the most practical option is to consider using heads-up digitising in conjunction with intermediate scale (1:30 000) stereo hard copy BW aerial photography and ground truthing. In all cases this should be backed up by the hard copy or digital 1:50 000 topographic sheets. The BW photography offers the enhanced image resolution lacking in the digital images and heads up digitising allows one to change the scale of the view, thus getting around the problems associated with manual transfer and hard copy line thickness in relation to on-ground distance. This facilitates more accurate digital boundary capture. Linking heads-up digitising to an automated classification and database management procedure also offers advantages over manual transfer methods in that it offers a standardized application requiring fewer mapping and transfer conventions. For those aspects of the inventory that will still require conventions (such as field datasheets, delineation of checksites and so on), one could tap into the wealth of experience and effort incorporated into the convention manuals already developed for the US and other wetland inventories. It is also likely that some new conventions will be required in order to standardize certain aspects of an automated transfer process such as heads-up digitising.

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APPENDIX 3.1

SPECIFICATIONS FOR CONVENTIONAL AND ORTHO-RECTIFIED BW PHOTOGRAPHY

All datasets acquired from Chief Directorate Surveys and Mapping (Dept of Land Affairs), unless otherwise specifically stated.

(A) Stereo and Non-Stereo BW Photographic Coverage (Conventional Hardcopy Prints)

Davel
18 x 1:50,000 scale contact prints, from Job 952 (1991)

HighMoor
1:30 000 scale contact prints, from Job KZN 985G(1996)

WalkerBay
12 x 1:60,000 scale contact prints, from Job 1004 (1997 / 98)

(B) Ortho-rectified BW Photographic Coverage (Digital Image Mosaics)

Davel
Ortho-rectified imagery generated from the 18 x 1:50,000 scale photography, from Job 952 (1991)

HighMoor
'Off-the-shelf' ortho-rectified digital image dataset, originally derived from 1:30,000 scale photography from Job 1047C (1996).

WalkerBay
Ortho-rectified imagery generated from the 12 x 1:60,000 scale photography, from Job 1004 (1997 / 98)

All new ortho-rectified image products were generated using ERDAS OrthoBase 8.4 software, using digital copies of photo diapositives (scanned at 12000 dpi), together with (digital) 1:50,000 scale topographic maps for control and 20 m contours for DEM creation. Using this approach it was possible to achieve a relative accuracy of ±10 m, and a (worst case) absolute accuracy of ±50 m.

The standard projection format used for all ortho-rectified digital photography was Transverse Mercator (Gauss Conformal), Clark 1880 and Cape spheroid and datum, using LO 29 or 19 depending on test site location.

APPENDIX 3.2

SPECIFICATIONS FOR DIGITAL RGB AND CIR AERIAL PHOTOGRAPHY

All datasets were acquired using either the Nikon D1 (RGB) or the Duncantech DT1100 (RGB-CIR) digital cameras operated and flown by GeoSpace International. These systems, using the integrated on-board (aircraft) GPS systems, are able to generate highly accurate, digital ortho-rectified products, with a relative accuracy of ± 2m and a (worst case) absolute accuracy of ± 10 m, using ENSO-MOSAIC software ©.

(a) RGB Only Ortho-Rectified Imagery

Davel

Date of image acquisition:	August 2001
Ground spatial resolution of imagery:	2.0 m
Maximum achievable mapping scale:	1:7500

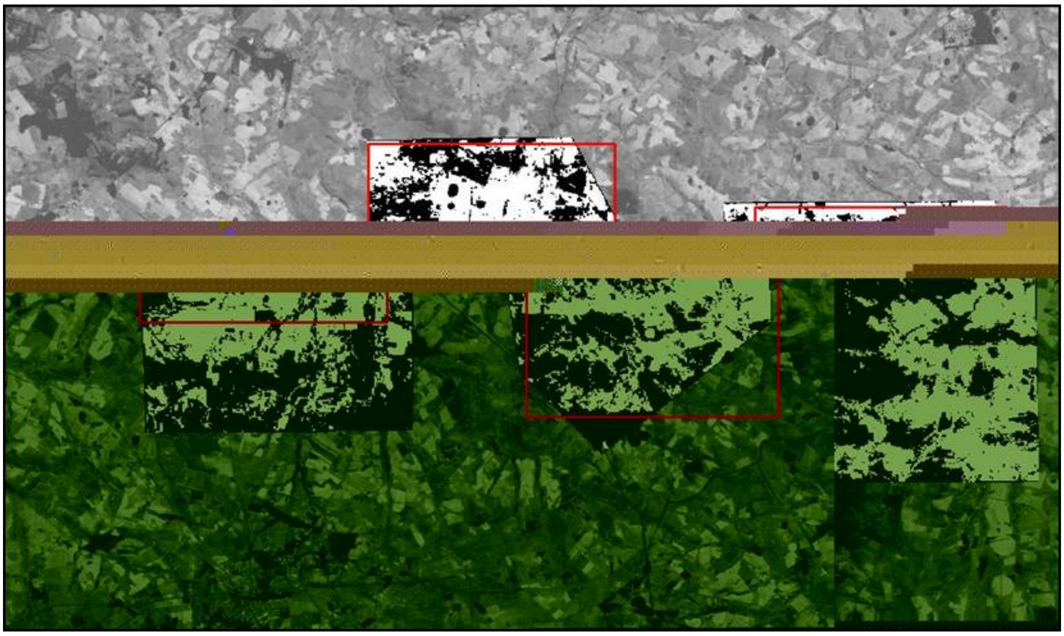
(b) RGB and CIR Combined Ortho-rectified Imagery

Davel

Date of image acquisition:	11 January 2002
Ground spatial resolution of imagery:	0.75 m
Maximum achievable mapping scale:	1:2500

The standard projection format used for all ortho-rectified digital photography was Transverse Mercator (Gauss Conformal), Clark 1880 and Cape spheroid and datum, using LO 29 or 19 depending on test site location.

The illustration below shows the location of the sub-areas within the Davel test site that were covered by the RGB (BW images) and CIR (red boundaries) digital photography. The grey-tone background is B4 from the Landsat 7 ETM+ image (2000-08-22).



CHAPTER 4 WETLAND INVENTORY DATABASE AND DATA DISSEMINATION

The housing and dissemination of wetland information is a vital component of the overall wetland inventory in that a well-structured, reliable, and accessible database lays the foundation for appropriate analysis, monitoring, and decision making of wetlands in South Africa. In this chapter we assess various methods of wetland data dissemination or accessibility and the feasibility of using the MedWet database, a database developed for Mediterranean country inventories, in South Africa.

4.1 APPROACH

4.1.1 Data Accessibility

The most appropriate and cost effective means of making wetland inventory data available has been investigated specifically considering three methods of data dissemination:

- Paper production of maps;
- CD-Rom; and
- Web based facilities for viewing and downloading of spatial and attribute data.

The advantages and disadvantages of each method have been analysed in terms of cost, effectiveness, labour, and long-term applicability.

Wetland inventory data should be accessible to all interested parties, including governmental organisations (national government and provincial counterparts), research organisations, NGO's and the public at large. Not all information will be made available to everyone, as there is a need to protect certain information, such as rare data species locations. Any method of data dissemination must therefore take into account different levels of security depending on the type of information as well as the user.

Cognisance has been taken of the experience gained by the US Fish and Wildlife Services who disseminate the United States National Wetlands Inventory information. The Fish and Wildlife Services have found that from 1991 there has been a huge shift in demand for paper copies of maps to vector data files of the wetlands, which are downloadable through the Internet (Robinson H, 1997). This trend will almost definitely continue into the 21st Century with the further growth of the Internet.

To illustrate different possibilities for accessing data over the web, and highlighting varying functionality and cost implications, two web-based approaches were adopted for this study:

1) **Dynamic spatial and attribute display, query and download of information.** This approach makes use of Internet Mapping software that allows for interactive query and display of both spatial and non-spatial (or attribute) information. The spatial display function allows a user to zoom in/out, pan, view contextual information such as roads and catchments etc. Other capabilities include basic map production and access to the most up-to-date wetland information. Information can be accessed through either spatial references (e.g. clicking on a polygon in KwaZulu-Natal) or non-spatial references (e.g. typing the name of a wetland).

2) **Static spatial display, with dynamic attribute query and download.** The static spatial option provides predefined maps or images (for example in the form of .jpg files) that would need to be updated by the wetland database managers and the Webmaster if and when the data changed. These static images are "dumb" pictures and cannot be queried, but they can be downloaded by users as a map. Non-spatial attributes can still be queried dynamically in much the same way as the interactive spatial approach.

The infrastructure at the CSIR has been used to host a demonstration web site, which illustrates the two web-based approaches.

Existing data dissemination facilities where data can be stored and made web-accessible have been investigated. Discussions were held with the Department of Environmental Affairs and Tourism (DEA&T) Directorate of Environmental information and reporting, the Department of Water Affairs and Forestry (DWAF), the Department of Land Affairs (DLA) NSIF initiative, and the South African

Integrated Spatial Information System (SA-ISIS) initiative funded through the Department of Art, Culture, Science, and Technology (DACST).

4.1.2 Database

Information about wetlands needs to be collected, and stored in a standardised fashion in a well-structured database that houses all spatial and non-spatial (attribute) information relevant to a wetland inventory. Easy access to this information is a key requirement of a successful database.

The MedWet (Mediterranean Wetland Inventory) database has been made available to the South African Inventory. The ToR required that MedWet be examined in terms of stability, accessibility, adaptability, ability to handle the expected size of the database and compatibility with Arc/Info and other database systems used by primary stakeholders such as DWAF, DLA, and NDA.

The approach to assessing the applicability of MedWet to the South African context was to:

1) Determine the requirements for South Africa based on the required attributes, stability of the database, accessibility, size, format, speed, compatibility with Arc/Info software, and compatibility with other primary stakeholder database systems;
2) Evaluate the MedWet database against the South African requirements;
3) Determine from MedWet owners and developers usage and/or modification rights to MedWet; and
4) Make recommendations as to whether to modify the current MedWet database or to develop a new database structure that meets South Africa's requirements.

A workshop to define the South African wetland inventory requirements was held with attendance from national, provincial and private representation. The following issues were discussed at this workshop:

- Attributes to be captured (this included considering attributes specified during the 4-5 November 1997 workshop);
- SA classification system;
- Scale of information capture for a national inventory (i.e. national, regional);
- Scalability of the database;
- Time series capture;
- Updating of information;
- Estimated size of the database;
- Current hardware and software capacities;
- Compatibility with DEA&T and other governmental organisations;
- Additional functionality e.g. reporting, querying;
- Database security; and
- Discussion around MedWet

A list of South African requirements was compiled from the workshop and compared with the MedWet database. MedWet had to be analysed against the **proposed** South African classification system, as the classification system has not yet been finalised. The proposed system is the Cowardin system with inclusion of additional modifiers (see Chapter 3, section 3.2.4).

The developers of MedWet were contacted to clarify and discuss certain issues. A new version of MedWet is already under development and according to the developers is almost complete. A copy of the new system was not made available in time for this analysis, therefore conclusions made around MedWet are based on the current MedWet system (MedWet 2000) with some consideration for the additions and changes made to the new system.

The housing and dissemination of wetland information is a vital component of the overall wetland inventory in that a well-structured, reliable, and accessible database lays the foundation for appropriate analysis, monitoring, and decision making of wetlands in South Africa. Three approaches to data dissemination were considered: paper hardcopy maps; CD-ROMS; and web-based facilities for viewing and downloading of data. The MedWet database, made available to South Africa for the inventory, will be analysed for applicability in South Africa. The assessment looks first as what is required for South Africa and then compares these requirements to the MedWet database. Compatibility with primary stakeholder database systems is also assessed.

4.2 RESULTS

4.2.1 Data Accessibility

The advantages, disadvantages, and cost implications of each of the three data dissemination methods analysed are detailed in Table 4.1 below.

Table 4.1 Advantages and disadvantages and cost implications for data dissemination methods.

Method	Advantages	Disadvantages	Running Cost Implications	Labour Cost Implications
Paper hardcopy maps	Cost of consumables is low. A programme can be set-up to automate the production of maps. Templates can be set-up beforehand that standardise the layout and content of the maps. People with no access to the internet are not compromised.	A GIS operator would need to be available to produce the maps. As requests are received on an ad-hoc basis depending on user needs, this procedure is disruptive to normal work requirements, unless the person is dedicated to map production. Still need to disseminate digital data (i.e. vector and associated attribute data)	A0 plotting paper: R300 per roll Plotting inks: R1500 per colour (need cyan, magenta, yellow, and black) A0 plotter: R60 000 to R150 000	High labour costs continuously, even with programme to automate map production. Procedure would be receiving order for map, creating and plotting map, checking results and finally delivering the map.
CD-Rom	Cheap and simple method of data dissemination. People with no access to the internet are not compromised.	High labour cost to distribute up-to-date information. Need a person available to respond to requests for CD's.	CD cost: between R10 – R20 per CD, CD burner: around R1000 to R2000.	High labour costs continuously. Level of labour requirements dependent on approach. For example two different approaches outlined below: 1) Batch process CD's with new data at a specified interval e.g. once a year. The batch process can be contracted out at minimal cost. The CD's can contain national

Method	Advantages	Disadvantages	Running Cost Implications	Labour Cost Implications
				and/or predefined subsets of data (e.g. provincial coverage) 2) Respond to individual user requests as and when received. This provides the user with customised and up-to-date information but is very labour intensive.
Web-based: spatial dynamic	The most up-to-date spatial and attribute information is always accessible to users for download or query. A user can define and download data for specific areas of interest, not predefined datasets at national or provincial levels. A user can create their own customised maps. Additional information which may be of interest to users is available through the mapping software e.g. distance measurements, area, surrounding land use etc. A seamless integration between the spatial vector data and the associated attribute information, no matter if the attribute data resides in and external database such as MSAccess or any of the major relational database such as Oracle, SQLServer etc. Low web-site maintenance in terms of	People with no access to the internet would have to be accommodated through either maps or CD-Rom. Downloading of large datasets through the internet may be a problem, depending on the users internet linkage capacity.	Internet Mapping software (IMS) e.g. ArcIMS approximately R100 000 (quoted @ $1 = R11.50) A dedicated ArcIMS Server Specifications: Dual P3 1 ghz processors 1024 mb SDRAM 36 gb SCSI Hard Drive e.g. Dell Computer cost approximately R 40 000 Web server with associated software and licenses to serve data over the web. Most organisations already have this capability, so potentially no additional cost here. See Appendix 4A for additional information re the web-based system requirements	High labour cost initially to set-up the system; very low maintenance cost once the system is established.

Method	Advantages	Disadvantages	Running Cost Implications	Labour Cost Implications
	presenting updated spatial information to users The query of both spatial and attribute data is interactive.		OR The cost for an existing facility to host the web site. Costs will vary depending on chosen facility.	
Web-based: spatial static	The most up-to-date attribute information (not spatial information however) is always accessible to users for download or query. Dynamic query of attribute information.	Updates are needed to the web site whenever the spatial vector data or attribute information change. New images would need to be recreated and loaded onto the web server. Maintenance of the system is higher than the dynamic spatial approach. Images cannot be queried for additional information, as is the case with the dynamic option. Separate functionality to download spatial information would need to be built into the site. for example, access through an FTP site.	Web server with associated software and licenses to serve data over the web. Most organisations already have this capability, so potentially no additional cost here.	High labour cost initially to set-up the system; medium maintenance cost once the system is established to provide updated spatial information.

A prototype web site, established at the following address, http://wetlands.csir.co.za/website/wetlands_inventory/ demonstrates the two approaches adopted for the web-based data dissemination study, i.e. the dynamic spatial and static spatial approaches. The data supporting the site is a spatial coverage (Arc/Info shapefile format) of all the field delineated wetlands derived for this pilot-inventory project, and the attributes of one wetland site in the Viskuile wetland complex (Davel area) entered into the MedWet database. The attributes in MedWet include: catchment information (B11A quaternary catchment) on land use, physiographic and locational information; wetland site and habitat information, hydrology characteristics, Ramsar criteria, wetland status and values, classifications, threats and pressures, and amphibian and mammal species presence.

The spatial wetland database has not been optimally designed or normalised and should not be regarded as a prototype design for the final wetland inventory. The spatial attribute database design should only be finalised once a decision has been made around the use of MedWet or an alternative database to store the final wetland inventory information.

Existing facilities for data storage and web-accessibility

Discussions have been held with DEA&T to determine their current capacities as well as their future long-term plans for database storage and spatial web-enablement. While DEA&T currently makes use of Arc/Info software for data manipulation, map production, and spatial analysis, they have no short to medium term plans to acquire the necessary software for database housing and web-enablement, such as a relational database (RDBMS) or Internet Mapping software (IMS) (Marais D, 2002).

While DEA&T defines their GIS requirements, a data storage and web hosting service could be offered by governmental organisations or commercial enterprises. A number of organisations were contacted to determine the feasibility of this service:

- The Department of Water Affairs and Forestry (DWAF) has a well-developed GIS section and the necessary facilities to host a web site. They use ESRI products, including Arc/Info, ArcIMS and ArcSDE (Informix). Initial conversations with DWAF indicate that they would be happy to pursue the idea of disseminating the wetlands database through their facilities (Gouws A, 2002).

- The Department of Land Affairs (DLA) is involved in several data sharing initiatives. The first, which has been ongoing for a number of years, is the National Spatial Information Framework (NSIF). The framework provides a Spatial Data Discovery Facility that allows users to browse through metadata records on nationally available spatial information. The second, in line with inter-governmental data sharing policies, is a prototype project, which generated an Interdepartmental Project Viewer (IDPV). The IDPV combines the data from Public works, DWAF, and DLA and presents it through Internet mapping software. There are plans to continue with this project along the lines of an information system, which is used to prepare spatial plans. The DLA, as with DWAF, is open to further discussions around the potential hosting of the wetlands inventory database (Osei S, 2002).

- The South African Integrated Spatial Information System, better known as SA-ISIS, is a DACST funded project, which is nearing the end of a three-year funding cycle. SA-ISIS integrates three separate spatial databases residing in different parts of the country: BioMap; AGIS; and MIDeSS. The innovative portion of the project is the facility, which combines the separate databases and presents a seamless interface of data and tools to a user. The mechanism of integration is through the Internet; clients request information through the web interface and the server sources information from various nodes (where the databases reside) to provide an answer.

  As SA-ISIS is a DACST funded project it is expected to become a commercial venture after project completion. The future of SA-ISIS is therefore being discussed at the moment. There are two proposed scenarios (Barwell L, 2002):

  1) CSIR Information Services (CSIRis) manages the integrative facility of SA-ISIS. The database management and updating resides with the original data owners. There is a requirement for a system administrator role to ensure that the system is stable and up and running at all times. The CSIRis would play that role. The commercial success of SA-ISIS would be dependent on the market forces and the level of demand for the data and solutions. A subscriber or per transaction cost is envisaged as a way to raise funds for maintenance of the system. Contributions in kind e.g. provision of important data sets, will be considered as an alternative to subscription or transaction costs.

  2) Sell off the code/development to a private company who will commercialise the product as they see fit.

  As the SA-ISIS system provides not only assess to data, but also to tools, it is possible to develop and integrate tools, which may be useful to the wetland inventory database. An existing tool is the reserve selection tool, which queries the BioMap database containing species information. A useful tool for the wetlands inventory may therefore be, for example, a “wetlands species selection tool” which interrogates species information residing in the BioMap database and populates delineated wetlands with species occurrences. Once/if a detailed species survey has been conducted on a particular wetland, the BioMap derived information could be replaced. Potentially the detailed wetland information could be made available to others through the SA-ISIS system.

- The CSIR, currently hosting the prototype web site, has the capacity to extend this support into long-term management of a final national wetland inventory web site.

The cost to host such a site has not been established. While government organisations would probably provide a free service to DEA&T, any commercial or parastatal organisation would most likely charge a monthly maintenance fee.

4.2.2 Database

The requirements for a South African wetland inventory database have been defined through workshops and discussions with stakeholders at various levels (governmental, provincial, NGO's). These requirements and a comparison of these requirements with the MedWet database are presented in this section.

4.2.2.1 South African Wetland Inventory Database Requirements

From a high level perspective the purposes of national wetland database have been identified as providing information for:

- Ramsar site identification (identifying the importance of wetlands and their Ramsar types);
- Policy Development and monitoring;
- Rehabilitation;
- State of Environment reporting - indicators (provides baseline data and includes the distribution of wetlands);
- Reserve determination (biota, habitat, water quality & water quantity);
- Determining the importance of wetlands from a socio-economic, ecological, and cultural perspective);
- Capturing the classification system;
- Delineation of wetlands;
- Prioritisation of areas that need attention; and
- Biodiversity conservation (presence/absence of species).

The specific database requirements for a national wetland inventory are defined as being:

- ***Spatially enabled***
  The mapping methodology of the SA wetland inventory will be to capture data spatially through the use of a GIS system. Viewing these wetland boundaries in context of each other and in the regional and national context is essential.

  Further, much of the information required for a national inventory can be derived from existing spatial data by performing spatial overlays and analysis. This approach is especially applicable at the catchment level where national datasets of approximately 1 : 250 000 scale would be appropriate. This approach allows for automated data capture saving the user a considerable amount of time, which would have been spent inputting the data manually (see Table 4.5).

- ***Time series based***
  A national inventory database must be applicable for monitoring and reporting. Monitoring to determine for example how successfully the wetlands are being managed / conserved over time. Reports which may be based on the current status of the wetlands are needed at various frequencies for example regions to the national office on the status of wetlands in the provinces on a yearly basis, and national office reporting to the Ramsar convention. It is therefore advantageous for the database to store time series information to allow for change detection and analysis, and facilitate report writing.

- ***Attributes***
  Attributes identified as essential for a national wetland inventory are listed in the table below (Table 4.2).

- ***Classification system(s)***

Classification systems which must be included in the database include the Ramsar classification, the South African classification, and a biological classification (not yet devised).

- ***Scalability of the database***
  The database should make provision for not only national level information i.e. information collected as part of a nationally conducted inventory, but also for regional level applicability. Database must suite the needs of both provincial and national offices, as well as NGO's and consultants. Not all attributes within the database need be populated during the national inventory, but the database must be designed to contain attributes relevant for more detailed studies that may be carried out at regional levels.

- ***Security***
  While it is a requirement that the database is freely and easily accessible to most parties, there will be information in the database which will have restricted access. A typical example is public access to rare species information. A database with the facility to create varying levels of access to different users will be necessary.

- ***Quantity of data***
  The size of the database is difficult to estimate as this depends on the amount and type of data stored. The KwaZulu-Natal database is approximately 20 Mb (not a large database), including spatial and attribute information. The attribute information stored is not as detailed as the list compiled for the national inventory (Table 4.2). A guestimate based on the wetlands captured during the pilot-study is that approximately 700 000 wetlands would be captured in a national inventory. Time series data and visual images (e.g. photographs) add considerably to the size of a database.

  All indications are that a national database with spatial and attribute information would be extremely large, especially if time series information and visuals (photographs) are incorporated.

- ***Updating/ Maintenance of the database***
  Once the national inventory has been conducted and the database populated, there will be a need for updates to keep the information in the database current. Updating is likely to take place in two ways:

  - By the provinces on a regular basis, performing more detailed surveys depending on their day-to-day management needs;
  - At the national level follow-up inventories may be commissioned from time to time for reporting needs.

- ***Functionality***
  Additional functionality includes reporting capabilities, for example site and attribute specific reports, and national and provincial state and trend reports, and query tools, for example does this wetland meet the RAMSAR criteria?

Table 4.2 List of required attributes for a national wetland database.

Attribute type	Description
Meta data	Meta data or "data about data" must be linked to each wetland polygon. For example the FGDC standard can be applied. This standard documents who collected the data, at what time, the accuracy of capture etc.
Published reference material	Publications, conference presentations, books etc.
Visual material	Visual material such as photographs or video clips are useful references to describe the characteristics of a wetland.
Current state of wetlands	Defines wetland *pressures* e.g. grazing, pollution, *extent of the impact* e.g. light, heavy, *persistence* e.g. continuous, intermittent, and *present ecological status* (link to reserve management)
Location	Includes such information as coordinate location, map number, farm

Attribute type	Description
	name, catchment number and name etc.
Threats at catchment and site level	Includes such information as the degree of threat, immanence, and type of threat.
Current uses of wetlands	Grazing, livestock watering, nutrient cycling
Hydrological determinants	Hydrological regime, groundwater, quality and quantity
Geomorphological determinants	Geomorphological setting, geological features, soils and topographical features
Ecological features	Habitats, species occurrence (RDB and others), species abundance, unique communities, person who collects data, date stamp
Physical attributes	Size, perimeter, depth, soil, geology, position in landscape e.g. ridge, valley bottom, local catchment size
Tenure	Ownership (state, private, communal), protection category e.g. national park, Ramsar etc.
List of benefits	Social cultural and economic benefits, and reasons why these are perceived to be important
Conservation importance	Includes information such as irreplaceablility, ecological reserve category
Functionality or functional type	Biological, hydrological, geomorphological and water quality functional types
Classification	Ramsar, SA system, Biological, and functional type classifications
Monitoring and research	Where, how, who, what, when.

4.2.2.2 MedWet Evaluation

Note: MedWet 2000 has been evaluated for this project, a newer version is being developed but unfortunately was not available in due time for an evaluation to be included in this report. New features have been added to the updated MedWet version. These new features include the ability to handle time series information and spatial data. How these new additions impact on South African requirements cannot be properly ascertained without viewing the software.

Background Information
The MedWet database is a computer programme created to enter, store and analyse the data recorded using the MedWet methodology for wetland inventory (MedWet Reference Manual: Manual 1). The software closely mimics the datasheets developed for recording the data of the inventory. The software therefore records such information as the location of wetlands, and individual wetland characteristics.

The database structures information in a hierarchical fashion – catchment area, wetland site, and wetland habitat. Wetland site data is linked to a particular catchment (through the use of a catchment code), and wetland habitat information is similarly linked to a site through a unique site code). Numerous data dictionaries are used in the application to speed-up and safeguard the data entry process. A data dictionary is a table with names and usually descriptions associated with a unique set of codes. A user entering data will select a value from the relevant data dictionary. This reduces the chance of typing errors, as the user does not have to type values from scratch. An example of a data dictionary would be the bird species dictionary: all South African bird species, with scientific and casual names, would be entered into the data dictionary, allowing a user to select the relevant species from a list instead of typing the species name etc manually.

The types of information stored in MedWet include:

At catchment level: code, name, area, climate, location, elevation, human characteristics e.g. population, land cover, references, maps, aerial photo's, key contacts

At wetland site level: location, elevation, catchment, area, length, bioclimate, met station, distance, inflow, outflow, and presence of water, geology/geomorphology

At habitat level: CORINE biotopes, habitat directive, Ramsar wetland types, Ramsar criteria, wetland values, status, habitats – classification, name, description, water permanency, water salinity, depth, condition, artificiality, activities and impacts, flora and fauna, and images, references, contacts, maps, aerial photo's

Reports are generated as an output from MedWet. The types of reports that can be generated include catchment summary reports, site lists, site information (functions, Ramsar criteria etc), habitat, and observations (flora, fauna, human activities).

MedWet Ease of Use
MedWet 2000 is programmed in Visual Basic and uses MSAccess as the data storage mechanism. It is supported on Win95/98, Pentium PC with at least 16 Mb RAM and 30 Mb free disk space. For the evaluation, the programme was installed on both Windows 98 and Windows 2000 (although officially only supported on Windows 98) and was found to operate similarly on both platforms.

From the author's perspective, the programme is well structured making the software relatively easy to use. On-line HELP documentation would have made the experience much easier, as would have explanation notes or tips relating to more complex entry fields. Readily accessible information detailing which data dictionary to edit in relation to which entry field would also have been very useful.

Errors and bugs were experienced during the use of MedWet, some of the errors relating to error trapping, for example, the software bombs if you choose to go to a selected site if you have not first selected a record from a list. This is a simple mistake that first time users can easily make. Other errors were experienced attempting to add and edit references and contact lists. Major problems were experienced if the programme is installed in any other directory other than the one recommended by the programme (i.e. c:/mwd2000).

Correspondence with the developers of MedWet revealed that MedWet 2000 had many problems being used in some countries due to system incompatibilities relating to the Visual Basic and MSAccess tools. (Costa LT, 2002). A new version is thus being developed by the Greek Wetland Biotope Centre (EKBY).

Usage rights to MedWet
Communications with Spyros Kouvelis, the MedWet Coordinator, in late January indicate that the use of the database for third parties is not yet fully clarified. In the interim, some sort of memorandum of understanding (MOU) for license use could be arranged which would detail any planned modifications.

4.2.2.3 Comparison of South African requirements and MedWet

For the purposes of this comparison it has been assumed that the South African classification system will be the Cowardin classification, with additional modifiers such as landscape and land use modifiers.

The comparison was conducted by finding the equivalent attribute(s) in MedWet that met a specific South African requirement (Table 4.2). If an equivalent attribute was located, it was then determined whether the requirement was fully or partially fulfilled (see column three Table 4.3: Yes if requirement fully met, No is requirement not met at all, and Partial if the requirement is partially met.)

Table 4.3 Comparison between SA attribute requirements and MedWet

List of South African Requirements	**MedWet comparison**	**Yes/No/ Partial**
Metadata	A list of key contacts and compilers but no other metadata e.g. capture accuracy, data sensitivity	No
Reference material	Reference facilities for books, need to be tweaked slightly to be applicable for journals	Partial
Visual material	Stores bitmap images relating to aerial photographs	No
Monitoring and research	Not time series based so difficult to use for monitoring or change based analysis	No
Per Wetland Site:		
Classification – Ramsar		Yes

List of South African Requirements	MedWet comparison	Yes/No/ Partial
Classification - South African	Includes the Cowardin classification. Does not include all the modifiers that have been proposed for the SA classification.	Partial
Classification - Biological		No
Current state of the wetland – pressure	In MedWet terminology: Activity	Yes
Current state of the wetland - extent of impact	MedWet terminology: Impact | Scale and possibly Activity | Importance	Yes
Current state of the wetland - persistence	MedWet Terminology: Activity | Trend	Yes
Current state of the wetland - present ecological status	Documented under Conservation Information	Yes
Threats to wetland (degree of threat, type and immanence)	MedWet terminology: Impact	
Current uses of the wetland	Similar to Activities, so therefore represented	Yes
Hydrological determinants - regime	Documented under MedWet classification | Hydric regime, and additional info recording Inflow and Outflow and Permanency (under Wetland sites | Description)	Yes
Hydrological determinants - groundwater		No
Hydrological determinants - quality and quantity	No direct reference to quantity or quality, but reference to water salinity and pH range, water permanency, depth.	Partial
Geomorphological determinants - setting, geological features, soils, and topography	Stores bioclimate, elevation, geology and geomorphology descriptions. No reference to topographic settings.	Partial
Ecological features - habitat	Stores Corine biotopes and Habitat Directives, which have no real connection to the SA situation. Preferable to include the South African NBI biomes, wetland eco-regions etc.	Partial
Ecological features - species occurrence, abundance, unique communities	Stores species, abundance, and status e.g. rare. Have not located anything on unique communities	Yes
Ecological features - collector of information, date stamp	Date time stamp, collector of info linked to site category, not specifically to species inventories.	Partial
Functionality or functional type (biological, hydrological, geomorphological and water quality types)	MedWet terminology: wetland values (Wetland site | Values)	Yes
Conservation importance - irreplaceability, reserve category	Gives reserve category, no assessment of irreplaceability, can specify RAMSAR criteria	Partial
Physical attributes (size, perimeter, depth, soil, geology, position in landscape)	Includes most physical attributes, but no soil or position in landscape information	Partial
List of benefits - social and economic		No
Tenure (ownership, protection category)	Included in comment fields under conservation information	Yes
Physical location - coordinates		Yes
Physical location - 1:50 000 or 1: 250 000 map sheet number		No
Physical location - farm name or landuse type		No

List of South African Requirements	MedWet comparison	Yes/No/ Partial
Physical location - catchment number and name	Can give the catchment code the quaternary catchment code number e.g. V20A	No
Per catchment area		
Threats to catchment	Land cover types (based on % artificial, agriculture, forest etc) per catchment area, and comment field for global impacts and threats.	Yes

MedWet stores additional information which has not been specified as necessary for the South African situation. For example CORINE Biotopes and Natura2000 which are initiatives that collect information on the environment in European Union countries. Equivalent or similar information, with South African applicability could be incorporate in place of these EU initiatives for example the NBI biome data, or the wetland eco-regions delineated by Cowan (Cowan 1995).

The dictionary structure can be used effectively in South Africa, but will need to be populated with South African data and standards.

4.2.3 Compatibility with DEA&T and other primary stakeholders

The ToR indicated that any wetland database that is developed should be compatible with DEA&T and other governmental departments and provincial offices. Current software and hardware capacities are listed in Table 4.4. Generally, compatibility is not a huge issue as open data sources like the ESRI ArcView shapefile format (recognisable by probably all GIS packages) can be used to transfer spatial information, and attribute data can be downloaded to ascii format if absolutely necessary and ported into another relational database. A better solution would be to write routines or programmes which automate exchange of data if this found necessary.

Table 4.4 DEA&T and primary stakeholder software and hardware capacities.

Current Software:	
DEAT	ESRI Arc/Info, ArcView3.2 and ArcView 8.1. MSAccess is the most widely used database.
DWAF:	ESRI range of products - Arc/Info, ArcView (3.2 and 8.1), ArcSDE, ArcIMS
Provincial offices:	Most regional offices are running ArcView 3.2, with the exception of one province which runs Geomedia. MSAccess is used throughout the provinces.
Current Hardware:	
DEAT	Pentium PC's, Unix
Provincial Offices	Pentium PC's

4.2.4 Existing National GIS Information Applicable to a National Wetland Inventory

GIS information can be used to populate many of the attributes required in a national inventory. An inventory system, integrated with GIS could automate the population of many fields required in the inventory database, thus negating the need for a user to laboriously enter the information manually. Generally this information is applicable at the catchment level, not at the wetland site level, where national level GIS datasets can provide qualitative and descriptive information about an area. A list of nationally available datasets, which could provide input to the inventory, is provided in Table 4.5.

Table 4.5 Existing GIS information available at a national level which can be used to populate catchment level inventory information.

Information	Inventory level	Scale	Source	Cost
Geographic coordinates	Catchment and site	Dependent on scale of data capture	Inherent in any GIS system	No cost
Catchment name and code (primary through	Catchment	1 : 500 000	DWAF	Free data sharing policy

Information	Inventory level	Scale	Source	Cost
to quaternary)				
Elevation (minimum, average, maximum)	Catchment and site	Available for the whole of SA at 200 or 400 metres applicable for catchment level Available for the whole of SA at a 50 x 50 m grid (derived from 20m contours)	Surveys and Mapping and Private organisations	200 or 400 m R250 per 1: 50 000 sheet 50 m DEM R400 per 1:50 000 sheet
Area (for example quaternary catchment and wetland site)	Catchment and site	Dependent on scale of data capture	Inherent in any GIS system	None
River length within the catchment	Catchment	1 : 250 000 or 1: 50 000 river coverage	DWAF	Free data sharing policy
Temperature	Catchment	1 x 1 km grid	CCWR	No cost
Rainfall	Catchment	1 x 1 km grid	CCWR	No cost
Geology	Catchment	1 : 250 000	Council for Geosciences	The cost for a 1: 250 000 sheet varies from sheet to sheet depending on the complexity of the polygons. A rough estimate is R1600 for simple sheets to R16 000 for complex sheets
Soil	Catchment	1 : 250 000	ISCW	Approx R1500 per 1:250 000 sheet
Topographic index or terrain characteristics	Catchment	Can be derived from elevation information	Derived	HR Cost to produce product only (if elevation data mentioned above has been purchased
Population statistics	Catchment	Linked to EA's	Statistics SA	R40 000 for the 1996 census data. 2001 census costs still being determined, but envisaged to be a similar price to the 1996 census data cost.
Land cover / Land use	Catchment	1 : 250 000	CSIR	No cost for the 1996 national land cover database. 2000 land cover initiative (capture at 1: 50000 scale) – cost still under discussion
Mean annual runoff (MAR) per quaternary catchment	Catchment	1 : 500 000	DWAF (WRC)	Free data sharing policy
Conservation information e.g. protected areas	Site	1 : 250 000	DEAT	Collection of data coordinated through DEAT.
Map name/number	Catchment and site	1 : 250 000 index 1 : 50 000 index	Surveys and Mapping	Available at no cost

Information	Inventory level	Scale	Source	Cost
Land tenure (state, private owned land)	Site	Attribute information drawn from deeds office; Spatial information from SG office 1 :50 000	Department of Land Affairs	No charge for government organisations
Species data	Catchment level or possibly site level	Quarter degree grid/ or possibly point locations	SA-ISIS	Cost to be negotiated depending on relationship between organisations

4.3 RECOMMENDATIONS

4.3.1 Data dissemination

A recommendation is made to implement a web-based data dissemination method, which allows for dynamic query of both spatial and non-spatial data. Although initial labour costs may be high while implementing such a system, the long-term benefits in terms of saved labour costs are substantial.

The web based approach can also effectively facilitate all the potential dissemination methods i.e. hardcopy paper maps can be printed or downloaded from the web interface, and vector data can be downloaded from the web to a users hard drive, making the distribution of CD's unnecessary.

4.3.2 Database

From the analysis in earlier sections, is it clear that modifications to MedWet 2000 would be needed in order to meet all the listed requirements for South Africa. Some modifications would be minor, for instance adding a field to store an additional hydrological determinant; other modifications would, however, be major. Significant modifications for example are transforming the database to capture time series information, and spatialising the database. Further, the size of the national South African inventory database is likely to be considerable, and MSAccess is known to be more suited to small-scale localised databases, rather than large-scale national databases. Speed of data retrieval becomes severely compromised if the database becomes too large.

Based on the fact that some of the modifications required to MedWet are significant, that the database has not been found to be stable enough for wide-spread use, that the size of the national database will exceed the capacity of the current MedWet database structure (MSAccess), and that 3rd party access rights to MedWet have not yet been fully determined, a recommendation is made to develop a new wetland inventory system. Certain of the MedWet concepts should be utilised in the new database and these will be discussed in the section below.

It is however suggested that the new MedWet system be assessed and more detailed discussions held with the MedWet owners to determine 3rd party access rights before making a final decision. The newer database contains additional functionality, which may very well meet several of the South African requirements. We were not able to secure access to this database in time to evaluate if these functions do indeed fulfil what is envisaged for South Africa.

Recommendations for a new national wetland inventory database

A full user needs assessment should be conducted to determine the exact requirements of the wetland inventory database (database here refers to the capture of wetland data, the data storage facility, and the interface that interrogates that data), however general database structure and functionalities can be described at this stage and are outlined below.

Database Structure:

- At the national level due to the volume of data that will be stored, a robust relational database (RDBMS) should be used as the storage mechanism, such as Oracle, Informix, or SQL

Server. The database can be easily web-enabled for data dissemination. A database such as MSAccess is not appropriate for the national database as it tends to slow down and become unusable when populated with too many records.

- At the provincial level however, the volume of data will be much less and therefore a database such as MSAccess can be used. There are obviously trade-offs in using MSAccess in terms of speed and security and ease of use. MSAccess is not as fast and does not have the security that the other RDBMS have, however it is a database that is easy to install and maintain. An added advantage is that all the provincial organisations already have MSAccess and therefore do not have to spend money and dedicate time to purchasing and managing a database such as Oracle or SQL Server.

- A non-database dependent interface should be developed to allow the same interface to query data residing in any relational database whether that be SQL Server, Oracle at the national level or MSAccess at the provincial level.

- The national database mirrors the structure of the provincial databases, and duplicates the provincial databases. This can be useful as a backup if data is corrupted. The provinces, who will be largely responsible for the updating of wetland information once the inventory is complete, would send the national office updates at a specified interval, perhaps yearly, and national office would collate the data into one database. The collation can be automated through routines.

- The database could be housed at any one of the existing facilities mentioned in section 4.2.1 or at DEA&T if the necessary infrastructure documented in Table 4.1 is purchased. As developments and changes are likely to take place in organisations from now until the national inventory project commences, more detailed investigations should be conducted once the inventory has been commissioned in order to determine the best possible solution for the housing of the inventory database.

Functionality:

- Time series based;
- Fully integrated with GIS
  GIS be used to capture wetland boundaries and classifications, for display and query of wetland information, as well to as to automate the population of relevant attributes at the catchment level. Table 4.5 details the spatial layers that can be used to generate attribute information;
- Use drop-down lists wherever possible to capture data;
- Make use of pre-compiled country wide data dictionaries;
- Select or query wetlands through either spatial or attribute means;
- Generate reports;
- Make provision for the capture and storage of data relevant at both provincial and the national level (Table 4.2);
- Different levels of data security depending on user.
- Set-up correct tolerances depending on minimum mapping units adopted for spatial capture of wetland boundaries (mainly applicable if using the heads–up digitising method)

Certain aspects of the MedWet system can be adopted for the South African system, such as the hierarchical structure (catchment, site, habitat) but should be modified to catchment, wetland complex, site, the data dictionary concept, and the database table structure itself which can be used as a starting point for future database design.

Another important issue to consider is the derivation of a unique numbering system for all wetlands across the whole of South Africa. This unique numbering system must be implemented so that each wetland and it's associated attributes can be uniquely identified. This system must be worked out before data capture of the wetland boundaries and attributes begin. Such issues have been considered, for example the alien vegetation national database, compiled by WfW, and a similar approach could be adopted here.

4.4 REFERENCES

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APPENDIX 4.1. PROPOSED SYSTEM REQUIREMENTS TO HOST A WEB-BASED IMS SITE

Recommended requirements to host a web-based IMS site:

- ArcIMS software
  Cost of approximately R100 000 (quoted @ $1 = R11.50)

- A dedicated ArcIMS Server

  Specifications:
  Dual P3 1 ghz processors
  1024 mb SDRAM
  36 gb SCSI Hard Drive
  3 year on site maintenance

  Cost of approximately R40 000 (quote from Dell Computers)

- A web server, which can be the same machine as the ArcIMS server. If the ArcIMS server and the web server are two different machines, they should be physically close to each other i.e. on the same sub-net. Web server software like Apache or MS Internet Information Server should be set up on this web server machine, along with a Servlet Engine like Tomcat or ServletExec. Most of these pieces of software are free or bundled with the operating system

- A relational database (RDBMS), while not essential, is an advantage for the storage of large databases such as the national wetland database. One of the cheaper RDBMS is MS SQL Server, which costs approximately R20 000 with 5 Client Access Licenses (CAL). Each additional CAL would cost R 2000.00. Alternatively, a Processor License which has unlimited access licenses, could be acquired at approximately R64 000.00. Other relational databases such as Oracle and Informix are typically 3 times the cost of SQL Server.

- Spatial Database Engine (SDE), while also not essential, is useful for storing spatial data within a relational database. The advantage is that all your information, spatial and attribute, can reside in one database, which makes management of your information easier.

  Cost of approximately R120 000 (two CPU).

- Additional CPU (i.e. 3rd CPU or greater) R37 000.
  Maintenance per year after 1 year:
  Two CPU R47 600
  Extra CPU R7 100

  Quote received from GIMS 26 February 2002.

CHAPTER 5: Cost Benefit Analysis

This chapter provides a summarised breakdown of the costs associated with each mapping methodology. Training will be required for some of the approaches to bring teams up to speed, and this has been indicated for methods where it is considered. Costs have generally not been specified at this stage as these will vary depending on the training organisation used, current level of skills of staff to be trained etc. The team is willing to advise DEA&T on possible approaches to take in this regard should they require assistance. An indication of whether specific hardware or software will be required has also been provided, but again, costs will vary depending on the service provider or organisation from which these items need to be purchased. Costs have therefore not been provided for this aspect, as they could be misleading.

These cost estimates provided are for a 1:50,000 topographic map sheets. For certain approaches, it is possible to provide accurate costs based on current prices of imagery etc. For the field related costs, accuracy will depend on the complexity of the wetlands to be delineated or captured. So illustrative costs have been provided based on a hypothetical 1:50,000 sheet with an array of wetlands chosen to reflect differing complexities and a likely scenario for a typical 1:50,000 map sheet in an area of average wetland density (Table 5.1). The density, perimeter and area of wetlands on the hypothetical 1:50,000 sheet was then compared with real data from the Steenkampsberg and the upper catchment area of the Olifants River, both areas of very high wetland density and varying complexity. This was done in order to try to establish the extreme ranges of densities of wetlands nationally and provide a perspective of where the hypothetical 1:50,000 sheet sits in relation to these. The percentage difference in numbers of wetlands, wetland areas and perimeters, and wetland complexity was then calculated and applied to cost-benefit calculations, thereby giving a range of cost estimates for the hypothetical 1:50,000, one map sheet 25% less complex, and one map sheet of an expected complexity close to the maximum that may be expected. This also tested the assumption that simpler wetland coverages would cost less to capture, while more complex wetland coverages would cost more.

Given the range of costs associated with the topographic sheets of differing densities of wetlands, there was simply no way that these could be accurately extrapolated to a national level. In other words, a direct extrapolation by multiplying these values by the number of 1:50 000 sheets nationally will not provide an accurate reflection of true costs. As such, the costs given below simply provide an illustrative estimate based on a range of possible 1:50 000 sheets and anyone wishing to extrapolate these to a national level should be aware of the limitations herein.

Table 5.1. Hypothetical 1:50,000 topographic sheet compared to actual data of 1:50,000 topographic sheets from the upper catchment of the Olifants River and the Steenkampsberg plateau. Wetland complexity = Perimeter^2/area.

	Hypothetical 1:50,000 sheet TOPO SHEET 1	Steenkampsberg Plateau TOPO SHEET 2	Upper Olifants River catchment TOPO SHEET 3
Total area of wetlands (ha)	1876.6	3487.54	6255.53
Average area of wetlands (ha)	125.08	7.52	26.73
Total perimeter of wetlands (km)	211.05	764.24	888.59
Average perimeter of wetlands (km)	14.07	1.65	3.80
Average wetland complexity	206.80	45.79	71.64
Minimum wetland complexity	13.56	12.85	12.63
Maximum wetland complexity	943.41	415.69	1038.42
Number of wetlands	15	464	234
1:50000 map sheet area (ha)	68957.86	69646.59	69250.22
Percentage area of wetlands	2.72	5.01	9.03

The wetland sheets all differed in terms of numbers of wetlands, total and average wetland area and perimeter, and average wetland complexity. The only similarity was the minimum value for wetland complexity that was in the order of 12. This value is similar throughout because it represents the simple pan type wetlands found at all three sites. These examples provide an idea of the difficulty in trying to cost for fieldwork and even mapping using the different techniques and extrapolating nationally. In order to illustrate the potential cost variability that may exist between 1:50,000 topographic sheets, all three of these have been included in the cost estimates for the different techniques. The field delineation costs are based on the man-hours required to delineate all the wetlands for each topo sheet, using only one check site per topo sheet. Field delineation costs are calculated at R300,00 per hour. Where disbursement costs are difficult to estimate, they are calculated based on a percentage of the people costs and as such no specifics are given on the costs for kilometers travelled and accommodation and so on. These values are therefore highly subjective but at least serve to provide an indication of these disbursement costs.

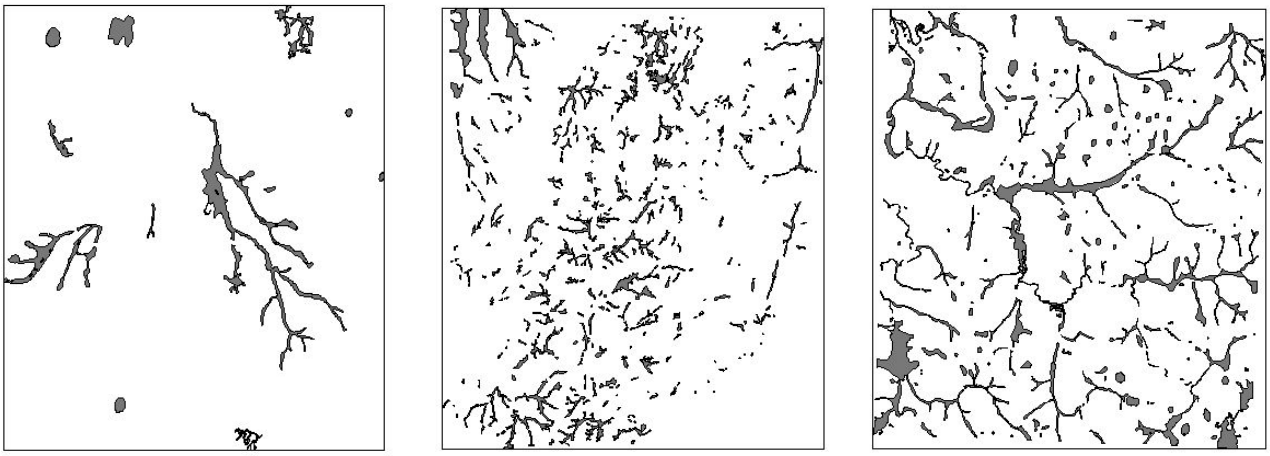
All other people cost calculations are based on the average values given in Table 5.1 above, and on a medium wetland boundary complexity based on a boundary delineation equivalent of 10 km per day. Despite the recognition that the three sites all had different average wetland complexity values, for the purpose of simplicity, field delineation cost calculations were only based on perimeter values for a medium boundary complexity. The estimated costs are given in Table 5.3 below.

The costs for aerial photography per topo sheet are based on an estimated number as per Table 5.2 below and the costs per photo as given in the running costs section of Table 5.3. For the purposes of costing, it is assumed that the scale of photography to be used will be 1:30,000 with a standard 30-60% overlap for all hard copy stereo prints.

Table 5.2. Estimated number of aerial photographs per 1:50,000 topographic sheet. Assumptions are that a map sheet is approximately 50,000 ha in area and that the contact photo standard is 9 inches or 22.8 cm.

Photo Scale	Width (km)	Area (ha)	Non-stereo 0% overlap	Non-stereo 30% overlap	Stereo 30-60 % overlap
1:60000	13.68	18714.24	4	9	12
1:40000	9.12	8317.44	9	16	24
1:30000	6.84	4678.56	12	30	48
1:10000	2.28	519.84	99	208	352

Table 5.3 provides the running costs for each method or approach. Table 5.4 Provides an estimated cost breakdown for each approach based on a hypothetical 1:50 000 sheet as depicted in Figure 5.1. Table 5.5 provides the training and hardware requirements for each approach. Finally, the benefits and disadvantages of each approach are provided in Table 5.6.



TOPO SHEET 1 TOPO SHEET 2 TOPO SHEET 3

Figure 5.1. 1:50,000 wetland maps based on a hypothetical topo sheet (TOPO SHEET1), real data from the Steenkampsberg plateau (TOPO SHEET 2) and real data from the upper catchment area of the Olifants River (TOPO SHEET 3).

Table 5.3: Running cost breakdown for each methodology. Note that all cost estimates exclude VAT.

Methodology	**Running Costs**
Black & White photos: Field delineation: Heads-up digitising non-stereo Heads-up digitising stereo Manual Transfer: Zoom transfer scope Manual transfer: visual non-stereo Manual transfer: visual stereo	Conventional format B/W (hardcopy) 9" aerial photo contact **prints** : R 30 each per print. Conventional format B/W (hardcopy) 9" aerial photo **diapositives** : R 45 per print. Diapositives print formats are required for digital scanning, prior to generation of ortho-corrected photo-mosaics using softcopy photogrammetric techniques. Generation of *new* digital ortho-photo mosaic from diapositive prints : R 400 per diapositive plate used in the mosaic Note : the number of contact prints, and equivalent diapositives need to cover a given area will depend on the original capture scale : the smaller the scale (i.e. 1:5000 as opposed to 1:50,000), the higher the photo detail, but the greater the number of photo prints / diapositives needed. Off-the-shelf digital ortho-photo mosaics (from limited archive available in the Dept. Land Affairs), approximately approx R 220 per ¼ 1:50,000 scale map sheet coverage. If stereo coverage is required, as opposed to non-stereo coverage, then additional contact prints / diapositives will be required in order to achieve the required 60 % overlap. A guide to the number of additional photo's required for stereo coverage is provided below (Table 5.4) Summarised costs (approximate) for a single 1:50,000 map sheet (i.e. 20x25kms ~ 50000 ha), based on 1: 30,000 scale photography : • non-stereo (zero % overlap), B/W contact prints R 360 • stereo, B/W contact prints R 1440 • new digital ortho-photo mosaic R 21120 • existing (off-the-shelf) digital ortho-photo mosaic R 880 All costs are approximated only.
Digital CIR Aerial	Digital CIR imagery prices vary according to spatial resolution and area coverage i.e.

Methodology	Running Costs
Ortho-Photos	• 0.5 m resolution, R 20 ha for < 1000 ha, down to R12 ha for areas > 30000 ha • 2.0 m resolution, R 5 ha for < 1000 ha, down to R2 ha for areas > 30000 ha Summarised costs (approximate) for a single 1:50,000 map sheet tile coverage : • 0.5 m resolution imagery R 600 000 • 2.0 m resolution imagery R 100 000 All prices are approximate and exclude additional once-off costs per aircraft flight (~ R 5 – 10000 depending on flying distances)
Digital RGB Aerial Ortho-Photos	Digital RGB imagery prices vary according to spatial resolution and area coverage i.e. • 0.5 m resolution, R 10 ha for < 1000 ha, down to R5 ha for areas > 30000 ha • 2.0 m resolution, R 3 ha for < 1000 ha, down to R 0.9 ha for areas > 30000 ha Summarised costs (approximate) for a single 1:50,000 map sheet tile coverage : • 0.5 m resolution imagery R 250 000 • 2.0 m resolution imagery R 45 000 All prices are approximate and exclude additional once-off costs per aircraft flight (~ R 5 – 10000 depending on flying distances)
Satellite images	US$ 625 / R 7200 per Landsat image (unprocessed). 72 images required for national coverage. A single Landsat image (180 x 180) will cover approximately 70 x 1: 50,000 scale map sheet tiles, but it is not possible to purchase such small sub-image areas as separate datasets. Currently it is still possible to purchase ¼ image sub-sections (approximately R 3600), but this may be retracted soon. By comparison, the cost of a single SPOT image (either multiispectral or panchromatic, but not both) is currently R 17000.

Table 5.4 Estimated cost breakdown for each approach based on a hypothetical 1:50 000 sheet as depicted in Figure 5.1 Note that all cost estimates exclude VAT.

Methodology	Professional or people costs	Running Costs	Total cost Per 1:50 000 sheet
Field delineation: whole topo sheet	TOPO SHEET 1 21 days R 50,400 TOPO SHEET 2 76 days R 182,400 TOPO SHEET 3 88 days R 211,200 Note that these costs only include the time spent delineating the wetland boundaries and classifying the wetlands and therefore exclude preparation, travel time, landowner and affected party consultation costs etc. which too could be substantial.	As mentioned above, running costs for the fieldwork are difficult to estimate since they depend on proximity to the study area, the number of people involved and the distances travelled to and between wetlands. One could provide an estimate of these simply by making these a percentage of the people costs. This is estimated at 25%. For each of the topo sheets therefore, the running costs are estimated at R12,600, R45,500 and R53,000 respectively.	TOPO SHEET 1 R 63,000 TOPO SHEET 2 R 227,900 TOPO SHEET 3 R 264,200

Methodology	Professional or people costs	Running Costs	Total cost Per 1:50 000 sheet
Field delineation: One check site only	EACH TOPO SHEET 5 days R 12,000	R 3,000,00	R 15,000
Heads up digitising: non-stereo	BASING THE COSTS ON NUMBER OF WETLANDS PER TOPO SHEET CLASSIFIED IN DETAIL TO SUB-CLASS LEVEL TOPO SHEET 1 R 10,125 TOPO SHEET 2 R 313,200 TOPO SHEET 3 R 157,950 Time per wetland was based on the average time spent (2.25 hours per wetland – see Section 3, Table 3.1) in the heads-up digitizing of the wetlands surveyed during this pilot project. Note that this time also includes the digitizing of individual polygons for the classification but excludes the filling in of the data tables to class level. Populating the data tables took on average an additional 40 min per wetland. A discounted rate could probably be considered if the classification was automated. BASING THE COSTS ON DIVIDING THE TOPO SHEET INTO BLOCKS OR UNITS BASED ON THE AERIAL PHOTO'S WITH 0% OVERLAP (Assuming 12 photos at 4hrs per photo for low density and 32 hrs per photo for high density areas and classification at a courser/smaller scale) TOPO SHEET 1 R 14,400 TOPO SHEET 2 R 115,200 TOPO SHEET 3 R 86,400 It is however also important to note that these costs exclude the costs for field verification and the delineation of test sites.	NON-STEREO DIGITAL ORTHO-PHOTOS R 22,000 for new digital ortho-photos R 1,000 for off-the-shelf digital ortho-photo (Plus a once off cost per software set-up of approximately R 15,600 for ArcView 3.2 or R24,000 for ArcView 8)	TOPO SHEET 1 R 11,125 or R 32,125 TOPO SHEET 2 R 314,200 or R 335,200 TOPO SHEET 3 R 158,950 or R 179,950 OR TOPO SHEET 1 R 15,400 or R 37,400 TOPO SHEET 2 R 116,200 or R 137,200 TOPO SHEET 3 R 87,400 or R 108,400 The values are intended to provide some idea of the range of costs that could be expected depending on the detail required in terms of the classification (or fixing of the scale)
Heads up digitising: stereo	TOPO SHEET 1 R 20,250 to R 28,800	NON-STEREO DIGITAL ORTHO (using stereo viewing capabilities of ERDAS ORTHOBASE software)	R 21,250 to R 50,800

Methodology	Professional or people costs	Running Costs	Total cost Per 1:50 000 sheet
	TOPO SHEET 2 R 230,400 to R 626,400 TOPO SHEET 3 R 172,800 to R 315,900 Time per wetland was based on the assumption (based on the digital stereo work undertaken in this project) that it will take at least twice the time to digitise the wetlands in stereo (thus 4.5 hours per wetland). Note that these costs exclude the costs for field verification and the delineation of test sites.	R 22,000 for new digital ortho-photos R 1,000 for off-the-shelf digital ortho-photo (Plus a once off cost per software set-up of approximately R 46,000 for Stereo Analyst excluding hardware, plus a cost of R15,600 for ArcView 3.2 or alternatively R24,000 for ArcView 8)	R231 400 to R648 400 R173 800 to R337 900
Manual Transfer: Visual non-stereo	Costs are calculated based on a manual delineation and classification time of 1hr per wetland for topo sheet 1 and 0.5hrs per wetland for topo sheets 2 and 3, plus 16 hrs preparation and orientation time per topo sheet (including flight plan orientation, overlay preparation, stereo orientation and so on). Scale is 1:30 000. TOPO SHEET 1 R 6,900 TOPO SHEET 2 R 72,000 TOPO SHEET 3 R 37,500 It is important to note that these costs exclude the manual transfer to digital format costs (this process is labour intensive and the costs could be substantial), the data table generation costs based on the hard copy information contained in the maps, and the costs for field verification and the delineation of test sites.	NON-STEREO B/W CONTACT PRINTS Purchase 1:30,000 scale non-stereo B/W contact prints, with zero overlap : R 360 Or Purchase 1:30,000 scale non-stereo B/W contact prints, with 30 % overlap : R 900	TOPO SHEET 1 R 7,260 or R 7,800 TOPO SHEET 2 R 72,360 or R 72,900 TOPO SHEET 3 R 37,860 or R 38,400
Manual Transfer: Visual stereo	Costs are calculated based on a manual delineation and classification time of 1hr per wetland for topo sheet 1 and 0.5hrs per wetland for topo sheets 2 and 3, plus 16 hrs preparation and orientation time per topo sheet (including flight plan orientation, overlay preparation, stereo orientation and so on). Scale is 1:30 000. TOPO SHEET 1 R 9,300 TOPO SHEET 2 R 74,400 TOPO SHEET 3 R 39,900 It is important to note that these costs exclude the manual transfer to digital format costs (this process is labour intensive and the costs could be	STEREO B/W CONTACT PRINTS Purchase 1:30,000 scale stereo B/W contact prints, with 60 % overlap : R 1440	Note that the main difference between manual non-stereo and stereo mapping lies in the slightly longer preparation times and the costs of the additional photos only. TOPO SHEET 1 R 10,740 TOPO SHEET 2 R 75,840 TOPO SHEET 3 R 41,340

Methodology	Professional or people costs	Running Costs	Total cost Per 1:50 000 sheet
	substantial), the data table generation costs based on the hard copy information contained in the maps, and the costs for field verification and the delineation of test sites.		
Satellite image processing	Approx 2-3 days per image for pre-classification data preparation, and 3 - 5 days per image (depending on landscape complexity) for actual wetland classification (although this includes the generation of the basic land-cover data). If land-cover data is already available, then could reduce manpower requirements by 50% (assuming experienced analysts). Assuming R 300 / hr manpower : Pre-processing : R 7,200 Classification : R 12,000 (all costs approximate, do not include any preliminary training, and assume equal experience by all analysts)	LANDSAT TM / ETM DATA Minimum data cost (1/4 image sub-scene) R 3,600 (unprocessed). .	R 22,800 (note because of larger image data area, actual cost is likely to be lower since a component of the data preparation and processing costs will be covered in adjacent 1:50,000 map tiles.

Table 5.5 The training and hardware and software requirements of each approach.

Methodology	Training requirements – experience and tools	Hardware/software requirements
Field delineation: whole topo sheet	Field delineators must have certain experience and training based skills in field delineation (e.g. the to distinguish hydric soils and hydric vegetation indicators). The delineator also needs certain cognitive skills (e.g. knowledge of landscapes, the ability to interpret topography, landforms and geology, and a basic understanding of wetland ecology and the region he/she is working in).	
Field delineation: One check site only	As above	
Heads up digitising: non-stereo	Heads-up digitizing requires the same skills as are required for photo interpretation of aerial photographs. These include certain physical skills (e.g. the ability to distinguish shades of grey or colours and to recognise contrast and wetland signatures) and cognitive skills (e.g. knowledge of landscapes, the ability to interpret topography, landforms and geology, and a basic understanding of wetland ecology).	ERDAS or ArcView 3.2 or 8
Heads up digitising: stereo	Heads-up digitizing requires the same skills as are required for photo interpretation of aerial photographs. These include certain physical skills (e.g. the ability to work in stereo, and to distinguish shades of grey or colours and to recognise contrast and wetland signatures) and cognitive skills (e.g. knowledge of landscapes, the ability to interpret topography, landforms and geology, and a basic understanding of wetland ecology).	ERDAS Orthobase or ArcView 3.2 or 8
Manual Transfer: Visual non-stereo	Photo interpreters must have certain physical skills (e.g. the ability to distinguish shades of grey or colours, to recognise contrast and wetland signatures and to accurately draw the boundaries and annotate the maps) and cognitive skills (e.g. knowledge of landscapes, the ability to interpret topography, landforms and geology, and a basic understanding of wetland ecology).	
Manual Transfer: Visual stereo	Photo interpreters must have certain physical skills (e.g. the ability to see in stereo, to distinguish shades of grey or colours, to recognise contrast and wetland signatures, and to accurately draw the boundaries and annotate the maps) and cognitive skills (e.g. knowledge of landscapes, the ability to interpret topography, landforms and geology, and a basic understanding of wetland ecology). They will also require	Desktop Stereo Plotter ArcView 3.2 or 8 A3 scanner: R2V Vectorisation software: R25 000

Methodology	Training requirements – experience and tools	Hardware/software requirements
	experience or training in remote sensing image processing software and vectorisation software.	
Satellite image processing	All image analysts to be fully trained in (ERDAS or equivalent) image processing software, with extensive image interpretation experience in terms of local geography and or ecology. Image interpretation skills (including local knowledge of wetland environments) is perhaps more important than extensive software knowledge, since once principles of digital image processing are understood, then re-training or familiarisation on alternative software systems is not too difficult.	Remote Sensing image processing software (PC-based) – approx R 54000 per licence, for **ERDAS Advantage**, excluding PC hardware costs. Note : ERDAS Advantage will be suitable for all image classification procedures, but not for initial all data preparation. This can either be requested via data suppliers as an integral cost component, or otherwise necessitates use of **ERDAS Professional** R 105000 per licence.

Table5.6: Costs and benefits of each approach. These are qualitative statements based on experience in the field.

Methodology	**Availability & suitability of data**	**Effectiveness of technique in terms of wetland mapping**	**Advantages of approach**	**Disadvantages of approach**	**Ability to classify to class level**	**Repeatability & practicality of approach**	**Expertise required**	**Efficiency, accuracy & scientific integrity**
Black & White photos	Most of SA covered, but considerable variability in terms of coverage scale and date of most recent photo acquisitions, especially in rural areas.	Reasonably cost and time-effective for wetland mapping.	Wetland signatures easily identifiable in most cases. Provides good resolution and contrast Easy to use in stereo. Can easily recognize different wetland units. Largely nationally applicable	Practicalities of use such as: It is often difficult to orientate when covering large areas and need to use flight plan info; Many images to work with.	Yes with stereo and/or with use with 1:50,000 topographic sheets.	Repeatable with training, check site orientation and experience	Require certain physical skills (e.g. the ability to distinguish shades of grey, and to recognise contrast and wetland signatures) and cognitive skills (e.g. knowledge of landscapes, the ability to interpret topography, landforms and geology, and a basic understanding of wetland ecology).	Dependent on scale of photography. (see also under CIR)
Colour Infrared Digital Ortho-Photos CIR format	Very little, but archive increasing, but still locally specific based on project related requests.	Not cost-effective, unless very specific areas requested in these specialised formats, or off-the-shelf conventional format B/W photography is not available. Considerably cheaper than flying new conventional format B/W photography and generating new ortho-photo digital mosaics.	Useful for identifying wet areas that have not been disturbed. in some areas (note this format is the mainstay of the US National Wetlands Inventory, so it could be that the test site examples do not represent the full capability of the data type)	Practicalities same as for black and white photos. Not available in stereo. Highly dependent on season in which photographs are taken. No apparent advantage over RGB for vegetated wetland mapping . Both RGB and CIR digital ortho's essentially capable of mapping surface representations of	Yes in conjunction with 1:50,000 topographic sheets.	Same as for black and white photos.	As for B/W and RGB photos, but requires understanding of NIR vegetation reflectance characteristics	Actual photo datasets very accurate in terms of spatial integrity (i.e. 2 m relative accuracy, and 10 m absolute accuracy). Accuracy of wetland (or other) feature mapping dependent on photo-interpreter skills, which will be subjective

Methodology	Availability & suitability of data	Effectiveness of technique in terms of wetland mapping	Advantages of approach	Disadvantages of approach	Ability to classify to class level	Repeatability & practicality of approach	Expertise required	Efficiency, accuracy & scientific integrity
				'core' wetland areas, based temporal vegetation characteristics, rather than sub-surface soil profile indicators.				
True Colour Digital Ortho-Photos RGB format	Not extensive, but archive increasing, but still locally specific based on project related requests.	Not cost-effective, unless very specific areas requested in these specialised formats, or off-the-shelf conventional format B/W photography is not available. Considerably cheaper than flying new conventional format B/W photography and generating new ortho-photo digital mosaics.	Useful in some areas such as the Western Cape, for example. Provides good resolution and contrast Can recognize different wetland units. Good for detailed mapping at large scale (1:5000).	Practicalities same as for black and white photos. Not always available in stereo. Highly dependent on season in which photographs are taken. (see also comments under CIR re core area mapping)	Yes	Same as for black and white photos.	Same as for black and white photos.	Same as for black and white photos, but more importantly the level of accuracy is highly dependent on timing of imagery.
Satellite images	National data coverage (including extensive multi-seasonal, archival imagery) is locally available, and is expected to continue in the future.	Very cost and time-effective for large area baseline inventories at medium levels of detail. Can easily be linked / incorporated into the proposed NLC2000 mapping programme.	Low (relative) cost. Fast and efficient data processing (digital environment), using standardised information to ensure uniformity of information. Possibility of additional ancillary data generation during	Low mapping accuracy in terms of required wetland objectives: minimum 50 percent total wetland area determination, with $\pm$ 80 accuracy of actual wetland identification. Satellite-based	Not able to identify any class-level categories from imagery alone, and need to integrate imagery with digital terrain / landscape data in-order to classify wetlands to **system** level.	Highly repeatable with comparable mapping accuracies. Factors that could influence repeatability are choice of image dates in relation to seasonal variations in wetland (and surrounding landscape condition), and	Key requirements are familiarity with image processing software (i.e. ERDAS Advantage), with strong natural science / environmental background to ensure good image interpretation	Highly efficient mapping techniques for large area presence / absence mapping of "core" wetland areas. Digital format allows consistent mapping accuracies to be achieved, with associated high

Methodology	Availability & suitability of data	Effectiveness of technique in terms of wetland mapping	Advantages of approach	Disadvantages of approach	Ability to classify to class level	Repeatability & practicality of approach	Expertise required	Efficiency, accuracy & scientific integrity
			wetland mapping, i.e. surrounding land-cover / use, and associated threat modelling. Image-based classifications tend to also identify non-wetland riparian zone vegetation communities.	mapping essentially limited to presence / absence mapping of "core" wetland areas as defined by surface vegetation characteristics, rather than sub-surface soil conditions. Digital processing techniques require some subjective input from image analyst, which necessitates use of skilled personnel, and pre-mapping analyst training to minimum any bias effects.		ability to standardise / quality control all analyst-controlled inputs.	skills. Normally this is expected to be equivalent to 1 – 2 years experience on chosen software, so that wetlands classification training is limited to application training and NOT software use training.	scientific integrity.
Field delineation	N/A	Not cost-effective – although when used to verify/supplement remote methods, it can increase the cost-effectiveness of remote methods.	Most accurate and can collect trend and functional data at the same time.	Time consuming and not cost-effective	Yes to all levels including modifiers.	Repeatable as long as standard techniques are applied.	Require experience and training skills in field delineation (e.g. the to distinguish hydric soils and hydric vegetation indicators). Also needs certain cognitive skills (e.g. knowledge of landscapes, the ability to interpret topography, landforms and geology, and a basic	Highly accurate, but is sometimes open to interpretation in difficult areas. Repeatable.

Methodology	Availability & suitability of data	Effectiveness of technique in terms of wetland mapping	Advantages of approach	Disadvantages of approach	Ability to classify to class level	Repeatability & practicality of approach	Expertise required	Efficiency, accuracy & scientific integrity
							understanding of wetland ecology and the region you are working in).	
Heads up digitising: non-stereo	Not available for large parts of the country but can be created.	Very effective as a complimentary dataset with the black and white or other imagery	Better accuracy of boundaries than, for example, free hand drawing, but only if used in conjunction with other methods. Can zoom in difficult areas.	Cannot be used on its own. Digital images are of poorer quality than hard copy. Non-stereo. Zooming in and out introduces scale dependence.	Yes but only in conjunction with other techniques.	As long as scale dependence id eliminated, it is repeatable.	Need some basic GIS training plus the same skills as are required for photo interpretation of aerial photographs (see table above).	Relatively inaccurate in most systems if used alone because digital imagery lacks good resolution.
Heads up digitising: stereo	Not available for large parts of the country but can be created.	Very time consuming and hard on one's eyes	Can see small changes in topography Can zoom in difficult areas.	Digital images are of poorer quality than hard copy. Zooming in and out introduces scale dependence. Impractical and very hard on one's eyes. Need regular breaks. Difficulties with viewing the whole picture.	Yes.	As long as scale dependence id eliminated, it is repeatable.	Need considerable GIS training plus the same skills as are required for photo interpretation of aerial photographs (see table above).	Level of accuracy not different to non-stereo in some wetland systems but generally inefficient in terms of additional time and effort costs required.
Manual transfer: visual non-stereo	Most of SA covered, but considerable variability in terms of coverage scale and date of most recent photo acquisitions, especially in rural areas.	Reasonably cost and time-effective for wetland mapping.	Wetland signatures easily identifiable in most cases. Provides good resolution and contrast Largely nationally applicable	Cannot easily map without stereo. Practicalities of use such as: It is often difficult to orientate when covering large areas and need to use flight plan info; Many images to	Yes but only in conjunction with 1:50,000 topographic sheets.	Open to interpretation if not used in stereo. May also over-estimate wetland areas	Require certain physical skills (e.g. the ability to distinguish shades of grey or colours, to recognise contrast and wetland signatures and to accurately draw the	Dependent on scale of photography. Low boundary accuracy because of non stereo and line width to ground width problems and ortho-rectification.

Methodology	**Availability & suitability of data**	**Effectiveness of technique in terms of wetland mapping**	**Advantages of approach**	**Disadvantages of approach**	**Ability to classify to class level**	**Repeatability & practicality of approach**	**Expertise required**	**Efficiency, accuracy & scientific integrity**
				work with.			boundaries and annotate the maps) and cognitive skills (e.g. knowledge of landscapes, the ability to interpret topography, landforms and geology, and a basic understanding of wetland ecology). Also, need experience with image processing software and / or vectorisation software to transfer hand delineated boundaries to digital format.	
Manual transfer: visual stereo	Most of SA covered, but considerable variability in terms of coverage scale and date of most recent photo acquisitions, especially in rural areas.	Reasonably cost and time-effective for wetland mapping.	Wetland signatures easily identifiable in most cases. Provides good resolution and contrast Can easily recognize different wetland units. Largely nationally applicable	Practicalities of use such as: It is often difficult to orientate when covering large areas and need to use flight plan info; Many images to work with.	Yes but it is recommended for use with 1:50,000 topographic sheets.	Repeatable with training, check site orientation and experience	Same as above but with the ability to work in stereo. Also, need experience with image processing software and / or vectorisation software to transfer hand delineated boundaries to digital format.	Dependent on scale of photography. Low boundary accuracy because of line width to ground width problems and ortho-rectification.