REPORT

South African National Land-cover Dataset

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Strategic Climate Policy Fund

Sustainability of Decentralised Renewable Energy Systems

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Prepared for
Department of Environmental Affairs

Prepared by
GeoTerraImage

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Contact Information

Department of Environmental Affairs

Environment House, 473 Steve Biko Street, Arcadia, Pretoria, 0001, South Africa.
www.evironment.gov.za
Attention: Jongikhaya Witi,
Tel +27 (0)12 399 9154, Fax +27 (0) 86 615 4321
jwiti@environment.gov.za

1. Introduction and background

The Department of Environment Affairs (DEA) has a stated need to be able to report on greenhouse gas (GHG) inventories and climate change mitigation activities for both national and international reporting requirements, on time scales ranging from one to four years. In support of this, there is a need to be able to quantify and describe landscape changes over time in terms of appropriate land-cover and land-use characteristics.

GeoTerraImage (GTI) has created comparable national land-cover/land-use maps for South Africa for the periods 1990 and 2013/14 that enable approximately 24 years of landscape change to be determined and quantified. These national land-cover/land-use datasets have been generated from multi-date (i.e. seasonal) Landsat satellite imagery in a digital format that is ideally suited for geographic information system (GIS)-based analysis and use.

The data, methods and procedures used to generate and verify these map datasets, together with the results of a preliminary change assessment between 1990 and 2013/14, are presented in the appendices to this report. The reports contained within each appendix are the stand-alone Data User and Metadata reports that were published and distributed with each digital map dataset. The appendices also include a report on the subsequent training that was provided to a wide range of potential data users upon completion of the national mapping activities in order to facilitate use and knowledge of this new information source.

Summary comments on South African landscape changes between 1990 and 2013/14

Comparison of the 1990 and 2013/14 South African National Land-cover Datasets shows that there are significant land-cover- and land-use-specific changes evident at both the national and regional scale. These include changes such as a 67% increase in the mining footprint in Mpumalanga and a 220% national-level increase in centre pivot-irrigated field areas over the approximately 24-year period. In general, the accuracy of land-use changes appears to be higher than that of the land-cover classes, especially vegetation, as a result of the influence and effect of class-level mapping accuracies and regional rainfall differences between the assessment years. In such cases, it is recommended that statistical representations of landscape change are validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

Appendix 1 contains the final report on the production of the **2013/14 South African National Land-cover Dataset**. In addition to the data report, the following digital data was also supplied as part of the final deliverables:

- Digital GIS-compatible thematic raster maps representing national land-cover/land-use characteristics for 2013/14, in both map-projected and geographic-coordinate formats, in both ERDAS Imagine© and TIFF formats.

- Digital GIS-compatible point-based map data representing the sample points from which the 2013/14 map accuracy was determined, in ArcGIS format.
- An Excel spreadsheet containing a full list of all the Landsat 8 satellite imagery used in the generation of the 2013/14 South African National Land-cover/ Land-use Dataset.
- AN Excel spreadsheet containing a summary of the land-cover/land-use class area statistics calculated from the 2013/14 South African National Land-cover/ Land-use Dataset.

Appendix 2 contains the final report on the production of the **1990 South African National Land-cover Dataset**. In addition to the data report, the following digital data was also supplied as part of the final deliverables:

- Digital GIS-compatible thematic raster maps representing 1990 national land-cover/land-use characteristics, in both map-projected and geographic-coordinate formats, in both ERDAS Imagine© and TIFF formats.
- An Excel spreadsheet containing a full list of all the Landsat 4 and Landsat 5 satellite imagery used in the generation of the 1990 South African National Land-cover/Land-use Dataset.
- An Excel spreadsheet containing a summary of the land-cover/land-use class area statistics calculated from the 1990 South African National Land-cover/ Land-use Dataset.

Appendix 3 contains the final report on the production of the **1990 to 2013/14 South African National Land-cover Change Assessment**. In addition to the data report, the following digital data was also supplied as part of the final deliverables:

- A digital GIS-compatible thematic raster map representing change in land-cover/land-use characteristics between 1990 and 2013/14 in map-projected ERDAS Imagine© format.
- An Excel spreadsheet containing a complete inventory of both national- and provincial-level landscape changes between 1990 and 2013/14, including pixel-level, class-specific change detail.

Appendix 4 contains the final report on the training sessions presented to a wide range of potential land-cover/land-use data users to enhance end-user awareness and understanding of the 1990 and 2013/14 South African National Land-cover Datasets and the associated Change Assessment. In addition to the data report, the following digital data was also supplied as part of the final deliverables:

- Digital copies of all the PowerPoint© slide presentations developed for and presented at the various training sessions.

APPENDIX 1

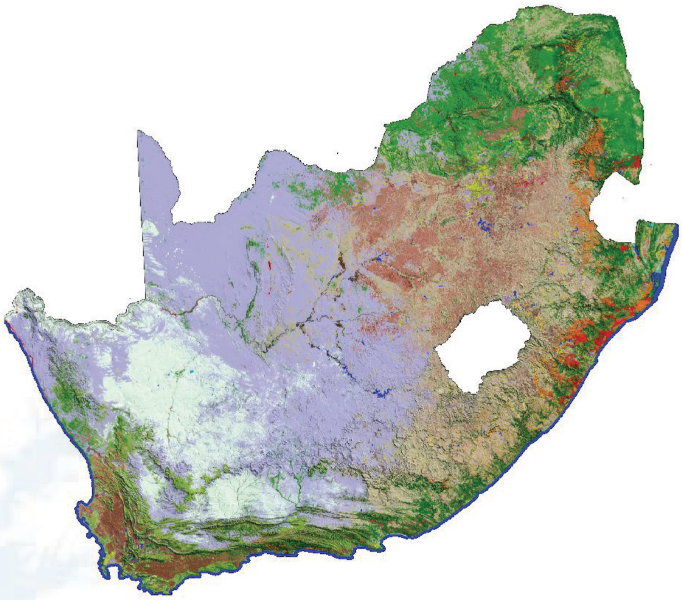
Report on the 2013/14 South African National Land-cover/ Land-use Dataset

GEOTERRA IMAGE

2013/2014 South African National Land-cover Dataset

DEA/CARDNO SCPF002: Implementation of Land-use Maps for South Africa

Project-specific Data User Report and Metadata



DATA PRODUCT CREATED BY

GEOTERRAIMAGE (South Africa)

www.geoterraimage.com

July 2015, version 05b *(pivot code-corrected data)*

OPEN ACCESS LICENCE

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CONTENTS

PLEASE NOTE:
This report provides information on the specific version of the 2013/14 GTI South African National Land-cover Dataset supplied to the South African Department of Environmental Affairs under the DEA/CARDNO Project: SCPF002: *Implementation of Land-use Maps for South Africa*.
The supplied dataset referred to in this report represents a *subset* of the full 2013/14 GTI South African National Land-cover Dataset, in terms of the supplied land-cover/land-use categories and associated class legend.
Use of this DEA/CARDNO data version is governed by the LICENCE AGREEMENT shown previously.

1. INTRODUCTION

Land cover is a key information requirement for a wide range of landscape planning, inventory and management activities, ranging from environmental resource management to telecommunication planning. The recent global availability of Landsat 8 satellite imagery offered the opportunity to create a new, national land-cover dataset[1] for South Africa, circa 2013/14, replacing and updating the previous 1994 and 2000 South African national land-cover datasets. The 2013/14 National Land-cover Dataset is based on 30 x 30 m raster cells, and is ideally suited for approximately 1:75 000- to 1:250 000-scale geographic information system (GIS)-based mapping and modelling applications.

The dataset has been derived from multi-seasonal Landsat 8 imagery, using operationally proven, semi-automated modelling procedures developed specifically for the generation of this dataset, based on repeatable and standardised modelling routines. The dataset has been created by GEOTERRAIMAGE (GTI) and is available as a commercial data product. The production of a comparable 1990 land-cover product is also in progress. This will provide, for the very first time, a standardised and directly comparable set of national land-cover datasets that can be used to determine landscape change in South Africa over a period exceeding 20 years[2].

2. BACKGROUND

The recent global availability of Landsat 8 imagery (April 2013) was the primary catalyst behind the development of new, innovative, automated land-cover modelling procedures, which allowed the creation of the 2013/14 South African National Land-cover Dataset; primarily because Landsat 8 offered a free and regular supply of radiometrically and geometrically standardised, medium-resolution, multi-spectral imagery, suitable for medium to large area mapping. Collectively, this offered an ideal opportunity for GTI to re-examine using automated land-cover mapping techniques as a more efficient alternative to conventional, analyst-assisted per-pixel classifiers, allowing the rapid production of standardised, yet informative land-cover information.

1 Note that the term “land cover” is used loosely to incorporate both land-cover and land-use information in the context of the GTI 2013/14 South African National Land-cover Dataset.

2 The existing 1994 and 2000 South African national land-cover datasets were generated independently, using very different source image formats (i.e. paper versus digital), and end-product formats (i.e. 1:250 000 scale digital vector versus 1:50 000 digital raster), despite being derived from equivalent Landsat imagery. See Thompson, MW, 1991. South African National Land-cover Database Project. Data users’ manual. Final report (Phases 1, 2 and 3). CSIR Project Report ENV/P/C 98136, February 1999; and Thompson, MW et al, 2001. Guideline procedures for national land-cover mapping and change monitoring. CSIR Client Project Report ENV/P/C 2001-006, March 2001.

3. OBJECTIVE

The primary objective was to generate a new, national land-cover dataset for the whole of South Africa, and to be able to release this as a commercial data product within about a year of image data acquisition to ensure that the dataset is up to date and current. In support of this primary objective was the requirement to develop operational procedures based on semi-automated (spectral) modelling techniques that would facilitate the rapid production of consistent, standardised land-cover information from multi-seasonal Landsat 8 imagery.

4. PRODUCT DESCRIPTION

The 2013/14 South African National Land-cover Dataset produced by GTI as a commercial data product has been generated from digital, multi-seasonal Landsat 8 multi-spectral imagery, acquired between April 2013 and March 2014. In excess of 600 Landsat images were used to generate the land-cover information, based on an average of eight different seasonal image-acquisition dates, within each of the 76 image frames required to cover South Africa. The land-cover dataset, which covers the whole of South Africa, is presented in a map-corrected, raster format, based on 30 x 30 m cells equivalent to the image resolution of the source Landsat 8 multi-spectral imagery. The full dataset contains 72 land-cover/land-use information classes, covering a wide range of natural and man-made landscape characteristics. The DEA/CARDNO dataset contains a summarised 35-class legend. Each data cell contains a single code, representing the dominant land-cover class (by area) within that 30 x 30 m unit, as determined from an analysis of the multi-date imagery acquired over that image frame. The original land-cover dataset was processed in UTM35 (north)/WGS84 map-projection format based on the Landsat 8 standard map-projection format as provided by the United States Geological Survey (USGS). The final product is available in UTM35 (north and south), WGS84 map projections and geographic coordinates.

4.1 Land-cover Legend

The 2013/14 South African National Land-cover Legend is aligned with the SANS 1877[3] South African National Land-cover Classification Standard in terms of class definitions and in hierarchical format. The complete list of information classes that have been mapped and supplied as part of the DEA/CARDNO land-cover dataset and the associated class definitions are supplied in Appendix A.

Note that in recent Chief Directorate: National Geospatial Information (CD: NGI) national land-cover mapping projects, the Food and Agriculture Organisation: Land Cover Classification vs 2 (FAO LCCS2) land-cover classification system has been adopted as an alternative to SANS 1877, although this is not a national standard. However, in September 2014, the South African Group Earth Observation (SA GEO) Group's Land-cover Community of Practice (CoP) task team, which includes CD: NGI representation, proposed that the class detail and content of SANS 1877 be retained/included in a proposed new South African national land-cover standard, which will be based on the latest, internationally accepted Land-Cover Metadata Language (LCML) classification system (ISO1944-2).

5. OVERVIEW OF THE AUTOMATED MODELLING APPROACH

Automated modelling procedures offer significant advantages in terms of ensuring data standards, minimising processing time, allowing easy repeatability and facilitating accurate change detection, when compared to more conventional image mapping approaches where there is a greater reliance on individual image analyst knowledge and inputs. To this end, a series of automated image-based modelling steps were developed that utilise the seasonal dynamics associated with the broad landscape characteristics across South Africa. These were then used to rapidly produce a set of foundation cover classes that could be easily converted into more meaningful land-cover information categories, using predefined geographical masks in the GTI data libraries.

The foundation cover classes represent the basic building blocks associated with all landscape characteristics, namely water, bare ground, grass and tree-bush-shrub cover types, with each being defined in terms of seasonal occurrence or permanence. These basic foundation cover classes represented the initial output from the automated modelling approach. The foundation cover classes are then converted into more conventional land-cover information classes, i.e. urban, forest plantation, etc., as part of the post-automated modelling data-processing steps.

The foundation cover classes are essentially "spectrally dependent" classes, since they are generated from automated modelling procedures that are based directly on the spectral characteristics associated with each image pixel over time (i.e. seasonal) and space (i.e. within an image frame). The final land-cover information classes are referred to as "spectrally independent" classes since different cover classes can share similar foundation class spectral characteristics in a one-to-many-type relationship. For example, the "bare ground" spectrally dependent cover classes could represent non-vegetated built-up urban areas, natural rock exposures, beach sand or a mine pit and tailings dump. Similarly, the tree-bush classes could represent natural vegetation cover, a timber plantation or a fruit orchard. The advantage of this approach is that the conversion of the initial, spectrally dependent foundation cover classes into the final, spectrally independent land-cover information classes can be tailored to suit a variety of end-user information requirements; simply by using a different set of predetermined masks and foundation class subdivisions and amalgamations.

5.1 Model portability to other geographical areas and sensors

Although model development was focused on using Landsat 8 imagery within South Africa, the same models have also been proven to work with equivalent success

3 SANS, 1877. South African Bureau of Standards (SABS)-designated national land-cover classification standard for South Africa.

on Landsat 8 imagery over sites in Botswana, Mozambique, Namibia, Sudan and Zimbabwe, as well as using comparable Landsat 5 archive imagery over South Africa; all of which indicate a high level of model portability. This should allow and support the production of directly comparable historical land-cover datasets for change detection, assuming of course that the required level of seasonal image coverage is available in the data archives.

5.2 Use of object-based modelling

No attempt was made to include or use object-based modelling in the automated mapping process, primarily because the medium-resolution format of multi-spectral Landsat 8 imagery does not lend itself to this type of modelling, since pixel resolution typically precludes the identification of true landscape "objects" in comparison to high- and ultra-high-resolution image formats. The 30 m Landsat resolution pixels typically represent a mix of land-cover characteristics rather than a pure cover surface, i.e. an urban pixel is typically a composite of building roofs, garden vegetation and/or road surfaces. However, object-based modelling may be a useful approach for helping to generate second-level information classes from the primary-level foundation class dataset, such as separating water in rivers (i.e. natural) from water in dams (i.e. artificial), based on size, shape and context.

6. LANDSAT IMAGERY

The primary imagery source used in the generation of the 2013/14 South African National Land-cover Dataset was 30 m-resolution Landsat 8 imagery, acquired between April 2013 and March 2014. Within each image frame, a range of seasonal image-acquisition dates were used (within the automated modelling procedures) to characterise the seasonal dynamics across the landscape in terms of the basic tree, bush, grass, water and bare foundation cover classes. Nine image-acquisition dates per image frame per complete seasonal cycle were taken as the optimal number of dates, based on Landsat's 16-day overpass schedule[4]. Unfortunately, due to localised, prolonged cloud-cover problems in some regions during this April 2013 to March 2014 period, it was not possible to achieve this. In such cases, archival Landsat 5 imagery was used as a substitute, but only if it was from a suitable seasonal period to complement the Landsat 8 data, and was almost 100% cloud-free. Figure 1 illustrates the total number of image-acquisition dates per image frame, while Figure 2 illustrates the location and number of Landsat 5 images that were also used.

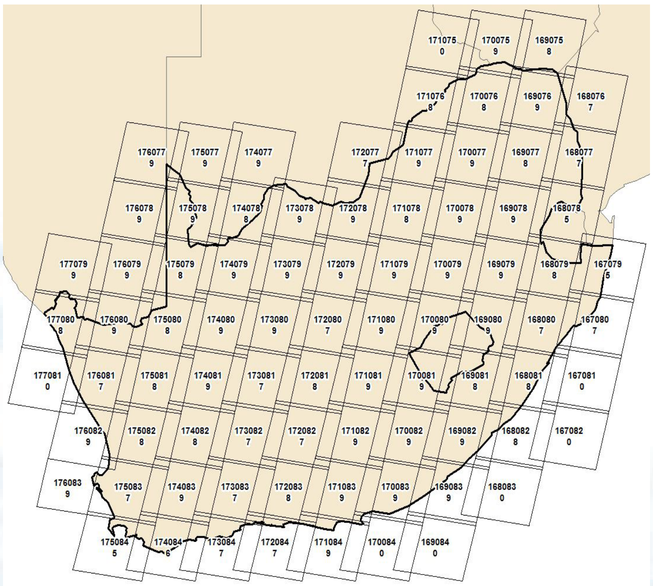


Figure 1. Total number of image-acquisition dates used in the land-cover modelling per image frame.

4 This seasonal window requirement, while improving the overall accuracy of interpretation and land-cover modelling, means that – in practice – between 12 and 16 months are actually required to acquire sufficient cloud-free seasonal imagery for input into the modelling processes. This means that a new land-cover dataset could only be generated approximately every two to three years (minimum), since a shorter period may not provide sufficient separation between the seasonal input image dates.

In summary, 76 Landsat image frames were required to provide complete coverage of Lesotho, South Africa and Swaziland. A total of 616 individual Landsat images were used to model and produce the land-cover data, representing an average of eight acquisitions per image frame per year. Of the 616 images, 592 images were from Landsat 8 (96%) and 24 images (4%) were from Landsat 5. The Landsat 5 images were, however, only used in 10 of the 76 image frames defining the geographic extent of the land-cover dataset.

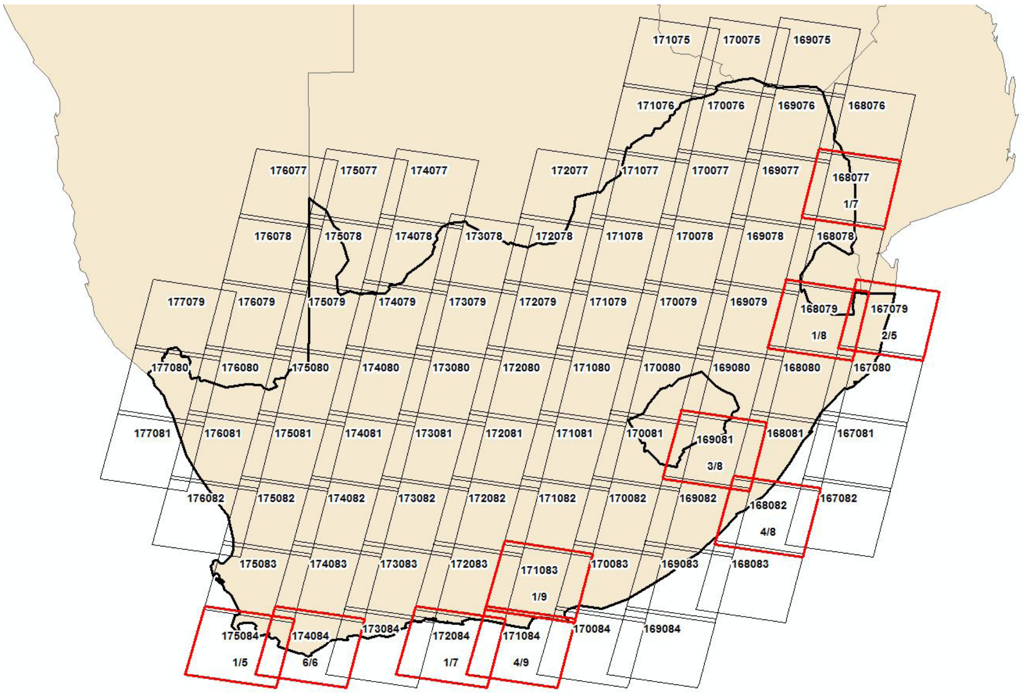


Figure 2. Location of the 10 image frames that required the use of archival Landsat 5 imagery due to the limited availability of Landsat 8 data during the period April 2013 to March 2014.

6.1 Landsat image sourcing

All Landsat 8 and Landsat 5 imagery used in the 2013/14 land-cover data modelling was sourced from the online data archives of the USGS[5]. The data is provided in a precise geo-corrected UTM35 (north)/ WGS84 map-projection format, and was used "as-is" without any further geo-correction. A complete list of the image-acquisition dates used in the modelling of the 2013/14 South African National Land-cover Dataset (for both Landsat 8 and Landsat 5) accompanies this document (see Appendix B).

5 See http://glovis.usgs.gov/.

6.2 Landsat data preparation

All Landsat 8 and Landsat 5 imagery was standardised to 16-bit, top-of-atmosphere (ToA) reflectance values prior to land-cover modelling, using a generic modelling approach. The original USGS-generated UTM35 (north), WGS84 map-projection format was retained without change or modification throughout all image frame-based modelling procedures. As far as possible, only cloud-free or image dates with limited cloud cover were used in the land-cover modelling (i.e. maximum of about 20% terrestrial cloud cover in any one date). Any cloud-affected regions were corrected by merging cloud-affected ToA-corrected imagery with cloud-free ToA-corrected data from preferably the preceding or following overpass date, so that, as far as possible, the final cloud-free merged imagery composite only represented a maximum difference of about 16 days.

Cloud masks were created using either conventional pixel classification procedures (within analyst-defined sub-image areas), or spectral-based modelling using generic thermal and blue light reflectance thresholds[6], depending on cloud characteristics. This was deemed acceptable in terms of minimising any changes in local vegetation cover growth changes. Approximately 35% of the 616 images used in the land-cover modelling were cloud-masked composites. No external atmospheric correction was applied to the image data.

7. LAND-COVER MODELLING

7.1 Spectral modelling

Derived spectral indices, generated from the ToA-corrected imagery, were used as the only inputs into the land-cover models. No original spectral (ToA reflectance) data was used as an input, although collectively, five out of the eight available non-thermal spectral bands were used in the various spectral indices[7]. A standardised set of spectral indices were identified from which the required foundation cover classes – (1) tree dominated, (2) bush dominated, (3) grass dominated, (4) water and (5) bare ground – could be modelled, using predetermined, generic spectral threshold values. The generic threshold values associated with each index and cover type were tested over several landscapes and seasons before being confirmed and accepted as such.

The spectral indices included both existing algorithms, such as the Normalised Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI), as well as algorithms developed in-house specifically for the GTI land-cover modelling requirements. All models were developed in ERDAS Imagine© image-processing software using the Model Maker function.

6 The spectral modelling approach could only be applied to Landsat 8 imagery (if applicable) due to its enhanced spectral band range, compared to Landsat 5.

7 (2) Green, (3) Red, (4) Red, (5) NIR, (6) SWIR-1 and (7) SWIR-2 Landsat 8 spectral bands.

The modelling and generation of each foundation cover class were undertaken as a separate modelling exercise, i.e. water was modelled separately from bare ground, which was modelled separately from tree and bush cover, etc. This approach simplified the modelling steps and facilitated easier desktop quality control of outputs, compared to attempting to model all foundation cover types simultaneously within a single model workflow. In most cases, the final geographic extent of a particular foundation cover class was generated from the combined use of several different spectral indices, since no single index was found to work well in all landscapes and all seasons.

All modelling was undertaken on an individual image frame-by-frame basis, where the original USGS-supplied UTM35 (north) map-projection format was retained "as-is". This allowed the models to be adapted according to the number of acquisition dates and associated seasonal ranges available for each particular image frame. The model modifications reflected the need to standardise the outputs according to predefined definitions of seasonal permanence, for example, whether a foundation cover class occurred, i.e. in only one image date; in several, but not all image dates; or in all image dates. Obviously, the more image-acquisition dates available per frame, and the wider the seasonal range, the more accurate the modelled interpretation of a particular cover class's seasonal characteristics.

Examples of the separate model outputs for bare ground and tree/bush foundation cover classes are shown in Figure 3 below. The examples show eastern Pretoria, from within Landsat 8 frame 170-078.

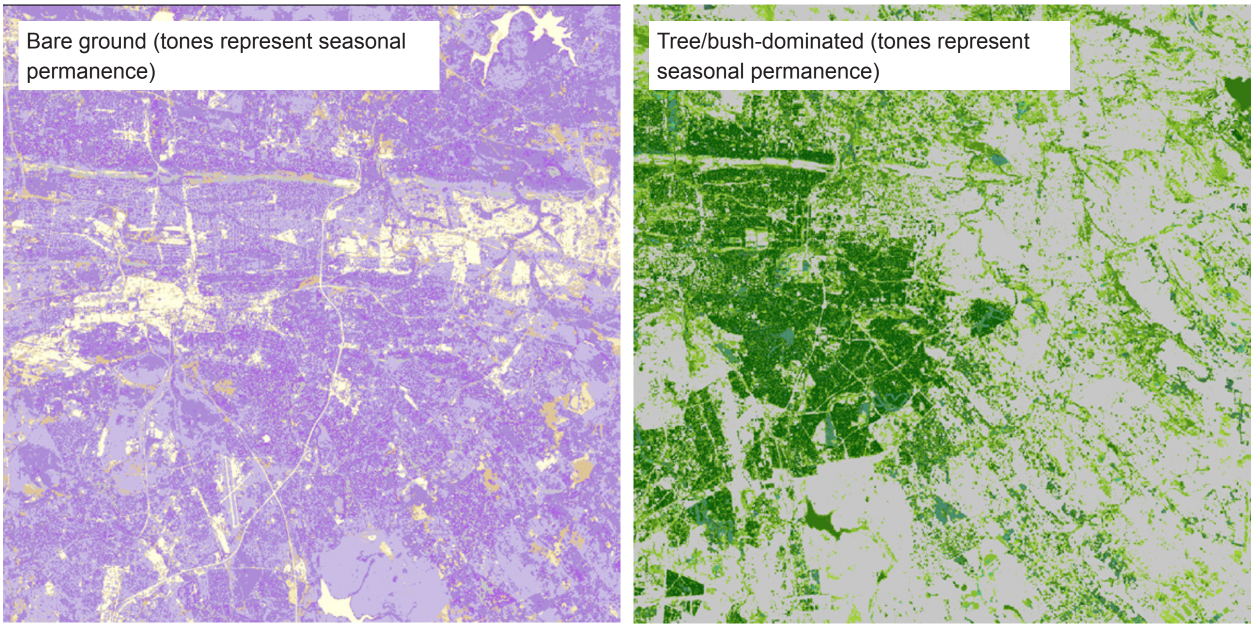


Figure 3. Spectral index-derived model outputs for bare ground and tree/bush-dominated foundation cover classes over eastern Pretoria (frame 170-078).

In some circumstances, modifications or additional modelling steps were used to account for regional landscape characteristics that could not be accurately modelled using only generic models. For example, in some of the far western arid areas, additional tree/bush modelling steps were taken using a slightly modified modelling approach in order to better detect and distinguish between the sparse, low bush and shrub covers in these landscapes.

7.2 Terrain modifications

Terrain-based modifications were included within some of the foundation cover class modelling procedures (i.e. water, bare and tree/bush classes) in order to minimise seasonally induced terrain shadowing effects, using a combination of solar illumination and slope parameters. These parameters were modelled independently using the 90 m-resolution Shuttle Radar Topography Mission (SRTM) dataset[8], with outputs being resampled to a Landsat-comparable 30 m-resolution format, prior to being incorporated into the foundation cover class models. For example, solar illumination and Digital Elevation Model (DEM) slope masks were used to minimise any spectral confusion between dark terrain shadow areas and comparable water body reflectance levels. Note that when creating the DEM-derived parameters, such as shadow extents, modelling was based on the full range of seasonal solar azimuth and zenith angles and not a specific date or season in order to better align with seasonal differences evident across any given range of image-acquisition dates.

8 Although the 30-m SRTM terrain dataset would have been preferable, it did not become publicly accessible until after the completion of the bulk of the 2013/14 land-cover modelling had been completed.

7.3 Individual frame spectral models

The basic modelling parameters used to create each of the foundation cover classes are described below. In each case, the modelled output would typically represent a (qualitative) gradient of spatial densities, as well as temporal, i.e. seasonal occurrence. For example, the bare ground model output consisted of a set of classes that represented a range of conditions from “pure bare” to “mixed bare/sparsely vegetated”, with each described in terms of seasonal, permanent or temporary occurrence. The foundation water class modelling was the only exception to this, with the model output describing water extent in terms of only permanent or seasonal occurrence.

7.3.1 Spectral modelling of water

Water was modelled using a combination of five spectral indices, including a burn index, and DEM-derived solar illumination and slope masks. The burn index was used to minimise any spectral confusion between dark burnt areas and comparable water body reflectance. The solar illumination and slope masks were used to minimise any spectral confusion between dark terrain shadow areas and comparable water body reflectance. Generic spectral water models were developed for both flat (standard) and hilly terrain, and for shallow water (pan)-dominated landscapes.

7.3.2 Spectral modelling of bare ground

Bare ground was modelled using a combination of two spectral indices, and DEM-derived solar illumination and slope masks. The solar illumination and slope masks were used to minimise any spectral confusion between dark terrain shadow areas and comparable bare ground reflectance. The output represented a gradient of bare ground from pure bare to sparsely vegetated cover.

7.3.3 Spectral modelling of tree/bush cover

Tree and bush cover was generated within the same spectral model. Both woody covers were modelled using a combination of four spectral indices, and a DEM-derived slope mask. The slope mask was used to minimise any spectral confusion between dark terrain shadow areas and comparable woody cover in two of the four spectral indices. “Trees” refers to dense, typically tall woody cover, such as natural and planted forests, dense woodland and thickets, whereas “bush” refers to more open, often lower mixed tree/bush communities, such as typical bushveld or open woodland. The spectral modelling procedure also separated woody cover spectral classes that showed similar characteristics to other vegetated covers, such as crops, sportsfields, golf courses (especially if irrigated), from those that did not show similar characteristics. An additional “desert” tree/bush model was developed as an extra model to be run in addition to the standard model in more arid areas to increase the representation of bush cover in these regions where the modelling thresholds used in the standard model were not sensitive enough.

7.3.4 Spectral modelling of grass

Grass cover was modelled using only a single spectral index. No DEM-derived solar illumination or slope mask modifiers were used.

7.3.5 Spectral modelling of burnt areas

Burnt cover was modelled using only a single spectral index. No DEM-derived solar illumination or slope mask modifiers were used.

7.4 Seasonally defined spectral land-cover per image frame

The modelled outputs for each foundation cover class were combined into a single composite dataset for each frame in a predetermined hierarchical order so that the final output cover class combinations could reflect the dominant and subdominant cover types in terms of seasonal occurrence. For example:

- water in all dates (permanent)
- water in many dates (seasonal)
- dominated by trees in all dates
- dominated by trees in many but not all dates, plus bare ground in one date, etc.

Figure 4 shows the output after all the separate foundation land-cover classes have been combined into a composite set of seasonally defined foundation land-cover classes. The illustrated area is the same eastern Pretoria area as shown in Figure 3. This interim land-cover product consists of 51 seasonally defined foundation cover classes, as listed in Appendix C. These seasonally combined foundation cover classes are still essentially “spectrally dependent” classes, since they have been generated using automated modelling procedures on only the spectral characteristics associated with each image pixel over time (i.e. seasonal) and space (i.e. within an image frame).

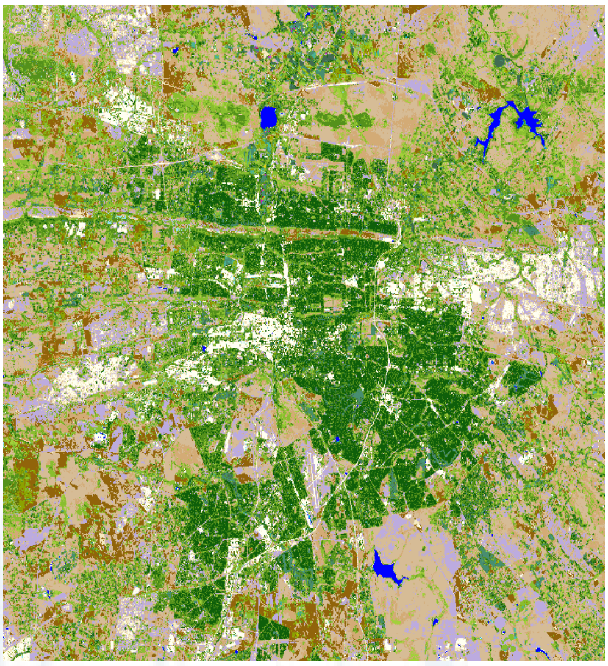


Figure 4. Interim spectral land-cover product after combining all the seasonally defined foundation cover classes (eastern Pretoria, frame 170-078).

Note that, in addition to the basic tree, bush, grass, water and bare ground foundation classes already described, fire scar extent and occurrence were also modelled and incorporated into the final combined foundation cover composite classes in order to provide an indication of whether or not fire was a factor in the modelled seasonal cover profiles, i.e. a single-date, bare ground area could be the result of a wildfire event that then revegetated later in the season.

The spectrally dependent and seasonally defined foundation cover classes in this base dataset represent the “building blocks”, from which more information-focused land-cover classes can be derived, especially if combined with ancillary datasets such as vegetation or land-use maps to facilitate further class subdivisions or area-based class modifications. The entire spectral modelling procedure is summarised graphically in Figure 5 below.

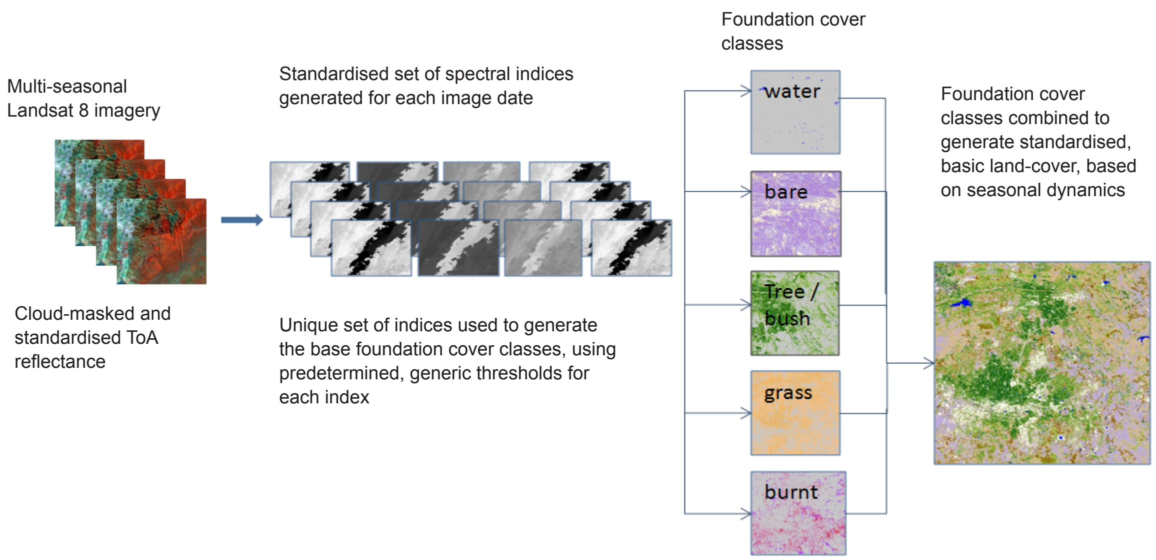


Figure 5. Summary of the full spectral land-cover modelling process.

7.5 Generation of full South African spectral class mosaic

Once the spectral modelling for the individual frames had been completed, the next step was to merge these into a single, seamless coverage for the whole of South Africa. Achieving this involved several processing steps. Individual image-frame datasets were first edge-cleaned to ensure that no frame-edge pixel anomalies would be carried over into the final countrywide mosaic. Cleaned image frames were then re-projected were necessary to a standardised UTM35 (north), WGS84 map projection, since the majority of image datasets covering South Africa were sourced from the USGS data archives, and were in this UTM zone.

Individual image frames were merged into a single, countrywide spectral foundation class composite, based on an analyst-determined sequence of image border overlap rules in order to ensure the best possible seamless integration of the individual frames. This approach was necessary since some image-to-image edge differences occur between image frames where spectral foundation classes have been generated from significantly different input acquisition dates, simply as a result of image data availability.

Although the standardised modelling approach used to generate the spectral classes supported the generation of spatial and content-comparable land-cover data in adjacent image frames (if both frames utilised comparable input image-acquisition dates), if there was a significant difference in the number or seasonal range of input images, then adjacent images often showed edge-matching differences. In such cases, the adjacent images were often spatially comparable, but not necessarily comparable in terms of content. In these cases, the edge-matching process was set up, as far as possible, so that the most prominent and spatially extensive landscape pattern was maintained across the image borders in order to provide a more visually seamless image frame overlap.

Note that for water ("seasonal" and "permanent") and bare ground ("pure bare, all dates") countrywide coverages, the maximum extent of each class, from all images, was transferred across to the final countrywide spectral class composite, regardless of any frame overlap edge-matching applied to other spectral classes.

7.5.1 Grassland corrections: inland

Persistent cloud-cover problems on several image-acquisition dates during the 2013/14 wet season period over the Highveld region resulted in the unavailability of usable, early wet-season imagery for modelling inputs. This resulted in the standard spectral models under-estimating the grassland extent. In order to correct this, an alternative grassland model was developed, based on a single – rather than multiple – image-acquisition date (the optimal single date representing the best dry-season image for visually separating green woody vegetation from senescent grassland vegetation, with minimal burn scars). For image frames covering areas of significant topographical relief, such as over the escarpment, the single-date grass-corrective model included the use of solar illumination and slope parameters to improve modelling outputs. For standardisation purposes, the inland grassland corrective model was applied to all image frames overlapping or contained within the South African National Botanical Institute (SANBI) grassland biome boundary. The resultant grassland extents for each image frame where then merged into a composite geographical mask and integrated back into the original countywide spectral class dataset to improve the overall grassland delineation.

7.5.2 Grassland corrections: coastal

In some high-rainfall coastal regions, the standard spectral models were unable to accurately distinguish between grassland and woody cover, where the grass biomass was exceptionally high as a result of high local rainfall during the 2013/14 wet season, even if suitable image-acquisition dates were available. This was especially the case around Pondoland (Eastern Cape) and Zululand and Maputoland (KwaZulu-Natal). To correct this, another grassland correction model was developed with alternate spectral thresholds to better delineate the correct grassland extent in these areas. The resultant frame-specific outputs were then merged into a composite geographical mask and integrated back into the original countywide spectral class dataset to improve the overall grassland delineation.

8. LAND-COVER INFORMATION GENERATION

Multi-seasonal Landsat imagery has been used to generate a comprehensive set of spectrally based outputs that describe the seasonal characteristics of tree, bush, grass, bare and water cover characteristics within each image pixel, as represented by the 51 spectral foundation classes. These were converted into more meaningful and informative land-cover and land-use information classes, aligned with the South African National Standard (SANS) 1877 South African National Land-cover Classification Standard (see Section 4.1). For example, a pixel may be described as having detectable tree cover on more than one image-acquisition date, but not all dates, and grass cover for several, but not all dates. This would then be interpreted as an open, deciduous tree-covered woody community (i.e. woodland), where the grass cover became evident when the tree canopy showed less than maximum foliage cover.

8.1 Conversion from spectral to information classes

The creation of both land-cover and land-use information classes involves the recoding and re-grouping of selected spectral foundation classes, either in a controlled or uncontrolled geographic area. In a controlled recoding, independently sourced and/or generated geographical masks are used to define the location and extent of the recode process. This is required because, in many situations, different landscape features can be represented by similar spectral characteristics. For example, a spectrally modelled area of permanent bare ground (spectral characteristics are representative of a non-vegetated surface in all image-acquisition dates) could be representative of a beach, a mine or a large building.

By using an appropriate geographical mask (essentially an independently defined or sourced polygon coverage), it is possible to code all bare ground pixels within the mask to, for example, mining, while allowing all other bare areas outside the mask to represent other bare ground surfaces, which can then be further recoded as and where required.

The key to this process is that the spectral modelling defines the exact footprint of the spectral cover class (in a user-independent manner), whereas the geographical mask defines the information content (based on user expertise and knowledge). This approach overcomes problems where spectral characteristics are shared between two or more separate land-cover/land-use classes, which is self-evident in many image-based mapping applications. Figure 6 illustrates the various procedural pathways that can be used to convert the spectral foundation classes into land-cover/land-use information classes.

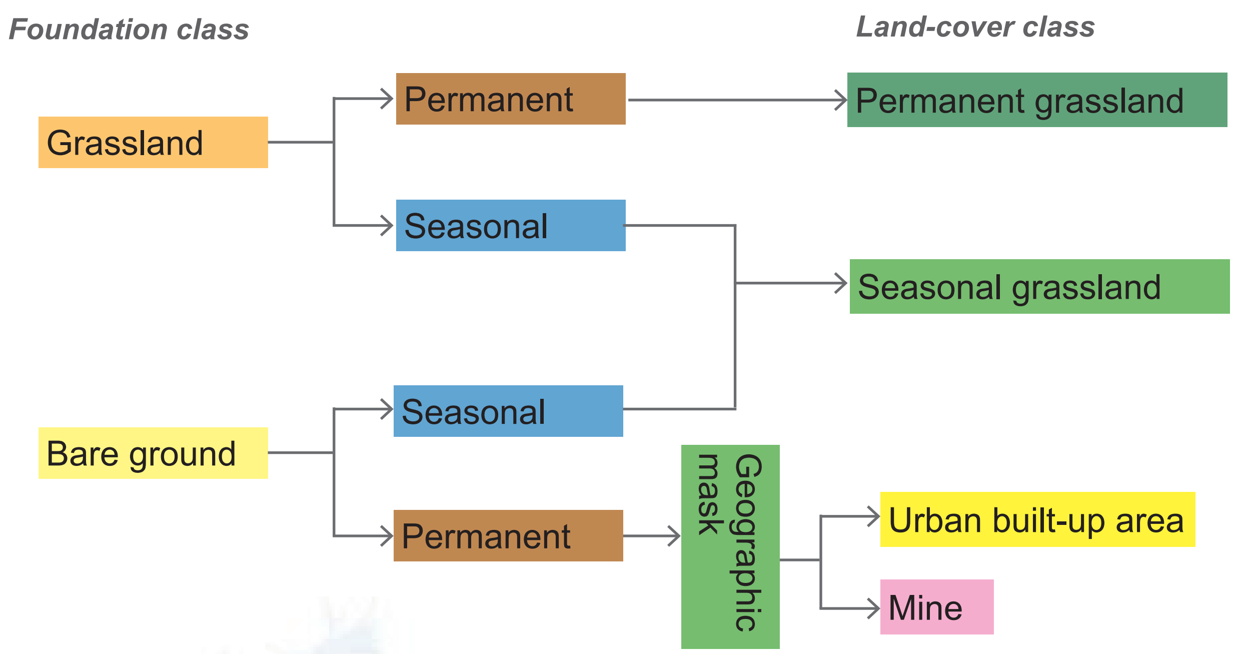


Figure 6. Processing pathways for converting spectral foundation classes to land-cover/land-use information classes, based on seasonal permanence and shared spectral characteristics.

8.2 Creating base vegetation land-cover classes

The natural vegetation base classes, namely thicket/dense bush, woodland/open bush, grassland, low shrubland and bare, non-vegetated areas, were created by merging selected groups of spectral classes. Generally, selected spectral classes were merged into the required vegetation cover classes without geographical control, using the original spectral class extent and distribution “as-is”. However, in some regions, and for some spectral classes, it was necessary for the recoding and merging process to be geographically controlled, and only allow the recode procedure within predetermined geographical regions. Controlled geographical recoding (i.e. masking) used pre-selected SANBI bioregion[9] boundaries to define where and how selected spectral classes were modified. Note that the final vegetative land-cover class boundary is always defined by the original spectral foundation class boundaries contained in the SANBI bioregion boundary, and not by the bioregion boundary itself, other than for the fynbos: low shrubland subclass.

9 Mucina, L and Rutherford, MC, 2006. *The vegetation of South Africa, Lesotho and Swaziland. Strelitzia* 19. SANBI: associated digital GIS database. Note that SANBI biome and bioregion boundaries, while generically applicable for 1:250 000 digital map scales, are often considerably more accurate on a local scale, even down to the nearest 100 m in some cases.

8.2.1 Fynbos

The sensitivity of the automated spectral models was insufficient to determine the transition between structurally similar fynbos: low shrubland communities and non-fynbos: low shrubland communities, except for the boundary with the structurally different Namaqualand (SKn and SKs) and Knersvlakte (Skk) bioregions. In these areas, the boundary between the fynbos and non-fynbos: low shrubland communities has been defined on the basis of the original spectral class boundaries[10].

8.2.2 Indigenous forests

The indigenous forest land-cover class was generated in a similar manner to the previously described base vegetation classes, although the geographical masks used to control the recoding of the selected spectral foundation classes were derived from a combination of independent datasets. These included the SANBI forest biome boundaries, higher detail regional masks created in-house in support of previous provincial-level land-cover mapping, shadow and altitude terrain parameters modelled from the higher 30 m-resolution SRTM DEM terrain data[11] and NDVI spectral datasets. The NDVI dataset represented a nationwide summary of the seasonal maximum NDVI recorded in each pixel, calculated from all image-acquisition dates used in the spectral land-cover modelling. Note that separate models were required to recode the different forest vegetation types (i.e. Northern Afromontane, sand, scarp, etc.), with each one based on different geographical mask combinations and associated data thresholds in order to correctly model the forest patch distributions in these regions. The final modelled forest extents were then integrated into the base vegetation land-cover classes.

10 This is primarily because satellite imagery such as Landsat, with its combination of medium spatial resolution and limited spectral capabilities (compared to hyper-spectral sensors), is primarily responsive to structural vegetation characteristics rather than community floristics. Accurate delineation of biome-related boundaries, especially if the boundary is a transition zone, rather than a distinct border, is – at best – challenging with imagery such as Landsat, especially if floristic differences play a greater role than structural differences in defining the border. This is likely to be the case between the fynbos, succulent Karoo, Nama Karoo and surrounding grassland and desert biomes.

11 The 30-m resolution SRTM terrain data for Africa was available for use at this time within the 2013/14 South African National Land-cover Project, despite not having been available for the initial spectral modelling phase.

8.2.3 Wetlands

The wetland class was created using independent and separate modelling routines that did not include reference to or recoding of any of the original 51 spectral foundation classes. Depending on the available image-acquisition dates per frame, wetland extent was modelled using either a dual or single image-acquisition-date process. The single-date approach used the best “wettest” image date, whereas the dual-date approach was based on the difference between wettest and driest image dates, where the single (wettest)-date modelling was only used as an alternative approach if the available acquisition dates did not provide suitable seasonal differences for the dual-date, wet-dry-date approach. Both modelling approaches only used inputs from multiple spectral indices, and did not use the 51 spectral foundation cover classes as used in the generation of the other vegetation class. A combination of eight indices were used in the dual-date approach, with each being applied to both dates, whereas only four spectral indices were used in the single (wettest)-date approach. Both modelling approaches generated a dataset that represented the likelihood of wetlands occurring in the landscape, within which a threshold was determined on a frame-by-frame basis in order to best represent actual wetland extent.

The single (wettest)-date modelling approach used terrain shadow masking to minimise spectral confusion with non-wetland regions, whereas the dual-date approach used more complex slope and floodplain modelling to limit the topographic areas within which wetlands were likely to occur. Both approaches used the 90 m SRTM terrain data as the source for topographic modelling.

The slope and floodplain model generated potential flooding zones, based on potential flood heights, which were taken to be indicative of areas most likely to be wet, and thus to contain the highest probability of having wetlands. The flood heights were created by estimating the water expansion level in river channels against a modelled stream surface height layer (in comparison to actual terrain surface). The modelling provides an indication of potential lateral water extent at a range of heights above the stream base height in relation to the stream channel profile at that location, irrespective of flood duration or time periods. The modelling does not take account of the surface roughness or flow blockage, which may result in the additional lateral extension of flood waters through backup, etc. The accuracy of the output is directly dependent on the scale, resolution and detail contained in the DEM. The modelled potential flooding zones were then used to restrict the dual-date wetland modelling where wetlands are most likely to occur.

Note that, in some localised areas, the results of both single- and dual-date wetland modelling approaches required post-modelling edits to improve the wetland delineation, especially if wetlands were not showing saturation or significant (vegetation) flushes. In such cases, analyst-assisted conventional unsupervised classifications were used to locally improve the modelled wetland output.

The modelled wetland extents were then integrated into the base vegetation land-cover classes.

8.2.4 Nama and succulent Karoo

The Nama and succulent Karoo categories and associated subclasses are included as a result of a specific DEA information requirement in the DEA/CARDNO land-cover data product. Since the sensitivity of the automated spectral models was insufficient to determine these biome boundaries, they have been defined solely on the SANBI biome boundaries, as per the previous fynbos explanation.

However, within these SANBI boundaries, the original level of modelled land-cover detail has been retained in terms of the forest, dense bush, open bush, low shrubland, grassland and bare ground subclasses. This is because each biome can contain a wide range of structural vegetation types, over and above the dominant structural form. For example, localised patches of thicket, tall bush and grasslike structural communities all occur within the general low shrub matrix that comprises the Nama Karoo biome, according to local species composition, terrain location and fire history.

8.3 Creating land-use classes

Land-use classes, such as cultivated lands, forest plantations, mines and settlements, were all derived as separate modelling procedures, typically using independently sourced and generated geographical masks to control where and how the original 51 seasonally defined spectral foundation classes were recoded and modified into the final land-use classes. The masking process also allowed independent, class-specific recoding to be applied, irrespective of spectral class data content, if required.

8.3.1 Cultivated lands

The Department of Agriculture, Forestry and Fisheries (DAFF) public domain 2013 national field boundary dataset (captured from 2.5 m-resolution, pan-merge SPOT5 imagery) was the initial source of the cultivated land-use classes. This existing dataset was updated nationally to represent the latest cultivated land patterns present on the latest 2014 Landsat 8 imagery used in each image frame. This typically involved capturing the distribution of new, commercially cultivated fields, especially centre pivot irrigation units, although all field types were included in the 2014 updating process, including subsistence cultivation areas, if clearly apparent.

In addition, the location, extent and distribution of all commercial pineapple and sugar cane crops were mapped from the same 2014 Landsat 8 imagery to increase the level of crop-specific subclass detail, in line with several of the previous provincial land-cover datasets generated by GTI.

All new cultivated lands (and crop types) mapped from the 2014 Landsat 8 imagery were captured manually using on-screen photo-interpretation techniques, since this facilitated and maintained similar interpretation accuracies to the source SPOT5-derived field boundary data. Furthermore, it also eliminated post-classification editing necessities typically associated with field boundary (as opposed to crop type) classification attempts.

The final cultivated land boundaries were used “as-is” to define the final geographical extent of all the cultivated land-use classes incorporated into the land-cover dataset. No use of or reference to the original 51 seasonally defined spectral foundation classes was made.

8.3.2 Plantations

Forestry plantations were derived from selected classes within the 51-class spectral foundation cover dataset, which were recoded and regrouped within controlled geographical areas, using independently sourced and generated geographical masks. The plantation area masks were sourced from several in-house provincial mapping projects, updated nationally to the plantation extent visible on the 2014 Landsat imagery.

Note that the final plantation class boundaries were always defined by the original spectral foundation class boundaries contained within the geographical masks, and not by the geographical mask boundaries themselves.

The geographical masks used to define the areas to be recoded for the clear-felled plantation subclass were only mapped off the latest 2014 Landsat imagery in order to ensure that the representation and interpretation was current.

8.3.3 Mines

Mines were derived from selected classes within the 51-class spectral foundation cover dataset, which were recoded and regrouped within controlled geographical areas, using independently sourced and generated geographical masks. The mine area masks were sourced from previous in-house, provincial mapping projects and national 1:50 000-scale map datasets[12], all of which were then updated nationally to the mine activity extent visible on the 2014 Landsat imagery. Note that mine-water subclasses were generated by identifying water classes that were located within the final mine geographical masks.

Note that major road and rail features were excluded from the mine area footprint if they intersected the mine mask.

Note that the final mine class boundaries were always defined by the original spectral foundation class boundaries contained within the geographical masks, and not by the geographical mask boundaries themselves.

12 Geographical masks from the national 1:50 000-scale topographic digital map data were created by extracting the relevant vector features and buffering them by one Landsat pixel extent. These were integrated with the in-house provincial mine masks, before updating them to the 2014 geographic extents off the 2014 Landsat 8 imagery.

8.3.4 Built-up areas/settlements

Built-up areas were generated independently of the spectral foundation cover dataset. The primary source for the cover class were several internally developed GTI urban map products and associated databases. These provided detailed information on the extent, distribution and land-use for all settlements nationally. This was verified in rural areas with the National Dwelling Frame Dataset, available from Statistics South Africa. This information was then spatially remodelled to represent built-up area outlines, which were then further updated and corrected nationally, using the 2014 Landsat imagery for visual reference. This was especially so in terms of rural village outlines.

The independently generated built-up area class boundaries were used “as-is” to define the final geographical extent of the settlement patterns incorporated into the land-cover dataset. No use of or reference to the original 51 seasonally defined spectral foundation classes was made.

8.3.5 Erosion

The erosion (donga) class was derived from selected classes (representative of bare ground) from within the 51-class spectral foundation cover dataset, which were recoded and regrouped within controlled geographical areas, using independently sourced and generated geographical masks. The erosion area masks were sourced from previous in-house, provincial mapping projects and other national erosion datasets, all of which were then updated nationally to represent the current extent of major dongas visible on the 2014 Landsat imagery. Note that, as a result of spectral modelling sensitivities and the need to be able to separate the bare ground within donga features from the surrounding non-eroded areas, the final modelled extent of erosion features is significantly better represented both spatially and numerically in the wetter, more vegetatively lush regions of the country, where the non-vegetated erosion surface is significantly different from the surrounding vegetation cover (i.e. bushveld and grassland regions). Donga feature detection in the drier, more arid region is not as accurate.

As with previous land-use classes, the final donga/erosion class boundaries were always defined by the original spectral foundation class boundaries contained within the geographical masks, and not by the geographical mask boundaries themselves.

8.3.5.1 Degraded areas

As part of the DEA-commissioned version of the 2014 GTI South African National Land-cover Dataset, an additional subclass defining "degraded" areas was also generated. This subclass is, however, not part of the standard land-cover data product. Degraded areas are defined in terms of this dataset as areas of significantly reduced vegetation cover compared to immediately adjacent pristine or semi-pristine natural areas. Degraded areas were modelled from selected classes from within the 51-class spectral foundation cover dataset, which were recoded and regrouped within controlled geographical areas, using independently generated geographical masks. The basic degraded area mask was created from image-derived, seasonally summarised NDVI maximum and standard deviation datasets. The extent of this mask allocation was limited to areas outside formally protected (conservation) areas[13], within non-arid biome regions[14], on terrain slopes less than 21 degrees[15], and not overlapping major roads, dry river beds, beaches and dune fields[16].

This modelling approach, while relevant in terms of practical, available input data, excluded the identification of cover-rich, species-poor degraded areas, as well as degraded low vegetation areas within naturally occurring low-vegetation regions. In the latter case, alternate modelling options were considered, based on buffered threshold distances around settlements and mines, but the generic outputs were not considered to be universally reliable or accurate.

As with previous land-use classes, the final degraded area boundaries were always defined by the original spectral foundation class boundaries contained within the geographical masks, and not by the geographical mask boundaries themselves.

13 As defined in the DEA Protected Areas 2014 Protected and Conservation Areas (PACA) Database.

14 To ensure that degraded areas were clearly identifiable as having a lower vegetation cover than the surrounding non-degraded areas, unless they were located within the boundaries of the former TBVC states (Transkei, Bophuthatswana, Venda and Ciskei) and closely associated with areas of dense rural settlements.

15 To exclude natural rocky slopes and cliff faces with similar non-vegetated spectral characteristics.

16 To exclude other land-cover and land-use features with similar non-vegetated spectral characteristics

9. ACCURACY ASSESSMENT

The 2013/14 South African National Land-cover Dataset has been verified in terms of mapping accuracy to provide a measure of end-user confidence in data use. The satellite image-generated land-cover/land-use information was verified visually, as part of a desktop-only procedure, against equivalent-date, high-resolution imagery and photography in Google Earth©. Accuracies are reported using industry-standard error (confusion) matrices, and include producer, user and kappa values.

9.1 Design and approach

Sample points for verification were selected using two separate approaches that considered the validity of statistical representation, the spatial resolution of Landsat imagery in relation to landscape features, the national reporting frame extent and the structure of the mapped land-cover information. Note that 33 land-cover/land-use classes were verified, in some cases representing primary rather than subclass land-cover or land-use characteristics. Where necessary, these were then amalgamated into the broader DEA/CARDNO land-cover/land-use classes for statistical reporting. For example, water, mines and plantations were verified at the primary level, since subclass detail was linked to short-term temporal effects that could not be verified on the single Google Earth© imagery.

The selection of samples representing potential commission errors was achieved by selecting about 150 samples for each of the 33 classes to be verified, given a total of approximately 3 500 points. Points were selected randomly across the full national land-cover dataset. Typically, about 100 samples were selected from thematic class units smaller than 100 ha and about 50 samples were selected from thematic class units greater than 100 ha in order to ensure a balanced representation of thematic unit areas. In all cases, the actual sample point represented the centre of the selected thematic unit, with placement set to exclude areas within 50 m of the thematic unit boundary to minimise class-edge effects.

The selection of samples representing potential omission errors was achieved by selecting approximately 2 500 samples without reference to class type initially with a stratified approach using the image frame extents, and then randomly, within the selected frames, across the original spectral foundation class dataset (as opposed to the final land-cover dataset). The boundaries of the spectral foundation classes were just used as a sampling frame. Points represented the centre of the selected thematic spectral unit, with placement set to exclude areas within 50 m of the thematic unit boundary to minimise class-edge effects. This approach was deemed appropriate since it ensured that the sample points at least reflected the spatial variability of the multi-date input imagery, which in turn reflected the seasonal landscape characteristics. Approximately 1 000 samples were selected from thematic class units between 100 and 200 ha in size, 1 000 from thematic class units between 200 and 500 ha, 400 from thematic class units between 500 and 1 000 ha, and 100 from thematic class units greater than 1 000 ha in order to ensure a balanced representation of thematic unit areas.

Note that the results presented below represent the DEA/CARDNO land-cover legend content, and not the full land-cover legend from which it has been derived.

Note that no map accuracy statistics are provided at the biome level, other than for the fynbos: low shrubland class, since the biome-defined boundaries have been derived from fixed, independent data and simply overlaid on the spectrally modelled structural vegetation categories. The fynbos: low shrubland class is retained within the accuracy assessment since its delineation has, in part, been defined on modelled spectral characteristics.

Note that no map accuracy is provided for the degraded class due to the difficulty of reliably determining – visually – that the vegetation at a specific sample point is significantly lower than that in surrounding, undisturbed natural vegetation areas, without in-field observation over wider areas. It is suggested that the calculated accuracy for bare ground and erosion is taken as indicative of the degraded mapping accuracy, since the degraded class is a modelled derivative of these classes.

Figure 7 illustrates the number and distribution of sample points across the full country extent.

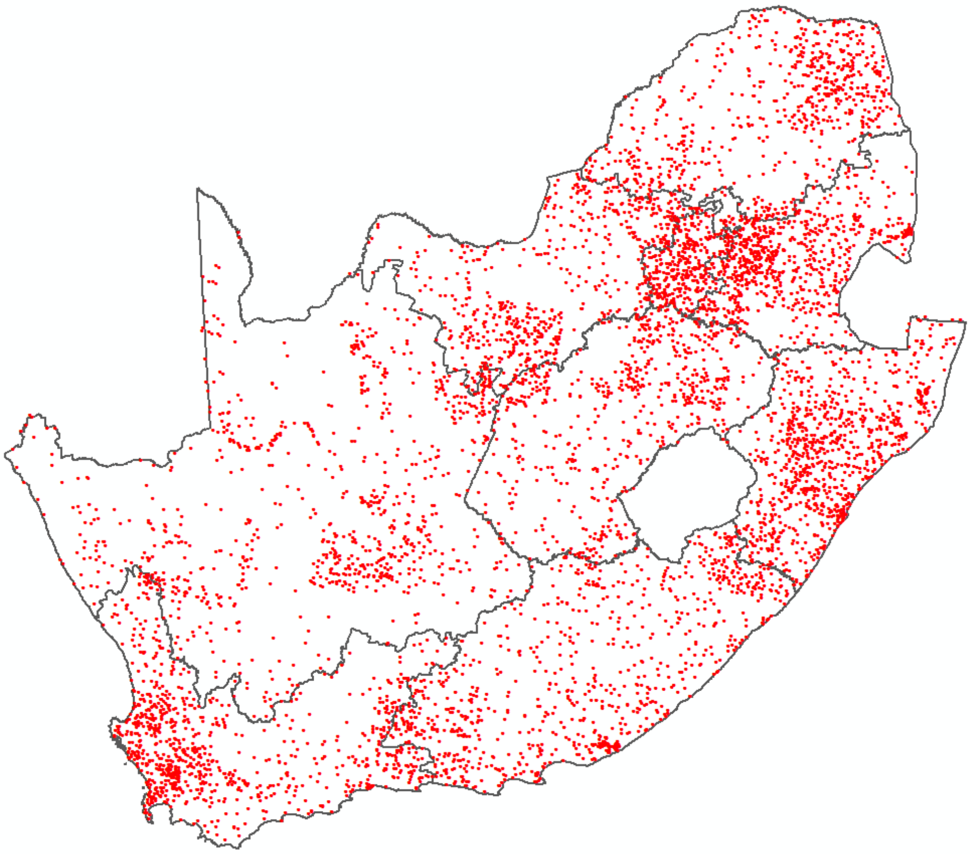


Figure 7.Number and distribution of 6 415 sample points across the full country extent.

9.2 Results

The map accuracy results for the 2013/14 South African National Land-cover Dataset, modelled from multi-seasonal Landsat 8 imagery, based on the modified-legend format representing the DEA/CARDNO information requirements, are as follows:

OVERALL SUMMARY		
Overall Map Accuracy	82.53	%
Mean Class Accuracy	88.36	%
90 % confidence limits	81.91	83.14
	low	high
Kappa Index	80.87	
Number of classes present (enter)		17
Number of sample sites		6415

The overall map accuracy for the 2013/14 South African National Land-cover Dataset in the DEA/CARDNO format, modelled from multi-seasonal Landsat 8 imagery, is 82.53%, with a mean land-cover/land-use class accuracy of 88.36%. This has been determined from 6 415 sample points representing 17 DEA/CARDNO land-cover/land-use classes. The Kappa Index value of 80.87 indicates that these results are very unlikely to be the result of chance occurrence.

A breakdown of individual class accuracies is provided below:

CLASS SUMARY STATISTICS			User	Prod	90% C.L		Omm	Comm
			Acc %	Acc %	low	high	Error	Error
LAND-COVER CLASS	Indignenous Forest	1	72.60	94.64	91.78	97.50	0.05	0.27
	Dense Bush, Thicket	2	53.74	83.64	80.72	86.55	0.16	0.46
	Woodland, Open Bush	3	60.84	54.13	51.27	57.00	0.46	0.39
	Low Shrub: Other	4	70.59	61.82	59.37	64.27	0.38	0.29
	Forest Plantation	5	89.30	94.35	92.31	96.39	0.06	0.11
	Cultivated Commercial Crop	6	91.91	99.54	98.69	100.00	0.00	0.08
	Cultivated Pivot Crop	7	95.38	92.42	91.18	93.66	0.08	0.05
	Cultivated Orchards	8	92.18	95.29	93.62	96.95	0.05	0.08
	Cultivated Vineyard	9	91.61	97.26	95.37	99.15	0.03	0.08
	Cultivated Subsistence	10	89.00	94.42	92.22	96.61	0.06	0.11
	Settlements	11	93.90	98.68	97.93	99.43	0.01	0.06
	Wetlands	12	88.07	91.18	88.30	94.05	0.09	0.12
	Grasslands	13	84.56	69.82	68.11	71.53	0.30	0.15
	Fynbos: Low Shrubland	17	79.64	93.31	91.15	95.46	0.07	0.20
	Water	33	98.77	97.58	95.89	99.27	0.02	0.01
	Bare Ground	34	78.69	85.92	83.86	87.97	0.14	0.21
		Total		82.53	81.91	83.14		

Note: Class numbers refer to the class numbers in the digital land-cover data, which includes additional subclass information relating to the fynbos, Nama and succulent Karoo biome groupings.

These results exceed the requirements as defined in the terms of reference, that “a minimum map accuracy of 70% is to be achieved at the 90% confidence limits, with a minimum 70% kappa index value ... with a minimum of 30 samples per class ... (and) a target of 1 000 samples in total”.

A significant majority of individual land-cover/land-use classes achieved user and producer accuracies of 70% or more (see yellow highlights). Fourteen out of 17 (82%) classes achieved a user accuracy greater than or equal to 70%. Thirteen out of 17 (76%) classes achieved a producer accuracy greater than or equal to 70%.

Producer accuracy (omission error) represents how well reference pixels of the true land cover are classified. User accuracy (commission error) represents the probability that a pixel classified in a given category actually represents that category on the ground. Producer accuracy therefore represents the accuracy of the sample points, whereas user accuracy represents what the data user will experience when using the land-cover data. The Kappa Index is a measure of statistical chance, with higher values (greater than 0.7) typically representing repeatable and reliable results.

The contingency matrix showing the per-cover class breakdown of these map accuracy statistics is shown in Appendix E.

9.3 Analysis and conclusions

Overall, the map accuracies for the 2013/14 South African National Land-cover Dataset are very good and indicate that the dataset is accurate and that data users can have confidence in the information contained in it. There are, however, some individual classes with less than 80% user and/or producer accuracy that need further analysis and comment. All of these, bar one, are associated with spectrally modelled base vegetation classes, rather than the post-modelling-derived land-use classes.

9.3.1 Dense bush/thicket

The dense bush/thicket class achieved a 83.64% producer accuracy, but only a 53.86% user accuracy. This appears to be primarily the result of confusion with woodland/open bush (76 out of 428 samples), grassland (51 out of 428 samples) and low shrubland[17] (45 out of 428 samples). There is no clear regional pattern associated with this misclassification.

Within the woodland/open bush confused samples, 52 of the 76 samples had a woody cover greater than or equal to 55%, and 26 of the 76 samples had a woody cover greater than or equal to 65%, which may explain this inter-class confusion, since the (Google Earth©) observed canopy cover amounts could be considered close to the transition to dense bush cover. The confusion with observed grassland areas is difficult to explain since very little woody cover is observed in these samples. A possible explanation may be that localised areas of extremely high grassland biomass are (spectrally) confused in the modelling process with woody cover. The dense bush/thicket confusion with low shrubland may be associated, in some cases, with the tall woody cover density of low shrubland[18], since 24 out of 45 of the incorrect sample sites have an observed woody cover greater than or equal to 15%, 15 out of 45 have an observed woody cover greater than or equal to 25%, nine out of 45 have an observed woody cover greater than or equal to 35% and five out of 45 have an observed woody cover greater than or equal to 45%.

If all the dense bush/thicket samples are grouped into tall woody versus non-woody (or low woody shrub) cover[19], then 349 out of 428 (81%) samples have a tall woody canopy cover greater than or equal to 15%, regardless of observed land-cover type, 331 out of 428 (77%) samples have a tall woody canopy cover greater than or equal to 25%, 323 out of 428 (75%) samples have a tall woody canopy cover greater than or equal to 35%, 310 out of 428 (72%) samples have a tall woody canopy cover greater than or equal to 45%, and 197 out of 428 (46%) samples have a tall woody canopy cover greater than or equal to 65%.

9.3.2 Woodland/open bushland

The woodland/open bushland class achieved a 60.84% user accuracy and a 54.13% producer accuracy. This appears to be primarily the result of confusion with grassland (59 out of 452 samples) and low shrubland[20] (80 out of 452 samples). There is no clear regional pattern associated with this misclassification.

17 Low shrubland fynbos and other subclasses combined.

18 The observed woody cover percentage for low shrubland (fynbos and other) is indicated in the accuracy spreadsheet, and represents the tall woody cover and not the general low matrix of woody shrubs.

19 Note that forest plantations do not have a woody canopy cover value recorded for either observed or mapped plantation sample sites, so it is likely that the accuracy of the modelled extent of dense woody cover is actually higher, since there are eight dense bush/ thicket sample points that were observed to be plantation forests.

20 Low shrubland fynbos and other subclasses combined.

The confusion with grassland is difficult to explain, other than that it is the result of modelling and interpretation errors associated with lower woody canopy cover densities and associated spectral characteristics, with 14 out of 59 (23%) of the observed grassland samples having a woody cover of greater than or equal to 15%. Similar confusion was found with low shrubland, with 17 out of 80 (21%) of the observed low shrubland samples having a tall woody cover of greater than or equal to 15%, irrespective of the background low woody shrub matrix.

If all the woodland/open bushland samples are grouped into tall woody versus non-woody (or low woody shrub) cover, then 320 out of 452 (70%) samples have a tall woody canopy cover greater than or equal to 15%, regardless of observed land-cover type, 289 out of 452 (63%) samples have a tall woody canopy cover greater than or equal to 25%, 284 out of 452 (62%) samples have a tall woody canopy cover greater than or equal to 35%, 221 out of 452 (48%) samples have a tall woody canopy cover greater than or equal to 45%, and 80 out of 452 (17%) samples have a tall woody canopy cover greater than or equal to 65%.

9.3.3 Grassland

The grassland class achieved a 84.56% user accuracy, but only a 69.82% producer accuracy. This appears to be primarily the result of confusion with woodland/open bush (82 out of 1 004 samples) and low shrubland[21] (55 out of 1 004 samples). There is no clear regional pattern associated with this misclassification.

The confusion with woodland/open bush is difficult to explain, other than that it is the result of modelling and interpretation errors, since the majority of observed woodland/open bush sample sites all have tall woody cover densities greater than or equal to 55%. However, on the majority of observed low shrubland sites, the woody cover density was less than 5%, irrespective of the background low woody shrub matrix, which is probably representative of a transitional zone.

If all the grassland samples are grouped into tall woody versus non-woody cover, then 813 out of 1 004 (80%) samples have a tall woody canopy cover less than or equal to 15%, regardless of observed land-cover type, and 711 out of 1 004 (70%) samples have a tall woody canopy cover less than or equal to 5%, regardless of observed land-cover type.

9.3.4 Low shrubland (fynbos and other subclasses combined)

The low shrubland classes for fynbos and other respectively achieved user accuracies of 79.64% and 70.59%, and producer accuracies of 93.31% and 61.82%. These two classes have been assessed in combination, since they are only differentiated on the basis of the overlaid SANBI biome boundary. In both cases, confusion was primarily with grassland (142 out of 858 samples). There is no clear regional pattern associated with this misclassification.

If all the low shrubland samples are grouped into (tall) woody versus non-woody cover, then 791 out of 858 (92%) samples have a tall woody canopy cover less than 15%, regardless of observed land-cover type, and 691 out of 858 (80%) samples have a tall woody canopy cover less than 5%, regardless of observed land-cover type.

9.3.5 Bare ground

The bare ground class achieved a user accuracy of 73.54% and a producer accuracy of 77.54%. This appears to be primarily the result of confusion with grassland (26 out of 378 samples) and low shrubland[22] (65 out of 378 samples). There is no clear regional pattern associated with this misclassification. The confusion with low shrubland is difficult to explain, other than that it is the result of modelling and interpretation errors, since 57 of the 65 observed low shrubland sample sites all have tall woody cover densities between 5 and 55%, with the majority being between 15 and 25%. However, these percentages, as indicated, only refer to the tall woody cover component, and not to the low woody shrub component, which may have been very sparse. The confusion with grassland may be due to a comparable, overall low vegetation base cover, although unlike with the observed low shrubland samples, the observed grassland samples all had, bar one, 0% tall woody cover densities.

9.3.6 Conclusion

In conclusion, it would seem that the majority of mapping errors associated with the base natural

21 Low shrubland fynbos and other subclasses combined.

22 Low shrubland fynbos and other subclasses combined.

vegetation cover classes can be broadly associated with transitional vegetation conditions, represented by structural vegetation gradients, within which the spectral-based modelling has defined a fixed boundary.

10. DATA USE

The digital raster data is supplied without any post-modelling or classification spatial filtering. Data users may wish to consider applying spatial cleaning techniques, such as applying a moving 3 x 3 pixel window filter to remove isolated single-class pixels from the dataset, especially if the raster data is to be converted to vector format.

11. METADATA

2013/14 GTI South African National Land-cover Dataset DEA/CARDNO 35-class Legend: Core metadata elements (SANS 1878)

1(M) Dataset title: 2013/14 GTI SA National Land-cover (DEA/CARDNO version) (*dea_cardno_2014_sa_lcov_utm35n_vs2b_pivot-corr.img*)

2(M) Dataset reference date: April 2013 to March 2014

3(O) Dataset responsible party: Produced by GeoTerra Image (GTI) (Pty) Ltd, South Africa

4(C) Geographic location of the dataset. MBR
WestBoundLongitude: -717294.00 (Upper Left X)
EastBoundLongitude: 1301256.00 (Lower Right X)
NorthBoundLongitude: -2239230.00 (Upper Left Y)
SouthBoundLongitude: -4046670.00 (Lower Right Y)

Projection coordinates based on Universal Transverse Mercator (UTM) 35 north, WGS84 (datum), metres.

5(M) Dataset language: “English” (eng)

6(C) Dataset character set: UTF8 (8-bit data)

7(M)Dataset topic category: 010 = Base map earth coverage

8(O) Scale of the dataset: Land cover mapped from 30 m-resolution Landsat satellite imagery, therefore recommended for approximately 1:75 000 to 1:90 000 scale or coarse mapping and modelling applications.

9(M) Abstract describing the dataset: The 2013/14 South African National Land-cover Dataset produced by GTI as a commercial data product has been generated from digital, multi-seasonal Landsat 8 multispectral imagery, acquired between April 2013 and March 2014. In excess of 600 Landsat images were used to generate the land-cover information, based on an average of eight different seasonal image-acquisition dates, within each of the 76 image frames required to cover South Africa. The land-cover dataset, which covers the whole of South Africa, is presented in a map-corrected, raster format, based on 30 x 30 m cells equivalent to the image resolution of the source Landsat 8 multi-spectral imagery. This specific version of the 2013/14 GTI South African National Land-cover Dataset is supplied to the South African Department of Environmental Affairs under the DEA/CARDNO Project: SCPF002: *Implementation of Land-use Maps for South Africa*. The supplied dataset referred to in this report represents a subset of the full 2013/14 GTI South African National Land-cover Dataset, in terms of supplied land-cover/land-use categories. Use of this DEA/CARDNO data version is governed by the LICENCE AGREEMENT contained in this report. The DEA/CARDNO dataset contains 35 land-cover/land-use information classes, covering a wide range of natural and man-made landscape characteristics. The original land-cover dataset was processed in UTM35 (north)/ WGS84 map-projection format based on the Landsat 8 standard map-projection format as provided by the USGS. The data remains the property of GTI, and is protected by copyright laws. All intellectual property rights pertaining to the data remain with GTI at all times.

This updated 2013/14 dataset corrects the coding error for DEA/CARDNO classes 6 and 7 (cultivated fields and pivot cultivated fields), which were inadvertently swapped in the previous version. Apart from the recoding of the two field-type classes, all other details and class codes remain exactly the same as the previously delivered datasets.

10(O) Dataset format name: ERDAS Imagine© *img raster formats

11(O) Dataset format version: version 01 (file#22)

12(O) Additional extent information for the dataset: (vertical and temporal)

Vertical extent:

Minimum value: N/A
Maximum value: N/A
Unit of measure: N/A
Vertical datum: N/A

Temporal extent: Land-cover datasets generated in January 2015, based on April 2013 to March 2014 multi-seasonal Landsat 8 and Landsat 5 satellite imagery.

14(O) Reference system: Universal Transverse Mercator (UTM) 35 north

CRS:

Projection used: Universal Transverse Mercator (UTM) 35 north
Spheroid used: WGS84
Datum used: WGS 84

Ellipsoid parameters:

Ellipsoid semi-major axis
Axis units
Denominator of flattening ratio

Projection parameters:

UTM Zone: 35 (north)
Standard parallel
Longitude of central meridian: 27:00:00.00 east
Latitude of projection origin: 00:00:00.00 east
False easting: 500 000.00 metres
False northing: 0.00 metres
Scale factor at equator: 0.999600
Projection units: metres

15(O) Lineage statement: Land-cover dataset generated in-house by GTI (Pretoria) in January 2015, based primarily on multi-date Landsat 8 imagery acquired between April 2013 and March 2014.

16(O) Online resource: N/A

17(O) Metadata file identifier: N/A

18(O) Metadata standard name: SANS I878

19(O) Metadata standard version: version 01

20(C) Metadata language: English (eng)

21(C) Metadata character set: 021 (UsAscii)

22(M) Metadata point of contact:

Name:	Mark Thompson
Position name:	Director Remote Sensing
Organisation name:	GeoTerraImage (Pty) Ltd

Physical address:

Building	Grain Building (1st Floor)
Street	Witherite
Street Suffix	Street
Street No	477
Suburb	Die Wilgers
City	Pretoria
Zip code	0041
State	Gauteng
Country	South Africa

Postal address:

Box	295
Suburb	Persequor Park
City	Pretoria
Zip code	0020
State	Gauteng
Country	South Africa

23(M) Metadata time stamp: 31 July 2015

APPENDIX A: The 2013/14 South African National Land-cover Legend (DEA/CARDNO legend)

The table below describes the 35 land-cover/land-use classes contained in the DEA/CARDNO-supplied subset of the 2013/14 South African National Land-cover Dataset, generated from multi-seasonal Landsat 8 imagery.
See Appendix D for visual examples of percentage cover densities per unit area.

Parent	DEA class name (and digital code)	Definition
Water	Water (33)	Areas of open, surface water that are detectable on all image dates used in the Landsat 8-based water modelling processes. The mapped extent represents the maximum detectable water extent from all available imagery acquired within the 2013/14 assessment period. Includes both natural and man-made water features.
Wetland	Wetland (12)	Wetland areas that are primarily vegetated on a seasonal or permanent basis. Defined on the basis of seasonal image-identifiable surface vegetation patterns (not subsurface soil characteristics). The vegetation can be either rooted or floating. Wetlands may be either daily (i.e. coastal), temporarily seasonal or permanently wet and/or saturated. Vegetation is predominately herbaceous. Includes, but is not limited to wetlands associated with seeps/springs, marshes, floodplains, lakes/pans, swamps, estuaries and some riparian areas. Wetlands associated with riparian zones represent image-identified vegetation along the edges of watercourses that show similar spectral characteristics to nearby wetland vegetation. Excludes mangrove swamps. Permanent or seasonal open-water areas within the wetlands are classified separately. Seasonal wetland occurrences within commercially cultivated field boundaries are not shown, although they have been retained within subsistence-level cultivation fields.
Forest	Indigenous forest (1)	Natural/semi-natural indigenous forest, dominated by tall trees, where tree canopy heights are typically greater than 5 m and tree canopy densities are typically more than 75%, often with multiple understory vegetation canopies. Note this class refers to grassland areas not within the fynbos, Nama Karoo and succulent Karoo biome boundaries (as defined in the SANBI 2006 *Vegetation of South Africa, Swaziland and Lesotho* map data).
Thicket and dense bush	Dense bush, thicket and tall dense shrubs (2)	Natural/semi-natural tree and/or bush-dominated areas, where typically canopy heights are between 2 and 5 m, and canopy density is typically more than 75%, but may include localised, sparser areas down to about 60%. Includes dense bush, thicket, closed woodland, tall, dense shrubs, scrub forest and mangrove swamps. Can include self-seeded bush encroachment areas if there is sufficient canopy density. Note: This class refers to grassland areas not within the fynbos, Nama Karoo and succulent Karoo biome boundaries (as defined in the SANBI 2006 *Vegetation of South Africa, Swaziland and Lesotho* map data).
Woodland/ open bush	Woodland and open bushland (3)	Natural/semi-natural tree and/or bush-dominated areas, where typically canopy heights are between 2 and 5 m, and canopy densities are typically between 40 and 75%, but may include localised, sparser areas down to 15 to 20%. (*Note: Normally, it is preferred that land-cover class definitions are mutually exclusive in terms of content and associated landscape characteristics. Due to the nature of the multi-seasonal spectral modelling approach used in compiling the land-cover dataset, it seems that there is some transitional overlap between "bushy/woody grassland" and "grassy woodland/ bushland" in terms of woody cover densities. For this reason, the class definitions for both "woodland/open bush" and "grassland" include both a class-specific core woody cover definition and a shared transitional woody cover definition. The sample points used to verify the map accuracy record the observed woody cover percentage for these vegetation types should the user wish to undertake further analysis.*)

Parent	DEA class name (and digital code)	Definition
Woodland/ open bush	Woodland and open bushland (3)	Includes sparse open bushland and woodland, including transitional wooded grassland areas. Can include self-seeded bush encroachment areas if canopy density is within the indicated range. In the arid western regions (i.e. Northern Cape), this cover class may be associated with a transitional bush/shrub cover that is lower than typical open bush/woodland cover, but higher and/or more dense than typical low shrub cover. Note: This class refers to grassland areas not within the fynbos, Nama Karoo and succulent Karoo biome boundaries (as defined in the SANBI 2006 *Vegetation of South Africa, Swaziland and Lesotho* map data).
Grassland	Grassland (13)	Natural/semi-natural grass-dominated areas, where the tree and/or bush canopy densities are typically less than 20%, but may include localised denser areas up to 40% (regardless of canopy heights).[7] Includes open grassland and sparse bushland and woodland areas, including transitional wooded grasslands. May include planted pasture (i.e. grazing) if not irrigated. Irrigated pastures will typically be classified as cultivated, and urban parks and golf courses under urban. Note: This class refers to grassland areas not within the fynbos, Nama Karoo and succulent Karoo biome boundaries (as defined in the SANBI 2006 *Vegetation of South Africa, Swaziland and Lesotho* map data).
Low shrubland	Low shrubland (4)	Natural/semi-natural low shrub-dominated areas, typically with a canopy height up to 2 m. Includes a range of canopy densities encompassing sparse to dense canopy covers. Very sparse covers may be associated with the bare ground class. Typically associated with low, woody shrub, Karoo-type vegetation communities, although can also represent locally degraded vegetation areas where there is a significantly reduced vegetation cover in comparison to surrounding, less impacted vegetation cover, including long-term wildfire scars in some mountainous areas in the Western Cape. Note that taller tree/bush/shrub communities within this vegetation type are typically classified separately as one of the other tree- or bush-dominated cover classes. Note: This class refers to low shrubland areas not within the fynbos, Nama Karoo and succulent Karoo biome boundaries (as defined in the SANBI 2006 *Vegetation of South Africa, Swaziland and Lesotho* map data).
Cultivated	Commercial annuals (rain-fed) (6)	Cultivated lands used primarily for the production of rain-fed, annual crops for commercial markets. Typically represented by large field units, often in dense local or regional clusters. In most cases, the defined cultivated extent represents the actual cultivated or potential extent. Includes sugarcane crops.
	Commercial pivot (7)	Cultivated lands used primarily for the production of centre pivot-irrigated, annual crops for commercial markets. In most cases, the defined cultivated extent represents the actual cultivated or potential extent. Includes sugarcane crops.
	Commercial permanent (orchards) (8)	Cultivated lands used primarily for the production of both rain-fed and irrigated permanent orchard crops for commercial markets. Includes both tree, shrub and non-woody crops, such as citrus, tea, coffee, grapes, lavender and pineapples. In most cases, the defined cultivated extent represents the actual cultivated or potential extent.
	Commercial permanent (vines) (9)	Cultivated lands used primarily for the production of both rain-fed and irrigated permanent vine (grape) crops for commercial markets. In most cases the defined cultivated extent represents the actual cultivated or potential extent.
	Subsistence (10)	Cultivated lands used primarily for the production of rain-fed, annual crops for local markets and/or home use. Typically represented by small field units, often in dense local or regional clusters. The defined area may include intra-field areas of non-cultivated land, which may be degraded or use-impacted if the individual field units are too small to be defined as separate features.

Parent	DEA class name (and digital code)	Definition
Forest plantation	Forest plantations (5)	Planted forestry plantations used for growing commercial timber tree species. The single class represents a combination of mature, young and temporary clear-felled stands. The class includes spatially smaller woodlots and windbreaks with the same cover characteristics. Note that young saplings are very difficult to identify on 30 m-resolution Landsat imagery if the actual tree canopy cover density is below 30 to 40%, because the background cover, for example, grassland, then dominates the spectral characteristics in that pixel area.
Mine	Mine (32)	Mining activity footprint, which includes extraction pits, tailings, waste dumps, flooded pits and associated surface infrastructure, such as roads and buildings (unless otherwise indicated), for both active and abandoned mining activities. Class may include open-cast pits, sand mines, quarries and borrow pits.
Bare	Bare (non-vegetated) (34)	Bare, non-vegetated ground with little or very sparse vegetation cover (i.e. typically up to 5 to 10% vegetation cover), occurring as a result of either natural or man-induced processes. Includes, but is not limited to natural rock exposures, dry river beds, dry pans, coastal dunes and beaches, sand and rocky desert areas, very sparse low shrublands and grasslands, erosion areas and major road networks. May also include long-term wildfire scars in some mountainous areas in the Western Cape.
	Degraded (35)	Sparsely vegetated areas, occurring as a result of man-induced processes, which show significantly lower overall vegetation cover compared to surrounding, natural undisturbed areas.
Built-up	Settlements (11)	All built-up areas, represented as a single class, including, but not limited to commercial, industrial, heath, education, religion, transport and residential land uses, including both formal and informal structures, across a range of structural densities from high to low. Includes high- and low-density areas containing high-density buildings and other built-up structures mainly associated with non-residential, commercial, administrative, sport, health, religious or transport (i.e. train station) activities. Includes agricultural smallholdings on the urban periphery.
Fynbos	Fynbos: forest (14)	Forest areas as per class (1) within the SANBI fynbos biome boundary.
	Fynbos: thicket (15)	Dense bush and thicket areas as per class (2) within the SANBI fynbos biome boundary.
	Fynbos: open bush (16)	Woodland and open bush areas as per class (3) within the SANBI fynbos biome boundary.
	Fynbos: low shrub (17)	Low shrubland areas as per class (4) within the SANBI fynbos biome boundary.
	Fynbos: grassland (18)	Grassland areas as per class (13) within the SANBI fynbos biome boundary.
	Fynbos: bare ground (19)	Bare ground areas as per class (14) within the SANBI fynbos biome boundary.
Nama Karoo	Nama Karoo: forest (20)	Forest areas as per class (1) within the SANBI Nama Karoo biome boundary.
	Nama Karoo: thicket (21)	Dense bush and thicket areas as per class (2) within the SANBI Nama Karoo biome boundary.
	Nama Karoo: open bush (22)	Woodland and open bush areas as per class (3) within the SANBI Nama Karoo biome boundary.
	Nama Karoo: low shrub (23)	Low shrubland areas as per class (4) within the SANBI Nama Karoo biome boundary.
	Nama Karoo: grassland (24)	Grassland areas as per class (13) within the SANBI Nama Karoo biome boundary.
	Nama Karoo: bare ground (25)	Bare ground areas as per class (14) within the SANBI Nama Karoo biome boundary.

Parent	DEA class name (and digital code)	Definition
Succulent Karoo	Succulent Karoo: forest (26)	Forest areas as per class (1) within the SANBI succulent Karoo biome boundary.
	Succulent Karoo: thicket (27)	Dense bush and thicket areas as per class (2) within the SANBI succulent Karoo biome boundary.
	Succulent Karoo: open bush (28)	Woodland and open bush areas as per class (3) within the SANBI succulent Karoo biome boundary.
	Succulent Karoo: low shrub (29)	Low shrubland areas as per class (4) within the SANBI succulent Karoo biome boundary.
	Succulent Karoo: grassland (30)	Grassland areas as per class (13) within the SANBI succulent Karoo biome boundary.
	Succulent Karoo: bare ground (31)	Bare ground areas as per class (14) within the SANBI succulent Karoo biome boundary.

Note: the fynbos, Nama Karoo and succulent Karoo vegetation subclasses are provided with additional class codes representing the parent primary vegetation class in order for different levels of class detail to be used and accessed by data users. This is illustrated on the next page.

Dual legend system for the DEA CARDNO 2013/14 South African land-cover classes (statistics for pivot code corrected dataset)

- Class_Names (Color) represents the full 35-class land-cover/land-use legend (with biome-level information)
- Class_Names2 (Color2) represents the amalgamated 17-class land-cover/land-use legend (no biome-level information)
- Area refers to hectares (ha) and histogram to the number of 30 x 30 m image pixels.

dea_cardno_2014_sa_lcov_utm35n_vs2b_pivot-corr.img

Row	Color	Class_Names	Color2	Class_Names2	Area	Histogram
0					0	0
1		Indigenous Forest		Indigenous Forest	395720	4396888
2		Thicket /Dense bush		Thicket /Dense bush	7.09698e+006	78855335
3		Woodlan/Open bush		Woodlan/Open bush	1.09087e+007	121207366
4		Low shrubland		Low shrubland	1.80007e+007	200008268
5		Plantations / Woodlots		Plantations / Woodlots	1.8737e+006	20818902
6		Cultivated commercial annual crops non-pivot		Cultivated commercial annual crops non-pivot	1.06108e+007	117898196
7		Cultivated commercial annual crops pivot		Cultivated commercial annual crops pivot	782049	8689435
8		Cultivated commercial permanent orchards		Cultivated commercial permanent orchards	346950	3855005
9		Cultivated commercial permanent vines		Cultivated commercial permanent vines	188711	2096791
10		Cultivated subsistence crops		Cultivated subsistence crops	2.04053e+006	22672521
11		Settlements		Settlements	2.90828e+006	32314218
12		Wetlands		Wetlands	1.0259e+006	11398887
13		Grasslands		Grasslands	2.37573e+007	263970479
14		Fynbos: forest		Indigenous Forest	32724	363600
15		Fynbos: thicket		Thicket /Dense bush	691164	7679603
16		Fynbos: open bush		Woodlan/Open bush	307674	3418605
17		Fynbos: low shrub		Low shrubland	5.32864e+006	59207100
18		Fynbos: grassland		Grasslands	381413	4237918
19		Fynbos: bare ground		Bare Ground	210113	2334586
20		Nama Karoo: forest		Indigenous Forest	0	0
21		Nama Karoo: thicket		Thicket /Dense bush	328724	3652485
22		Nama Karoo: open bush		Woodlan/Open bush	540805	6008941
23		Nama Karoo: low shrub		Low shrubland	1.40578e+007	156197442
24		Nama Karoo: grassland		Grasslands	1.31982e+006	14664675
25		Nama Karoo: bare ground		Bare Ground	9.38285e+006	104253894
26		Succuelent Karoo: forest		Indigenous Forest	0	0
27		Succulent Karoo: thicket		Thicket /Dense bush	174801	1942236
28		Succulent Karoo: open bush		Woodlan/Open bush	677790	7530997
29		Succulent Karoo: low shrub		Low shrubland	4.44011e+006	49334527
30		Succulent Karoo: grassland		Grasslands	335397	3726633
31		Succulent Karoo: bare ground		Bare Ground	1.97062e+006	21895741
32		Mines		Mines	328973	3655254
33		Waterbodies		Waterbodies	2.04562e+006	22729092
34		Bare Ground		Bare Ground	1.49435e+006	16603927
35		Degraded		Degraded	944061	10489566

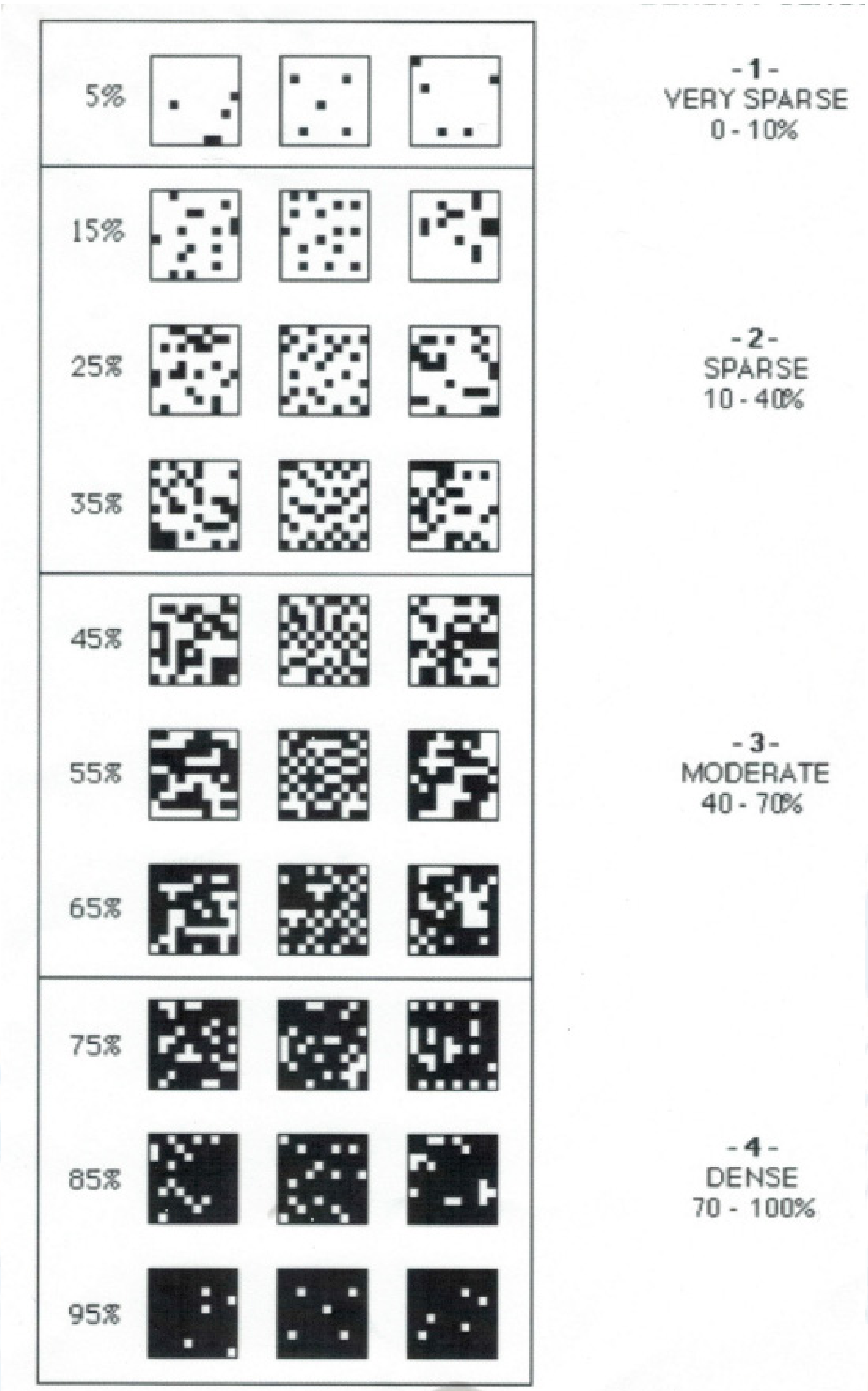
APPENDIX B: List of accompanying documents and files

- An Excel spreadsheet containing the full list of Landsat 8 and Landsat 5 acquisition dates, per image frame, as used in the generation of the 2013/14 South African National Land-cover Dataset. Note that the listed acquisition dates represent the primary dates used in the land-cover modelling, and not any additional image dates that were only used for localised cloud masking on the primary image date. Additional image dates are, however, listed if they themselves were also considered primary acquisition dates and used as modelling inputs.
- ESRI ArcGIS point coverage (UTM35 north) representing the sample points used to verify the 2013/14 South African National Land-cover Dataset (version 4), and to calculate the DEA-CARDNO legend format mapping accuracies.

APPENDIX C: The 51-class Seasonally Defined Spectral Foundation Class Legend

Row	Color	Class_Names
0		
1		water seasonal
2		water permanent
3		bare mix 1 date only, no overlap with any pure bare class
4		bare mix >1 but < all dates, no overlap with any pure bare class
5		bare mix all dates, no overlap witrh any pure bare class
6		bare pure 1 date only
7		bare pure >1 but < all dates
8		bare pure all dates
9		Tree/Bush mix 1 date only
10		Tree 1 date only
11		Tree/Bush mix >1 but < all dates
12		Tree >1 but <all dates
13		Tree/Bush mix all dates
14		Tree all dates
15		golf-irrig combo Tree/Bush mix 1 date only
16		golf-irrig combo Tree 1 date only
17		golf-irrig combo Tree/Bush mix >1 but < all dates
18		golf-irrig combo Tree >1 but < all dates
19		golf-irrig combo Tree/Bush mix all dates
20		golf-irrig combo Tree all dates
21		Tree/Bush 1 date only + Bare pure 1 date only
22		Tree 1 date only + Bare pure 1 date only
23		Tree/Bush multi dates + Bare pure 1 date only
24		Tree multi dates + Bare pure 1 date only
25		Tree/Bush multi dates + Bare pure multi dates
26		Tree multi dates + Bare pure multi dates
27		Tree/Bush 1 date only + Bare pure multi dates
28		Tree 1 date only + Bare pure multi dates
29		golf-irrig combo / Tree/Bush mix 1 date only + Bare pure 1 date
30		golf-irrig combo / Tree 1 date only + Bare pure 1 date only
31		golf-irrig combo / Tree/Bush mix multi dates + Bare pure 1 date
32		golf-irrig combo / Tree multi dates + Bare pure 1 date only
33		golf-irrig combo / Tree/Bush mix multi dates + Bare pure multi dates
34		golf-irrig combo / Tree multi dates + Bare pure multi dates
35		golf-irrig combo / Tree/Bush mix 1 date only + Bare multi dates
36		golf-irrig combo / Tree 1 date only + Bare pure multi dates
37		Grass (all dates)
38		Grass (any date) / Bare pure 1 date
39		Grass (any date) / Bare mix 1 date
40		Grass (any date) / Bare pure multi dates
41		Grass (any date) / Bare mix multi dates (model overlap)
42		Grass (any date) / Bare mix all dates (model overlap)
43		Tree/Bush mix 1 date only + Bare 1 date only + burn (any date)
44		Tree 1 date only + Bare pure 1 date only + burn (any date)
45		Tree/Bush mix multi dates + Bare pure 1 date only + burn (any date)
46		Tree multi dates + Bare pure 1 date only + burn (any date)
47		golf-irrig combo / Tree/Bush mix 1 date only + Bare pure 1 date only + burn (any date)
48		golf-irrig combo / Tree 1 date only + Bare pure 1 date only + burn (any date)
49		golf-irrig combo / Tree/Bush mix multi dates + Bare pure 1 date only + burn (any date)
50		golf-irrig combo / Tree multi dates + Bare pure 1 date only + burn (any date)
51		grass (all dates) + burn (any date)

APPENDIX D: Visual representation of canopy cover density percentages per unit area



Adapted from Paine, D.P. 1981. *Aerial photography and image interpretation for resource management*. New York: John Wiley & Sons, 422 p.

APPENDIX E: Contingency matrix representing the map accuracy results for all 33 land-cover/land-use classes

CLASSIFIED LAND-COVER (IMAGE)

ACTUAL LAND COVER (FIELD)

		Indigneous Forest 1	Dense Bush, Thicket 2	Woodland, Open Bush 3	Low Shrub: Other 4	Forest Plantation 5	Cultivated Commercial Crop 6	Cultivated Pivot Crop 7	Cultivated Orchards 8	Cultivated Vineyard 9	Cultivated Subsistence 10	Settlements 11	Wetlands 12	Grasslands 13	Fynbos: Low Shrubland 17	Mines 32	Water 33	Bare Ground 34	S	Pr	
Indignenous Forest	1	106	2	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	112	0.017	6
Dense Bush, Thicket	2	22	230	7	3	5	0	0	1	0	0	2	1	1	3	0	0	0	275	0.043	45
Woodland, Open Bush	3	5	76	275	10	7	4	3	0	0	7	4	11	82	12	5	0	7	508	0.079	233
Low Shrub: Other	4	0	33	80	408	0	0	1	0	0	1	0	0	54	9	0	0	74	660	0.103	252
Forest Plantation	5	1	8	1	0	217	0	0	0	0	0	1	1	0	0	0	1	0	230	0.036	13
Cultivated Commercial Crop	6	0	0	0	0	0	216	1	0	0	0	0	0	0	0	0	0	0	217	0.034	1
Cultivated Pivot Crop	7	0	3	2	1	2	14	744	18	7	2	4	1	5	2	0	0	0	805	0.125	61
Cultivated Orchards	8	0	0	0	1	1	1	5	283	5	1	0	0	0	0	0	0	0	297	0.046	14
Cultivated Vineyard	9	0	1	0	0	0	0	0	3	142	0	0	0	0	0	0	0	0	146	0.023	4
Cultivated Subsistence	10	0	1	5	0	0	0	0	0	0	186	0	0	3	0	0	0	2	197	0.031	11
Settlements	11	0	0	0	1	0	0	2	0	0	0	523	0	2	0	1	0	1	530	0.083	7
Wetlands	12	0	5	7	3	0	0	0	0	0	0	0	155	0	0	0	0	0	170	0.027	15
Grasslands	13	12	51	59	112	9	0	24	2	0	11	20	6	849	30	3	0	28	1216	0.190	367
Fynbos: Low Shrubland	17	0	12	0	1	0	0	0	0	0	0	0	0	1	223	0	0	2	239	0.037	16
Mines	32	0	0	0	1	0	0	0	0	0	0	1	0	0	0	155	1	0	158	0.025	3
Water	33	0	0	0	0	0	0	0	0	1	0	1	1	0	0	1	161	0	165	0.026	4
Bare Ground	34	0	6	14	37	0	0	0	0	0	1	1	0	7	1	2	0	421	490	0.076	69
	S	146	428	452	578	243	235	780	307	155	209	557	176	1004	280	167	163	535	6415		459
	Pc	0.023	0.067	0.070	0.090	0.038	0.037	0.122	0.048	0.024	0.033	0.087	0.027	0.157	0.044	0.026	0.025	0.083		0.08659	
		40	198	177	170	26	19	36	24	13	23	34	21	155	57	12	2	114	1121		

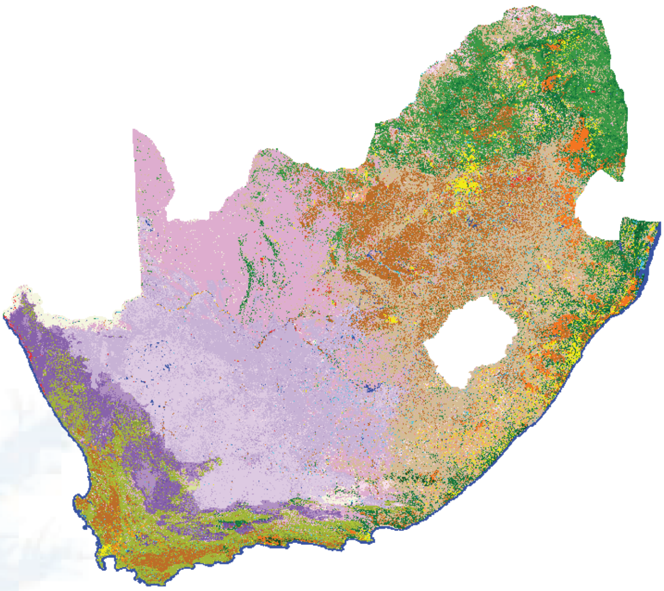
APPENDIX 2

Report on the 1990 South African National Land-cover/land-use Dataset

1990 South African National Land-Cover Dataset

DEA/CARDNO SCPF002: Implementation of Land-Use Maps for South Africa

Project Specific Data User Report and Metadata



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GEOTERRAIMAGE (South Africa)
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July 2015, version 05

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CONTENTS

PLEASE NOTE:
This report provides information on the specific version of the 1990 GTI South African National Land-cover Dataset supplied to the South African Department of Environmental Affairs under the DEA/CARDNO Project: SCPF002 Implementation of Land-use Maps for South Africa.
The supplied dataset referred to in this report represents a subset of the full 1990 GTI South African National Land-cover Dataset, in terms of the supplied land-cover/land-use categories and associated class legend.
Use of this DEA/CARDNO data version is governed by the LICENCE AGREEMENT shown previously.

1. INTRODUCTION

This report details the production of a 35-class National Land-cover Dataset for South Africa, circa 1990, generated primarily from multi-seasonal Landsat 5 imagery, acquired mainly between 1989 and 1991.This is a complementary dataset to the previous 35-class[23] 2013/14 South African National Land-cover Dataset, generated from comparable Landsat 8 imagery acquired between 2013 and 2014. These two comparable datasets can be used to determine land-cover and land-use change over a period of about 24 years across the South African landscape.

It is recommended that this report be read in conjunction with the previous report, *2013/14 South African National Land-cover Dataset. DEA/CARDNO SCFP002: Implementation of Land-use Maps for South Africa. Project-specific Data User Report and Metadata. February 2015, version 5*.

Similar to the 2013/14 National Land-cover Dataset, the 1990 National Land-cover Dataset is based on 30 x 30 m raster cells. It is ideally suited for approximately 1:75 000- to 1:250 000-scale geographic information system (GIS)-based mapping and modelling applications. The 1990 land-cover dataset has been generated using the same operationally proven, semi-automated modelling procedures used to generate the comparable Landsat 8-derived 2013/14 South African National Land-cover Dataset.

2. BACKGROUND

The recent global availability of Landsat 8 imagery (April 2013) was the primary catalyst behind the development of new, innovative automated land-cover modelling procedures, which allowed the creation of the 2013/14 South African National Land-cover Dataset. Primarily because Landsat 8 offered a free and regular supply of radiometrically and geometrically standardised, medium-resolution, multi-spectral imagery, suitable for medium to large area mapping. Collectively, this offered an ideal opportunity for GTI to re-examine using automated land-cover mapping techniques as a more efficient alternative to conventional, analyst-assisted per-pixel classifiers, allowing the rapid production of standardised, yet informative land-cover information.

The methodologies and procedures developed for the 2013/14 Landsat 8 imagery have been repeated, using historical Landsat 5 imagery, to generate the 1990 South African National Land-cover Dataset described in this report. The migration of procedures and data-processing models developed for the Landsat 8 image data processing to the historical 1990 Landsat 4 and Landsat 5 imagery is possible because the image data format and specifications are essentially the same between these two satellite-based sensor platforms.

3. OBJECTIVE

The primary objective was to generate a new, historical national land-cover dataset for the whole of South Africa, circa 1990, which is directly comparable with the previously generated full 35- and simplified 17-class versions of the 2013/14 National Land-cover Dataset, supplied as part of the DEA/CARDNO SCPF002 project.

4. PRODUCT DESCRIPTION

The 1990 35-class/17-class South African National Land-cover Dataset produced by GTI has been generated primarily from digital, multi-seasonal Landsat 5 multi-spectral imagery, acquired mainly between 1990 and 1991. In excess of 600 Landsat images were used to generate the land-cover information, based on an average of eight different seasonal image-acquisition dates, within each of the 76 image frames required to cover South Africa. The land-cover dataset, which covers the whole of South Africa, is presented in a map-corrected, raster format, based on 30 x 30 m cells equivalent to the image resolution of the source Landsat 8 multi-spectral imagery. The 1990 DEA/CARDNO land-cover dataset is based on the same 35-class legend used for the 2013/14 DEA/CARDNO South African National Land-cover Dataset. A simplified 17-class legend dataset is also supplied. Each data cell contains a single code representing the dominant land-cover class (by area) within that 30 x 30 m unit, as determined from analysis of the multi-date imagery acquired over that image frame. The original land-cover dataset was processed in UTM35 (north)/WGS84 map-projection format based on the standard Landsat map-projection format provided by the United States Geological Survey (USGS). The final

23 The 35-class Land-cover Legend has, for both the 2013/14 and the 1990 Dataset, also been supplied as a simplified 17-class Legend for change detection procedures, as per client specifications and requests.

product is available in UTM35 (north and south), WGS84 map projections and geographic coordinates.

4.1 Land-cover Legend

The 1990 DEA/CARDNO data legend is the same as the one used in the 2013/14 dataset, and is aligned with the SANS 1877[24] South African National Land-cover Classification Standard in terms of class definitions and in hierarchical format. The complete list of information classes that have been mapped and supplied as part of the DEA/CARDNO land-cover dataset, and the associated class definitions are supplied in Appendix A.

5. OVERVIEW OF THE AUTOMATED MODELLING APPROACH

The generation of the 1990 National Land-cover Dataset is based on the same mapping and modelling techniques developed for and used in the operational production of the 2013/14 South African National Land-cover Dataset. The descriptions supplied below are essentially the same as those contained in the 2013/14 data report, but have been modified where necessary to show the changes applied during the production of the 1990 land-cover dataset.

Automated modelling procedures offer significant advantages in terms of ensuring data standards, minimising processing time, allowing easy repeatability and facilitating accurate change detection, when compared to more conventional image mapping approaches where there is a greater reliance on individual image analyst knowledge and inputs. To this end, a series of automated image-based modelling steps were developed that utilise the seasonal dynamics associated with the broad landscape characteristics across South Africa. These were then used to rapidly produce a set of foundation cover classes that could be easily converted into more meaningful land-cover information categories, using predefined geographical masks in the GTI data libraries.

24 SANS 1877: South African Bureau of Standards (SABS)-designated National Land-cover Classification Standard for South Africa.

The foundation cover classes represent the basic building blocks associated with all landscape characteristics, namely water, bare ground, grass and tree-bush-shrub cover types, with each being defined in terms of seasonal occurrence or permanence. These basic foundation cover classes represented the initial output from the automated modelling approach. The foundation cover classes are then converted into more conventional land-cover information classes, i.e. urban, forest plantation, etc., as part of the post-automated modelling data-processing steps.

The foundation cover classes are essentially "spectrally dependent" classes, since they are generated from automated modelling procedures that are based directly on the spectral characteristics associated with each image pixel over time (i.e. seasonal) and space (i.e. within an image frame). The final land-cover information classes are referred to as "spectrally independent" classes since different cover classes can share similar foundation class spectral characteristics in a one-to-many-type relationship. For example, the "bare ground" spectrally dependent cover classes could represent non-vegetated built-up urban areas, natural rock exposures, beach sand or a mine pit and tailings dump. Similarly, the tree-bush classes could represent a natural vegetation cover, a timber plantation or a fruit orchard. The advantage of this approach is that the conversion of the initial, spectrally dependent foundation cover classes into the final, spectrally independent land-cover information classes can be tailored to suit a variety of end-user information requirements; simply by using a different set of predetermined masks and foundation class subdivisions and amalgamations.

5.1 Model portability to other geographical areas and sensors

Although initial model development was focused on using Landsat 8 imagery within South Africa, the same models have also been proven to work with equivalent success on Landsat 8 imagery over sites in Botswana, Mozambique, Namibia, Sudan and Zimbabwe, as well as using comparable Landsat 5 archive imagery over South Africa; all of which indicate a high level of model portability. This has also allowed and supported the production of directly comparable historical land-cover datasets for change detection using the historical

Landsat 4/Landsat 5 imagery used to generate the 1990 South African dataset.

5.2 Use of object-based modelling

No attempt was made to include or use object-based modelling in the automated mapping process, primarily because the medium-resolution format of multi-spectral Landsat imagery does not lend itself to this type of modelling, since pixel resolution typically precludes the identification of true landscape "objects" in comparison to high- and ultra-high-resolution image formats. The 30 m Landsat resolution pixels typically represent a mix of land-cover characteristics rather than a pure cover surface, i.e. an urban pixel is typically a composite of building roofs, garden vegetation and/or road surfaces. However, object-based modelling may be a useful approach for helping to generate second-level information classes from the primary-level foundation class dataset, such as separating water in rivers (i.e. natural) from water in dams (i.e. artificial), based on size, shape and context.

6. LANDSAT IMAGERY

The imagery used in the generation of the 1990 DEA/CARDNO South African National Land-cover Dataset was 30 m-resolution Landsat 4 and Landsat 5 imagery, acquired between April 1989 and October 1993, with the bulk of the imagery acquired between 1990 and 1991. Within each image frame, a range of seasonal image-acquisition dates were used (within the automated modelling procedures) to characterise the seasonal dynamics across the landscape in terms of the basic tree, bush, grass, water and bare foundation cover classes. Nine image-acquisition dates per image frame per complete seasonal cycle were taken as the optimal number of dates, based on Landsat's 16-day overpass schedule[25]. Unfortunately, due to localised cloud-cover problems in some regions during this 1989–1992 period, it was not always possible to achieve this, and fewer image dates had to be used. Figure 1 illustrates the total number of image-acquisition dates per image frame.

25 This seasonal window requirement, while improving the overall accuracy of interpretation and land-cover modelling, means that – in practice – between 12 and 16 months are actually required to acquire sufficient cloud-free seasonal imagery for input into the modelling processes. This means that a new land-cover dataset could only be generated approximately every two to three years (minimum), since a shorter period may not provide sufficient separation between the seasonal input image dates.

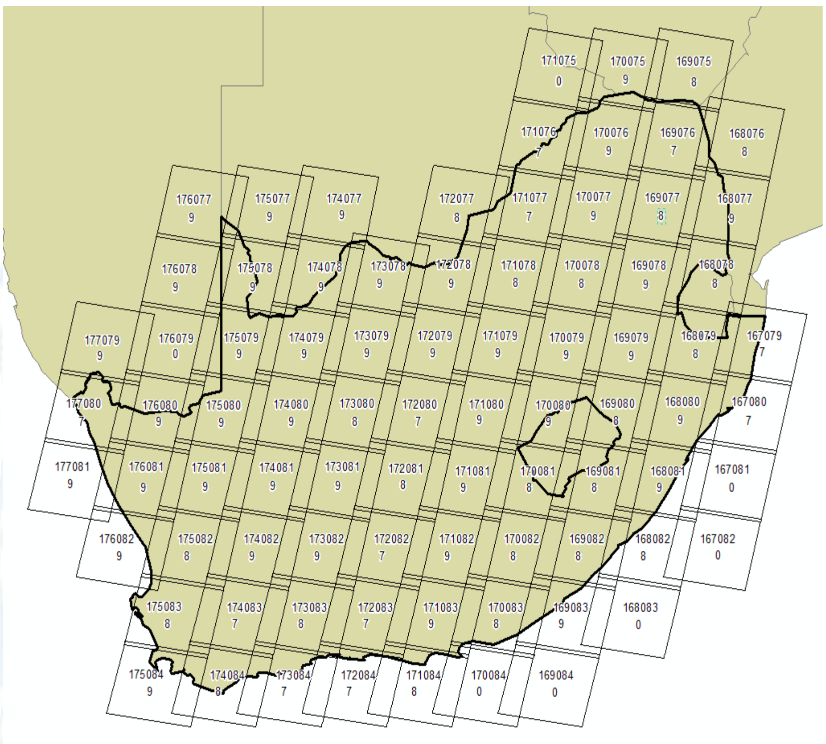


Figure 1. Total number of image-acquisition dates used in the 1990 land-cover modelling per image frame.

Figure 2 illustrates the date range of the multi-seasonal images used in the processing of each image frame.

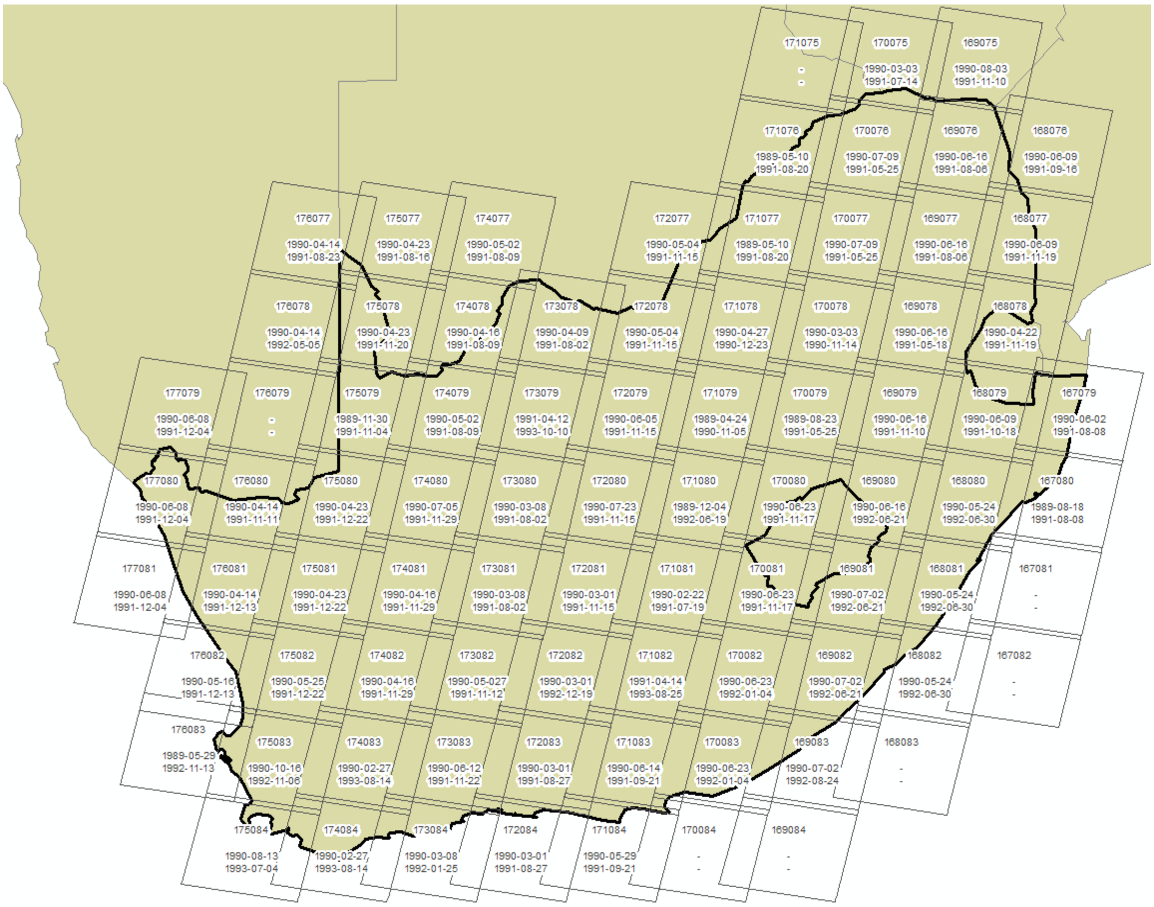


Figure 2. First and last image-acquisition dates used per frame in the production of the 1990 land-cover data.

In summary, 76 Landsat image frames were required to provide complete coverage of Lesotho, South Africa and Swaziland. A total of 646 individual Landsat images were used to model and produce the land-cover data, representing an average of eight acquisitions per image frame per year.

6.1 Landsat image sourcing

All Landsat imagery used in the 1990 land-cover data modelling was sourced from the online data archives of the USGS[26]. The data is provided in a precise geo-corrected UTM35 (north)/WGS84 map-projection format, and was used "as-is" without any further geo-correction. A complete list of the image-acquisition dates used in the modelling of the 1990 South African Land-cover Dataset accompanies this document (see Appendix B).

26 See http://glovis.usgs.gov/

6.2 Landsat data preparation

All Landsat imagery was standardised to 16-bit, top-of-atmosphere (ToA) reflectance values prior to land-cover modelling, using a generic modelling approach[27]. The original USGS-generated UTM35 (north), WGS84 map-projection format was retained without change or modification throughout all image frame-based modelling procedures. As far as possible, only cloud-free or image dates with limited cloud cover were used in the land-cover modelling (i.e. maximum about 20% terrestrial cloud cover in any one date). Any cloud-affected regions were corrected by merging cloud-affected ToA-corrected imagery with cloud-free

27 Note that a modified version of the Landsat 8 ToA-correction model was used to create the ToA-corrected versions of the historical Landsat 4/Landat 5 imagery due to different image calibration requirements.

ToA-corrected data from preferably the preceding or following overpass date, so that, as far as possible, the final cloud-free merged imagery composite only represented a maximum difference of about 16 days. Cloud masks were created using either conventional pixel classification procedures (within analyst-defined sub-image areas) or spectral-based modelling using generic thermal and blue light reflectance thresholds[28], depending on cloud characteristics. This was deemed acceptable in terms of minimising any changes in local vegetation cover growth changes. Approximately 25% of the 646 images used in the 1990 land-cover modelling were cloud-masked composites. No external atmospheric correction was applied to the image data.

7. LAND-COVER MODELLING

7.1 Spectral modelling

Derived spectral indices, generated from the ToA-corrected imagery, were used as the only inputs into the land-cover models. No original spectral (ToA reflectance) data was used as an input, although collectively, five out of the six available non-thermal spectral bands were used in the various spectral indices[29]. A standardised set of spectral indices were identified from which the required foundation cover classes – (1) tree dominated, (2) bush dominated, (3) grass dominated, (4) water and (5) bare ground – could be modelled, using predetermined, generic spectral threshold values. The generic threshold values associated with each index and cover type were tested over several landscapes and seasons before being confirmed and accepted as such.

The spectral indices included both existing algorithms such as the Normalised Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI), as well as algorithms developed in-house specifically for the GTI land-cover modelling requirements. All models were developed in ERDAS Imagine© image-processing software using the Model Maker function.

The modelling and generation of each foundation cover class was undertaken as a separate modelling exercise, i.e. water was modelled separately from bare ground, which was modelled separately from tree and bush cover, etc. This approach simplified the modelling steps and facilitated easier desktop quality control of outputs, compared to attempting to model all foundation cover types simultaneously within a single model workflow. In most cases, the final geographic extent of a particular foundation cover class was generated from the combined use of several different spectral indices, since no single index was found to work well in all landscapes and all seasons.

All modelling was undertaken on an individual image frame-by-frame basis, where the original USGS-supplied UTM35 (north) map-projection format was retained “as-is”. This allowed the models to be adapted according to the number of acquisition dates and associated seasonal ranges available for each particular image frame. The model modifications reflected the need to standardise the outputs according to predefined definitions of seasonal permanence, for example, whether a foundation cover class occurred, i.e. in only one image date; in several, but not all image dates; or in all image dates. Obviously, the more image-acquisition dates available per frame, and the wider the seasonal range, the more accurate the modelled interpretation of a particular cover class’s seasonal characteristics.

Examples of the separate model outputs for bare ground and tree/bush foundation cover classes are shown in Figure 3. The examples show eastern Pretoria, from within Landsat 8 frame 170-078 (using 2013/14 data).

28 The spectral modelling approach could only be applied to Landsat 8 imagery (if applicable) due to its enhanced spectral band range, compared to Landsat 5.

29 (2) Green, (3) Red, (4) Red, (5) NIR, (6) SWIR-1 and (7) SWIR-2 Landsat spectral bands.

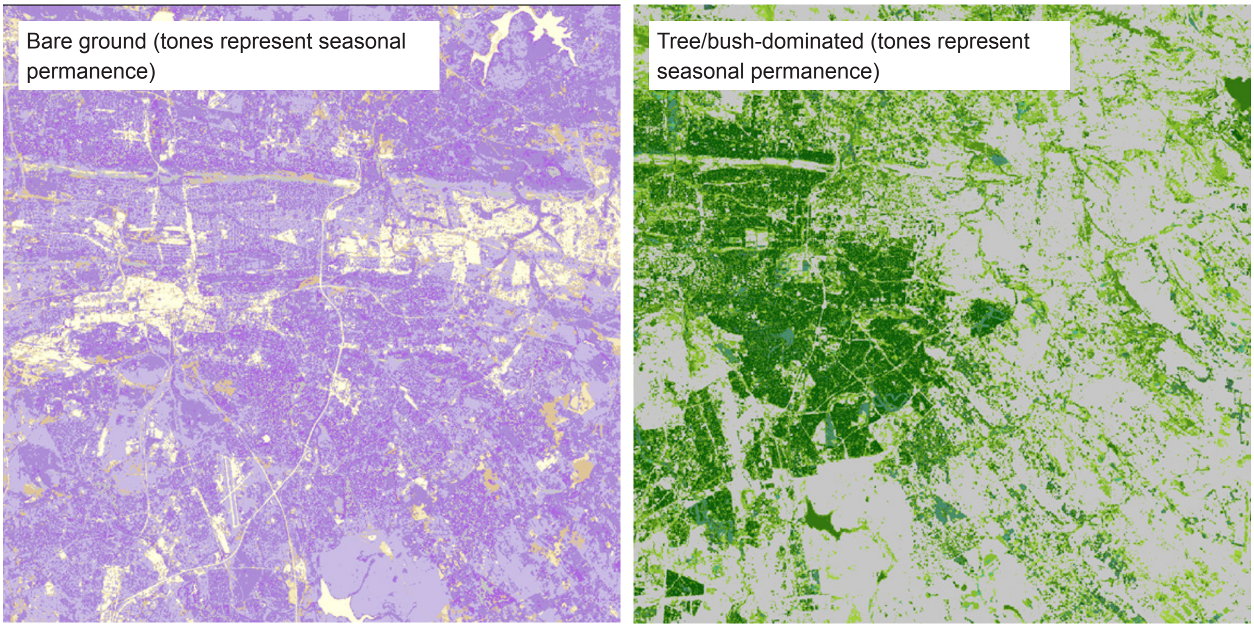


Figure 3. Spectral index-derived model outputs for bare ground and tree/bush-dominated foundation cover classes over eastern Pretoria (frame 170-078).

In some circumstances, modifications or additional modelling steps were used to account for regional landscape characteristics that could not be accurately modelled using only generic models. For example, in some of the far western arid areas, additional tree-bush modelling steps were taken using a slightly modified modelling approach in order to better detect and separate between the sparse, low bush and shrub covers in these landscapes.

7.2 Terrain modifications

Terrain-based modifications were included within some of the foundation cover class modelling procedures (i.e. water, bare and tree/bush classes) in order to minimise seasonally induced terrain shadowing effects, using a combination of solar illumination and slope parameters. These parameters were modelled independently using the 90 m-resolution Shuttle Radar Topography Mission (SRTM) dataset[30], with outputs being re-sampled to a Landsat-comparable 30 m
-resolution format, prior to being incorporated into the foundation cover class models. For example, solar illumination and Data Elevation Model (DEM) slope masks were used to minimise any spectral confusion between dark terrain shadow areas and comparable water body reflectance levels. Note that when creating the DEM-derived parameters, such as shadow extents, modelling was based on the full range of seasonal solar azimuth and zenith angles and not a specific date or season in order to better align with seasonal differences evident across any given range of image-acquisition dates.

7.3 Individual frame spectral models

The basic modelling parameters used to create each of the foundation cover classes are described below. In each case, the modelled output would typically represent a (qualitative) gradient of spatial densities, as well as temporal, i.e. seasonal occurrence. For example, the bare ground model output consisted of a set of classes that represented a range of conditions from “pure bare” to “mixed bare/sparsely vegetated”, with each described in terms of seasonal permanent or temporary occurrence. The foundation water class modelling was the only exception to this, with the model output describing water extent in terms of only permanent or seasonal occurrence.

7.3.1 Spectral modelling of water

Water was modelled using a combination of five spectral indices, including a burn index, and DEM-derived solar illumination and slope masks. The burn index was used

30 Although the 30 m-SRTM terrain dataset would have been preferable, it did not become publicly accessible until after the completion of the bulk of the 2013/14 land-cover modelling had been completed.

to minimise any spectral confusion between dark burnt areas and comparable water body reflectance. The solar illumination and slope masks were used to minimise any spectral confusion between dark terrain shadow areas and comparable water body reflectance. Generic spectral water models were developed for both flat (standard) and hilly terrain, and for shallow water (pan)-dominated landscapes.

7.3.2 Spectral modelling of bare ground

Bare ground was modelled using a combination of two spectral indices, and DEM-derived solar illumination and slope masks. The solar illumination and slope masks were used to minimise any spectral confusion between dark terrain shadow areas and comparable bare ground reflectance. The output represented a gradient of bare ground from pure bare to sparsely vegetated cover.

7.3.3 Spectral modelling of tree/bush cover

Tree and bush cover was generated within the same spectral model. Both woody covers were modelled using a combination of four spectral indices, and a DEM-derived slope mask. The slope mask was used to minimise any spectral confusion between dark terrain shadow areas and comparable woody cover in two of the four spectral indices. “Trees” refers to dense, typically tall woody cover, such as natural and planted forests, dense woodland and thickets, whereas “bush” refers to more open, often lower mixed tree/bush communities, such as typical bushveld or open woodland. The spectral modelling procedure also separated woody cover spectral classes that showed similar characteristics to other vegetated covers, such as crops, sportsfields, golf courses (especially if irrigated), from those that did not show similar spectral characteristics. An additional “desert” tree/bush model was developed as an extra model to be run in addition to the standard model in more arid areas, to increase the representation of bush cover in those regions where the modelling thresholds used in the standard model were not sensitive enough.

7.3.4 Spectral modelling of grass

Grass cover was modelled using only a single spectral index. No DEM-derived solar illumination or slope mask modifiers were used.

7.3.5 Spectral modelling of burnt areas

Burnt cover was modelled using only a single spectral index. No DEM-derived solar illumination or slope mask modifiers were used.

7.4 Seasonally defined spectral land-cover per image frame

The modelled outputs for each foundation cover class were combined into a single composite dataset for each frame, in a predetermined hierarchical order, so that the final output cover class combinations reflected the dominant and subdominant cover types in terms of seasonal occurrence. For example:

- water in all dates (permanent)
- water in many dates (seasonal)
- dominated by trees in all dates
- dominated by trees in many, but not all dates, plus bare ground in one date, etc.

Figure 4 shows the output after all the separate foundation land-cover classes have been combined into a composite set of seasonally defined foundation land-cover classes. The illustrated area is the same eastern Pretoria area as shown in Figure 3. This interim land-cover product consists of 51 seasonally defined foundation cover classes, as listed in Appendix C. These seasonally combined foundation cover classes are still essentially “spectrally dependent” classes, since they have been generated using automated modelling procedures on only the spectral characteristics associated with each image pixel over time (i.e. seasonal) and space (i.e. within an image frame).

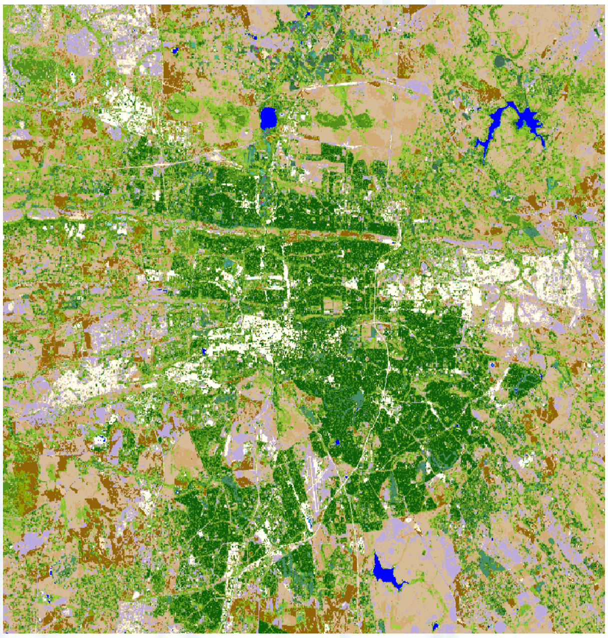


Figure 4. Interim spectral land-cover product after combining all the seasonally defined foundation cover classes (eastern Pretoria, frame 170-078).

Note that, in addition to the basic tree, bush, grass, water and bare ground foundation classes already described, fire scar extent and occurrence were also modelled and incorporated into the final combined foundation cover composite classes in order to provide an indication of whether or not fire was a factor in the modelled seasonal cover profiles, i.e. a single-date, bare ground area could be the result of a wildfire event that then revegetated later in the season.

The spectrally dependent and seasonally defined foundation cover classes in this base dataset represent the "building blocks", from which more information-focused land-cover classes can be derived, especially if combined with ancillary datasets such as vegetation or land-use maps to facilitate further class subdivisions or area-based class modifications. The entire spectral modelling procedure is summarised graphically in Figure 5 below.

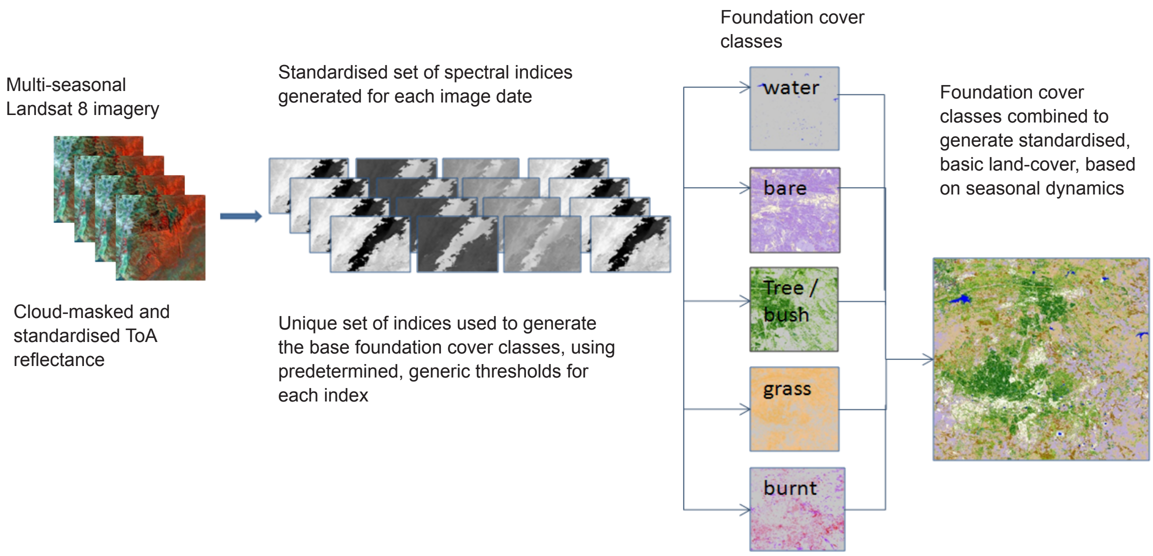


Figure 5. Summary of the full spectral land-cover modelling process.

7.5 Generation of full South African spectral class mosaic

Once the spectral modelling for the individual frames had been completed, the next step was to merge these into a single, seamless coverage for the whole of South Africa. Achieving this involved several processing steps. Individual image-frame datasets were first edge-cleaned to ensure that no frame-edge pixel anomalies would be carried over into the final countrywide mosaic. Cleaned image frames were then reprojected, were necessary, to a standardised UTM35 (north), WGS84 map projection, since the majority of image datasets covering South Africa were sourced from the USGS data archives, and were in this UTM zone.

Individual image frames were merged into a single, countrywide spectral foundation class composite, based on an analyst-determined sequence of image border overlap rules in order to ensure the best possible seamless integration of the individual frames. This approach was necessary since some image-to-image edge differences occur between image frames where spectral foundation classes have been generated from significantly different input acquisition dates, simply as a result of image data availability.

Although the standardised modelling approach used to generate the spectral classes supported the generation of spatial and content-comparable land-cover data in adjacent image frames (if both frames utilised comparable input image-acquisition dates), if there was a significant difference in the number or seasonal range of input images, then adjacent images often showed edge-matching differences. In such cases, the adjacent images were often spatially comparable, but not necessarily comparable in terms of content. In these cases, the edge-matching process was set up, as far as possible, so that the most prominent and spatially extensive landscape pattern was maintained across the image borders in order to provide a more visually seamless image frame overlap.

Note that for water ("seasonal" and "permanent") and bare ground ("pure bare, all dates") countrywide coverages, the maximum extent of each class, from all images, was transferred across to the final countrywide spectral class composite, regardless of any frame overlap edge-matching applied to other spectral classes.

7.5.1 Grassland corrections: inland

Persistent cloud-cover problems on several image-acquisition dates during the 1990s wet season period over the Highveld region resulted in the unavailability of usable, early wet-season imagery for modelling inputs. This resulted in the standard spectral models under-estimating the grassland extent. In order to correct this, an alternative grassland model was developed, based on a single – rather than multiple – image-acquisition date (the optimal single date representing the best dry-season image for visually separating green woody vegetation from senescent grassland vegetation, with minimal burn scars). For image frames covering areas of significant topographical relief, such as over the escarpment, the single-date grass corrective model included the use of solar illumination and slope parameters to improve modelling outputs. For standardisation purposes, the inland grassland corrective model was applied to all image frames overlapping or contained within the South African National Botanical Institute (SANBI) grassland biome boundary. The resultant grassland extents for each image frame were then merged into a composite geographical mask and integrated back into the original countywide spectral class dataset to improve the overall grassland delineation. The same approach was used in the production of the 2013/14 land-cover dataset.

7.5.2 Grassland corrections: coastal

In some high-rainfall coastal regions, the standard spectral models were unable to accurately distinguish between grassland and woody cover, where the grass biomass was exceptionally high as a result of high local rainfall during the 1990s wet season, even if suitable image-acquisition dates were available.

This was especially the case around Pondoland (Eastern Cape) and Zululand and Maputoland (KwaZulu-Natal). To correct this, another grassland correction model was developed with alternate spectral thresholds to better delineate the correct grassland extent in these areas. The resultant frame-specific outputs were then merged into a composite geographical mask and integrated back into the original countywide spectral class dataset to improve the overall grassland delineation. The same approach was used in the production of the 2013/14 land-cover dataset.

8. LAND-COVER INFORMATION GENERATION

Multi-seasonal Landsat imagery has been used to generate a comprehensive set of spectrally based outputs that describe the seasonal characteristics of tree, bush, grass, bare and water cover characteristics within each image pixel, as represented by the 51 spectral foundation classes. These were converted into more meaningful and informative land-cover and land-use information classes, aligned with the South African National Standard (SANS) 1877 South African National Land-cover Classification Standard (see Section 4.1). For example, a pixel may be described as having a detectable tree cover on more than one image-acquisition date, but not all dates, and grass cover for several, but not all dates. This would then be interpreted as an open, deciduous tree-covered woody community (i.e. woodland), where the grass cover became evident when the tree canopy showed less than maximum foliage cover.

8.1 Conversion from spectral to information classes

The creation of both land-cover and land-use information classes involves the recoding and regrouping of selected spectral foundation classes, either in a controlled or uncontrolled geographic area. In a controlled recoding, independently sourced and/or generated geographical masks are used to define the location and extent of the recode process. This is required because, in many situations, different landscape features can be represented by similar spectral characteristics. For example, a spectrally modelled area of permanent bare ground (spectral characteristics are representative of a non-vegetated surface in all image-acquisition dates) could be representative of a beach, a mine or a large building. By using an appropriate geographical mask (essentially an independently defined or sourced polygon coverage), it is possible to code all bare ground pixels within the mask to, for example, mining, while allowing all other bare areas outside the mask to represent other bare ground surfaces, which can then be further recoded as and where required.

The key to this process is that the spectral modelling defines the exact footprint of the spectral cover class (in a user-independent manner), whereas the geographical mask defines the information content (based on user expertise and knowledge). This approach overcomes problems where spectral characteristics are shared between two or more separate land-cover/land-use classes, which is self-evident in many image-based mapping applications. Figure 6 illustrates the various procedural pathways that can be used to convert the spectral foundation classes into land-cover/land-use information classes.

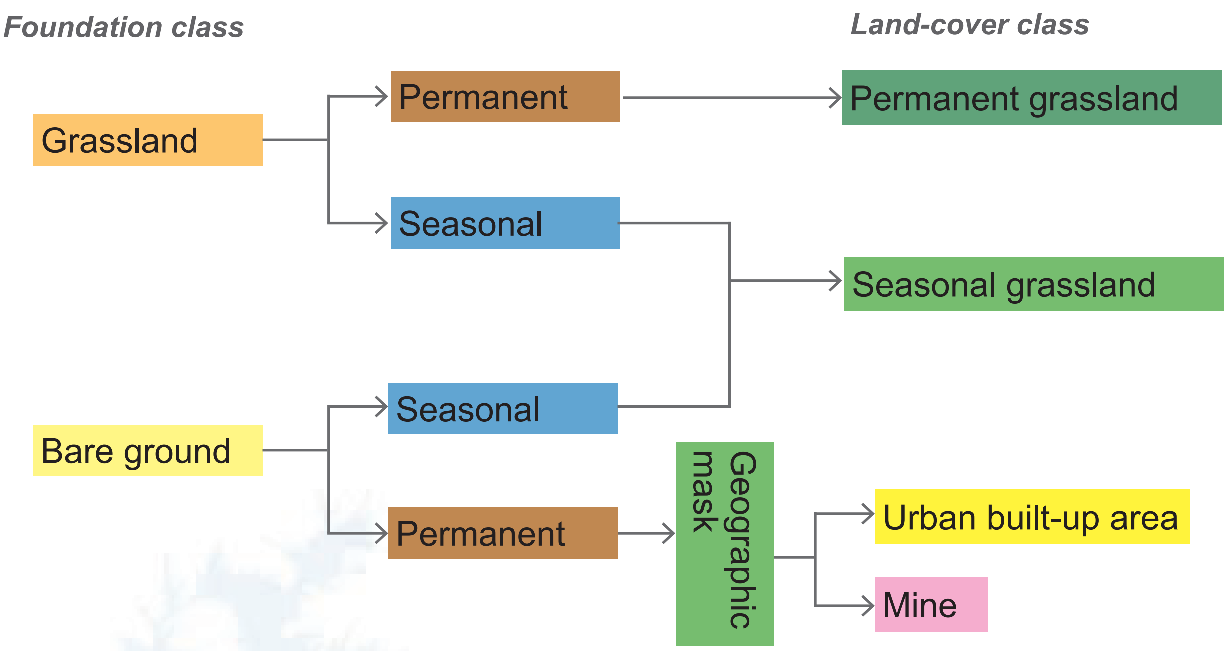


Figure 6. Processing pathways for converting spectral foundation classes to land-cover/ land-use information classes, based on seasonal permanence and shared spectral characteristics.

8.2 Creating base vegetation land-cover classes

The natural vegetation base classes, namely thicket/dense bush, woodland/open bush, grassland, low shrubland and bare, non-vegetated areas, were created by merging selected groups of spectral classes. Generally, selected spectral classes were merged into the required vegetation cover classes without geographical control, using the original spectral class extent and distribution "as-is". However, in some regions and for some spectral classes, it was necessary for the recoding and merging process to be geographically controlled, and only allow the recode procedure within predetermined geographical regions. Controlled geographical recoding (i.e. masking), used preselected SANBI bioregion[31] boundaries to define where and how selected spectral classes were modified. Note that the final vegetative land-cover class boundary was always defined by the original spectral foundation class boundaries contained within the SANBI bioregion boundary, and not by the bioregion boundary itself, other than for

31 Mucina, L and Rutherford, MC, 2006. *The vegetation of South Africa, Lesotho and Swaziland. Strelitzia* 19. SANBI: associated digital GIS database. Note that SANBI biome and bioregion boundaries, while generically applicable for 1:250 000 digital map scales, is often considerably more accurate on a local scale, even down to the nearest 100 m in some cases.

the fynbos: low shrubland subclass. This was the same approach used in the production of the 2013/14 land-cover dataset. All independent, non-image sourced geographical masks used in the 2013/14 data-modelling process were used again in the 1990 data-modelling process to ensure consistency of mapping outputs.

8.2.1 Fynbos

The sensitivity of the automated spectral models was insufficient to determine the transition between structurally similar fynbos: low shrubland communities and non-fynbos: low shrubland communities, except for the boundary with the structurally different Namaqualand (SKn and SKs) and Knersvlakte (Skk) bioregions. In these areas, the boundary between the fynbos and non-fynbos: low shrubland communities has been defined on the basis of the original spectral class boundaries[32]. The same approach was used in the production of the 2013/14 land-cover dataset. All independent, non-image sourced geographical masks used in the 2013/14 data-modelling process were used again in the 1990 data-modelling process to ensure consistency of mapping outputs.

8.2.2 Indigenous forests

The indigenous forest land-cover class was generated in a similar manner to the previously described base vegetation classes, although the geographical masks used to control the recoding of the selected spectral foundation classes were derived from a combination of independent datasets. These included the SANBI forest biome boundaries, higher detail regional masks created in-house in support of previous provincial-level land-cover mapping, shadow and altitude terrain parameters modelled from the higher 30 m-resolution SRTM DEM terrain data[33], and NDVI spectral datasets. The NDVI dataset represented a nationwide summary of the seasonal maximum NDVI recorded in each pixel, calculated from all image-acquisition dates used in the spectral land-cover modelling. Note that separate models were required to recode the different forest vegetation types (i.e. Northern Afromontane, sand, scarp, etc.), with each one being based on different geographical mask combinations and associated data thresholds in order to correctly model the forest patch distributions in these regions. The final, modelled forest extents were then integrated into the base vegetation land-cover classes. The same approach was used in the production of the 2013/14 land-cover dataset. All independent, non-image sourced geographical masks used in the 2013/14 data modelling process were used again in the 1990 data modelling process to ensure consistency of mapping outputs.

8.2.3 Wetlands

The 1990 wetland class coverage was created using the 2013/14 wetlands as a base dataset and then adding additional wetlands evident on the historical imagery to this existing wetland coverage. In addition, the 1990 wetland data coverage was extended to cover the entire country as opposed to the 2013/14 wetland data, which was primarily limited to the wetter parts of the country. This was possible because the historical 1990 imagery represented much wetter conditions in the normally drier northwestern regions than was evident on the 2013/14 imagery in terms of observable surface water and wetland features.

The additional 1990 wetlands were created using the same procedures as for the 2013/14 wetlands, namely using independent and separate modelling routines that did not include reference to, or recoding of any of the original 51 spectral foundation classes. Depending on the available image-acquisition dates per frame, wetland extent was modelled using either a dual or single image-acquisition date process. The single-date approach used the best "wettest" image date, whereas the dual-date approach was based on the difference between wettest and driest image dates. The single (wettest)-date modelling approach was only used as an alternative approach if the available acquisition dates did not provide suitable seasonal differences for the dual-date, wet-dry-date approach. Both modelling approaches only used inputs from multiple spectral indices, and did not use the 51 spectral foundation cover classes as used in the generation of the other vegetation classes. A combination of eight indices was used in the

32 This is primarily because satellite imagery, such as Landsat, with its combination of medium spatial resolution and limited spectral capabilities (compared to hyper-spectral sensors), is primarily responsive to structural vegetation characteristics rather than community floristics. Accurate delineation of biome-related boundaries, especially if the boundary is a transition zone, rather than distinct border, is – at best – challenging with imagery such as Landsat, especially if floristic differences play a greater role than structural differences in defining the border. This is likely to be the case between the fynbos, succulent Karoo, Nama Karoo and surrounding grassland and desert biomes.

33 The 30 m-resolution SRTM terrain data for Africa was used for this processing step to ensure comparability with the previous 2013/14 data processing.

dual-date approach, with each being applied to both dates, whereas only four spectral indices were used in the single (wettest)-date approach. Both modelling approaches generated a dataset that represented the likelihood of wetlands occurring in the landscape, within which a threshold was determined on a frame-by-frame basis in order to best represent actual wetland extent.

The single (wettest)-date modelling approach used terrain shadow masking to minimise spectral confusion with non-wetland regions, whereas the dual-date approach used more complex slope and floodplain modelling to limit the topographic areas within which wetlands were likely to occur. Both approaches used the 90 m-SRTM terrain data as the source for topographic modelling.

The slope and floodplain model generated potential flooding zones, based on potential flood heights, which were taken to be indicative of areas most likely to be wet, and thus contain the highest probability of having wetlands. The flood heights were created by estimating the water expansion level in river channels against a modelled stream surface height layer (in comparison to actual terrain surface). The modelling provides an indication of potential lateral water extent at a range of heights above the stream base height in relation to the stream channel profile at that location, irrespective of flood duration or time periods. The modelling does not take account of the surface roughness or flow blockage, which may result in the additional lateral extension of flood waters through backup, etc. The accuracy of the output is directly dependent on the scale, resolution and detail contained in the DEM. The modelled potential flooding zones were then used to restrict the dual-date wetland modelling where wetlands are most likely to occur.

Note that in some localised areas, the results of both single- and dual-date wetland modelling approaches required post-modelling edits to improve the wetland delineation, especially if wetlands were not showing saturation or significant (vegetation) flushes. In such cases, analyst-assisted conventional unsupervised classifications were used to locally improve the modelled wetland output.

The modelled wetland extents were then integrated into the base vegetation land-cover classes.

8.2.4 Nama and succulent Karoo

The Nama and succulent Karoo categories and associated subclasses are included as a result of a specific DEA information requirement in the DEA/CARDNO land-cover data product. Since the sensitivity of the automated spectral models was insufficient to determine these biome boundaries, they have been defined solely on the SANBI biome boundaries, as per the previous fynbos explanation.

However, within these SANBI boundaries, the original level of modelled land-cover detail has been retained in terms of forest, dense bush, open bush, low shrubland, grassland and bare ground subclasses. This is because each biome can contain a wide range of structural vegetation types, over and above the dominant structural form. For example, localised patches of thicket, tall bush and grasslike structural communities all occur within the general low shrub matrix that comprises the Nama Karoo biome, according to local species composition, terrain location and fire history. The same approach was used in the production of the 2013/14 land-cover dataset. All independent, non-image sourced geographical masks used in the 2013/14 data-modelling process were used again in the 1990 data-modelling process to ensure consistency of mapping outputs.

8.3 Creating land-use classes

Land-use classes, such as cultivated lands, forest plantations, mines and settlements, were all derived as separate modelling procedures, typically using independently sourced and generated geographical masks to control where and how the original 51 seasonally defined, spectral foundation classes were recoded and modified into the final land-use classes. The same approach was used in the production of the 2013/14 land-cover dataset. All independent, non-image sourced geographical masks used in the 2013/14 data-modelling process were used again in the 1990 data-modelling process to ensure consistency of mapping outputs.

8.3.1 Cultivated lands

The Department of Agriculture, Forestry and Fisheries (DAFF) public domain 2013 national field boundary dataset (captured from 2.5 m-resolution, pan-merge SPOT5 imagery) was the initial source of the 1990 cultivated land-use classes. This existing dataset was edited nationally to represent the historical 1990 cultivation patterns observable on the 1990 Landsat imagery. This typically involved deleting current fields that did not previously exist (especially in terms of pivot fields), as well as limited amounts of field boundary modifications and new field additions.

All 1990 cultivated land edits were captured manually using on-screen photo-interpretation techniques, since this facilitated and maintained similar interpretation accuracies to the original SPOT5-derived field boundary data. Furthermore, it also eliminated post-classification editing necessities typically associated with field boundaries defined with pixel-classification methods.

The final cultivated land boundaries were used "as-is" to define the final geographical extent of all the cultivated land-use classes incorporated into the land-cover dataset. No use of, or reference to, the original 51 seasonally defined spectral foundation classes was made.

8.3.2 Plantations

Forestry plantations were derived from selected classes within the 51-class spectral foundation cover dataset, which were recoded and regrouped within controlled geographical areas, using independently sourced and generated 1990-specific geographical masks. The plantation area masks were sourced from several in-house provincial mapping projects, updated nationally to the plantation extent visible on the 1990 Landsat imagery.

Note that the final plantation class boundaries were always defined by the original spectral foundation class boundaries contained within the geographical masks, and not by the geographical mask boundaries themselves.

8.3.3 Mines

Mines were derived from selected classes within the 51-class spectral foundation cover dataset, which were recoded and regrouped within controlled geographical areas, using independently sourced and generated geographical masks. The 2013/14 mine area masks were used in the 1990 modelling process since the 2013/14 masks typically represented the maximum extent of the mining footprint over time. The only regions where this assumption did not hold true and required modifications for 1990 use were the Middleburg/Witbank and Newcastle coalfields, and the dune-mining activities near St Lucia. The original 2013/14 masks were sourced from previous in-house, provincial mapping projects and national 1:50 000-scale map datasets[34], all of which were then updated nationally to the mine activity extent visible on the 2014 Landsat imagery. Note that mine water subclasses were generated by identifying image-mapped water bodies located within the final 1990 mine mask.

Note that major road and rail features were excluded from the mine area footprint if they intersected the mine mask, and that the final mine class boundaries were always defined by the original spectral foundation class boundaries contained within the geographical masks, and not by the geographical mask boundaries themselves. The same approach was used in the production of the 2013/14 land-cover dataset.

8.3.4 Built-up areas/settlements

The 1990 built-up areas were generated using the existing 2013/14 built-up areas dataset as a base, and then modifying this manually to match the observable features on the historical 1990 imagery. As with the original 2013/14 built-up areas dataset, no use of or reference to the original 51 seasonally defined spectral foundation classes was made.

8.3.5 Erosion

The 1990 erosion dataset was generated using the same base masks as were used for the 2013/14 imagery in order to maintain consistency. The physical extent of the 1990 erosion features within these generic masks was determined from the extent of non-vegetated ground determined from the historical 1990 imagery. The final 1990 erosion (donga) class was derived from the same set of spectral classes used in the 2013/14 modelling to represent the bare ground areas.

The original erosion masks were sourced from previous in-house, provincial mapping projects and other national erosion datasets, all of which were then updated nationally to represent the current extent of major

34 Geographical masks from the national 1:50 000-scale topographic digital map data were created by extracting the relevant vector features and buffering them by one Landsat pixel extent. These were integrated with the in-house provincial mine masks, before updating to 2014 geographic extents off the 2014 Landsat 8 imagery.

dongas visible on the 2014 Landsat imagery (which are assumed to be the maximum extent between 1990 and 2014). Note that, as with the 2013/14 dataset, the 1990 erosion dataset is significantly better represented both spatially and numerically in the wetter, more vegetatively lush regions of the country, where the non-vegetated erosion surface is significantly different from the surrounding vegetation cover (i.e. bushveld and grassland regions). Donga feature detection in the drier, more arid region is not as accurate.

As with previous land-use classes, the final donga/erosion class boundaries were always defined by the original spectral foundation class boundaries contained within the geographical masks, and not by the geographical mask boundaries themselves.

8.3.5.1 Degraded areas

As part of the DEA-commissioned version of the 2014 GTI South African National Land-cover Dataset, an additional subclass, defining "degraded" areas, was also generated. This has been repeated for the 1990 land-cover dataset. Degraded areas are defined in terms of this dataset as areas of significantly reduced vegetation cover compared to immediately adjacent pristine or semi-pristine natural areas. Degraded areas were modelled from selected classes from within the 51-class spectral foundation cover dataset, which were recoded and regrouped within controlled geographical areas, using independently generated geographical masks. The basic degraded area mask was created from 1990 image-derived, seasonally summarised NDVI maximum and standard deviation datasets. The extent of this mask allocation was limited to areas outside formally protected (conservation) areas[35], within non-arid biome regions[36], on terrain slopes less than 21 degrees[37], and not overlapping major roads, dry river beds, beaches and dune fields[38].

These masks were the same as those used in the production of the 2013/14 land-cover dataset.

This modelling approach, while relevant in terms of practical available input data, meant that the 1990 dataset again excluded the identification of cover-rich, species-poor degraded areas, as well as degraded low vegetation areas within naturally occurring low-vegetation regions, as occurred in the 2013/14 dataset.

As with previous land-use classes, the final degraded area boundaries were always defined by the original spectral foundation class boundaries contained within the geographical masks, and not by the geographical mask boundaries themselves.

9. ACCURACY ASSESSMENT

No accuracy assessment was undertaken on the historical 1990 DEA/CARDNO South African National Land-cover Dataset, because no suitable historical reference data was available in the same format as that used for the verification of the 2013/14 dataset. However since exactly the same mapping and modelling procedures and image formats have been used in the generation of the 1990 land-cover data, the map accuracies determined for the 2013/14 dataset can be used as a reliable indication of the likely mapping accuracies achieved for the 1990 dataset. A full description of the method used to determine the 2013/14 map accuracy is provided in the 2013/14 Data User Report. The overall map accuracy for the 2013/14 South African National Land-cover Dataset in the DEA/CARDNO format, modelled from multi-seasonal Landsat 8 imagery, is 82.53%, with a mean land-cover/land-use class accuracy of 88.36%. This was determined from 6 415 sample points, representing statistical coverage of all the validated land-cover/land-use classes. The associated Kappa Index value of 80.87 indicates that these results are very unlikely to be the result of chance occurrence.

35 As defined in the DEA Protected Areas 2014 Protected and Conservation Areas (PACA) database.

36 To ensure that degraded areas were clearly identifiable as having a lower vegetation cover than the surrounding non-degraded areas, unless they were in located within the boundaries of the former TBVC states (Transkei, Bophuthatswana, Venda and Ciskei) and closely associated with areas of dense rural settlements.

37 To exclude natural rocky slopes and cliff faces with similar non-vegetated spectral characteristics.

38 To exclude other land-cover and land-use features with similar non-vegetated spectral characteristics.

10.DATA USE

The digital raster data is supplied without any post-modelling or classification spatial filtering. Data users may wish to consider applying spatial cleaning techniques, such as applying a moving 3 x 3 pixel window filter to remove isolated single-class pixels from the dataset, especially if the raster data is to be converted to vector format.

11. METADATA

1990 GTI South African National Land-cover Dataset
DEA/CARDNO 35-class Legend:
Core metadata elements (SANS 1878)

1(M) Dataset title: 1990 GTI SA National Land-cover (DEA/CARDNO version) (*dea_cardno_1990_sa_lcov_utm35n_vs39.img*)

2(M) Dataset reference date: April 1989 to October 1993

3(O) Dataset responsible party: Produced by GeoTerra Image (GTI) (Pty) Ltd, South Africa

4(C) Geographic location of the dataset. MBR
WestBoundLongitude: -717294.00 (Upper Left X)
EastBoundLongitude: 1301256.00 (Lower Right X)
NorthBoundLongitude: -2239230.00 (Upper Left Y)
SouthBoundLongitude: -4046670.00 (Lower Right Y)

Projection coordinates based on Universal Transverse Mercator (UTM) 35 north, WGS84 (datum), metres.

5(M) Dataset language : “English” (eng)

6(C) Dataset character set: UTF8 (8-bit data)

7(M)Dataset topic category: 010 = Base map earth coverage

8(O) Scale of the dataset: Land-cover mapped from 30 m-resolution Landsat satellite imagery, therefore recommended for approximately 1:90 000 scale or coarse mapping and modelling applications.

9(M) Abstract describing the dataset: The 1990 South African National Land-cover Dataset produced by GTI as a commercial data product has been generated from digital, multi-seasonal Landsat 4/Landsat 5 multi-spectral imagery, acquired between April 2013 and October 1993. In excess of 600 Landsat images were used to generate the land-cover information, based on an average of eight different seasonal image-acquisition dates, within each of the 76 image frames required to cover South Africa. The land-cover dataset, which covers the whole of South Africa, is presented in a map-corrected, raster format, based on 30 x 30 m cells, equivalent to the image resolution of the source Landsat 4 and Landsat 5 multi-spectral imagery. This specific version of the 1990 GTI South African National Land-cover Dataset is supplied to the South African Department of Environmental Affairs under the DEA/CARDNO Project: SCPF002: *Implementation of Land-use Maps for South Africa*. Use of this DEA/CARDNO data version is governed by the LICENCE AGREEMENT contained in this report. The DEA/CARDNO dataset contains 35 land-cover/land-use information classes, covering a wide range of natural and man-made landscape characteristics. A simplified 17-class format legend is also supplied as per client requirements. The original land-cover dataset was processed in UTM35 (north)/WGS84 map-projection format based on the Landsat 4 and Landsat 5 standard map-projection format as provided by the USGS. All intellectual property rights pertaining to the data remain with GTI at all times.

10(O) Dataset format name: ERDAS Imagine *img raster formats

11(O) Dataset format version: version 01 (file#39)

12(O) Additional extent information for the dataset: (vertical and temporal)

Vertical extent:

Minimum value: N/A
Maximum value: N/A
Unit of measure: N/A
Vertical datum: N/A

Temporal extent: Land-cover datasets generated in July 2015, based on April 1989 to October 1993 multi-seasonal Landsat 4 and Landsat 5 satellite imagery.

14(O) Reference system: Universal Transverse Mercator (UTM) 35 north

CRS:

Projection Used: Universal Transverse Mercator (UTM) 35 North
Spheroid used: WGS84
Datum used: WGS 84
Ellipsoid parameters:
Ellipsoid semi-major axis
Axis units
Denominator of flattening ratio

Projection parameters:

UTM Zone: 35 (north)
Standard parallel
Longitude of central meridian: 27:00:00.00 east
Latitude of projection origin: 00:00:00.00 east
False easting: 500000.00 metres
False northing: 0.00 metres
Scale factor at equator: 0.999600
Projection units: metres

15(O) Lineage statement: Land-cover dataset generated in-house by GTI (Pretoria) in July 2015, based primarily on multi-date Landsat 4 and Landsat 5 imagery acquired between April 1989 and October 1993.

16(O) Online resource: N/A

17(O) Metadata file identifier: N/A

18(O) Metadata standard name: SANS I878

19(O) Metadata standard version: version 01

20(C) Metadata language: English (eng)

21(C) Metadata character set: 021 (UsAscii)

22(M) Metadata point of contact:

Name:	Mark Thompson
Position name:	Director Remote Sensing
Organisation name:	GeoTerraImage (Pty) Ltd

Physical address:

Building	Grain Building (1st Floor)
Street	Witherite
Street Suffix	Street
Street No	477
Suburb	Die Wilgers
City	Pretoria
Zip code	0041
State	Gauteng
Country	South Africa

Postal address:

Box	295
Suburb	Persequor Park
City	Pretoria
Zip	0020
State	Gauteng
Country	South Africa

23(M) Metadata time stamp: 31 July 2015

APPENDIX A: The 1990 South African National Land-cover Legend (DEA/CARDNO legend)

The table below describes the 35 land-cover/land-use classes contained in the DEA/CARDNO-supplied subset of the 1990 South African National Land-cover Dataset, generated from multi-seasonal Landsat 8 imagery. See Appendix D for visual examples of percentage cover densities per unit area.

Parent	DEA class name (and digital code)	Definition
Water	Water (33)	Areas of open, surface water that are detectable on all image dates used in the Landsat 8-based water modelling processes. The mapped extent represents the maximum detectable water extent from all available imagery acquired within the 2013/14 assessment period. Includes both natural and man-made water features.
Wetland	Wetland (12)	Wetland areas that are primarily vegetated on a seasonal or permanent basis. Defined on the basis of seasonal image identifiable surface vegetation patterns (not subsurface soil characteristics). The vegetation can be either rooted or floating. Wetlands may be either daily (i.e. coastal), temporarily seasonal or permanently wet and/or saturated. Vegetation is predominately herbaceous. Includes, but is not limited to wetlands associated with seeps/springs, marshes, floodplains, lakes/pans, swamps, estuaries and some riparian areas. Wetlands associated with riparian zones represent image-identified vegetation along the edges of watercourses that show similar spectral characteristics to nearby wetland vegetation. Excludes mangrove swamps. Permanent or seasonal open-water areas within the wetlands are classified separately. Seasonal wetland occurrences within commercially cultivated field boundaries are not shown, although they have been retained within subsistence level cultivation fields. *Note that, due to wetter seasonal conditions during the 1990 image-acquisition period (compared to that in 2013/14), the geographical extent of modelled wetlands has now been extended across the entire country, and is not restricted to the usually wetter eastern and southern regions as was required in the 2013/14 land-cover modelling. This means that wetlands that only appear in the 1990 land-cover dataset and not in the 2013/14 dataset, in the drier eastern and northern regions of the country, have not necessarily been lost, just that they were not observable on the significantly drier 2013/14 satellite imagery.*
Forest	Indigenous forest (1)	Natural/semi-natural indigenous forest, dominated by tall trees, where tree canopy heights are typically greater than 5 m and tree canopy densities are typically more than 75%, often with multiple understory vegetation canopies. Note: This class refers to grassland areas not within the fynbos, Nama Karoo and succulent Karoo biome boundaries (as defined in the SANBI 2006 *Vegetation of South Africa, Swaziland and Lesotho* map data).
Thicket and dense bush	Dense bush, thicket and tall dense shrubs (2)	Natural/semi-natural tree and/or bush-dominated areas, where typically canopy heights are between 2 and 5 m, and canopy density is typically more than 75%, but may include localised sparser areas down to about 60%. Includes dense bush, thicket, closed woodland, tall, dense shrubs, scrub forest and mangrove swamps. Can include self-seeded bush encroachment areas if there is sufficient canopy density. Note: This class refers to grassland areas not within the fynbos, Nama Karoo and succulent Karoo biome boundaries (as defined in the SANBI 2006 *Vegetation of South Africa, Swaziland and Lesotho* map data).

Parent	DEA class name (and digital code)	Definition
Woodland/ open bush	Woodland and open bushland (3)	Natural/semi-natural tree and/or bush-dominated areas, where typically canopy heights are between 2 and 5 m, and canopy densities typically between 40 and 75%, but may include localised sparser areas down to 15 to 20%.(*Note: Normally, it is preferred that land-cover class definitions are mutually exclusive in terms of content and associated landscape characteristics. Due to the nature of the multi-seasonal spectral modelling approach used in compiling the land-cover dataset, it seems that there is some transitional overlap between "bushy/woody grassland" and "grassy woodland/bushland" in terms of woody cover densities. For this reason, the class definitions for both "woodland/open bush" and "grassland" include both a class-specific core woody cover definition and a shared transitional woody cover definition. The sample points used to verify the map accuracy record the observed woody cover percentage for these vegetation types should the user wish to undertake further analysis.*) Includes sparse open bushland and woodland, including transitional wooded grassland areas. Can include self-seeded bush-encroachment areas if canopy density is within the indicated range. In the arid western regions (i.e. Northern Cape), this cover class may be associated with a transitional bush/shrub cover that is lower than typical open bush/woodland cover, but higher and/or more dense than typical low shrub cover. Note: This class refers to grassland areas not within the fynbos, Nama Karoo and succulent Karoo biome boundaries (as defined in the SANBI 2006 *Vegetation of South Africa, Swaziland and Lesotho* map data).
Grassland	Grassland (13)	Natural/semi-natural grass-dominated areas, where typically the tree and/or bush canopy densities are typically less than 20%, but may include localised denser areas up to 40% (regardless of canopy heights). Includes open grassland, and sparse bushland and woodland areas, including transitional wooded grasslands. May include planted pasture (i.e. grazing) if not irrigated. Irrigated pastures will typically be classified as cultivated, and urban parks and golf courses under urban. Note: This class refers to grassland areas not within the fynbos, Nama Karoo and succulent Karoo biome boundaries (as defined in the SANBI 2006 *Vegetation of South Africa, Swaziland and Lesotho* map data).
Low shrubland	Low shrubland (4)	Natural/semi-natural low shrub-dominated areas, typically with less than 2 m canopy height. Includes a range of canopy densities encompassing sparse to dense canopy covers. Very sparse covers may be associated with the bare ground class. Typically associated with low, woody shrub, Karoo-type vegetation communities, although it can also represent locally degraded vegetation areas where there is a significantly reduced vegetation cover in comparison to surrounding, less impacted vegetation cover, including long-term wildfire scars in some mountainous areas in the Western Cape. Note that taller tree/bush/shrub communities within this vegetation type are typically classified separately as one of the other tree- or bush-dominated cover classes. Note: This class refers to low shrubland areas not within the fynbos, Nama Karoo and succulent Karoo biome boundaries (as defined in the SANBI 2006 *Vegetation of South Africa, Swaziland and Lesotho* map data).

Parent	DEA class name (and digital code)	Definition
Cultivated	Commercial annuals (rain-fed) (6)	Cultivated lands used primarily for the production of rain-fed, annual crops for commercial markets. Typically represented by large field units, often in dense local or regional clusters. In most cases, the defined cultivated extent represents the actual cultivated or potential extent. Includes sugarcane crops.
	Commercial pivot (7)	Cultivated lands used primarily for the production of centre pivot-irrigated, annual crops for commercial markets. In most cases the defined cultivated extent represents the actual cultivated or potential extent. Includes sugarcane crops.
	Commercial permanent (orchards) (8)	Cultivated lands used primarily for the production of both rain-fed and irrigated permanent orchard crops for commercial markets. Includes both tree, shrub and non-woody crops, such as citrus, tea, coffee, grapes, lavender and pineapples. In most cases, the defined cultivated extent represents the actual cultivated or potential extent.
	Commercial permanent (vines) (9)	Cultivated lands used primarily for the production of both rain-fed and irrigated permanent vine (grape) crops for commercial markets. In most cases the defined cultivated extent represents the actual cultivated or potential extent.
	Subsistence (10)	Cultivated lands used primarily for the production of rain-fed, annual crops for local markets and/or home use. Typically represented by small field units, often in dense local or regional clusters. The defined area may include intra-field areas of non-cultivated land, which may be degraded or use-impacted, if the individual field units are too small to be defined as separate features.
Forest plantation	Forest plantations (5)	Planted forestry plantations used for growing commercial timber tree species. The single class represents a combination of mature, young and temporary clear-felled stands. The class includes spatially smaller woodlots and windbreaks with the same cover characteristics. Note that young saplings are very difficult to identify on 30 m-resolution Landsat imagery if the actual tree canopy cover density is below 30 to 40%, because the background cover, for example, grassland, then dominates the spectral characteristics in that pixel area.
Mine	Mine (32)	Mining activity footprint, which includes extraction pits, tailings, waste dumps, flooded pits and associated surface infrastructure such as roads and buildings (unless otherwise indicated), for both active and abandoned mining activities. Class may include open-cast pits, sand mines, quarries and borrow pits.
Bare	Bare (non-vegetated) (34)	Bare, non-vegetated ground, with little or very sparse vegetation cover (i.e. typically up to 5 to 10% vegetation cover), occurring as a result of either natural or man-induced processes. Includes, but is not limited to natural rock exposures, dry river beds, dry pans, coastal dunes and beaches, sand and rocky desert areas, very sparse low shrublands and grasslands, erosion areas and major road networks. May also include long-term wildfire scars in some mountainous areas in the Western Cape.
	Degraded (35)	Sparsely vegetated areas, occurring as a result of man-induced processes, which show significantly lower overall vegetation cover compared to surrounding, natural undisturbed areas.
Built-up	Settlements (11)	All built-up areas, represented as a single class, including, but not limited to commercial, industrial, heath, education, religion, transport and residential land uses, including both formal and informal structures, across a range of structural densities from high to low. Includes agricultural smallholdings on the urban periphery.

Parent	DEA class name (and digital code)	Definition
Fynbos	Fynbos: forest (14)	Forest areas as per class (1) within the SANBI fynbos biome boundary.
	Fynbos: thicket (15)	Dense bush and thicket areas as per class (2) within the SANBI fynbos biome boundary.
	Fynbos: open bush (16)	Woodland and open bush areas as per class (3) within the SANBI fynbos biome boundary.
	Fynbos: low shrub (17)	Low shrubland areas as per class (4) within the SANBI fynbos biome boundary.
	Fynbos: grassland (18)	Grassland areas as per class (13) within the SANBI fynbos biome boundary.
	Fynbos: bare ground (19)	Bare ground areas as per class (14) within the SANBI fynbos biome boundary.
Nama Karoo	Nama Karoo: forest (20)	Forest areas as per class (1) within the SANBI Nama Karoo biome boundary.
	Nama Karoo: thicket (21)	Dense bush and thicket areas as per class (2) within the SANBI Nama Karoo biome boundary.
	Nama Karoo: open bush (22)	Woodland and open bush areas as per class (3) within the SANBI Nama Karoo biome boundary.
	Nama Karoo: low shrub (23)	Low shrubland areas as per class (4) within the SANBI Nama Karoo biome boundary.
	Nama Karoo: grassland (24)	Grassland areas as per class (13) within the SANBI Nama Karoo biome boundary.
	Nama Karoo: bare ground (25)	Bare ground areas as per class (14) within the SANBI Nama Karoo biome boundary.
Succulent Karoo	Succulent Karoo: forest (26)	Forest areas as per class (1) within the SANBI succulent Karoo biome boundary.
	Succulent Karoo: thicket (27)	Dense bush and thicket areas as per class (2) within the SANBI succulent Karoo biome boundary.
	Succulent Karoo: open bush (28)	Woodland and open bush areas as per class (3) within the SANBI succulent Karoo biome boundary.
	Succulent Karoo: low shrub (29)	Low shrubland areas as per class (4) within the SANBI succulent Karoo biome boundary.
	Succulent Karoo: grassland (30)	Grassland areas as per class (13) within the SANBI succulent Karoo biome boundary.
	Succulent Karoo: bare ground (31)	Bare ground areas as per class (14) within the SANBI succulent Karoo biome boundary.

Note: the fynbos, Nama Karoo and succulent Karoo vegetation subclasses are provided with additional class codes representing the parent primary vegetation class, in order for different levels of class detail to be used and accessed by data users. This is illustrated on the following page

Dual legend system for the DEA CARDNO 1990 South African land-cover classes

- Class_Names (Color) represents the full 35-class land-cover/land-use class legend (with biome-level information).
- Class_Names2 (Color2) represents the amalgamated 17-class land-cover/land-use class legend (no biome-level information).
- Area refers to hectares (ha) and histogram to the number of 30 x 30 m image pixels.

1990_landcover_mosaic_v39b_subset_and_snap_xtra_subs.img

Row	Color	Class_Names	Color2	Class_Names2	Area	Histogram
0					0	0
1		Indigenous Forest		Indigenous Forest	346291	3847679
2		Thicket /Dense bush		Thicket /Dense bush	5.91609e+006	65734323
3		Woodlan/Open bush		Woodlan/Open bush	9.78827e+006	108758601
4		Low shrubland		Low shrubland	1.82786e+007	203095039
5		Plantations / Woodlots		Plantations / Woodlots	1.92282e+006	21364651
6		Cultivated commercial annu		Cultivated commercial annu	1.14866e+007	127628703
7		Cultivated commercial annu		Cultivated commercial annu	244269	2714095
8		Cultivated commercial perma		Cultivated commercial perma	313572	3484129
9		Cultivated commercial perma		Cultivated commercial perma	162354	1803936
10		Cultivated subsistence crop		Cultivated subsistence crop	1.9843e+006	22047815
11		Settlements		Settlements	2.74292e+006	30476891
12		Wetlands		Wetlands	1.52614e+006	16957092
13		Grasslands		Grasslands	2.53174e+007	281304875
14		Fynbos: forest		Indigenous Forest	30359.6	337329
15		Fynbos: thicket		Thicket /Dense bush	283922	3154692
16		Fynbos: open bush		Woodlan/Open bush	211541	2350458
17		Fynbos: low shrub		Low shrubland	5.91976e+006	65775057
18		Fynbos: grassland		Grasslands	534043	5933806
19		Fynbos: bare ground		Bare Ground	149179	1657548
20		Nama Karoo: forest		Indigenous Forest	0	0
21		Nama Karoo: thicket		Thicket /Dense bush	170367	1892965
22		Nama Karoo: open bush		Woodlan/Open bush	520970	5788557
23		Nama Karoo: low shrub		Low shrubland	1.28932e+007	143257708
24		Nama Karoo: grassland		Grasslands	1.22216e+006	13579527
25		Nama Karoo: bare ground		Bare Ground	1.05612e+007	117346137
26		Succuelent Karoo: forest		Indigenous Forest	0	0
27		Succulent Karoo: thicket		Thicket /Dense bush	275606	3062284
28		Succulent Karoo: open bush		Woodlan/Open bush	487004	5411160
29		Succulent Karoo: low shrub		Low shrubland	4.04836e+006	44981772
30		Succulent Karoo: grassland		Grasslands	417329	4636986
31		Succulent Karoo: bare grou		Bare Ground	1.70222e+006	18913566
32		Mines		Mines	291757	3241741
33		Waterbodies		Waterbodies	2.20204e+006	24467125
34		Bare Ground		Bare Ground	1.4899e+006	16554424

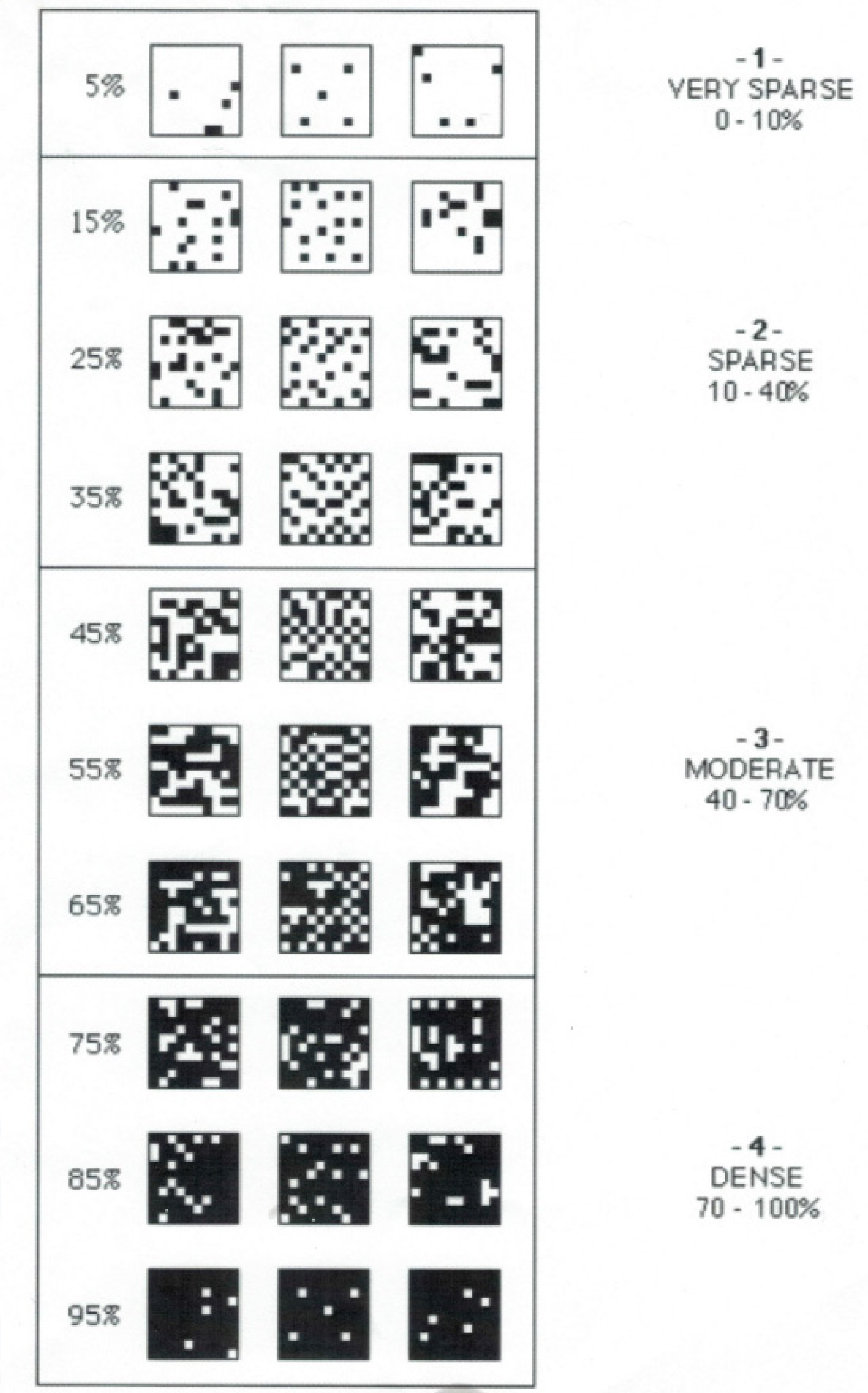
APPENDIX B: List of accompanying documents and files

- An Excel spreadsheet containing the full list of Landsat 4 and Landsat 5 acquisition dates, per image frame, as used in the generation of the 1990 South African National Land-cover Dataset. Note that the listed acquisition dates represent the primary dates used in the land-cover modelling, and not any additional image dates that were only used for localised cloud masking on the primary image date. Additional image dates are, however, listed if they themselves were also considered primary acquisition dates and used as modelling inputs.

APPENDIX C: The 51-class Seasonally Defined Spectral Foundation Class Legend

Row	Color	Class_Names
0		
1		water seasonal
2		water permanent
3		bare mix 1 date only, no overlap with any pure bare class
4		bare mix >1 but < all dates, no overlap with any pure bare class
5		bare mix all dates, no overlap witrh any pure bare class
6		bare pure 1 date only
7		bare pure >1 but < all dates
8		bare pure all dates
9		Tree/Bush mix 1 date only
10		Tree 1 date only
11		Tree/Bush mix >1 but < all dates
12		Tree >1 but < all dates
13		Tree/Bush mix all dates
14		Tree all dates
15		golf-irrig combo Tree/Bush mix 1 date only
16		golf-irrig combo Tree 1 date only
17		golf-irrig combo Tree/Bush mix >1 but < all dates
18		golf-irrig combo Tree >1 but < all dates
19		golf-irrig combo Tree/Bush mix all dates
20		golf-irrig combo Tree all dates
21		Tree/Bush 1 date only + Bare pure 1 date only
22		Tree 1 date only + Bare pure 1 date only
23		Tree/Bush multi dates + Bare pure 1 date only
24		Tree multi dates + Bare pure 1 date only
25		Tree/Bush multi dates + Bare pure multi dates
26		Tree multi dates + Bare pure multi dates
27		Tree/Bush 1 date only + Bare pure multi dates
28		Tree 1 date only + Bare pure multi dates
29		golf-irrig combo / Tree/Bush mix 1 date only + Bare pure 1 date
30		golf-irrig combo / Tree 1 date only + Bare pure 1 date only
31		golf-irrig combo / Tree/Bush mix multi dates + Bare pure 1 date
32		golf-irrig combo / Tree multi dates + Bare pure 1 date only
33		golf-irrig combo / Tree/Bush mix multi dates + Bare pure multi dates
34		golf-irrig combo / Tree multi dates + Bare pure multi dates
35		golf-irrig combo / Tree/Bush mix 1 date only + Bare multi dates
36		golf-irrig combo / Tree 1 date only + Bare pure multi dates
37		Grass (all dates)
38		Grass (any date) / Bare pure 1 date
39		Grass (any date) / Bare mix 1 date
40		Grass (any date) / Bare pure multi dates
41		Grass (any date) / Bare mix multi dates (model overlap)
42		Grass (any date) / Bare mix all dates (model overlap)
43		Tree/Bush mix 1 date only + Bare 1 date only + burn (any date)
44		Tree 1 date only + Bare pure 1 date only + burn (any date)
45		Tree/Bush mix multi dates + Bare pure 1 date only + burn (any date)
46		Tree multi dates + Bare pure 1 date only + burn (any date)
47		golf-irrig combo / Tree/Bush mix 1 date only + Bare pure 1 date only + burn (any date)
48		golf-irrig combo / Tree 1 date only + Bare pure 1 date only + burn (any date)
49		golf-irrig combo / Tree/Bush mix multi dates + Bare pure 1 date only + burn (any date)
50		golf-irrig combo / Tree multi dates + Bare pure 1 date only + burn (any date)
51		grass (all dates) + burn (any date)

APPENDIX D: Visual representation of canopy cover density percentages per unit area



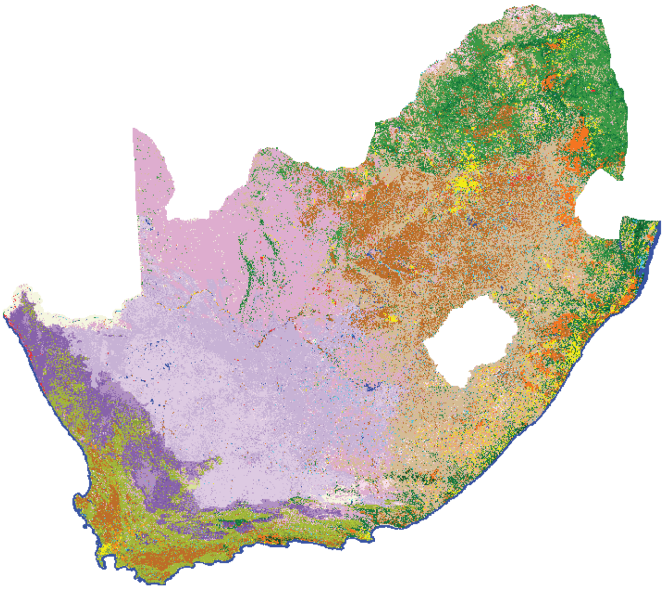
APPENDIX 3

Report on the 1990 to 2013/14 National Land-cover/Land-use Change Assessment

GEOTERRA IMAGE

1990 to 2013/14 South African National Land-cover Change

DEA/CARDNO SCPF002:
Implementation of Land-use Maps for South Africa



DATA PRODUCT CREATED BY

GEOTERRAIMAGE (South Africa)

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CONTENTS

PLEASE NOTE:
This report provides information on the land-cover change statistics derived from a comparison of the specific versions of the 1990 and 2013/14 GTI South African National Land-cover Dataset supplied to the South African Department of Environmental Affairs under the DEA/CARDNO Project: SCPF002: Implementation of Land-use Maps for South Africa. These datasets represent information subsets of the full 1990 and 2013/14 GTI South African National Land-cover Datasets, in terms of supplied land-cover/land-use categories and associated class legend.

1. BACKROUND

An assessment of land-cover change has been undertaken using the 1990 and 2013/14 South African National Land-cover Datasets. Both of these datasets have been generated from comparable historical and current Landsat satellite imagery, using the same model-based mapping techniques.

The two source datasets are therefore, as far as possible, directly comparable in terms of land-cover content, spatial detail and associated mapping accuracies. The production of both of these national land-cover datasets is fully documented in separate reports pertaining to each land-cover dataset. It is assumed that a user of the statistical land-cover change data is fully aware and appreciative of the information contained in these land-cover data generation reports.

In preparation for the land-cover change assessment, the original 35-class national land-cover datasets were reformated into the DEA-requested, simplified 17-class legend format to be used for land-cover change reporting.

Table 1 and Table 2 illustrate the class and code conversions that were used to collapse the 35-class legend into a 17-class legend.

dea_cardno_2014_sa_lcov_utm35n_vs2b.img

Row	Color	Class_Names	Color2	Class_Names2	Area	Histogram	Opacity
0					0	0	0
1		Indigenous Forest		Indigenous Forest	395720	4396888	1
2		Thicket /Dense bush		Thicket /Dense bush	7.09698e+006	78855335	1
3		Woodlan/Open bush		Woodlan/Open bush	1.09087e+007	121207366	1
4		Low shrubland		Low shrubland	1.80007e+007	200008268	1
5		Plantations / Woodlots		Plantations / Woodlots	1.8737e+006	20818902	1
6		Cultivated commercial annual crops non-pivot		Cultivated commercial annual crops non-pivot	782049	8689435	1
7		Cultivated commercial annual crops pivot		Cultivated commercial annual crops pivot	1.06108e+007	117898196	1
8		Cultivated commercial permanent orchards		Cultivated commercial permanent orchards	346950	3855005	1
9		Cultivated commercial permanent vines		Cultivated commercial permanent vines	188711	2096791	1
10		Cultivated subsistence crops		Cultivated subsistence crops	2.04053e+006	22672521	1
11		Settlements		Settlements	2.90828e+006	32314218	1
12		Wetlands		Wetlands	1.0259e+006	11398887	1
13		Grasslands		Grasslands	2.37573e+007	263970479	1
14		Fynbos: forest		Indigenous Forest	32724	363600	1
15		Fynbos: thicket		Thicket /Dense bush	691164	7679603	1
16		Fynbos: open bush		Woodlan/Open bush	307674	3418605	1
17		Fynbos: low shrub		Low shrubland	5.32864e+006	59207100	1
18		Fynbos: grassland		Grasslands	381413	4237918	1
19		Fynbos: bare ground		Bare Ground	210113	2334586	1
20		Nama Karoo: forest		Indigenous Forest	0	0	1
21		Nama Karoo: thicket		Thicket /Dense bush	328724	3652485	1
22		Nama Karoo: open bush		Woodlan/Open bush	540805	6008941	1
23		Nama Karoo: low shrub		Low shrubland	1.40578e+007	156197442	1
24		Nama Karoo: grassland		Grasslands	1.31982e+006	14664675	1
25		Nama Karoo: bare ground		Bare Ground	9.38285e+006	104253894	1
26		Succuelent Karoo: forest		Indigenous Forest	0	0	1
27		Succulent Karoo: thicket		Thicket /Dense bush	174801	1942236	1
28		Succulent Karoo: open bush		Woodlan/Open bush	677790	7530997	1
29		Succulent Karoo: low shrub		Low shrubland	4.44011e+006	49334527	1
30		Succulent Karoo: grassland		Grasslands	335397	3726633	1
31		Succulent Karoo: bare ground		Bare Ground	1.97062e+006	21895741	1
32		Mines		Mines	328973	3655254	1
33		Waterbodies		Waterbodies	2.04562e+006	22729092	1
34		Bare Ground		Bare Ground	1.49435e+006	16603927	1
35		Degraded		Degraded	944061	10489566	1

35 x Class Full DEA / CARDNO Legend	Simplified 17 x Class DEA / CARDNO legend	
Indigenous forests	Indigenous forests	1
Forest: Fynbos		
Thicket/dense bush	Thicket/dense bush	2
Thicket: Fynbos		
Thicket: Nama-Karoo		
Thicket: Succulent Karoo		
Woodland/open bush	Woodland/open bush	3
Open bush: Fynbos		
Open bush: Nama-Karoo		
Open bush: Succulent Karoo		
Low shrubland	Low shrubland	4
Low shrubland: Fynbos		
Low shrubland: Nama-Karoo		
Low shrubland: Succulent Karoo		
Plantations/woodlots	Plantations/woodlots	5
Cultivated commercial annual: non-pivot	Cultivated commercial annual: non-pivot	6
Cultivated commercial annual: pivot	Cultivated commercial annual: pivot	7
Cultivated commercial permanent orchards	Cultivated commercial permanent orchards	8
Cultivated commercial permanent vines	Cultivated commercial permanent vines	9
Cultivated subsistence crops	Cultivated subsistence crops	10
Settlements	Settlements	11
Wetlands	Wetlands	12
Grasslands	Grasslands	13
Grasslands: Fynbos		
Grasslands: Nama-Karoo		
Grasslands: Succulent Karoo		
Mines	Mines	14
Waterbodies	Waterbodies	15
Bare ground	Bare ground	16
Bare ground: Fynbos		
Bare ground: Nama-Karoo		
Bare ground: Succulent Karoo		
Degraded	Degraded	17

2. COMMENTS ON 1990 TO 2014 SOUTH AFRICAN LAND-COVER CHANGE ASSESSMENT

There are three basic factors that may have influenced land-cover change results and associated statistics, namely land-cover mapping accuracies, seasonal/climatic conditions under which the original source imagery was acquired, and the level of (landscape) detail that is being compared over time.

2.1 Influence of mapping accuracies on land-cover change

Mapping accuracies have been calculated for the 2013/14 land-cover dataset and are reported in the 2013-14 Data User's Report. The results of the 2013/14 map accuracy assessment are assumed to be representative of the 1990 accuracies, since comparable image data and modelling/mapping techniques were used for both datasets. No independent map accuracy assessment was undertaken for the 1990 dataset due to the unavailability of suitable reference data. The reliability of (land-cover) change statistics are greatly influenced by the accuracy of the input data against which change is determined. In simplistic terms, the sum of the known mapping error associated with a particular land-cover class over two time periods can indicate the level of "statistical change" that is, in fact, a result of compounded mapping errors over time, and not actual land-cover change. For this reason, all statistical (land-cover) change values must be interpreted and evaluated in the context of the reported land-cover class mapping accuracy, especially the user (as opposed to the producer) accuracy. Class-specific mapping accuracies are included in the land-cover change results reported below and in the accompanying spreadsheet.

2.2 Influence of seasonal/climatic differences on land-cover change

It is important to understand the influence that seasonal and possible climatic differences between 1990 and 2013/14 may have had on the generation of each land-cover dataset in terms of landscape characteristics, and the possible effect of such differences on the change assessment results and associated spatial statistics.

The seasonal representation and range of monthly acquisition dates is generally better for the 1990 land-cover dataset than for the 2013/14 dataset, despite the same average number of acquisition dates per frame for the two datasets. This is because the 2013/14 dataset was limited to what cloud-free imagery was recorded between April 2013 and the designated March 2014 cut-off date, whereas the 1990 dataset had access to a wider range of imagery from 1989 to 1993. This greater seasonal representation may have influenced the modelling results in terms of the distribution and extent of some of the natural vegetation classes (excluding indigenous forests), since a better seasonal profile was often possible in 1990 compared to 2014 in some image frame locations.

The 1990 period appears to have been generally wetter than the 2013/14 period in most regions, as observed qualitatively through the increase in observable surface water features in 1990. This is especially evident in the pans across the central regions of the Free State and Northern Cape, where many pans are water-filled in 1990 and dry in 2013-14[39]. These differences will reflect as changes between the two assessment periods, but do not necessarily represent a permanent loss of water bodies over the approximately 24-year period, but rather a seasonal (or climate)-induced difference. This fact needs to be noted during modelling and the interpretation of the land-cover change results and associated statistics.

The wetter conditions that were prevalent in the 1990 dataset have allowed the wetland modelling to be extended across the full national coverage, unlike the

39 This difference in observable surface water extents does not infer that the 1990 or the 2013/14 period was wetter or drier than normal long-term trends, just that, in many geographic locations, there appears to have been more rainfall in 1990 than in 2013/14 during the image-acquisition periods under analysis.

drier 2013/14 image data, which restricted wetland modelling to the wetter eastern and southern regions. These differences will reflect as statistical and spatial changes between the two assessment periods. They do not necessarily represent a permanent loss of wetlands over the approximately 24-year period, but rather indicate a seasonal (or climate)-induced difference that could be temporary. This fact needs to be noted during the modelling and interpretation of land-cover change results.

The apparent wetter conditions prevalent in the 1990 dataset may also have influenced the boundary between low-shrub (i.e. Karoo type) and Highveld grassland vegetation, since the 1990 grassland/low shrub transition in the western Free State region appears to have shifted generally to the west compared to 2013/14, which may be a result of a greater grass component being present in the Karoo/grass transition zone in 1990.

The (Highveld, montane and coastal) grassland correction procedures applied to the 1990 dataset are considered to be slightly more accurate than those applied to the 2013/14 data, as a result of both modified procedures used and better image seasonal representation in 1990. It is therefore potentially possible that some of the “grassland” to “open woody vegetation” changes in these regions may be a result of the improved grassland delineation in 1990 and not actual bush cover increases in 2013/14.

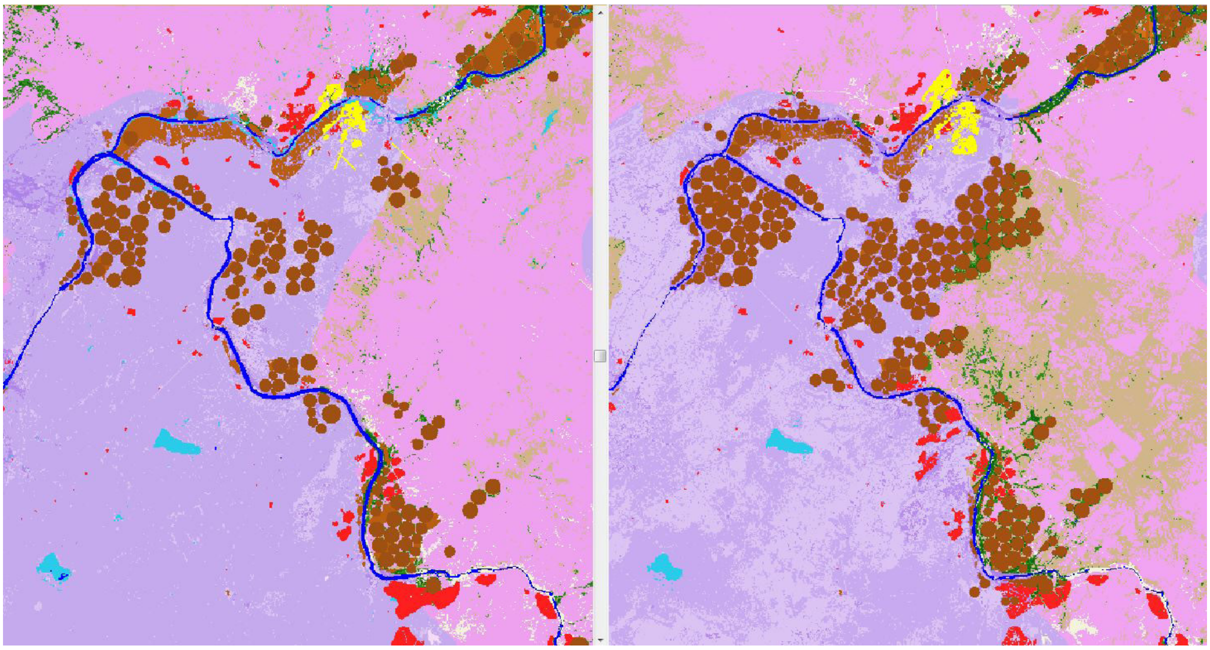
2.3 Influence of mapping detail on land-cover change

The ability to determine change is obviously dependent on the level of detail that is being observed and compared. For example, changes in the extent of urban areas between 1990 and 2013/14 may not be as locally significant as may be expected, since the total built-up footprint defined in the “settlements” class in both the 1990 and 2013/14 datasets includes peripheral smallholding areas around the main built-up areas, and these tend to be the first land use that is converted to formal urban areas before further expansion into natural and cultivated lands.

3. QUALITATIVE EXAMPLES OF LAND-COVER CHANGE 1990 TO 2013/14

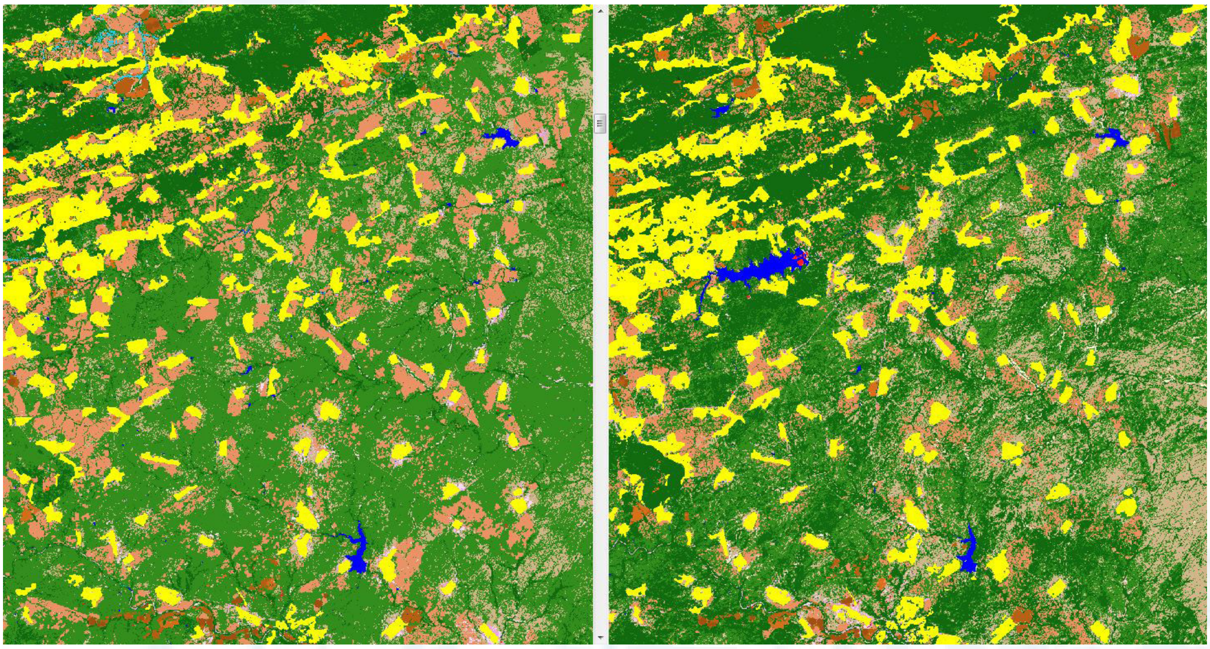
The following screen shots provide visual examples of the type of land-cover changes that have been observed and mapped over the approximately 24-year period between 1990 and 2013/14, based on the Landsat-derived land-cover datasets. The 1990 land cover is on the left and the 2013/14 land cover is on the right in all examples.

Orange/Vaal River confluence, Douglas, Northern Cape



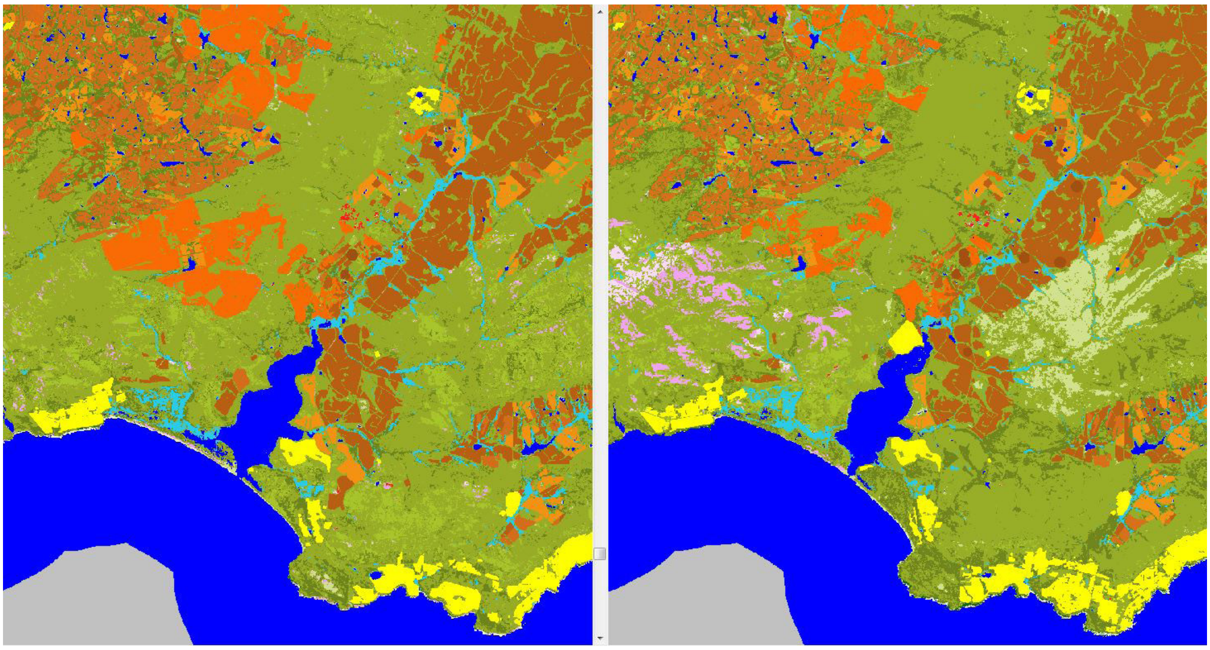
Note the significant increase in centre pivot-irrigation fields in 2013/14 compared to 1990.

Villages, Giyani, Limpopo



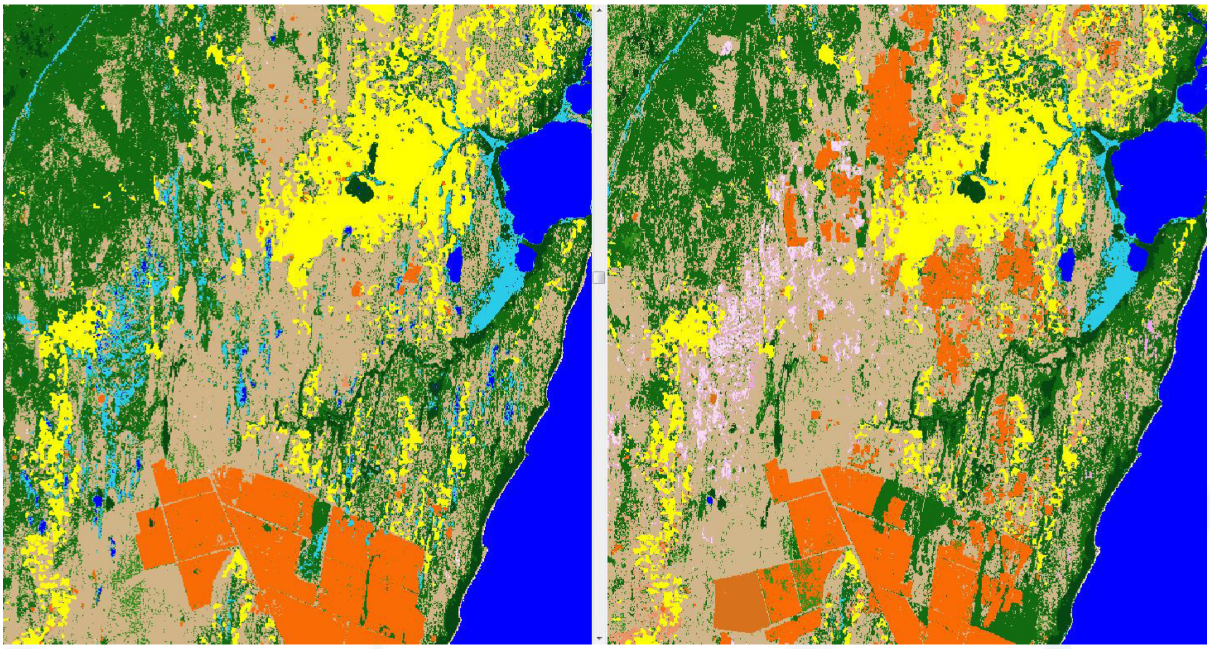
Note the bush-clearing effects around the villages in 2013/14 compared to 1990, and a new dam in 2013/14.

Kleinmond, Western Cape



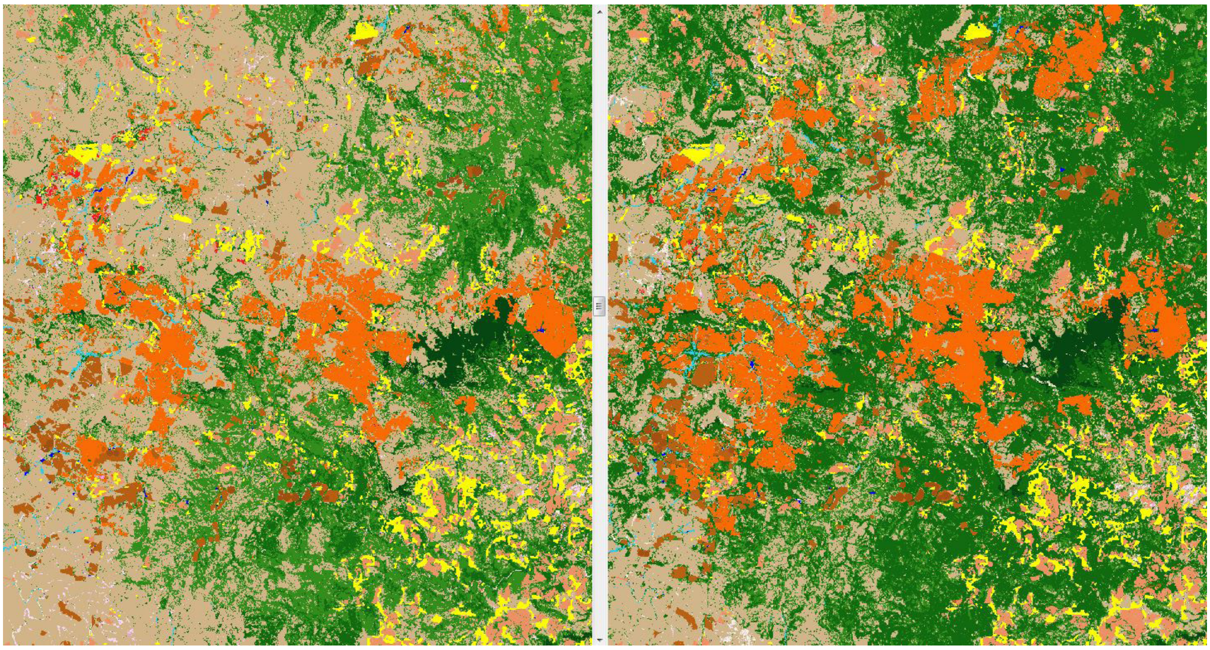
Note the new settlements and reduction in plantations (orange) in 2013/14 compared to 1990. The light green and pink areas in 2013/14 are low-vegetation areas, likely the result of mountain fire scars that were not evident in 1990.

Kosi Bay, KwaZulu-Natal



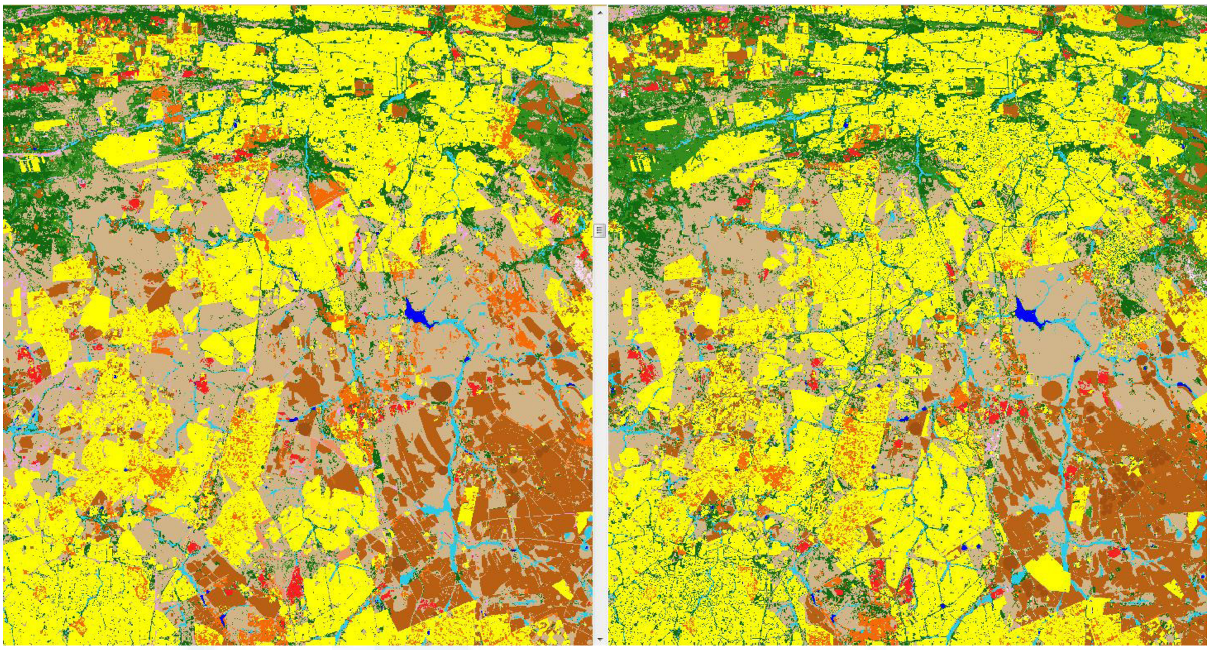
Note the increase in plantation forestry (orange) in 2013/14 and the greater extent of wetlands (light blue) in 1990 as a result of the (generally) wetter conditions.

KwaZulu-Natal Midlands, KwaZulu-Natal



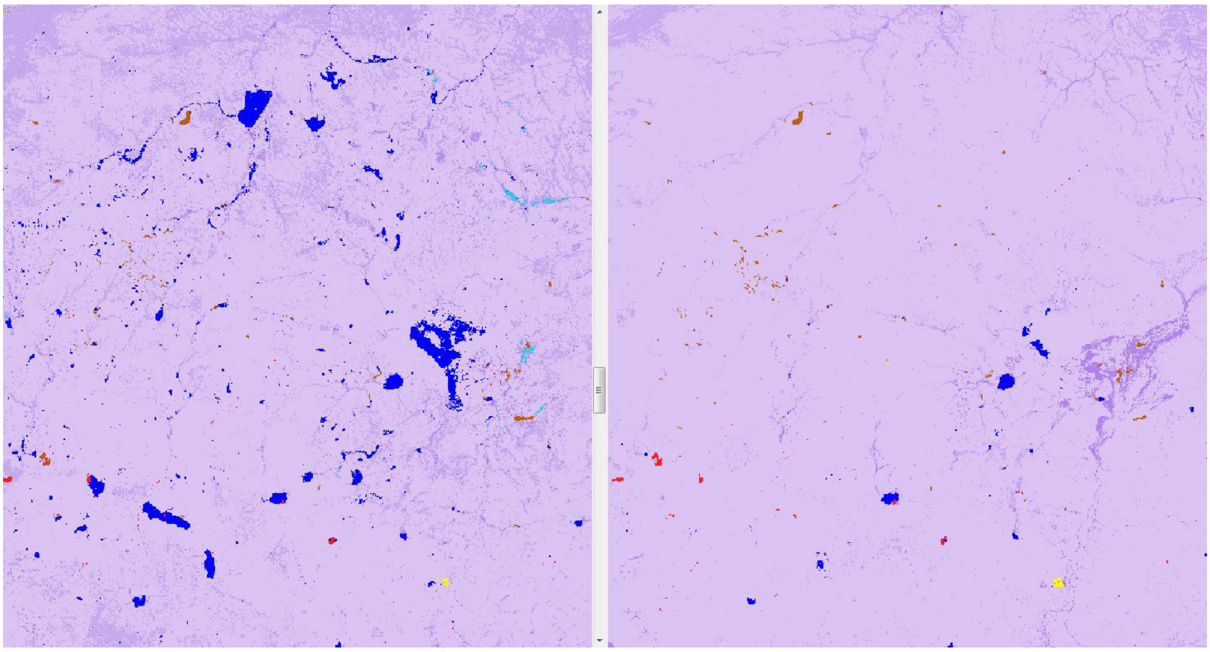
Note the increase in plantation forestry (orange) in 2013/14.

Midrand, Gauteng



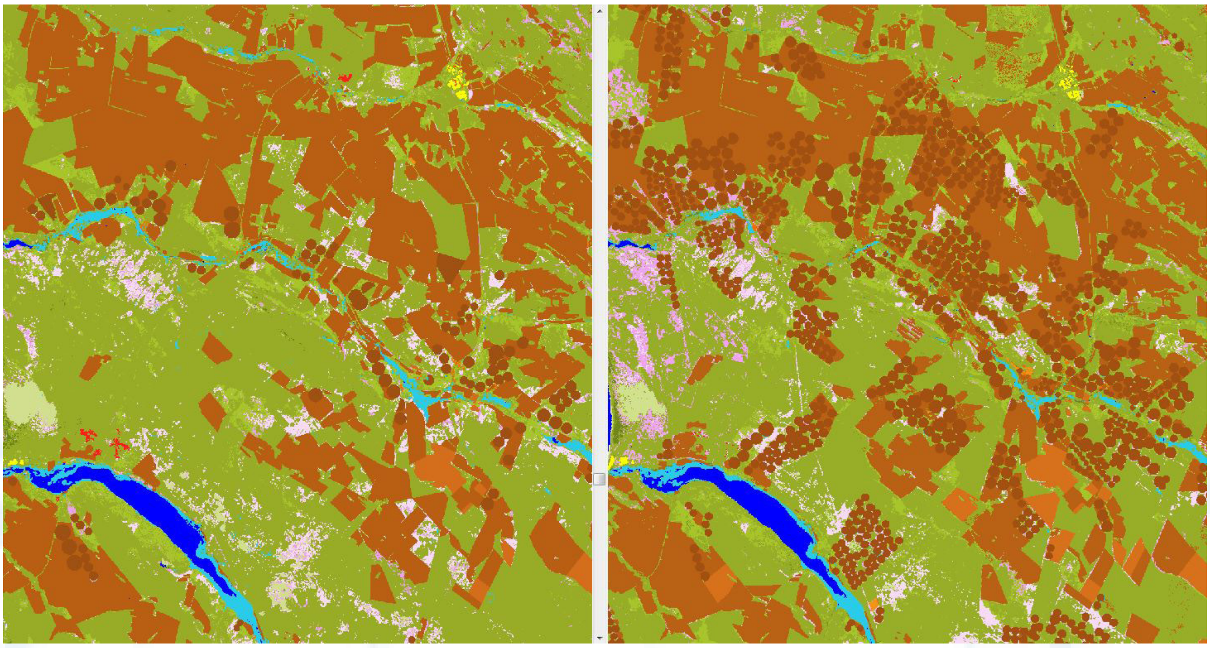
Note the significant expansion of settlements (yellow) in 2013/14 compared to 1990. Note that the settlement class includes smallholdings, so in this area, the expansion of settlements has gone into other land-cover classes as well, such as natural grasslands.

Pan (wetlands), Northern Cape



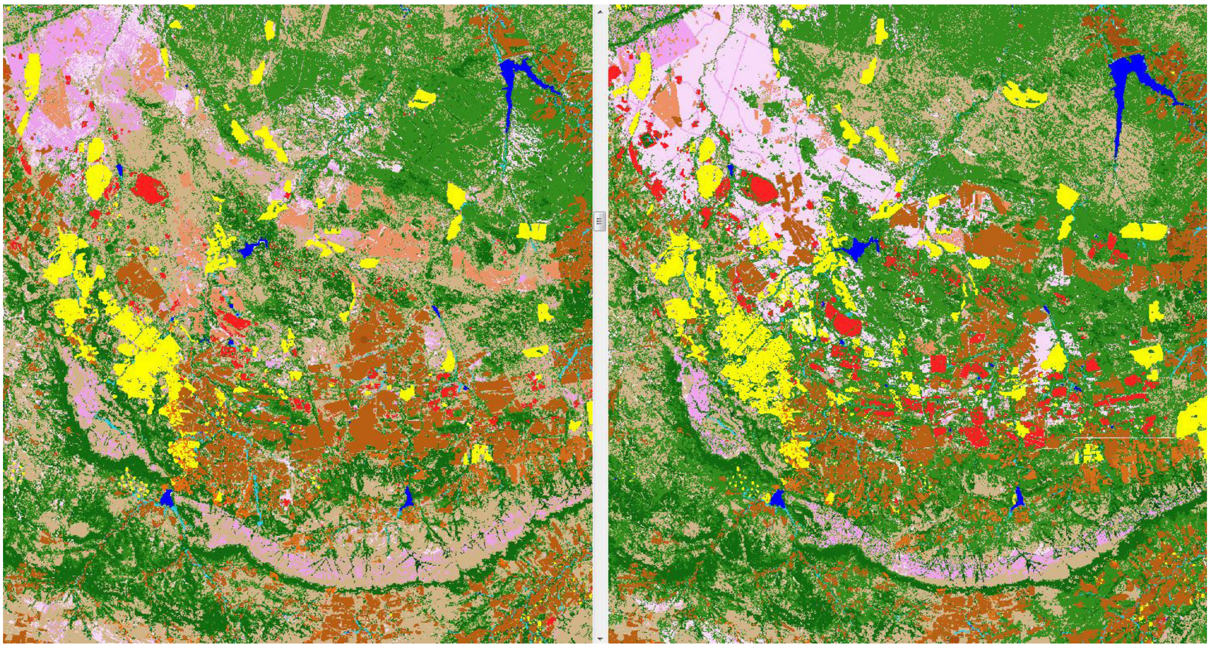
Note the significantly greater extent and number of water features evident in the pans in 1990 as result of the apparent wetter conditions compared to 2013/14.

Olifants River, Western Cape



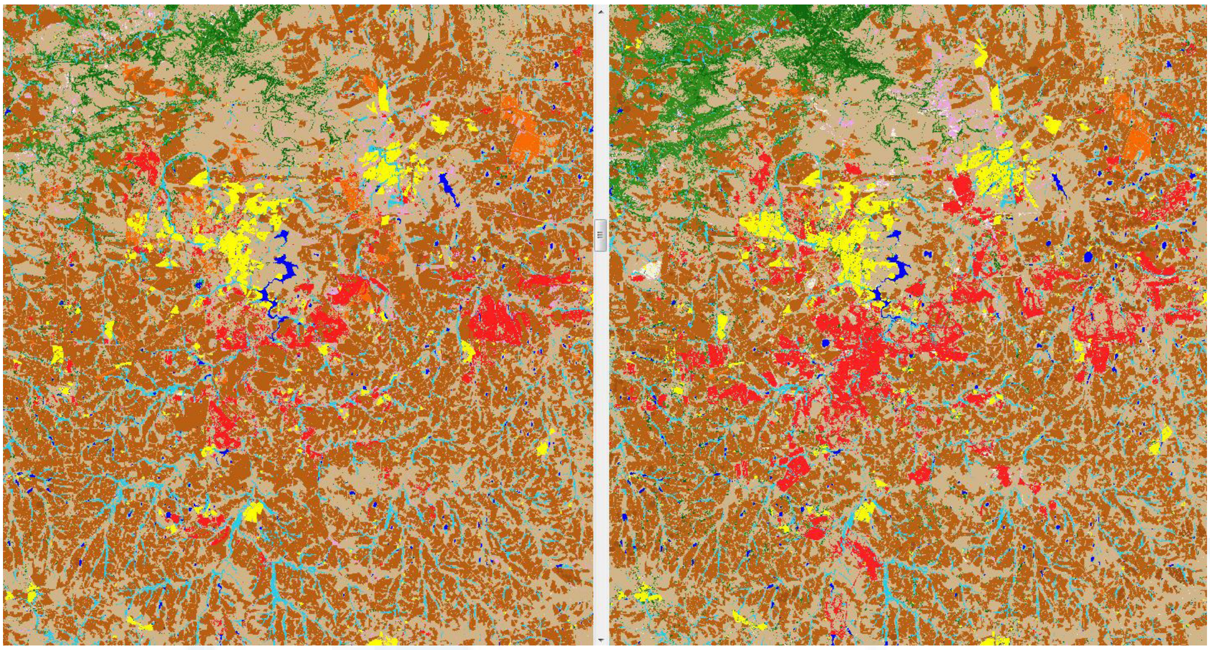
Note the significant increase in centre pivot-irrigation fields in 2013/14 compared to 1990.

Rustenburg, North West



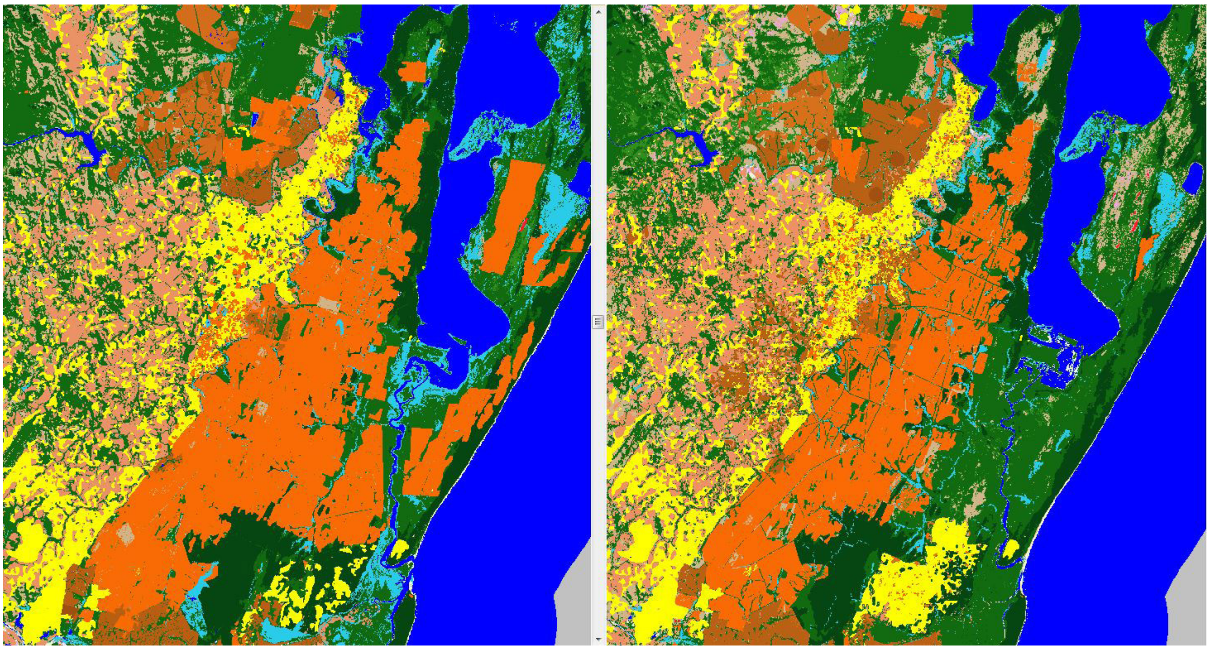
Note the significant increase in mining activity (red) in 2013/14 compared to 1990.

Witbank/eMalahleni, Mpumalanga



Note the significant increase in mining activity (red) in 2013/14 compared to 1990, and the urban expansion.

St. Lucia, KwaZulu-Natal



Note the reduction of plantations (orange) on the eastern shores of St Lucia in 2013/14 and the significant settlement expansion (yellow) and loss of indigenous forest (dark green) in Dukuduku Forest in 2013/14, in the southern central section. The apparent wetter conditions in 1990 have resulted in more observable wetlands (light blue) compared to 2013/14.

4. QUANTITATIVE ASSESSMENT OF LAND-COVER CHANGE 1990 TO 2013/14

A quantitative assessment of land-cover change between 1990 and 2013/14 has been completed, with the results presented below in respect of both change reported in terms of the original 30 m-resolution raster cell format, and also in terms of a spatially resampled 90 x 90 cell format.

The resampled 90 m cell format data was created by a spatial aggregation process that determined the majority land-cover from a window of 3 x 3 original 30 m cells and returned this to a new, single 90 m raster cell representing the equivalent spatial area. Comparison of (national) change statistics derived from both the original 30 m-resolution raster cell data and the resampled 90 m-resolution cell data would provide an indication of whether or not a significant level of variation was introduced into the change results from pixel-level mapping anomalies compared to the local majority land-cover characteristics.

4.1 National-level land-cover change results

The tables below show the results of comparing the 1990 land-cover data to the 2013/14 land cover on a national basis, based on both the original 30 m raster format data and the spatially resampled 90 m raster cell format data, which represents the majority land-cover class in an area of approximately 1 ha. Users are again reminded to interpret all statistical (land-cover) change values in the context of the reported land-cover class mapping accuracy (especially user accuracy), and the overall number of mapped image pixels. Class-specific mapping accuracies are included in the land-cover change results reported below and in the accompanying spreadsheet.

Table 3: National change statistics 1990 to 2013/14, based on original 30 m raster data

National change based on the 30m pixels			*(change based on standardised areas)*					
	1990 Land Cover		2014 Land Cover		Change from 1990 to 2014			*Class mapping*
	Pixels	Hectares	Pixels	Hectares	Pixels	Hectares	%	*accuracy (2013)*
Indigenous Forest	4185008	376650.72	4760488	428443.92	575480	51793.20	13.75	72.6 / 94.64
Thicket /Dense bush	73844264	6645983.76	92129659	8291669.31	18285395	1645685.55	24.76	53.74 / 83.64
Woodlan/Open bush	122308776	11007789.84	138165909	12434931.81	15857133	1427141.97	12.96	60.84 / 54.13
Low shrubland	457109576	41139861.84	464747337	41827260.33	7637761	687398.49	1.67	70.59 / 61.82
Plantations / Woodlots	21364651	1922818.59	20818902	1873701.18	-545749	-49117.41	-2.55	89.3 / 94.35
Cultivated commercial annual crops non-pivot	127628703	11486583.27	117898196	10610837.64	-9730507	-875745.63	-7.62	91.91 / 99.54
Cultivated commercial annual crops pivot	2714095	244268.55	8689435	782049.15	5975340	537780.60	220.16	95.38 / 92.42
Cultivated commercial permanent orchards	3484129	313571.61	3855005	346950.45	370876	33378.84	10.64	92.18 / 95.29
Cultivated commercial permanent vines	1803936	162354.24	2096791	188711.19	292855	26356.95	16.23	91.61 / 97.26
Cultivated subsistence crops	22047815	1984303.35	22672521	2040526.89	624706	56223.54	2.83	89.00 / 94.00
Settlements (incl smallholdings)	30476891	2742920.19	32314218	2908279.62	1837327	165359.43	6.03	93.90 / 98.68
Wetlands	16957092	1526138.28	11398887	1025899.83	-5558205	-500238.45	-32.78	88.07 / 91.18
Grasslands	305455194	27490967.46	286599705	25793973.45	-18855489	-1696994.01	-6.17	84.56 / 69.82
Mines	3241741	291756.69	3655254	328972.86	413513	37216.17	12.76	92.82 / 98.10
Waterbodies	24467125	2202041.25	22729092	2045618.28	-1738033	-156422.97	-7.10	79.64 / 93.31
Bare Ground	154471675	13902450.75	145088148	13057933.32	-9383527	-844517.43	-6.07	98.77 / 97.58
Degraded	16548442	1489359.78	10489566	944060.94	-6058876	-545298.84	-36.61	78.69 / 85.95
totals	*1388109113*	*124929820*	*1388109113*	*124929820*				*User / Producer*
								class accuracies

Table 4: National change statistics 1990 to 2013/14, based on resampled 90 m raster data

National change based on the resampled 90m pixels (ha majority equivalent)			*(change based on standardised areas)*					
	1990 Land Cover		2014 Land Cover		Change from 1990 to 2014			*Class mapping*
	Pixels	Hectares	Pixels	Hectares	Pixels	Hectares	%	*accuracy (2013)*
Indigenous Forest	4319408	3498720.48	4760488	3855995.28	441080	357274.80	10.21	72.6 / 94.64
Thicket /Dense bush	73624120	59635537.20	92129659	74625023.79	18505539	14989486.59	25.14	53.74 / 83.64
Woodlan/Open bush	119332961	96659698.41	138165909	111914386.29	18832948	15254687.88	15.78	60.84 / 54.13
Low shrubland	464138942	375952543.02	464747337	376445342.97	608395	492799.95	0.13	70.59 / 61.82
Plantations / Woodlots	21680621	17561303.01	20818902	16863310.62	-861719	-697992.39	-3.97	89.3 / 94.35
Cultivated commercial annual crops non-pivot	132002937	106922378.97	117898196	95497538.76	-14104741	-11424840.21	-10.69	91.91 / 99.54
Cultivated commercial annual crops pivot	2763000	2238030.00	8689435	7038442.35	5926435	4800412.35	214.49	95.38 / 92.42
Cultivated commercial permanent orchards	3626973	2937848.13	3855005	3122554.05	228032	184705.92	6.29	92.18 / 95.29
Cultivated commercial permanent vines	1911159	1548038.79	2096791	1698400.71	185632	150361.92	9.71	91.61 / 97.26
Cultivated subsistence crops	22763294	18438268.14	22672521	18364742.01	-90773	-73526.13	-0.40	89.00 / 94.00
Settlements	31096545	25188201.45	32314218	26174516.58	1217673	986315.13	3.92	93.90 / 98.68
Wetlands	15706154	12721984.74	11398887	9233098.47	-4307267	-3488886.27	-27.42	88.07 / 91.18
Grasslands	298885099	242096930.19	286599705	232145761.05	-12285394	-9951169.14	-4.11	84.56 / 69.82
Mines	3193829	2587001.49	3655254	2960755.74	461425	373754.25	14.45	92.82 / 98.10
Waterbodies	24456512	19809774.72	22729092	18410564.52	-1727420	-1399210.20	-7.06	79.64 / 93.31
Bare Ground	154114261	124832551.41	145088148	117521399.88	-9026113	-7311151.53	-5.86	98.77 / 97.58
Degraded	14341471	11616591.51	10489566	8496548.46	-3851905	-3120043.05	-26.86	78.69 / 85.95
totals	*1387957286*	*1124245402*	*1388109113*	*1124368382*				*User / Producer*
								class accuracies

The percentage change results for all classes show very similar values in both the original 30 m and resampled 90 m datasets, which indicates that the comparison of the original 30 m datasets is not introducing any significant difference as a result of single-pixel anomalies. The 2013/14 land-cover mapping accuracies have been included in the tables to allow the change results to be assessed in terms of the class-mapping accuracies achieved, and the influence that this may have had on the reported class changes.

4.2 Provincial-level land-cover change results

The change statistics for each province are shown below. These have been generated from the original 30 m-resolution format data, and show regional trends in land-cover/land-use change over the approximately 24-year period between 1990 and 2013/14. The 2013/14 land-cover mapping accuracies have been included in tables 5 to 13 below to allow the provincial change results to be assessed in terms of the associated class-mapping accuracies.

Limpopo Province change based on the 30m pixels			*(change based on standardised areas)*					
	1990 Land Cover		**2014 Land Cover**		**Change from 1990 to 2014**			*Class mapping*
	Pixels	**Hectares**	**Pixels**	**Hectares**	**Pixels**	**Hectares**	**%**	*accuracy (2013)*
Indigenous Forest	439022	39511.98	512695	46142.55	73673	6630.57	16.78	72.6 / 94.64
Thicket /Dense bush	18813387	1693204.83	19466135	1751952.15	652748	58747.32	3.47	53.74 / 83.64
Woodlan/Open bush	59679073	5371116.57	69245654	6232108.86	9566581	860992.29	16.03	60.84 / 54.13
Low shrubland	3289562	296060.58	2712468	244122.12	-577094	-51938.46	-17.54	70.59 / 61.82
Plantations / Woodlots	1141021	102691.89	867962	78116.58	-273059	-24575.31	-23.93	89.3 / 94.35
Cultivated commercial annual crops non-pivot	7921472	712932.48	6317003	568530.27	-1604469	-144402.21	-20.25	91.91 / 99.54
Cultivated commercial annual crops pivot	870662	78359.58	1862126	167591.34	991464	89231.76	113.87	95.38 / 92.42
Cultivated commercial permanent orchards	865438	77889.42	1213977	109257.93	348539	31368.51	40.27	92.18 / 95.29
Cultivated commercial permanent vines	0	0.00	0	0.00	0	0.00	0.00	91.61 / 97.26
Cultivated subsistence crops	5179200	466128.00	4488068	403926.12	-691132	-62201.88	-13.34	89.00 / 94.00
Settlements (incl smallholdings)	3932762	353948.58	5066036	455943.24	1133274	101994.66	28.82	93.90 / 98.68
Wetlands	890913	80182.17	525103	47259.27	-365810	-32922.90	-41.06	88.07 / 91.18
Grasslands	30503379	2745304.11	21863009	1967670.81	-8640370	-777633.30	-28.33	84.56 / 69.82
Mines	316164	28454.76	312494	28124.46	-3670	-330.30	-1.16	92.82 / 98.10
Waterbodies	176402	15876.18	221105	19899.45	44703	4023.27	25.34	79.64 / 93.31
Bare Ground	107769	9699.21	792185	71296.65	684416	61597.44	635.08	98.77 / 97.58
Degraded	5766293	518966.37	4426499	398384.91	-1339794	-120581.46	-23.23	78.69 / 85.95
totals	*139892519*	*12590327*	*139892519*	*12590327*				*User / Producer*
								class accuracies

Mpumalanga Province change based on the 30m pixels			*(change based on standardised areas)*					
	1990 Land Cover		**2014 Land Cover**		**Change from 1990 to 2014**			*Class mapping*
	Pixels	**Hectares**	**Pixels**	**Hectares**	**Pixels**	**Hectares**	**%**	*accuracy (2013)*
Indigenous Forest	258220	23239.80	346439	31179.51	88219	7939.71	34.16	72.6 / 94.64
Thicket /Dense bush	7046448	634180.32	9615408	865386.72	2568960	231206.40	36.46	53.74 / 83.64
Woodlan/Open bush	15095444	1358589.96	14380996	1294289.64	-714448	-64300.32	-4.73	60.84 / 54.13
Low shrubland	856885	77119.65	416834	37515.06	-440051	-39604.59	-51.35	70.59 / 61.82
Plantations / Woodlots	8261786	743560.74	8358195	752237.55	96409	8676.81	1.17	89.3 / 94.35
Cultivated commercial annual crops non-pivot	14511612	1306045.08	12676152	1140853.68	-1835460	-165191.40	-12.65	91.91 / 99.54
Cultivated commercial annual crops pivot	176799	15911.91	640740	57666.60	463941	41754.69	262.41	95.38 / 92.42
Cultivated commercial permanent orchards	352775	31749.75	477595	42983.55	124820	11233.80	35.38	92.18 / 95.29
Cultivated commercial permanent vines	0	0.00	0	0.00	0	0.00	0.00	91.61 / 97.26
Cultivated subsistence crops	1020965	91886.85	742550	66829.50	-278415	-25057.35	-27.27	89.00 / 94.00
Settlements (incl smallholdings)	1987731	178895.79	2382966	214466.94	395235	35571.15	19.88	93.90 / 98.68
Wetlands	2641304	237717.36	2270547	204349.23	-370757	-33368.13	-14.04	88.07 / 91.18
Grasslands	31813622	2863225.98	31198853	2807896.77	-614769	-55329.21	-1.93	84.56 / 69.82
Mines	516604	46494.36	861892	77570.28	345288	31075.92	66.84	92.82 / 98.10
Waterbodies	456789	41111.01	508625	45776.25	51836	4665.24	11.35	79.64 / 93.31
Bare Ground	81686	7351.74	273093	24578.37	191407	17226.63	234.32	98.77 / 97.58
Degraded	136047	12244.23	63832	5744.88	-72215	-6499.35	-53.08	78.69 / 85.95
totals	*85214717*	*7669325*	*85214717*	*7669325*				*User / Producer*
								class accuracies

Gauteng Province change based on the 30m pixels			*(change based on standardised areas)*					
	1990 Land Cover		**2014 Land Cover**		**Change from 1990 to 2014**			*Class mapping*
	Pixels	**Hectares**	**Pixels**	**Hectares**	**Pixels**	**Hectares**	**%**	*accuracy (2013)*
Indigenous Forest	2	0.18	29	2.61	27	2.43	1350.00	72.6 / 94.64
Thicket /Dense bush	1064404	95796.36	1171881	105469.29	107477	9672.93	10.10	53.74 / 83.64
Woodland/Open bush	1811216	163009.44	2159919	194392.71	348703	31383.27	19.25	60.84 / 54.13
Low shrubland	232843	20955.87	88873	7998.57	-143970	-12957.30	-61.83	70.59 / 61.82
Plantations / Woodlots	472403	42516.27	296695	26702.55	-175708	-15813.72	-37.19	89.3 / 94.35
Cultivated commercial annual crops non-pivot	3897750	350797.50	3697032	332732.88	-200718	-18064.62	-5.15	91.91 / 99.54
Cultivated commercial annual crops pivot	68352	6151.68	223211	20088.99	154859	13937.31	226.56	95.38 / 92.42
Cultivated commercial permanent orchards	11483	1033.47	18527	1667.43	7044	633.96	61.34	92.18 / 95.29
Cultivated commercial permanent vines	0	0.00	0	0.00	0	0.00	0.00	91.61 / 97.26
Cultivated subsistence crops	30416	2737.44	13285	1195.65	-17131	-1541.79	-56.32	89.00 / 94.00
Settlements (incl smallholdings)	3473234	312591.06	3840546	345649.14	367312	33058.08	10.58	93.90 / 98.68
Wetlands	651038	58593.42	572043	51483.87	-78995	-7109.55	-12.13	88.07 / 91.18
Grasslands	6227097	560438.73	5946964	535226.76	-280133	-25211.97	-4.50	84.56 / 69.82
Mines	231305	20817.45	195821	17623.89	-35484	-3193.56	-15.34	92.82 / 98.10
Waterbodies	105313	9478.17	105983	9538.47	670	60.30	0.64	79.64 / 93.31
Bare Ground	12854	1156.86	22768	2049.12	9914	892.26	77.13	98.77 / 97.58
Degraded	106337	9570.33	42466	3821.94	-63871	-5748.39	-60.06	78.69 / 85.95
totals	*18396047*	*1655644*	*18396043*	*1655644*				*User / Producer*
								class accuracies

Free State Province change based on the 30m pixels			*(change based on standardised areas)*					
	1990 Land Cover		2014 Land Cover		Change from 1990 to 2014			*Class mapping*
	Pixels	Hectares	Pixels	Hectares	Pixels	Hectares	%	*accuracy (2013)*
Indigenous Forest	68057	6125.13	75559	6800.31	7502	675.18	11.02	72.6 / 94.64
Thicket /Dense bush	1303575	117321.75	1665474	149892.66	361899	32570.91	27.76	53.74 / 83.64
Woodlan/Open bush	1559397	140345.73	1255780	113020.20	-303617	-27325.53	-19.47	60.84 / 54.13
Low shrubland	24740213	2226619.17	36760959	3308486.31	12020746	1081867.14	48.59	70.59 / 61.82
Plantations / Woodlots	584008	52560.72	563687	50731.83	-20321	-1828.89	-3.48	89.3 / 94.35
Cultivated commercial annual crops non-pivot	42092634	3788337.06	39985067	3598656.03	-2107567	-189681.03	-5.01	91.91 / 99.54
Cultivated commercial annual crops pivot	306826	27614.34	1810827	162974.43	1504001	135360.09	490.18	95.38 / 92.42
Cultivated commercial permanent orchards	26126	2351.34	38406	3456.54	12280	1105.20	47.00	92.18 / 95.29
Cultivated commercial permanent vines	0	0.00	0	0.00	0	0.00	0.00	91.61 / 97.26
Cultivated subsistence crops	209381	18844.29	327142	29442.78	117761	10598.49	56.24	89.00 / 94.00
Settlements (incl smallholdings)	994363	89492.67	1147053	103234.77	152690	13742.10	15.36	93.90 / 98.68
Wetlands	4145335	373080.15	2500935	225084.15	-1644400	-147996.00	-39.67	88.07 / 91.18
Grasslands	65232798	5870951.82	55751383	5017624.47	-9481415	-853327.35	-14.53	84.56 / 69.82
Mines	268735	24186.15	265584	23902.56	-3151	-283.59	-1.17	92.82 / 98.10
Waterbodies	1780207	160218.63	1085829	97724.61	-694378	-62494.02	-39.01	79.64 / 93.31
Bare Ground	416832	37514.88	920003	82800.27	503171	45285.39	120.71	98.77 / 97.58
Degraded	499721	44974.89	74520	6706.80	-425201	-38268.09	-85.09	78.69 / 85.95
totals	*144228208*	*12980539*	*144228208*	*12980539*				*User / Producer*
								class accuracies

N.West Province change based on the 30m pixels			*(change based on standardised areas)*					
	1990 Land Cover		2014 Land Cover		Change from 1990 to 2014			*Class mapping*
	Pixels	Hectares	Pixels	Hectares	Pixels	Hectares	%	*accuracy (2013)*
Indigenous Forest	8124	731.16	10737	966.33	2613	235.17	32.16	72.6 / 94.64
Thicket /Dense bush	3462931	311663.79	2577328	231959.52	-885603	-79704.27	-25.57	53.74 / 83.64
Woodlan/Open bush	17937089	1614338.01	19385150	1744663.50	1448061	130325.49	8.07	60.84 / 54.13
Low shrubland	30934272	2784084.48	33918389	3052655.01	2984117	268570.53	9.65	70.59 / 61.82
Plantations / Woodlots	218282	19645.38	188391	16955.19	-29891	-2690.19	-13.69	89.3 / 94.35
Cultivated commercial annual crops non-pivot	24511201	2206008.09	21195525	1907597.25	-3315676	-298410.84	-13.53	91.91 / 99.54
Cultivated commercial annual crops pivot	274098	24668.82	958619	86275.71	684521	61606.89	249.74	95.38 / 92.42
Cultivated commercial permanent orchards	58982	5308.38	59651	5368.59	669	60.21	1.13	92.18 / 95.29
Cultivated commercial permanent vines	0	0.00	0	0.00	0	0.00	0.00	91.61 / 97.26
Cultivated subsistence crops	2977197	267947.73	2545552	229099.68	-431645	-38848.05	-14.50	89.00 / 94.00
Settlements (incl smallholdings)	2121938	190974.42	2407802	216702.18	285864	25727.76	13.47	93.90 / 98.68
Wetlands	1061447	95530.23	405520	36496.80	-655927	-59033.43	-61.80	88.07 / 91.18
Grasslands	32352041	2911683.69	28742737	2586846.33	-3609304	-324837.36	-11.16	84.56 / 69.82
Mines	533282	47995.38	668719	60184.71	135437	12189.33	25.40	92.82 / 98.10
Waterbodies	365068	32856.12	284141	25572.69	-80927	-7283.43	-22.17	79.64 / 93.31
Bare Ground	21952	1975.68	487730	43895.70	465778	41920.02	2121.80	98.77 / 97.58
Degraded	1567497	141074.73	4569410	411246.90	3001913	270172.17	191.51	78.69 / 85.95
totals	*118405401*	*10656486*	*118405401*	*10656486*				*User / Producer*
								class accuracies

N.Cape Province change based on the 30m pixels			*(change based on standardised areas)*					
	1990 Land Cover		2014 Land Cover		Change from 1990 to 2014			*Class mapping*
	Pixels	Hectares	Pixels	Hectares	Pixels	Hectares	%	*accuracy (2013)*
Indigenous Forest	0	0.00	0	0.00	0	0.00	0.00	72.6 / 94.64
Thicket /Dense bush	3366213	302959.17	2620780	235870.20	-745433	-67088.97	-22.14	53.74 / 83.64
Woodlan/Open bush	12906026	1161542.34	12308962	1107806.58	-597064	-53735.76	-4.63	60.84 / 54.13
Low shrubland	273284146	24595573.14	266589150	23993023.50	-6694996	-602549.64	-2.45	70.59 / 61.82
Plantations / Woodlots	16021	1441.89	10553	949.77	-5468	-492.12	-34.13	89.3 / 94.35
Cultivated commercial annual crops non-pivot	1878099	169028.91	1524185	137176.65	-353914	-31852.26	-18.84	91.91 / 99.54
Cultivated commercial annual crops pivot	487327	43859.43	1034169	93075.21	546842	49215.78	112.21	95.38 / 92.42
Cultivated commercial permanent orchards	64495	5804.55	82917	7462.53	18422	1657.98	28.56	92.18 / 95.29
Cultivated commercial permanent vines	325303	29277.27	358636	32277.24	33333	2999.97	10.25	91.61 / 97.26
Cultivated subsistence crops	48383	4354.47	43488	3913.92	-4895	-440.55	-10.12	89.00 / 94.00
Settlements (incl smallholdings)	505185	45466.65	595935	53634.15	90750	8167.50	17.96	93.90 / 98.68
Wetlands	1383159	124484.31	508456	45761.04	-874703	-78723.27	-63.24	88.07 / 91.18
Grasslands	16278690	1465082.10	22292088	2006287.92	6013398	541205.82	36.94	84.56 / 69.82
Mines	1150633	103556.97	1128435	101559.15	-22198	-1997.82	-1.93	92.82 / 98.10
Waterbodies	1484259	133583.31	597399	53765.91	-886860	-79817.40	-59.75	79.64 / 93.31
Bare Ground	102786035	9250743.15	107782286	9700405.74	4996251	449662.59	4.86	98.77 / 97.58
Degraded	1516457	136481.13	2992	269.28	-1513465	-136211.85	-99.80	78.69 / 85.95
totals	*417480431*	*37573239*	*417480431*	*37573239*				*User / Producer*
								class accuracies

W.Cape Province change based on the 30m pixels			(change based on standardised areas)					
	1990 Land Cover		2014 Land Cover		Change from 1990 to 2014			Class mapping
	Pixels	Hectares	Pixels	Hectares	Pixels	Hectares	%	accuracy (2013)
Indigenous Forest	613558	55220.22	620891	55880.19	7333	659.97	1.20	72.6 / 94.64
Thicket /Dense bush	6566621	590995.89	8837553	795379.77	2270932	204383.88	34.58	53.74 / 83.64
Woodlan/Open bush	4529692	407672.28	5983259	538493.31	1453567	130821.03	32.09	60.84 / 54.13
Low shrubland	68281558	6145340.22	73218655	6589678.95	4937097	444338.73	7.23	70.59 / 61.82
Plantations / Woodlots	1335352	120181.68	902534	81228.06	-432818	-38953.62	-32.41	89.3 / 94.35
Cultivated commercial annual crops non-pivot	18774280	1689685.20	18150014	1633501.26	-624266	-56183.94	-3.33	91.91 / 99.54
Cultivated commercial annual crops pivot	209325	18839.25	816599	73493.91	607274	54654.66	290.11	95.38 / 92.42
Cultivated commercial permanent orchards	1182748	106447.32	1158901	104301.09	-23847	-2146.23	-2.02	92.18 / 95.29
Cultivated commercial permanent vines	1478633	133076.97	1738155	156433.95	259522	23356.98	17.55	91.61 / 97.26
Cultivated subsistence crops	11463	1031.67	8049	724.41	-3414	-307.26	-29.78	89.00 / 94.00
Settlements (incl smallholdings)	1152346	103711.14	1296109	116649.81	143763	12938.67	12.48	93.90 / 98.68
Wetlands	1597375	143763.75	1201787	108160.83	-395588	-35602.92	-24.76	88.07 / 91.18
Grasslands	7856963	707126.67	5774440	519699.60	-2082523	-187427.07	-26.51	84.56 / 69.82
Mines	68726	6185.34	103314	9298.26	34588	3112.92	50.33	92.82 / 98.10
Waterbodies	624675	56220.75	632120	56890.80	7445	670.05	1.19	79.64 / 93.31
Bare Ground	30290215	2726119.35	24439993	2199599.37	-5850222	-526519.98	-19.31	98.77 / 97.58
Degraded	578680	52081.20	269837	24285.33	-308843	-27795.87	-53.37	78.69 / 85.95
totals	145152210	13063699	145152210	13063699				User / Producer
								class accuracies

E.Cape Province change based on the 30m pixels			(change based on standardised areas)					
	1990 Land Cover		2014 Land Cover		Change from 1990 to 2014			Class mapping
	Pixels	Hectares	Pixels	Hectares	Pixels	Hectares	%	accuracy (2013)
Indigenous Forest	1228483	110563.47	1447897	130310.73	219414	19747.26	17.86	72.6 / 94.64
Thicket /Dense bush	13359572	1202361.48	23983177	2158485.93	10623605	956124.45	79.52	53.74 / 83.64
Woodland/Open bush	2899673	260970.57	6257286	563155.74	3357613	302185.17	115.79	60.84 / 54.13
Low shrubland	49812767	4483149.03	45612154	4105093.86	-4200613	-378055.17	-8.43	70.59 / 61.82
Plantations / Woodlots	1700089	153008.01	1717407	154566.63	17318	1558.62	1.02	89.3 / 94.35
Cultivated commercial annual crops non-pivot	6036456	543281.04	5414653	487318.77	-621803	-55962.27	-10.30	91.91 / 99.54
Cultivated commercial annual crops pivot	112612	10135.08	578446	52060.14	465834	41925.06	413.66	95.38 / 92.42
Cultivated commercial permanent orchards	646710	58203.90	529148	47623.32	-117562	-10580.58	-18.18	92.18 / 95.29
Cultivated commercial permanent vines	0	0.00	0	0.00	0	0.00	0.00	91.61 / 97.26
Cultivated subsistence crops	8014517	721306.53	8524339	767190.51	509822	45883.98	6.36	89.00 / 94.00
Settlements (incl smallholdings)	7024149	632173.41	6818491	613664.19	-205658	-18509.22	-2.93	93.90 / 98.68
Wetlands	2429514	218656.26	1696628	152696.52	-732886	-65959.74	-30.17	88.07 / 91.18
Grasslands	71195882	6407629.38	77548852	6979396.68	6352970	571767.30	8.92	84.56 / 69.82
Mines	83262	7493.58	44781	4030.29	-38481	-3463.29	-46.22	92.82 / 98.10
Waterbodies	710949	63985.41	689420	62047.80	-21529	-1937.61	-3.03	79.64 / 93.31
Bare Ground	17044376	1533993.84	6305249	567472.41	-10739127	-966521.43	-63.01	98.77 / 97.58
Degraded	5466225	491960.25	597308	53757.72	-4868917	-438202.53	-89.07	78.69 / 85.95
totals	187765236	16898871	187765236	16898871				User / Producer
								class accuracies

KZN Province change based on the 30m pixels			(change based on standardised areas)					
	1990 Land Cover		2014 Land Cover		Change from 1990 to 2014			Class mapping
	Pixels	Hectares	Pixels	Hectares	Pixels	Hectares	%	accuracy (2013)
Indigenous Forest	1562303	140607.27	1737698	156392.82	175395	15785.55	11.23	72.6 / 94.64
Thicket /Dense bush	18224568	1640211.12	21644486	1948003.74	3419918	307792.62	18.77	53.74 / 83.64
Woodland/Open bush	5539515	498556.35	6679261	601133.49	1139746	102577.14	20.57	60.84 / 54.13
Low shrubland	793855	71446.95	421930	37973.70	-371925	-33473.25	-46.85	70.59 / 61.82
Plantations / Woodlots	7626157	686354.13	7898486	710863.74	272329	24509.61	3.57	89.3 / 94.35
Cultivated commercial annual crops non-pivot	8014310	721287.90	8947473	805272.57	933163	83984.67	11.64	91.91 / 99.54
Cultivated commercial annual crops pivot	208201	18738.09	752526	67727.34	544325	48989.25	261.44	95.38 / 92.42
Cultivated commercial permanent orchards	275452	24790.68	275947	24835.23	495	44.55	0.18	92.18 / 95.29
Cultivated commercial permanent vines	0	0.00	0	0.00	0	0.00	0.00	91.61 / 97.26
Cultivated subsistence crops	4556007	410040.63	5935919	534232.71	1379912	124192.08	30.29	89.00 / 94.00
Settlements (incl smallholdings)	9285448	835690.32	8760355	788431.95	-525093	-47258.37	-5.66	93.90 / 98.68
Wetlands	2059826	185384.34	1653356	148802.04	-406470	-36582.30	-19.73	88.07 / 91.18
Grasslands	43293284	3896395.56	36954844	3325935.96	-6338440	-570459.60	-14.64	84.56 / 69.82
Mines	59789	5381.01	58698	5282.82	-1091	-98.19	-1.82	92.82 / 98.10
Waterbodies	2381049	214294.41	2233886	201049.74	-147163	-13244.67	-6.18	79.64 / 93.31
Bare Ground	377880	34009.20	771169	69405.21	393289	35396.01	104.08	98.77 / 97.58
Degraded	909550	81859.50	441160	39704.40	-468390	-42155.10	-51.50	78.69 / 85.95
totals	105167194	9465047	105167194	9465047				User / Producer
								class accuracies

4.3 Inter-class land-cover change results

The tables below illustrate the inter-class changes between 1990 and 2013/14, and allow an interpretation of (a) what the 1990 extent of land-cover class X has changed to in 2013/14; or (b) what the current extent of class Y in 2013/14 was, in terms of 1990 land-cover characteristics. These statistics are based on the fact that a 17-class land-cover legend in both 1990 and 2013/14 means that there are 289 possible solutions to what a 1990 class can become in 2013/14. Interpretation of these inter-class changes should again be assessed in terms of the associated class mapping accuracies. Note that the table statistics are based on the original 30 m-resolution datasets.

Table 14 below shows the numeric codes used to represent all 289 possible inter-class changes between 1990 and 2013/14.

1990 to 2013 Land Cover Change Matrix

CHANGE MAP CODES

				2013																
				Indigenous Forest	Thicket/dense bush	Woodland/open bush	Low shrubland	Plantations/woodlots	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodies	Bare ground	Degraded
	ORIGINAL VALUE		RECODE VALUE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1990	1	Indigenous Forest	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	2	Thicket/dense bush	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
	3	Woodland/open bush	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
	4	Low shrubland	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69
	5	Plantations/woodlots	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
	6	Cultivated commercial annual: non-pivot	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
	7	Cultivated commercial annual: pivot	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
	8	Cultivated commercial permanent orchards	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137
	9	Cultivated commercial permanent vines	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154
	10	Cultivated subsistence crops	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171
	11	Settlements	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188
	12	Wetlands	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205
	13	Grasslands	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222
	14	Mines	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239
	15	Waterbodies	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256
	16	Bare ground	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273
	17	Degraded	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290

Table 15 below provides the definition of each of the 289 inter-class changes in terms of what 1990 class changed to what 2013/14 class, together with the number of 30 m-resolution pixel (not hectare) occurrences.

Change Map Codes	1990 Class	2013 Class	Class names in Change Dataset	Histogram Values in Change Dataset
2	Indigenous Forest	Indigenous Forest	Indigenous Forest-NO_CHANGE	3425197
3	Indigenous Forest	Thicket/dense bush	Indigenous Forest-CHANGE-TO-Thicket/dense bush	496041
4	Indigenous Forest	Woodland/open bush	Indigenous Forest-CHANGE-TO-Woodland/open bush	87036
5	Indigenous Forest	Low shrubland	Indigenous Forest-CHANGE-TO-Low shrubland	15980
6	Indigenous Forest	Plantations/woodlots	Indigenous Forest-CHANGE-TO-Plantations/woodlots	10211
7	Indigenous Forest	Cultivated commercial annual: non-pivot	Indigenous Forest-CHANGE-TO-Cultivated commercial annual: non-pivot	9394
8	Indigenous Forest	Cultivated commercial annual: pivot	Indigenous Forest-CHANGE-TO-Cultivated commercial annual: pivot	157
9	Indigenous Forest	Cultivated commercial permanent orchards	Indigenous Forest-CHANGE-TO-Cultivated commercial permanent orchards	7518
10	Indigenous Forest	Cultivated commercial permanent vines	Indigenous Forest-CHANGE-TO-Cultivated commercial permanent vines	4
11	Indigenous Forest	Cultivated subsistence crops	Indigenous Forest-CHANGE-TO-Cultivated subsistence crops	10813
12	Indigenous Forest	Settlements	Indigenous Forest-CHANGE-TO-Settlements	22459
13	Indigenous Forest	Wetlands	Indigenous Forest-CHANGE-TO-Wetlands	15482
14	Indigenous Forest	Grasslands	Indigenous Forest-CHANGE-TO-Grasslands	74806
15	Indigenous Forest	Mines	Indigenous Forest-CHANGE-TO-Mines	2937
16	Indigenous Forest	Waterbodies	Indigenous Forest-CHANGE-TO-Waterbodies	387
17	Indigenous Forest	Bare ground	Indigenous Forest-CHANGE-TO-Bare ground	6096
18	Indigenous Forest	Degraded	Indigenous Forest-CHANGE-TO-Degraded	490
19	Indigenous Forest	Indigenous Forest	Indigenous Forest-CHANGE-TO-Indigenous Forest	535829
20	Thicket/dense bush	Thicket/dense bush	Thicket/dense bush-NO_CHANGE	41489926
21	Thicket/dense bush	Woodland/open bush	Thicket/dense bush-CHANGE-TO-Woodland/open bush	14380109
22	Thicket/dense bush	Low shrubland	Thicket/dense bush-CHANGE-TO-Low shrubland	4262575
23	Thicket/dense bush	Plantations/woodlots	Thicket/dense bush-CHANGE-TO-Plantations/woodlots	124836
24	Thicket/dense bush	Cultivated commercial annual: non-pivot	Thicket/dense bush-CHANGE-TO-Cultivated commercial annual: non-pivot	1127386
25	Thicket/dense bush	Cultivated commercial annual: pivot	Thicket/dense bush-CHANGE-TO-Cultivated commercial annual: pivot	106823
26	Thicket/dense bush	Cultivated commercial permanent orchards	Thicket/dense bush-CHANGE-TO-Cultivated commercial permanent orchards	261667
27	Thicket/dense bush	Cultivated commercial permanent vines	Thicket/dense bush-CHANGE-TO-Cultivated commercial permanent vines	42843
28	Thicket/dense bush	Cultivated subsistence crops	Thicket/dense bush-CHANGE-TO-Cultivated subsistence crops	570577
29	Thicket/dense bush	Settlements	Thicket/dense bush-CHANGE-TO-Settlements	525574
30	Thicket/dense bush	Wetlands	Thicket/dense bush-CHANGE-TO-Wetlands	461453
31	Thicket/dense bush	Grasslands	Thicket/dense bush-CHANGE-TO-Grasslands	9379956
32	Thicket/dense bush	Mines	Thicket/dense bush-CHANGE-TO-Mines	95493
33	Thicket/dense bush	Waterbodies	Thicket/dense bush-CHANGE-TO-Waterbodies	121670
34	Thicket/dense bush	Bare ground	Thicket/dense bush-CHANGE-TO-Bare ground	243213
35	Thicket/dense bush	Degraded	Thicket/dense bush-CHANGE-TO-Degraded	114337
36	Woodland/open bush	Indigenous Forest	Woodland/open bush-CHANGE-TO-Indigenous Forest	112400
37	Woodland/open bush	Thicket/dense bush	Woodland/open bush-CHANGE-TO-Thicket/dense bush	16947193
38	Woodland/open bush	Woodland/open bush	Woodland/open bush-NO_CHANGE	61875159
39	Woodland/open bush	Low shrubland	Woodland/open bush-CHANGE-TO-Low shrubland	14546501
40	Woodland/open bush	Plantations/woodlots	Woodland/open bush-CHANGE-TO-Plantations/woodlots	403028
41	Woodland/open bush	Cultivated commercial annual: non-pivot	Woodland/open bush-CHANGE-TO-Cultivated commercial annual: non-pivot	1072568
42	Woodland/open bush	Cultivated commercial annual: pivot	Woodland/open bush-CHANGE-TO-Cultivated commercial annual: pivot	380461
43	Woodland/open bush	Cultivated commercial permanent orchards	Woodland/open bush-CHANGE-TO-Cultivated commercial permanent orchards	129177
44	Woodland/open bush	Cultivated commercial permanent vines	Woodland/open bush-CHANGE-TO-Cultivated commercial permanent vines	18826
45	Woodland/open bush	Cultivated subsistence crops	Woodland/open bush-CHANGE-TO-Cultivated subsistence crops	792577
46	Woodland/open bush	Settlements	Woodland/open bush-CHANGE-TO-Settlements	902541
47	Woodland/open bush	Wetlands	Woodland/open bush-CHANGE-TO-Wetlands	256720
48	Woodland/open bush	Grasslands	Woodland/open bush-CHANGE-TO-Grasslands	20502381
49	Woodland/open bush	Mines	Woodland/open bush-CHANGE-TO-Mines	170431
50	Woodland/open bush	Waterbodies	Woodland/open bush-CHANGE-TO-Waterbodies	131075
51	Woodland/open bush	Bare ground	Woodland/open bush-CHANGE-TO-Bare ground	1795439
52	Woodland/open bush	Degraded	Woodland/open bush-CHANGE-TO-Degraded	2272812
53	Low shrubland	Indigenous Forest	Low shrubland-CHANGE-TO-Indigenous Forest	54894
54	Low shrubland	Thicket/dense bush	Low shrubland-CHANGE-TO-Thicket/dense bush	6698306
55	Low shrubland	Woodland/open bush	Low shrubland-CHANGE-TO-Woodland/open bush	15910778
56	Low shrubland	Low shrubland	Low shrubland-NO_CHANGE	353889933
57	Low shrubland	Plantations/woodlots	Low shrubland-CHANGE-TO-Plantations/woodlots	136003
58	Low shrubland	Cultivated commercial annual: non-pivot	Low shrubland-CHANGE-TO-Cultivated commercial annual: non-pivot	2551230
59	Low shrubland	Cultivated commercial annual: pivot	Low shrubland-CHANGE-TO-Cultivated commercial annual: pivot	713514
60	Low shrubland	Cultivated commercial permanent orchards	Low shrubland-CHANGE-TO-Cultivated commercial permanent orchards	153208
61	Low shrubland	Cultivated commercial permanent vines	Low shrubland-CHANGE-TO-Cultivated commercial permanent vines	154873
62	Low shrubland	Cultivated subsistence crops	Low shrubland-CHANGE-TO-Cultivated subsistence crops	107219
63	Low shrubland	Settlements	Low shrubland-CHANGE-TO-Settlements	631219
64	Low shrubland	Wetlands	Low shrubland-CHANGE-TO-Wetlands	393885
65	Low shrubland	Grasslands	Low shrubland-CHANGE-TO-Grasslands	46144882
66	Low shrubland	Mines	Low shrubland-CHANGE-TO-Mines	87795
67	Low shrubland	Waterbodies	Low shrubland-CHANGE-TO-Waterbodies	140265
68	Low shrubland	Bare ground	Low shrubland-CHANGE-TO-Bare ground	28132624
69	Low shrubland	Degraded	Low shrubland-CHANGE-TO-Degraded	1208540
70	Plantations/woodlots	Indigenous Forest	Plantations/woodlots-CHANGE-TO-Indigenous Forest	297592
71	Plantations/woodlots	Thicket/dense bush	Plantations/woodlots-CHANGE-TO-Thicket/dense bush	1511452
72	Plantations/woodlots	Woodland/open bush	Plantations/woodlots-CHANGE-TO-Woodland/open bush	512937
73	Plantations/woodlots	Low shrubland	Plantations/woodlots-CHANGE-TO-Low shrubland	270400
74	Plantations/woodlots	Plantations/woodlots	Plantations/woodlots-NO_CHANGE	16403751
75	Plantations/woodlots	Cultivated commercial annual: non-pivot	Plantations/woodlots-CHANGE-TO-Cultivated commercial annual: non-pivot	285536
76	Plantations/woodlots	Cultivated commercial annual: pivot	Plantations/woodlots-CHANGE-TO-Cultivated commercial annual: pivot	6562
77	Plantations/woodlots	Cultivated commercial permanent orchards	Plantations/woodlots-CHANGE-TO-Cultivated commercial permanent orchards	70818
78	Plantations/woodlots	Cultivated commercial permanent vines	Plantations/woodlots-CHANGE-TO-Cultivated commercial permanent vines	8215
79	Plantations/woodlots	Cultivated subsistence crops	Plantations/woodlots-CHANGE-TO-Cultivated subsistence crops	26000
80	Plantations/woodlots	Settlements	Plantations/woodlots-CHANGE-TO-Settlements	306544
81	Plantations/woodlots	Wetlands	Plantations/woodlots-CHANGE-TO-Wetlands	171567
82	Plantations/woodlots	Grasslands	Plantations/woodlots-CHANGE-TO-Grasslands	1420820
83	Plantations/woodlots	Mines	Plantations/woodlots-CHANGE-TO-Mines	39850
84	Plantations/woodlots	Waterbodies	Plantations/woodlots-CHANGE-TO-Waterbodies	15341
85	Plantations/woodlots	Bare ground	Plantations/woodlots-CHANGE-TO-Bare ground	10488
86	Plantations/woodlots	Degraded	Plantations/woodlots-CHANGE-TO-Degraded	6899
87	Cultivated commercial annual: non-pivot	Indigenous Forest	Cultivated commercial annual: non-pivot-CHANGE-TO-Indigenous Forest	8055
88	Cultivated commercial annual: non-pivot	Thicket/dense bush	Cultivated commercial annual: non-pivot-CHANGE-TO-Thicket/dense bush	1037970
89	Cultivated commercial annual: non-pivot	Woodland/open bush	Cultivated commercial annual: non-pivot-CHANGE-TO-Woodland/open bush	2470525
90	Cultivated commercial annual: non-pivot	Low shrubland	Cultivated commercial annual: non-pivot-CHANGE-TO-Low shrubland	4441322
91	Cultivated commercial annual: non-pivot	Plantations/woodlots	Cultivated commercial annual: non-pivot-CHANGE-TO-Plantations/woodlots	325617
92	Cultivated commercial annual: non-pivot	Cultivated commercial annual: non-pivot	Cultivated commercial annual: non-pivot-NO_CHANGE	103779265

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93	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot	Cultivated commercial annual: non-pivot-CHANGE-TO-Cultivated commercial annual: pivot	4326260
94	Cultivated commercial annual: non-pivot	Cultivated commercial permanent orchards	Cultivated commercial annual: non-pivot-CHANGE-TO-Cultivated commercial permanent orchards	352492
95	Cultivated commercial annual: non-pivot	Cultivated commercial permanent vines	Cultivated commercial annual: non-pivot-CHANGE-TO-Cultivated commercial permanent vines	96170
96	Cultivated commercial annual: non-pivot	Cultivated subsistence crops	Cultivated commercial annual: non-pivot-CHANGE-TO-Cultivated subsistence crops	191151
97	Cultivated commercial annual: non-pivot	Settlements	Cultivated commercial annual: non-pivot-CHANGE-TO-Settlements	308848
98	Cultivated commercial annual: non-pivot	Wetlands	Cultivated commercial annual: non-pivot-CHANGE-TO-Wetlands	398645
99	Cultivated commercial annual: non-pivot	Grasslands	Cultivated commercial annual: non-pivot-CHANGE-TO-Grasslands	8998529
100	Cultivated commercial annual: non-pivot	Mines	Cultivated commercial annual: non-pivot-CHANGE-TO-Mines	415666
101	Cultivated commercial annual: non-pivot	Waterbodies	Cultivated commercial annual: non-pivot-CHANGE-TO-Waterbodies	24353
102	Cultivated commercial annual: non-pivot	Bare ground	Cultivated commercial annual: non-pivot-CHANGE-TO-Bare ground	113120
103	Cultivated commercial annual: non-pivot	Degraded	Cultivated commercial annual: non-pivot-CHANGE-TO-Degraded	340494
104	Cultivated commercial annual: pivot	Indigenous Forest	Cultivated commercial annual: pivot-CHANGE-TO-Indigenous Forest	39
105	Cultivated commercial annual: pivot	Thicket/dense bush	Cultivated commercial annual: pivot-CHANGE-TO-Thicket/dense bush	31372
106	Cultivated commercial annual: pivot	Woodland/open bush	Cultivated commercial annual: pivot-CHANGE-TO-Woodland/open bush	64179
107	Cultivated commercial annual: pivot	Low shrubland	Cultivated commercial annual: pivot-CHANGE-TO-Low shrubland	31680
108	Cultivated commercial annual: pivot	Plantations/woodlots	Cultivated commercial annual: pivot-CHANGE-TO-Plantations/woodlots	1474
109	Cultivated commercial annual: pivot	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot-CHANGE-TO-Cultivated commercial annual: non-pivot	276629
110	Cultivated commercial annual: pivot	Cultivated commercial annual: pivot	Cultivated commercial annual: pivot-NO_CHANGE	2165075
111	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards	Cultivated commercial annual: pivot-CHANGE-TO-Cultivated commercial permanent orchards	38822
112	Cultivated commercial annual: pivot	Cultivated commercial permanent vines	Cultivated commercial annual: pivot-CHANGE-TO-Cultivated commercial permanent vines	10317
113	Cultivated commercial annual: pivot	Cultivated subsistence crops	Cultivated commercial annual: pivot-CHANGE-TO-Cultivated subsistence crops	3895
114	Cultivated commercial annual: pivot	Settlements	Cultivated commercial annual: pivot-CHANGE-TO-Settlements	10501
115	Cultivated commercial annual: pivot	Wetlands	Cultivated commercial annual: pivot-CHANGE-TO-Wetlands	5044
116	Cultivated commercial annual: pivot	Grasslands	Cultivated commercial annual: pivot-CHANGE-TO-Grasslands	59212
117	Cultivated commercial annual: pivot	Mines	Cultivated commercial annual: pivot-CHANGE-TO-Mines	7278
118	Cultivated commercial annual: pivot	Waterbodies	Cultivated commercial annual: pivot-CHANGE-TO-Waterbodies	485
119	Cultivated commercial annual: pivot	Bare ground	Cultivated commercial annual: pivot-CHANGE-TO-Bare ground	1835
120	Cultivated commercial annual: pivot	Degraded	Cultivated commercial annual: pivot-CHANGE-TO-Degraded	6258
121	Cultivated commercial permanent orchards	Indigenous Forest	Cultivated commercial permanent orchards-CHANGE-TO-Indigenous Forest	1629
122	Cultivated commercial permanent orchards	Thicket/dense bush	Cultivated commercial permanent orchards-CHANGE-TO-Thicket/dense bush	164211
123	Cultivated commercial permanent orchards	Woodland/open bush	Cultivated commercial permanent orchards-CHANGE-TO-Woodland/open bush	94690
124	Cultivated commercial permanent orchards	Low shrubland	Cultivated commercial permanent orchards-CHANGE-TO-Low shrubland	66696
125	Cultivated commercial permanent orchards	Plantations/woodlots	Cultivated commercial permanent orchards-CHANGE-TO-Plantations/woodlots	17875
126	Cultivated commercial permanent orchards	Cultivated commercial annual: non-pivot	Cultivated commercial permanent orchards-CHANGE-TO-Cultivated commercial annual: non-pivot	200708
127	Cultivated commercial permanent orchards	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards-CHANGE-TO-Cultivated commercial annual: pivot	40679
128	Cultivated commercial permanent orchards	Cultivated commercial permanent orchards	Cultivated commercial permanent orchards-NO_CHANGE	2601967
129	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Cultivated commercial permanent orchards-CHANGE-TO-Cultivated commercial permanent vines	112248
130	Cultivated commercial permanent orchards	Cultivated subsistence crops	Cultivated commercial permanent orchards-CHANGE-TO-Cultivated subsistence crops	44868
131	Cultivated commercial permanent orchards	Settlements	Cultivated commercial permanent orchards-CHANGE-TO-Settlements	11874
132	Cultivated commercial permanent orchards	Wetlands	Cultivated commercial permanent orchards-CHANGE-TO-Wetlands	10464
133	Cultivated commercial permanent orchards	Grasslands	Cultivated commercial permanent orchards-CHANGE-TO-Grasslands	109016
134	Cultivated commercial permanent orchards	Mines	Cultivated commercial permanent orchards-CHANGE-TO-Mines	644
135	Cultivated commercial permanent orchards	Waterbodies	Cultivated commercial permanent orchards-CHANGE-TO-Waterbodies	1293
136	Cultivated commercial permanent orchards	Bare ground	Cultivated commercial permanent orchards-CHANGE-TO-Bare ground	1976
137	Cultivated commercial permanent orchards	Degraded	Cultivated commercial permanent orchards-CHANGE-TO-Degraded	3291
138	Cultivated commercial permanent vines	Indigenous Forest	Cultivated commercial permanent vines-CHANGE-TO-Indigenous Forest	2
139	Cultivated commercial permanent vines	Thicket/dense bush	Cultivated commercial permanent vines-CHANGE-TO-Thicket/dense bush	56336
140	Cultivated commercial permanent vines	Woodland/open bush	Cultivated commercial permanent vines-CHANGE-TO-Woodland/open bush	6175
141	Cultivated commercial permanent vines	Low shrubland	Cultivated commercial permanent vines-CHANGE-TO-Low shrubland	59039
142	Cultivated commercial permanent vines	Plantations/woodlots	Cultivated commercial permanent vines-CHANGE-TO-Plantations/woodlots	2146
143	Cultivated commercial permanent vines	Cultivated commercial annual: non-pivot	Cultivated commercial permanent vines-CHANGE-TO-Cultivated commercial annual: non-pivot	32272
144	Cultivated commercial permanent vines	Cultivated commercial annual: pivot	Cultivated commercial permanent vines-CHANGE-TO-Cultivated commercial annual: pivot	6516
145	Cultivated commercial permanent vines	Cultivated commercial permanent orchards	Cultivated commercial permanent vines-CHANGE-TO-Cultivated commercial permanent orchards	38015
146	Cultivated commercial permanent vines	Cultivated commercial permanent vines	Cultivated commercial permanent vines-NO_CHANGE	1569751
147	Cultivated commercial permanent vines	Cultivated subsistence crops	Cultivated commercial permanent vines-CHANGE-TO-Cultivated subsistence crops	0
148	Cultivated commercial permanent vines	Settlements	Cultivated commercial permanent vines-CHANGE-TO-Settlements	6140
149	Cultivated commercial permanent vines	Wetlands	Cultivated commercial permanent vines-CHANGE-TO-Wetlands	7576
150	Cultivated commercial permanent vines	Grasslands	Cultivated commercial permanent vines-CHANGE-TO-Grasslands	16097
151	Cultivated commercial permanent vines	Mines	Cultivated commercial permanent vines-CHANGE-TO-Mines	33
152	Cultivated commercial permanent vines	Waterbodies	Cultivated commercial permanent vines-CHANGE-TO-Waterbodies	1787
153	Cultivated commercial permanent vines	Bare ground	Cultivated commercial permanent vines-CHANGE-TO-Bare ground	1924
154	Cultivated commercial permanent vines	Degraded	Cultivated commercial permanent vines-CHANGE-TO-Degraded	127
155	Cultivated subsistence crops	Indigenous Forest	Cultivated subsistence crops-CHANGE-TO-Indigenous Forest	3000
156	Cultivated subsistence crops	Thicket/dense bush	Cultivated subsistence crops-CHANGE-TO-Thicket/dense bush	926626
157	Cultivated subsistence crops	Woodland/open bush	Cultivated subsistence crops-CHANGE-TO-Woodland/open bush	2005372
158	Cultivated subsistence crops	Low shrubland	Cultivated subsistence crops-CHANGE-TO-Low shrubland	150274
159	Cultivated subsistence crops	Plantations/woodlots	Cultivated subsistence crops-CHANGE-TO-Plantations/woodlots	21873
160	Cultivated subsistence crops	Cultivated commercial annual: non-pivot	Cultivated subsistence crops-CHANGE-TO-Cultivated commercial annual: non-pivot	501104
161	Cultivated subsistence crops	Cultivated commercial annual: pivot	Cultivated subsistence crops-CHANGE-TO-Cultivated commercial annual: pivot	20097
162	Cultivated subsistence crops	Cultivated commercial permanent orchards	Cultivated subsistence crops-CHANGE-TO-Cultivated commercial permanent orchards	30839
163	Cultivated subsistence crops	Cultivated commercial permanent vines	Cultivated subsistence crops-CHANGE-TO-Cultivated commercial permanent vines	3013
164	Cultivated subsistence crops	Cultivated subsistence crops	Cultivated subsistence crops-NO_CHANGE	17116412
165	Cultivated subsistence crops	Settlements	Cultivated subsistence crops-CHANGE-TO-Settlements	96593
166	Cultivated subsistence crops	Wetlands	Cultivated subsistence crops-CHANGE-TO-Wetlands	15456
167	Cultivated subsistence crops	Grasslands	Cultivated subsistence crops-CHANGE-TO-Grasslands	865519
168	Cultivated subsistence crops	Mines	Cultivated subsistence crops-CHANGE-TO-Mines	15791
169	Cultivated subsistence crops	Waterbodies	Cultivated subsistence crops-CHANGE-TO-Waterbodies	10686
170	Cultivated subsistence crops	Bare ground	Cultivated subsistence crops-CHANGE-TO-Bare ground	63648
171	Cultivated subsistence crops	Degraded	Cultivated subsistence crops-CHANGE-TO-Degraded	201516
172	Settlements	Indigenous Forest	Settlements-CHANGE-TO-Indigenous Forest	11562
173	Settlements	Thicket/dense bush	Settlements-CHANGE-TO-Thicket/dense bush	791009
174	Settlements	Woodland/open bush	Settlements-CHANGE-TO-Woodland/open bush	371976
175	Settlements	Low shrubland	Settlements-CHANGE-TO-Low shrubland	211660
176	Settlements	Plantations/woodlots	Settlements-CHANGE-TO-Plantations/woodlots	154235
177	Settlements	Cultivated commercial annual: non-pivot	Settlements-CHANGE-TO-Cultivated commercial annual: non-pivot	199312
178	Settlements	Cultivated commercial annual: pivot	Settlements-CHANGE-TO-Cultivated commercial annual: pivot	1465
179	Settlements	Cultivated commercial permanent orchards	Settlements-CHANGE-TO-Cultivated commercial permanent orchards	8007
180	Settlements	Cultivated commercial permanent vines	Settlements-CHANGE-TO-Cultivated commercial permanent vines	2453
181	Settlements	Cultivated subsistence crops	Settlements-CHANGE-TO-Cultivated subsistence crops	348146
182	Settlements	Settlements	Settlements-NO_CHANGE	27135957
183	Settlements	Wetlands	Settlements-CHANGE-TO-Wetlands	43837
184	Settlements	Grasslands	Settlements-CHANGE-TO-Grasslands	1104986
185	Settlements	Mines	Settlements-CHANGE-TO-Mines	15905
186	Settlements	Waterbodies	Settlements-CHANGE-TO-Waterbodies	7021
187	Settlements	Bare ground	Settlements-CHANGE-TO-Bare ground	36828
188	Settlements	Degraded	Settlements-CHANGE-TO-Degraded	32532
189	Wetlands	Indigenous Forest	Wetlands-CHANGE-TO-Indigenous Forest	40226
190	Wetlands	Thicket/dense bush	Wetlands-CHANGE-TO-Thicket/dense bush	1729337
191	Wetlands	Woodland/open bush	Wetlands-CHANGE-TO-Woodland/open bush	895070
192	Wetlands	Low shrubland	Wetlands-CHANGE-TO-Low shrubland	1479148
193	Wetlands	Plantations/woodlots	Wetlands-CHANGE-TO-Plantations/woodlots	98639
194	Wetlands	Cultivated commercial annual: non-pivot	Wetlands-CHANGE-TO-Cultivated commercial annual: non-pivot	530799
195	Wetlands	Cultivated commercial annual: pivot	Wetlands-CHANGE-TO-Cultivated commercial annual: pivot	67641
196	Wetlands	Cultivated commercial permanent orchards	Wetlands-CHANGE-TO-Cultivated commercial permanent orchards	26126
197	Wetlands	Cultivated commercial permanent vines	Wetlands-CHANGE-TO-Cultivated commercial permanent vines	25811
198	Wetlands	Cultivated subsistence crops	Wetlands-CHANGE-TO-Cultivated subsistence crops	173086
199	Wetlands	Settlements	Wetlands-CHANGE-TO-Settlements	41391
200	Wetlands	Wetlands	Wetlands-NO_CHANGE	7043659

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201	Wetlands	Grasslands	Wetlands-CHANGE-TO-Grasslands	4525139
202	Wetlands	Mines	Wetlands-CHANGE-TO-Mines	21442
203	Wetlands	Waterbodies	Wetlands-CHANGE-TO-Waterbodies	130659
204	Wetlands	Bare ground	Wetlands-CHANGE-TO-Bare ground	112062
205	Wetlands	Degraded	Wetlands-CHANGE-TO-Degraded	16857
206	Grasslands	Indigenous Forest	Grasslands-CHANGE-TO-Indigenous Forest	263981
207	Grasslands	Thicket/dense bush	Grasslands-CHANGE-TO-Thicket/dense bush	18699512
208	Grasslands	Woodland/open bush	Grasslands-CHANGE-TO-Woodland/open bush	34080118
209	Grasslands	Low shrubland	Grasslands-CHANGE-TO-Low shrubland	43194219
210	Grasslands	Plantations/woodlots	Grasslands-CHANGE-TO-Plantations/woodlots	3059156
211	Grasslands	Cultivated commercial annual: non-pivot	Grasslands-CHANGE-TO-Cultivated commercial annual: non-pivot	7065338
212	Grasslands	Cultivated commercial annual: pivot	Grasslands-CHANGE-TO-Cultivated commercial annual: pivot	757172
213	Grasslands	Cultivated commercial permanent orchards	Grasslands-CHANGE-TO-Cultivated commercial permanent orchards	120470
214	Grasslands	Cultivated commercial permanent vines	Grasslands-CHANGE-TO-Cultivated commercial permanent vines	20166
215	Grasslands	Cultivated subsistence crops	Grasslands-CHANGE-TO-Cultivated subsistence crops	2553768
216	Grasslands	Settlements	Grasslands-CHANGE-TO-Settlements	2141715
217	Grasslands	Wetlands	Grasslands-CHANGE-TO-Wetlands	1796988
218	Grasslands	Grasslands	Grasslands-NO_CHANGE	184383601
219	Grasslands	Mines	Grasslands-CHANGE-TO-Mines	579306
220	Grasslands	Waterbodies	Grasslands-CHANGE-TO-Waterbodies	251139
221	Grasslands	Bare ground	Grasslands-CHANGE-TO-Bare ground	2436517
222	Grasslands	Degraded	Grasslands-CHANGE-TO-Degraded	4052016
223	Mines	Indigenous Forest	Mines-CHANGE-TO-Indigenous Forest	31
224	Mines	Thicket/dense bush	Mines-CHANGE-TO-Thicket/dense bush	82675
225	Mines	Woodland/open bush	Mines-CHANGE-TO-Woodland/open bush	209152
226	Mines	Low shrubland	Mines-CHANGE-TO-Low shrubland	97741
227	Mines	Plantations/woodlots	Mines-CHANGE-TO-Plantations/woodlots	9537
228	Mines	Cultivated commercial annual: non-pivot	Mines-CHANGE-TO-Cultivated commercial annual: non-pivot	12300
229	Mines	Cultivated commercial annual: pivot	Mines-CHANGE-TO-Cultivated commercial annual: pivot	1264
230	Mines	Cultivated commercial permanent orchards	Mines-CHANGE-TO-Cultivated commercial permanent orchards	100
231	Mines	Cultivated commercial permanent vines	Mines-CHANGE-TO-Cultivated commercial permanent vines	12
232	Mines	Cultivated subsistence crops	Mines-CHANGE-TO-Cultivated subsistence crops	4560
233	Mines	Settlements	Mines-CHANGE-TO-Settlements	14026
234	Mines	Wetlands	Mines-CHANGE-TO-Wetlands	20498
235	Mines	Grasslands	Mines-CHANGE-TO-Grasslands	557721
236	Mines	Mines	Mines-NO_CHANGE	2183569
237	Mines	Waterbodies	Mines-CHANGE-TO-Waterbodies	2211
238	Mines	Bare ground	Mines-CHANGE-TO-Bare ground	28696
239	Mines	Degraded	Mines-CHANGE-TO-Degraded	17648
240	Waterbodies	Indigenous Forest	Waterbodies-CHANGE-TO-Indigenous Forest	2786
241	Waterbodies	Thicket/dense bush	Waterbodies-CHANGE-TO-Thicket/dense bush	298299
242	Waterbodies	Woodland/open bush	Waterbodies-CHANGE-TO-Woodland/open bush	169719
243	Waterbodies	Low shrubland	Waterbodies-CHANGE-TO-Low shrubland	310052
244	Waterbodies	Plantations/woodlots	Waterbodies-CHANGE-TO-Plantations/woodlots	9158
245	Waterbodies	Cultivated commercial annual: non-pivot	Waterbodies-CHANGE-TO-Cultivated commercial annual: non-pivot	41978
246	Waterbodies	Cultivated commercial annual: pivot	Waterbodies-CHANGE-TO-Cultivated commercial annual: pivot	1915
247	Waterbodies	Cultivated commercial permanent orchards	Waterbodies-CHANGE-TO-Cultivated commercial permanent orchards	3120
248	Waterbodies	Cultivated commercial permanent vines	Waterbodies-CHANGE-TO-Cultivated commercial permanent vines	1536
249	Waterbodies	Cultivated subsistence crops	Waterbodies-CHANGE-TO-Cultivated subsistence crops	9028
250	Waterbodies	Settlements	Waterbodies-CHANGE-TO-Settlements	12064
251	Waterbodies	Wetlands	Waterbodies-CHANGE-TO-Wetlands	609557
252	Waterbodies	Grasslands	Waterbodies-CHANGE-TO-Grasslands	392102
253	Waterbodies	Mines	Waterbodies-CHANGE-TO-Mines	2811
254	Waterbodies	Waterbodies	Waterbodies-NO_CHANGE	21575609
255	Waterbodies	Bare ground	Waterbodies-CHANGE-TO-Bare ground	1022673
256	Waterbodies	Degraded	Waterbodies-CHANGE-TO-Degraded	4718
257	Bare ground	Indigenous Forest	Bare ground-CHANGE-TO-Indigenous Forest	3067
258	Bare ground	Thicket/dense bush	Bare ground-CHANGE-TO-Thicket/dense bush	912848
259	Bare ground	Woodland/open bush	Bare ground-CHANGE-TO-Woodland/open bush	2365435
260	Bare ground	Low shrubland	Bare ground-CHANGE-TO-Low shrubland	39284146
261	Bare ground	Plantations/woodlots	Bare ground-CHANGE-TO-Plantations/woodlots	8072
262	Bare ground	Cultivated commercial annual: non-pivot	Bare ground-CHANGE-TO-Cultivated commercial annual: non-pivot	32666
263	Bare ground	Cultivated commercial annual: pivot	Bare ground-CHANGE-TO-Cultivated commercial annual: pivot	21028
264	Bare ground	Cultivated commercial permanent orchards	Bare ground-CHANGE-TO-Cultivated commercial permanent orchards	2513
265	Bare ground	Cultivated commercial permanent vines	Bare ground-CHANGE-TO-Cultivated commercial permanent vines	29770
266	Bare ground	Cultivated subsistence crops	Bare ground-CHANGE-TO-Cultivated subsistence crops	3812
267	Bare ground	Settlements	Bare ground-CHANGE-TO-Settlements	51055
268	Bare ground	Wetlands	Bare ground-CHANGE-TO-Wetlands	88152
269	Bare ground	Grasslands	Bare ground-CHANGE-TO-Grasslands	2144355
270	Bare ground	Mines	Bare ground-CHANGE-TO-Mines	9491
271	Bare ground	Waterbodies	Bare ground-CHANGE-TO-Waterbodies	309464
272	Bare ground	Bare ground	Bare ground-NO_CHANGE	109176933
273	Bare ground	Degraded	Bare ground-CHANGE-TO-Degraded	28868
274	Degraded	Indigenous Forest	Degraded-CHANGE-TO-Indigenous Forest	198
275	Degraded	Thicket/dense bush	Degraded-CHANGE-TO-Thicket/dense bush	256546
276	Degraded	Woodland/open bush	Degraded-CHANGE-TO-Woodland/open bush	2667479
277	Degraded	Low shrubland	Degraded-CHANGE-TO-Low shrubland	2435971
278	Degraded	Plantations/woodlots	Degraded-CHANGE-TO-Plantations/woodlots	33291
279	Degraded	Cultivated commercial annual: non-pivot	Degraded-CHANGE-TO-Cultivated commercial annual: non-pivot	179711
280	Degraded	Cultivated commercial annual: pivot	Degraded-CHANGE-TO-Cultivated commercial annual: pivot	72806
281	Degraded	Cultivated commercial permanent orchards	Degraded-CHANGE-TO-Cultivated commercial permanent orchards	10146
282	Degraded	Cultivated commercial permanent vines	Degraded-CHANGE-TO-Cultivated commercial permanent vines	783
283	Degraded	Cultivated subsistence crops	Degraded-CHANGE-TO-Cultivated subsistence crops	716609
284	Degraded	Settlements	Degraded-CHANGE-TO-Settlements	95717
285	Degraded	Wetlands	Degraded-CHANGE-TO-Wetlands	59904
286	Degraded	Grasslands	Degraded-CHANGE-TO-Grasslands	5920583
287	Degraded	Mines	Degraded-CHANGE-TO-Mines	6812
288	Degraded	Waterbodies	Degraded-CHANGE-TO-Waterbodies	5647
289	Degraded	Bare ground	Degraded-CHANGE-TO-Bare ground	1904076
290	Degraded	Degraded	Degraded-NO_CHANGE	2182163

Table 16 below describes the actual 1990 to 2013/14 inter-class land-cover changes for the whole of South Africa in hectares.

1990	ORIGINAL VALUE	Quantitative units: Hectares (1990 vs 2013)	RECODE VALUE	2013: Indigenous Forest	Thicket/dense bush	Woodland/open bush	Low shrubland	Plantations/woodlots	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodies	Bare ground	Degraded	TOTAL Change (Hectares)
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
	1	Indigenous Forest	1	308267.73	44643.69	7833.24	1438.20	918.99	845.46	14.13	676.62	0.36	973.17	2021.31	1393.38	6732.54	264.33	34.83	548.64	44.10	376650.72
	2	Thicket/dense bush	18	48224.61	3734093.34	1294209.81	383631.75	11235.24	101464.74	9614.07	23550.03	3855.87	51351.93	47301.66	41530.77	844196.04	8594.37	10950.30	21889.17	10290.33	6645984.03
	3	Woodland/open bush	35	10116.00	1525247.37	5568764.31	1309185.09	36272.52	96531.12	34241.49	11625.93	1694.34	71331.93	81228.69	23104.80	1845214.29	15338.79	11796.75	161589.51	204553.08	11007836.01
	4	Low shrubland	52	4940.46	602847.54	1431970.02	31850093.97	12240.27	229610.70	64216.26	13788.72	13938.57	9649.71	56809.71	35449.65	4153039.38	7901.55	12623.85	2531936.16	108768.60	41139825.12
	5	Plantations/woodlots	69	26783.28	136030.68	46164.33	24336.00	1476337.59	25698.24	590.58	6373.62	739.35	2340.00	27588.96	15441.03	127873.80	3586.50	1380.69	943.92	620.91	1922829.48
	6	Cultivated commercial annual: non-pivot	86	724.95	93417.30	222347.25	399718.98	29305.53	9340133.85	389363.40	31724.28	8655.30	17203.59	27796.32	35878.05	809867.61	37409.94	2191.77	10180.80	30644.46	11486563.38
	7	Cultivated commercial annual: pivot	103	3.51	2823.48	5776.11	2851.20	132.66	24896.61	194856.75	3493.98	928.53	350.55	945.09	453.96	5329.08	655.02	43.65	165.15	563.22	244268.55
	8	Cultivated commercial permanent orchards	120	146.61	14778.99	8522.10	6002.64	1608.75	18063.72	3661.11	234177.03	10102.32	4038.12	1068.66	941.76	9811.44	57.96	116.37	177.84	296.19	313571.61
	9	Cultivated commercial permanent vines	137	0.18	5070.24	555.75	5313.51	193.14	2904.48	586.44	3421.35	141277.59	0.00	552.60	681.84	1448.73	2.97	160.83	173.16	11.43	162354.24
	10	Cultivated subsistence crops	154	270.00	83396.34	180483.48	13524.66	1968.57	45099.36	1808.73	2775.51	271.17	1540477.08	8693.37	1391.04	77896.71	1421.19	961.74	5728.32	18136.44	1984303.71
	11	Settlements	171	1040.58	71190.81	33477.84	19049.40	13881.15	17938.08	131.85	720.63	220.77	31333.14	2442236.13	3945.33	99448.74	1431.45	631.89	3314.52	2927.88	2742920.19
	12	Wetlands	188	3620.34	155640.33	80556.30	133123.32	8877.51	47771.91	6087.69	2351.34	2322.99	15577.74	3725.19	633929.31	407262.51	1929.78	11759.31	10085.58	1517.13	1526138.28
	13	Grasslands	205	23758.29	1682956.08	3067210.62	3887479.71	275324.04	635880.42	68145.48	10842.30	1814.94	229839.12	192754.35	161728.92	16594524.09	52137.54	22602.51	219286.53	364681.44	27490966.38
	14	Mines	222	2.79	7440.75	18823.68	8796.69	858.33	1107.00	113.76	9.00	1.08	410.40	1262.34	1844.82	50194.89	196521.21	198.99	2582.64	1588.32	291756.69
	15	Waterbodies	239	250.74	26846.91	15274.71	27904.68	824.22	3778.02	172.35	280.80	138.24	812.52	1085.76	54860.13	35289.18	252.99	1941804.81	92040.57	424.62	2202041.25
	16	Bare ground	256	276.03	82156.32	212889.15	3535573.14	726.48	2939.94	1892.52	226.17	2679.30	343.08	4594.95	7933.68	192991.95	854.19	27851.76	9825923.97	2598.12	13902450.75
	17	Degraded	273	17.82	23089.14	240073.11	219237.39	2996.19	16173.99	6552.54	913.14	70.47	64494.81	8614.53	5391.36	532852.47	613.08	508.23	171366.84	196394.67	1489359.78
				428443.92	8291669.31	12434931.81	41827260.33	1873701.18	10610837.64	782049.15	346950.45	188711.19	2040526.89	2908279.62	1025899.83	25793973.45	328972.86	2045618.28	13057933.32	944060.94	

Table 17 below describes the actual 1990 to 2013/14 inter-class land-cover changes for the whole of South Africa, expressed in terms of the percentage of the original 1990 class extent and what it has become in 2013/14. For example, 81.84% of what was mapped as indigenous forest in 1990 is still indigenous forest in 2013/14, and 11.85% of what was indigenous forest in 1990 is mapped as thicket/dense bush in 2013/14.

1990	ORIGINAL VALUE	Quantitative units: Percentage of original 1990 extent in 2013 (only read table across rows)	RECODE VALUE	2013: Indigenous Forest	Thicket/dense bush	Woodland/open bush	Low shrubland	Plantations/woodlots	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodies	Bare ground	Degraded	TOTAL Change (%)
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
	1	Indigenous Forest	1	81.84	11.85	2.08	0.38	0.24	0.22	0.00	0.18	0.00	0.26	0.54	0.37	1.79	0.07	0.01	0.15	0.01	100
	2	Thicket/dense bush	18	0.73	56.19	19.47	5.77	0.17	1.53	0.14	0.35	0.06	0.77	0.71	0.62	12.70	0.13	0.16	0.33	0.15	100
	3	Woodland/open bush	35	0.09	13.86	50.59	11.89	0.33	0.88	0.31	0.11	0.02	0.65	0.74	0.21	16.76	0.14	0.11	1.47	1.86	100
	4	Low shrubland	52	0.01	1.47	3.48	77.42	0.03	0.56	0.16	0.03	0.03	0.02	0.14	0.09	10.09	0.02	0.03	6.15	0.26	100
	5	Plantations/woodlots	69	1.39	7.07	2.40	1.27	76.78	1.34	0.03	0.33	0.04	0.12	1.43	0.80	6.65	0.19	0.07	0.05	0.03	100
	6	Cultivated commercial annual: non-pivot	86	0.01	0.81	1.94	3.48	0.26	81.31	3.39	0.28	0.08	0.15	0.24	0.31	7.05	0.33	0.02	0.09	0.27	100
	7	Cultivated commercial annual: pivot	103	0.00	1.16	2.36	1.17	0.05	10.19	79.77	1.43	0.38	0.14	0.39	0.19	2.18	0.27	0.02	0.07	0.23	100
	8	Cultivated commercial permanent orchards	120	0.05	4.71	2.72	1.91	0.51	5.76	1.17	74.68	3.22	1.29	0.34	0.30	3.13	0.02	0.04	0.06	0.09	100
	9	Cultivated commercial permanent vines	137	0.00	3.12	0.34	3.27	0.12	1.79	0.36	2.11	87.02	0.00	0.34	0.42	0.89	0.00	0.10	0.11	0.01	100
	10	Cultivated subsistence crops	154	0.01	4.20	9.10	0.68	0.10	2.27	0.09	0.14	0.01	77.63	0.44	0.07	3.93	0.07	0.05	0.29	0.91	100
	11	Settlements	171	0.04	2.60	1.22	0.69	0.51	0.65	0.00	0.03	0.01	1.14	89.04	0.14	3.63	0.05	0.02	0.12	0.11	100
	12	Wetlands	188	0.24	10.20	5.28	8.72	0.58	3.13	0.40	0.15	0.15	1.02	0.24	41.54	26.69	0.13	0.77	0.66	0.10	100
	13	Grasslands	205	0.09	6.12	11.16	14.14	1.00	2.31	0.25	0.04	0.01	0.84	0.70	0.59	60.36	0.19	0.08	0.80	1.33	100
	14	Mines	222	0.00	2.55	6.45	3.02	0.29	0.38	0.04	0.00	0.00	0.14	0.43	0.63	17.20	67.36	0.07	0.89	0.54	100
	15	Waterbodies	239	0.01	1.22	0.69	1.27	0.04	0.17	0.01	0.01	0.01	0.04	0.05	2.49	1.60	0.01	88.18	4.18	0.02	100
	16	Bare ground	256	0.00	0.59	1.53	25.43	0.01	0.02	0.01	0.00	0.02	0.00	0.03	0.06	1.39	0.01	0.20	70.68	0.02	100
	17	Degraded	273	0.00	1.55	16.12	14.72	0.20	1.09	0.44	0.06	0.00	4.33	0.58	0.36	35.78	0.04	0.03	11.51	13.19	100

Table 18 below describes the actual 1990 to 2013/14 inter-class land-cover changes for the whole of South Africa, expressed in terms of the percentage of the current 2013/14 class extent and what it was originally in 1990. For example, 71.95% of what was mapped as indigenous forest in 2013/14 was also indigenous forest in 1990, and 11.26% of what is indigenous forest in 2013/14 was mapped as thicket/dense bush in 1990.

1990 ORIGINAL VALUE	***Quantitative units:*** ***Percentage of final 2013 extent in 1990 (only read table down columns)***	RECODE VALUE	2013: Indigenous Forest 1	Thicket/dense bush 2	Woodland/open bush 3	Low shrubland 4	Plantations/woodlots 5	Cultivated commercial annual: non-pivot 6	Cultivated commercial annual: pivot 7	Cultivated commercial permanent orchards 8	Cultivated commercial permanent vines 9	Cultivated subsistence crops 10	Settlements 11	Wetlands 12	Grasslands 13	Mines 14	Waterbodies 15	Bare ground 16	Degraded 17
1	Indigenous Forest	1	71.95	0.54	0.06	0.00	0.05	0.01	0.00	0.20	0.00	0.05	0.07	0.14	0.03	0.08	0.00	0.00	0.00
2	Thicket/dense bush	18	11.26	45.03	10.41	0.92	0.60	0.96	1.23	6.79	2.04	2.52	1.63	4.05	3.27	2.61	0.54	0.17	1.09
3	Woodland/open bush	35	2.36	18.39	44.78	3.13	1.94	0.91	4.38	3.35	0.90	3.50	2.79	2.25	7.15	4.66	0.58	1.24	21.67
4	Low shrubland	52	1.15	7.27	11.52	76.15	0.65	2.16	8.21	3.97	7.39	0.47	1.95	3.46	16.10	2.40	0.62	19.39	11.52
5	Plantations/woodlots	69	6.25	1.64	0.37	0.06	78.79	0.24	0.08	1.84	0.39	0.11	0.95	1.51	0.50	1.09	0.07	0.01	0.07
6	Cultivated commercial annual: non-pivot	86	0.17	1.13	1.79	0.96	1.56	88.02	49.79	9.14	4.59	0.84	0.96	3.50	3.14	11.37	0.11	0.08	3.25
7	Cultivated commercial annual: pivot	103	0.00	0.03	0.05	0.01	0.01	0.23	24.92	1.01	0.49	0.02	0.03	0.04	0.02	0.20	0.00	0.00	0.06
8	Cultivated commercial permanent orchards	120	0.03	0.18	0.07	0.01	0.09	0.17	0.47	67.50	5.35	0.20	0.04	0.09	0.04	0.02	0.01	0.00	0.03
9	Cultivated commercial permanent vines	137	0.00	0.06	0.00	0.01	0.01	0.03	0.07	0.99	74.86	0.00	0.02	0.07	0.01	0.00	0.01	0.00	0.00
10	Cultivated subsistence crops	154	0.06	1.01	1.45	0.03	0.11	0.43	0.23	0.80	0.14	75.49	0.30	0.14	0.30	0.43	0.05	0.04	1.92
11	Settlements	171	0.24	0.86	0.27	0.05	0.74	0.17	0.02	0.21	0.12	1.54	83.98	0.38	0.39	0.44	0.03	0.03	0.31
12	Wetlands	188	0.84	1.88	0.65	0.32	0.47	0.45	0.78	0.68	1.23	0.76	0.13	61.79	1.58	0.59	0.57	0.08	0.16
13	Grasslands	205	5.55	20.30	24.67	9.29	14.69	5.99	8.71	3.13	0.96	11.26	6.63	15.76	64.33	15.85	1.10	1.68	38.63
14	Mines	222	0.00	0.09	0.15	0.02	0.05	0.01	0.01	0.00	0.00	0.02	0.04	0.18	0.19	59.74	0.01	0.02	0.17
15	Waterbodies	239	0.06	0.32	0.12	0.07	0.04	0.04	0.02	0.08	0.07	0.04	0.04	5.35	0.14	0.08	94.93	0.70	0.04
16	Bare ground	256	0.06	0.99	1.71	8.45	0.04	0.03	0.24	0.07	1.42	0.02	0.16	0.77	0.75	0.26	1.36	75.25	0.28
17	Degraded	273	0.00	0.28	1.93	0.52	0.16	0.15	0.84	0.26	0.04	3.16	0.30	0.53	2.07	0.19	0.02	1.31	20.80
	TOTAL Change (%)		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

5. THE 1990 TO 2013/14 CHANGE RESULTS ANALYSIS

5.1 Indigenous forest

According to the land-cover data, there was a 13.75% increase nationally in the indigenous forest class extent between 1990 and 2013/14. However, the 2013/14 map accuracy results indicate a 72.6% user accuracy, which may mean that, in many cases, the reported change is a result of mapping error between true forest and the spectrally similar woody vegetation classes, such as "thicket/dense bush", as indicated in the 2013/14 accuracy report. In Gauteng, there is a highly unlikely 1 350% statistical increase in the extent of indigenous forest in 2013/14, but this is simply due to the fact that in 1990, two pixels were mapped as forest, whereas in 2013/14, 29 pixels were mapped as forest. This difference is likely to be a result of the reported mapping inaccuracies, with 29 pixels representing only 0.0006% of the total mapped area of indigenous forest in 2013/14. National and provincial statistics should not, however, detract from the very relevant and real changes in indigenous forest cover change that are contained within the land-cover datasets on a local basis, such as around Dukuduku, St Lucia (see example above).

5.2 Thicket/dense bush

According to the land-cover data, there was a national increase of 24.76% in the thicket/dense bush class extent between 1990 and 2013/14. However, the 2013/14 map accuracy results indicate only a 53.74% user accuracy, which may mean that, in many cases, the reported change will be due to mapping error between this class and other spectrally similar woody vegetation classes, as indicated in the 2013/14 accuracy report. Provincial changes in the woody-dominated areas vary from +16.03% in Limpopo, +18.77% in KwaZulu-Natal, +36.46% in Mpumalanga, +79.52% in the Eastern Cape and -25.57% in North West. It is recommended that such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

5.3 Woodland/open bush

According to the land-cover data, there was a national increase of 12.96% in the woodland/open bush class extent between 1990 and 2013/14. However, the 2013/14 map accuracy results indicate only a 60.84% user accuracy, which may mean that, in many cases, the reported change will be due to mapping error between this class and other spectrally similar woody vegetation classes, as indicated in the 2013/14 accuracy report. Provincial changes in the woody-dominated areas vary from +3.47% in Limpopo, +20.57% in KwaZulu-Natal, -4.73% in Mpumalanga, +115.79% in the Eastern Cape and +8.07% in North West. It is recommended that such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

5.4 Low shrubland

According to the land-cover data, there was a national increase of 1.67% in the low shrub class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 70.59% user accuracy, which may mean that the limited amount of change is a function of both increasing map accuracy and the extremely large national class footprint within which any local change is insignificant in terms of the total area affected. Provincial changes in low shrub/Karoo/fynbos-dominated areas vary from +48.59% in the Free State, -2.45% in the Northern Cape and +7.23% in the Western Cape. In most cases, the changes in low shrub extent seem to be along a transitional gradient with grasslands, and may be reflecting local annual changes in grass component cover in response to different annual rainfall conditions, as is evident in the difference in open water/wetland areas between 1990 and 2013/14. It is recommended that such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

5.5 Plantations/woodlots

According to the land-cover data, there was a national decrease of 2.55% in the plantation/woodlot class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 89.3% user accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. The national statistic does not, however, reflect provincial or local area changes over the same approximately 24-year period, with some areas definitely showing losses and others expansion. Provincial changes in traditional forestry areas vary from -23.93% in Limpopo, +1.1% in Mpumalanga, +1.02% in the Eastern Cape and +3.57% in KwaZulu-Natal.

5.6 Cultivated commercial annual crop non-pivot

According to the land-cover data, there was a national decrease of 7.62% in the cultivated commercial annual crop non-pivot class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 91.91% user accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. The national statistic does not, however, reflect provincial or local area changes over the same approximately 24-year period, with some areas definitely showing losses and others expansion. Provincial changes in traditional forestry areas vary from -20.25% in Limpopo, -12.65% in Mpumalanga, +11.64% in KwaZulu-Natal, -10.30% in the Eastern Cape and -3.33% in the Western Cape, for example. On a local scale, many of these losses and expansions also appear to relate to associated increases in other cultivation land uses, such as orchards, vines and pivots, and losses due to new mining and urban areas.

5.7 Cultivated commercial annual crop pivots

According to the land-cover data, there was a national 220.16% increase in the cultivated commercial annual crop pivot class extent between 1990 and 2013/14. This is by far the biggest increase in any land-cover class extent over the approximately 24-year period and represents a huge increase in irrigation activities and associated water consumption. The 2013/14 map accuracy results indicate a 95.381% user accuracy, which should mean that both the mapped and statistical representations of change are plausible and very likely to be accurate. The national statistic does not, however, reflect provincial or local area changes over the same approximately 24-year period, with provincial changes in pivot class extent varying from +113.87% in Limpopo, +262.41% in Mpumalanga, +261.41% in KwaZulu-Natal, +413.66% in the Eastern Cape and +290.11% in the Western Cape, for example. All provinces showed increases in pivot class extent since 1990. On a local scale, this expansion appears to have resulted in losses to both other cultivated land uses and natural vegetation types, depending on location.

5.8 Cultivated commercial permanent orchards

According to the land-cover data, there was a national increase of 10.64% in the cultivated commercial permanent orchard class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 92.18% user accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. The national statistic does not, however, reflect provincial or local area changes over the same approximately 24-year period, with some areas definitely showing losses and others expansion. Provincial changes in traditional orchard areas vary from +40.27% in Limpopo, +35.38% in Mpumalanga, +28.56% in the Northern Cape and -18.18% in the Eastern Cape, for example. On a local scale, many of these losses and expansions appear to relate to associated increases in other cultivated land uses, such as orchards, vines and pivots, and losses due to new mining and urban areas.

5.9 Cultivated commercial permanent vines

According to the land-cover data, there was a national increase of 16.23% in the cultivated commercial permanent vines class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 91.61% user accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. The national statistic reflects provincial-level changes over the same approximately 24-year period, with similar percentage increases being reported in both the Western Cape and the Northern Cape. All provinces with vines in 1990 show an increase in 2013/14.

5.10 Cultivated subsistence crops

According to the land-cover data, there was only a national increase of 2.83% in the cultivated subsistence crop class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 89.00% user accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. It is important to note, however, that, unlike commercial fields that were (originally) mapped on an individual field unit basis, subsistence fields were mapped according to the outer extent of clusters of subsistence fields, as necessitated by their characteristically small areas compared to image resolution. This resulted in varied levels and patterns of inter-field non-crop land being included in the subsistence cluster boundaries. During the land-cover mapping, these inter-field non-crop areas have been reclassified, where possible, into their basic vegetation cover types, i.e. grass, dense bush, etc. Since this was based on a generic modelling procedure as opposed to image-specific classification routines, it is possible that the extent and coverage of such inter-field non-crop areas has been influenced by (a) the accuracies associated with these vegetation classes, and (b) any modifying effect resulting from 1990 conditions appearing to be generally wetter than those in 2013/14. Furthermore, the actual intensity of land use (i.e. subsistence crop yield) cannot be gauged from the single "subsistence class" defined in the 17-class legend format, since all subsistence fields have been included within one amalgamated class on the basis of (image) observable field boundaries, regardless of whether such fields were cultivated, temporary or long-term fallow (i.e. abandoned) in the assessment year. A subdivision of land-use activity intensity (also known as cropping), based on annual Normalised Difference Vegetation Index (NDVI) profiles, is available as part of the associated 72-class DEA/GTI national land-cover dataset for 2013/14, but not presently for 1990. This may be a consideration for future work and analysis, since it will allow the historical and current extents of high-intensity subsistence cropping units to be compared, as opposed to just the overall extent of image-observable field cluster boundaries.

The national statistic does not, however, reflect provincial or local area changes over the same approximately 24-year period, with some areas showing losses and others expansion. Provincial changes in subsistence cropping vary from -13.34% in Limpopo, -27.27% in Mpumalanga and +30.29% in KwaZulu-Natal. It is recommended that, until such time as subsistence changes can be validated in terms of land-use intensity changes (i.e. productive to productive, productive to fallow, fallow to productive, etc.), such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

5.11 Settlements (including smallholdings)

According to the land-cover data, there was only a national increase of 6.03% in the settlement class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 93.90% user accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. The national statistic does not, however, reflect provincial or local area changes over the same approximately 24-year period, with some areas definitely showing losses and others expansion, ranging from +28.82% in Limpopo to (surprisingly) -2.93% in KwaZulu-Natal. Gauteng only shows a +10.58% increase, which – from an anecdotal perspective – may be lower than expected. This is potentially explained by the fact that the settlement footprint defined in the two land-cover datasets includes a variety of urban subclasses, including commercial, residential, villages, schools and smallholdings. Peripheral smallholdings around urban centres are typically the first land-use class to be converted to formal urban areas under urban expansion. Thus, the total settlement footprint, as defined in terms of the DEA/CARDNO national land-cover datasets, will not change over time when smallholdings are converted to formal residential or industrial areas. Settlement subclasses defining separate commercial, industrial, residential, informal, village and smallholding categories are available within the full 72-class DEA/GTI national land-cover dataset for 2013/14, but not presently for 1990. This may be a consideration for future work and analysis since it will allow a more representative interpretation of urban expansion to be evaluated.

5.12 Wetlands

According to the land-cover data, there was a national decrease of 32.78% in the wetland class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 88.07% user accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. However, wetlands is a specific land-cover class that has been significantly affected by the general wetter landscape conditions in 1990 compared to 2013/14, especially in the conventionally drier western areas. The generally wetter landscape conditions in 1990 allowed wetland modelling to be undertaken across the entire country, whereas in 2013/14, because of drier conditions, wetland modelling was restricted to the southern and eastern regions. Thus, any wetlands in the normally drier western regions that were mapped in 1990 have not been remapped in 2013/14, simply because they were not visible as such on the imagery under these drier conditions. This does not mean that such wetlands have been "lost", but rather that they are temporarily absent in terms of surface representation in 2013/14. This must be noted when interpreting the statistics. A possible solution may be to take the combined area of wetlands from 1990 and 2013/14, and to subtract appropriate non-wetland land-use class extents from this for both 1990 and 2013/14 landscapes in order to derive a more accurate picture of wetland loss.

The national statistic does not, however, reflect provincial or local area changes over the same approximately 24-year period, with losses ranging from -63.24% in the Northern Cape to -12.13% in Gauteng, where the Northern Cape difference is likely to be due to the landscape wetness differences already discussed, and the Gauteng difference probably being more representative of actual loss. All provinces showed a loss in wetland extent between 1990 and 2013/14. It is therefore recommended that such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

5.13 Grasslands

According to the land-cover data, there was a national decrease of 6.17% in the grassland class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 84.56% user accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. As indicated in the 1990 DEA/CARDNO South African Land-cover Data Report, the post-modelling grassland correction edits are potentially more accurate than those applied to the 2013/14 land-cover dataset, as a result of better image dates and modified correction procedures. This may mean that the actual grassland extent, as represented in the 1990 dataset, is slightly more accurate than that represented in the 2013/14 dataset, and that there could be a corresponding increase in the level of grassland/woody vegetation cover confusion in 2013/14. It is recommended that such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

The generally wetter landscape conditions in 1990, especially in the typically arid Karoo regions, may also have experienced a regional annual increase in the grass component in the low shrub/grassland transition zone, also increasing the extent of the grassland class mapped in 1990.

The national statistic does not, however, reflect provincial or local area changes over the same approximately 24-year period, with some areas showing losses and others expansion. Provincial changes vary from -28.33% in Limpopo, +1.93% in Mpumalanga, and +36.94% in the Northern Cape.

5.14 Mines

According to the land-cover data, there was a national increase of 12.76% in the mining class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 92.82% user accuracy, which should mean that both the mapped and statistical representations of change are plausible and very likely to be accurate. The national statistic does not, however, reflect provincial or local area changes over the same approximately 24-year period, with both losses and increases being recorded, ranging from -46.22% in the Eastern Cape to +66.84% in Mpumalanga (as would be expected due to the expansion of open-cast coal mining in this area). Since mapping accuracies are high for this class, interpretation of the statistical changes must be made in the context of the original and current spatial extents.

5.15 Water bodies

According to the land-cover data, there was a national decrease of -7.10% in the water class extent between 1990 and 2013/14, which includes both natural, man-made, seasonal and permanent water features. The 2013/14 map accuracy results indicate a 79.64% user accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. The national statistic does not, however, reflect provincial or local area changes over the same approximately 24-year period, with both losses and increases being recorded, ranging from +25.34% in Limpopo, 11.35% in Mpumalanga, and -59.75% in the Northern Cape. These regional differences are likely to have been influenced by a combination of both the generally wetter landscape conditions in 1990, especially in the typically drier western regions, and by the construction of several new major dams after 1990 that are observable in 2013/14. Since mapping accuracies are high for this class, interpretation of the statistical changes must be made in the context of the original and current spatial extents, so that small spatial features do not become over-represented statistically if they have shown significant statistical, but not necessarily spatial growth.

5.16 Bare ground

According to the land-cover data, there was a national decrease of -6.07% in the bare ground class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 98.77% user accuracy, which should mean that both the mapped and statistical representations of change are plausible and very likely to be accurate. The national statistic does not, however, reflect provincial or local area changes over the same approximately 24-year period, with both losses and increases being recorded, ranging from +635.08% in Limpopo, 2 121.80% in North West and -63.01% in the Eastern Cape. Since mapping accuracies are high for this class, interpretation of the statistical changes must be made in the context of the original and current spatial extents in any given area, so that small spatial features do not become over-represented statistically if they have shown significant statistical, but not necessarily spatial growth. The 2013/14 dataset may have been influenced by the generally drier conditions in some areas, perhaps resulting in lower vegetative cover, although in some regions human activity will have increased the bare ground extent.

5.17 Degraded areas

According to the land-cover data, there was a national decrease of -36.61% in the degraded class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 78.69% user accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. However, the degraded class is defined as areas showing significantly lower total vegetation cover to surrounding non-impacted areas, in terms of the viewed landscape. It is feasible, therefore, that a significant portion of the difference in degraded areas between 1990 and 2013/14 could be attributed to the generally wetter conditions in 1990 compared to the drier 2013/14 conditions. The provincial results show a significantly higher area of bare ground in 1990 than in 2013/14, apart from North West. This would appear to be the opposite of what would be expected, give that 1990 was the apparently wetter period, and thus the vegetation cover would be assumed to be more extensive. However, an alternative suggestion may be that, in terms of the generic modelling procedures used to define this class, when all the vegetation is generally lower (as in a drier period), the difference between impacted (i.e. degraded) land and non-impacted land is harder to determine, compared to when non-impacted land is much greener in wetter conditions. It is recommended that such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

ADDITIONAL INFORMATION

(1) EXCEL SPREADSHEET OF LAND-COVER CHANGE RESULTS

- A digital Excel spreadsheet is supplied with this report. It contains digital copies of all the tables presented in this report so that data users have access to the actual numeric information.

(2) DIGITAL RASTER MAP OF LAND-COVER CHANGE RESULTS

- A digital raster copy of the 289-class 1990 to 2013/14 change matrix map is supplied, based on 30 m-resolution cells, equivalent to the source 1990 and 2013/14 South African national land-cover 17-class legend datasets. This dataset is the source of the land-cover class change values represented in Table 15, based on the class change codes listed in Table 15. The raster change dataset is supplied in its original UTM35 north map projection in ERDAS Imagine© format. No TIFF format is supplied since the dataset is 11Gb in size due to the 16-bit format needed to accommodate the 289 classes, which exceeds the 4Gb limit for TIFF formats.

PLEASE NOTE THAT THIS IS NOT A LAND-COVER MAP DATASET, BUT A SPATIAL REPRESENTATION OF 1990 TO 2013/14 LAND-COVER CHANGE ON A PER-PIXEL BASIS.

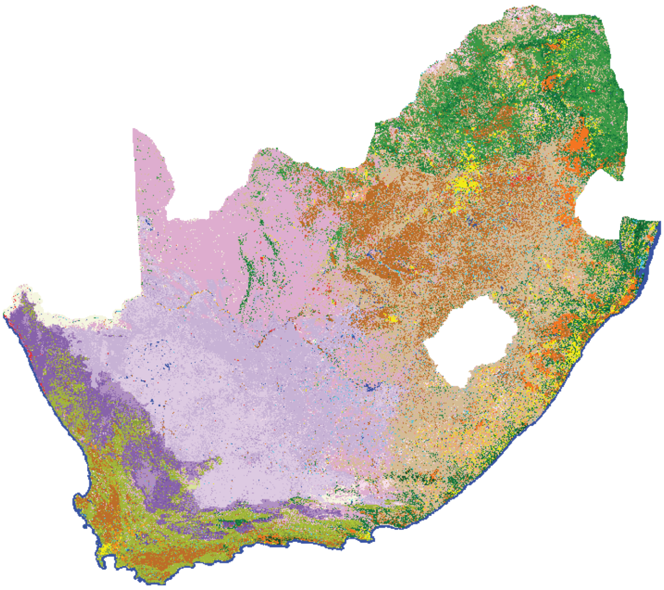
APPENDIX 4

Report on the 1990 to 2013/14 Land-Cover/Land-use Data End-User Training

1990 to 2013/14 South African National Land-cover Data Training Report

DEA/CARDNO SCPF002: Implementation of Land-use Maps for South Africa

Project-specific Data Report



DATA PRODUCT CREATED BY
GEOTERRAIMAGE (South Africa)
www.geoterraimage.com
August 2015, version 01

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CONTENTS

1. BACKROUND

Various levels of training on the use and interpretation of the 1990 and 2013/14 South African National Land-cover Datasets have been provided in support of potential end-user awareness and understanding, as detailed in the SCFP002 tender conditions and deliverables.

The final training programme, as detailed below, replaced the details contained in Section 20 (training of two DEA GIS Unit staff members) and Section 21 (DEA-requested conference activities) of the DEA/CARDNO SCPF002 contract, as agreed between DEA, CARDNO and GTI. The new training programme was designed to present different levels of (land-cover data) information, content and detail for a range of potential data users, from GIS professionals to management.

A total of 235 participants have been through the various training and presentation sessions, with 54 participants from a range of government and non-governmental organisations having completed the formal training sessions involving hands-on analysis of the spatial data in a GIS software environment.

2. TRAINING PROGRAMME

The training programme consisted of the following presentations and audiences. Note that all logistical arrangements pertaining to location and invited participants were the agreed responsibility of the DEA.

- One five-day training session to professional GIS data users (first session)
- One half-day presentation to professional data users and managers
- One four-day training session to professional GIS data users (second session)
- One half-day presentation at the 2015 Geomatics Indaba Conference
- Two one-day training sessions to environmental specialists (or equivalent)

2.1 One five-day training session to professional GIS data users (first session)

This five-day training session took place at the DEA offices in Pretoria from 25 to 29 May 2015. The presentation was attended by 11 delegates. A copy of the signed attendance register is contained in Appendix 1. The training session was designed to provide sufficient information on the land-cover data product for GIS data analysts to understand how the data was generated and how it can be used in an operational environment. Detailed information on the background principles, satellite imagery, data modelling, mapping techniques and accuracy assessment procedures was presented and discussed. The five-day programme consisted of three days of presentations and discussions, followed by two days of hands-on training, using the digital land-cover data in practical demonstrations of land-cover data-use applications, using ArcGIS software. A copy of the PowerPoint slides used for this presentation is included as part of the deliverables.

2.2 One half-day presentation to professional data users and managers

The half-day presentation was part of the DEA-coordinated National 2013/14 South African Land-cover data day, which took place at the DEA's offices in Pretoria on 9 June 2015. The presentation was attended by 152 delegates. A copy of the signed attendance register is contained in Appendix 2. The presentation was designed to provide sufficient information on the land-cover data product for managers and users to understand how the data was generated and how it can be used in an operational environment. The half-day session was presented as a series of lectures, using a combination of PowerPoint and live data demonstrations. No hands-on practical data-use training based on GIS software was included in this training component. A copy of the PowerPoint slides used for this presentation is included as part of the deliverables.

2.3 One four-day training session to professional GIS data users (second session)

This four-day training session took place at the DEA's offices in Pretoria from 3 to 6 August 2015. The presentation was attended by 23 delegates. A copy of the signed attendance register is contained in Appendix 3. The training session was designed to provide sufficient information on the land-cover data product for GIS data analysts to understand how the data was generated and how it can be used in an operational environment. Detailed information on the background principles, satellite imagery, data modelling, mapping techniques and accuracy assessment procedures was presented and discussed. The four-day programme consisted of two days of presentations and discussions, followed by two days of hands-on training, using the digital land-cover data in practical demonstrations of land-cover data-use applications, using ArcGIS software.

2.4 One half-day presentation to GIS data users

The half-day presentation was made during the 2015 Geomatics Indaba Conference, which took place at Emperors Palace, Ekurhurleni, Gauteng, between 11 and 13 August 2015. The land-cover presentation was made on 12 August 2015. The presentation was attended by approximately 20 delegates. No formal record of session attendees was made, although a photograph is included in Appendix 4. The presentation was designed to provide sufficient information on the land-cover data product for managers and users to understand how the data was generated and how it can be used in an operational environment. The half-day session was presented as a series of lectures, using a combination of PowerPoint and live data demonstrations, including hands-on training, using the digital land-cover data in practical demonstrations of land-cover data-use applications, using ArcGIS software. A copy of the PowerPoint slides used for this presentation is included as part of the deliverables.

2.5 Two one-day training sessions to environmental specialists (or equivalent)

A series of two one-day training presentations are to be made to regional DEA representatives based in Durban (KwaZulu-Natal) and East London (Eastern Cape), as arranged and coordinated by the DEA. A total of 17 participants attended the East London presentation, and 12 participants attended the Durban presentation. A copy of the signed attendance register for East London is contained in Appendix 5. Unfortunately, no attendance register was available for the Durban training at the time of going to press, but the audience included representation from the provincial departments of Agriculture, Environmental Affairs, Disaster Management and Cooperative Governance and Traditional Affairs (CoGTA), as well as the local municipality. The training programme provided sufficient information on the land-cover data product for environmental specialists (and other users), both with and without GIS skills, to understand the land-cover data from a basic user perspective. The course content will include information covering the land-cover change assessment results (1990 and 2013/14) since presentations will be made after this project component has been completed. These presentations are mainly targeted at the DEA's climate change mitigation community. The morning will focus on background information on the remote sensing data, modelling and mapping techniques, and the accuracy assessment process used to generate the national land-cover datasets. The afternoon will focus on practical examples of GIS applications and land-cover data usage. All sessions will be presented as a series of lectures, using a combination of PowerPoint and live data demonstrations. No hands-on practical data-use training based on GIS software was included in this training component. A copy of the PowerPoint slides used for this presentation is included as part of the deliverables.

Additional Information supplied with this report:

- A digital copy of the PowerPoint slides used in the five-day training session
- A digital copy of the PowerPoint slides used in the half-day training session
- A digital copy of the PowerPoint slides used in the one-day training session

APPENDIX 1: Attendance register for five-day professional GIS data users' training session, DEA offices, 25 to 19 May 2015

Land cover 2013/2014 Training Sessions for GIS Professionals.
Date: 25 – 29 May 2015
Time: 9h00 – 16h00 *(Friday 14h00)*
Venue: Environment House Computer lab (15 seater)
DEA will provide the training material, data, computers and software (ArcGIS and Spatial analysis)

Title	Name	Surname	Organisation	E-mail	Tel	Plato Number	Day 1	Day 2	Day 3	Day 4	Day 5
✓ Mr	Simon	Moloele	Department of Water and Sanitation	moloeles@dwa.gov.za	012 336 6872						
Mr	Mark	Thompson	GeoTerraImage (Pty) Ltd	Mark.Thompson@geoterraimage	823307992	PGP050					
Mrs	Nicolene	Fourie	DEA	nfourie@environment.gov.za	123999293	PGP 1292/SA					
✓ Mrs	Kabelo	Mhlanga	DEA	Kmhlanga@environment.gov.za	012 399 9297	GT 1358					
✓ Miss	Elanie	van Staden	Gondwana Environmental Solutions	elanie@gesza.co.za	011 472 3112	PGP					
✓ Mr	Stuart	Martin	GeoTerraImage (Pty) Ltd	stuart.martin@geoterraimage.cor	079 491 8124	PGP0039					
✓ Miss	Patricia	Duncan	CD:NGI	patricia.duncan@drdlr.gov.za	216584470	PGP0126					
✓ Miss	Siphokazi	Mayekiso	CD:NGI	Siphokazi.Mayekiso@drdlr.gov.z	078 069 2053						
✓ Mr	Luncedo	Ngcofe	CD:NGI	luncedo.ngcofe@drdlr.gov.za	736000553						
✓ Mr	Sibonelo	Dlamini	CD:NGI	Sibonelo.Dlamini@drdlr.gov.za	767405246	GO817					
✓ Miss	Lenette	TSHIKOVH	DEA	Ltshikovhi@environment.gov.za	012 399 9298	SI0796					
✓ Mr	Ligwa Julius	SAKATA	DAFF	juliusS@daff.gov.za	012 3095867	GO867		hospital			

Ligwa Julius SAKATA

APPENDIX 2: Attendance register for half-day professional data users/managers' training session, DEA offices, 9 June 2015

Land Cover 2013/2014 Data Launch

Signed attendees 59 57

Attendance Register: Surnames A-K

Date of data launch: *9 June 2015*

Time:

Registration: *09:00 -09:45*

Launch: *10:00 - 12:15*

Technical session: *13h15 – 16:00*

Venue: *Department of Environmental Affairs, Environment House, Corner Soutpansberg and Steve Biko Roads, Pretoria.*

Name and Surname	Organisation	Email Address	Plato Registration	Signature
Mr Ishaam Abader	DEA	IAbader@environment.gov.za		
Mr Goke Akinnusi	Gauteng Department - Roads & Transport	olamigoke.akinnusi@gauteng.gov.za		
Mr Rob Anderson	STATISTICS SOUTH AFRICA	roba@statssa.gov.za	PGP0163	
Mr Lee Annamalai	CSIR	LAnnamalai@csir.co.za		
Ms Ingrid Booysen	University of Pretoria	Ingrid.Booysen@up.ac.za		
Mrs Adrie Borman	Ilifa Africa Consulting Engineers	a.borman@ilifa.biz	PGP0182	
Mr Andre Brand	STATISTICS SOUTH AFRICA	andreb@statssa.gov.za		
Mr André Breytenbach	CSIR	ABreytenbach@csir.co.za	PGP1197	
Mr Gitesh Brijman	Public Works	gitesh.brijman@dpw.gov.za	G0866	
Mr Sabelo Cele	STATISTICS SOUTH AFRICA	sabeloc@statssa.gov.za		
Mrs Thiru Chetty	DWS	chettyt@dwa.gov.za		
Dr Wisemen Chingombe	University of Fort Hare	wchingombe@ufh.ac.za		
Mr Dirk Cilliers	North West University	dirk.cilliers@nwu.ac.za		
Ms Nicolene Fourie	DEA - EGIM	nfourie@environment.gov.za	PGP	

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Name and Surname	Organisation	Email Address	Plato Registration	Signature
Dr Derek Clark	DRDLR: NGI	DClarke@ruraldevelopment.gov.za		
Mr Alan Cochran	ERM	alan.cochran@erm.com		
Mrs Sonja Coetsee	Eskom	coetses@eskom.co.za		
Mr Marius Coetzer	DARDLEA	mcoe.mpu@gmail.com		
Mr Sarel Coetzer	Gijima	sarel.coetzer@gijima.com		
Mrs Anneliza Collett	DAFF	AnnelizaC@daff.gov.za		
Mrs Fatima Coovadia	Rand Water	fcoovadi@randwater.co.za	PGP 1255	
Mrs Frances Craigie	DEA	fcraigie@environment.gov.za		
Mr Joe De Beer	STATSAS SOUTH AFRICA	JoedB@statssa.gov.za		
Mr Stanford de Jong	Computer Foundation	stanforddj@cf.co.za		
Mr Adri de la Rey	Eskom	dlreya@eskom.co.za		
Mrs Lizeth de la Rouviere	Sasol Mining	lizeth.delarouviere@sasol.com		
Miss Annette Dethioux	DWS	apl@dwa.gov.za	GT 0950	
Mrs Ndomupei Dhemba	ILISO Consulting	ndomupei@iliso.com		
Mr Ayanda Dlomo	Department of economic development , environmental affairs and tourism	Ayanda.dlomo@dedea.gov.za		
Mrs Coleen du Pessis	GISCOE	cduplessis@giscoe.com	to provide.	
Mrs Anina du Plessis	GISSA Gauteng	aninadh@gmail.com	G0759	
Mr Pierre du Plessis	CSIR	pduplessis@csir.co.za	G0804	
Mrs Lydia Du Toit	GIS Consultant	Lydiadt@mweb.co.za	PGP0175	
Miss Inge Erasmus	Hatch Goba Ltd	ierasmus@hatch.co.za		

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Name and Surname	Organisation	Email Address	Plato Registration	Signature
Mrs Karien Erasmus	Promethium Carbon	karien@promethium.co.za		
Miss Monja Esterhuizen	UWP Consulting	monjae@uwp.co.za	GISc Prof.	
Mrs Helene Ferreira-Fensham	The Presidency, DPME	Helene@presidency-dpme.gov.za	PGP072	
Miss Dee Fischer	DEA	DFischer@environment.gov.za		
Mr Alex Fortescue	DigitalGlobe Inc.	alex.fortescue@digitalglobe.com		
Mrs Helena Fourie	DRDLR (NSIF)	Helena.Fourie@drdlr.gov.za	PGP 0067	
Mrs Susan George	IAIAsa	president@iaiasa.co.za		
Mr Henno Gericke	DWS	gerickeh@dws.gov.za		
*Miss Nosihle Goba	STATISTICS SOUTH AFRICA	nosihleg@statssa.gov.za		
Mr Dirk Griesel	AAM Geomatics	d.griesel@aamgroup.com		
Mr Riaan Grobler	STATISTICS SOUTH AFRICA	RiaanG@statssa.gov.za		
Miss Zimasa Groom	Housing Development Agency	zimasa.groom@thehda.co.za		
Miss Zanele Gwala	Department of Mineral Resources	zanele.gwala@dmr.gov.za		
Mr Nkosiyethu Hadebe	City of Tshwane	nwhadebe@yahoo.com		
Prof Hamisai Hamandawana	University of Fort Hare	hhamandawana@ufh.ac.za		
Mr Mark Heunis	M S Heunis & Associates	msheunis@icon.co.za	VKW9169T	
Ms Sibusisiwe Hlela	DEA	Shlela@environment.gov.za		
Mr Bruce Humphries	Hatch Goba	bhumphries@hatch.co.za		
Dr Michelle Jackson	University of Pretoria	mjackson@zoology.up.ac.za		
Mrs Dorette Jacobs	DWS	jacobsd@dwa.gov.za	GT1151	

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Name and Surname	Organisation	Email Address	Plato Registration	Signature
Dr Dawie Jansen van Vuuren	MetroGIS	dawie@metrogis.co.za		
Mr Danzel Januarie	Mpumalanga Department of Economic Development and Tourism	djanuarie@mpg.gov.za		
Miss Janavi Jardine	Azzurro Environmental	janavilove@gmail.com		
Mrs Debbie Jewitt	Ezemvelo KZN Wildlife	Debbie.Jewitt@kznwildlife.com	Sacnasp.	
Mr Wandisile Kahlane	DRDLR	wandisile.kahlane@drdlr.gov.za		
Mr Matheri Kangethe	Agizo Solutions	matheri.kangethe@agizo.co.za	PR 1271	
Mr Aubrey Kekana	SANSA	akekana@sansa.org.za		
Mr Tebogo Kgongwana	DEA	tkgongwana@environment.gov.za		
Mrs Nqobile Khanyile	Department of Mineral Resources	nqobile.khanyile@dmr.gov.za		
Mr Vuyani Khweshiwe	Tokologo Local Municipality	khwesh@webmail.co.za		
Mrs Ester Koch	STATISTICS SOUTH AFRICA	esterk@statssa.gov.za		
Mr Francois Koegelenberg	Mpumalanga DARDLEA	francois.agric@gmail.com	PGP-1272	
Miss Andiswa Koya	DRDLR - NGI	Andiswa.Koya@drdlr.gov.za		
Mr Ubbo Kraak	NW Provincial - Office of the Premier	ukraak@nwpg.gov.za		
Dirk Grobbelaar ✓	Council for Geoscience.	dgrob@geoscience.org.za.		
Dr. Elhadi Adam ✓	Wits university -	Elhadi.Adam@wits.ac.za.		
N MASAKASI ✓	AGIZO Solution -	nondzuzo.masakasi@agizo.co.za		
Dr. S. Merlo ✓	WITS UNIVERSITY	stefania.merlo@wits.ac.za		
Norman R ✓	DRDLR	norman.rakhumba@drdlr.gov.za		

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Land Cover 2013/2014 Data Launch

Signed attendees (48)

Attendance Register: Surnames L - O

Date of data launch: *9 June 2015*

Time:

Registration: *09:00 -09:45*

Launch: *10:00 - 12:15*

Technical session: *13h15 – 16:00*

Venue: *Department of Environmental Affairs, Environment House, Corner Soutpansberg and Steve Biko Roads, Pretoria.*

Name and Surname	Organisation	Email Address	Plato Registration	Signature
Mr Molefe Lebethe	DEA	mlebethe@environment.gov.za		
Mr Madiga Lediga	DEA	lediga.madiga@gmail.com		
Miss Tshegofatso Lekgetho	YB Mashalaba & Associates Consultants	tshego@ybmac.co.za	GT1427	
Mr Hein Lindemann	DAFF	HeinL@daff.gov.za		
Mr Wolfgang Luck	Forest Sense	wolfluck@mweb.co.za		
* Mr Peter Lukey	DEA	Plukey@environment.gov.za		
Ms Lena Lukhele	SANParks	lena.lukhele@sanparks.org		
Mr Siyanda Lurwengu	DMR	siyanda.lurwengu@dmr.gov.za		
Mr Bongani Machabe	Gemini GIS and Environmental Services	bonganim@gges.co.za		
Mr Khathutshelo Mafenya	GDARD	Khathutshelo.mafenya@gauteng.gov.za		
Mr Mpho Makaleng	Tshwane University of Technology	makalengzm@gmail.com	GT1381	
Miss Cindy Makhathini	Gauteng Department of Agriculture and Rural Development	cindy.makhathini@gauteng.gov.za	GT1669	
Mrs Johanna Makinta	DAFF	JohannaMAK@daff.gov.za	GT1210	

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Name and Surname	Organisation	Email Address	Plato Registration	Signature
Miss Dorcas makoe	Gemini GIS and environmental services	dorcasm@gges.co.za		
Avhurengwi Malange	LEDET	malangeab@ledet.gov.za		
Mr Michael Malema	GDARD	Mike.Malema@gauteng.gov.za		
Miss Anna Mampye	DEA	amampye@environment.gov.za		
* Mrs Wadzi Mandivenyi	DEA	wmandivenyi@environment.gov.za	Loshudufhala Katana attended in her place *	
Mr Tebogo Mapulana	DWS	mapulanaj@dwa.gov.za		
Mr Deon Marais	DEA	Dmarais@environment.gov.za		
Mr Ndifelani Mararakanye	Department of Agriculture, Rural Development, Land and Environmental Affairs (DARDLEA)	nmararak@gmail.com	G0813	
Mr Stuart Martin	GeoTerraImage (Pty) Ltd	stuart.martin@geoterraimage.com	PgP0039	
Mr David Masango	DEA	DMasango@environment.gov.za		
Mrs Nosiseko Mashiyi	SANSA	nmashiyi@sansa.org.za	→	
Mrs Matsatsi Masungwini	STATISTICS SOUTH AFRICA	matsatsis@statssa.gov.za		*
Mrs Mercy Matheri	STATISTICS SOUTH AFRICA	mercym@statssa.gov.za		
Mr Odirile Matsobe	Eskom	matsobol@eskom.co.za		
Miss Namhla Mbona	SANBI	n.mbona@sanbi.org.za		
Mr Patrick Mc Kivergan	Esri South Africa	dschulz@esri-southafrica.com		
Mr Siyabonga Mdubeki	DRDLR	siyabonga.mdubeki@drdlr.gov.za		
Mr Feleke Mekiso	Tshwane University of Technology	badogom@gmail.com	NA	
Mr Bruno Meyer	SANSA	bmeyer@sansa.org.za		
Mrs Kabelo Mhlanga	DEA	kmhlanga@environment.gov.za		

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Name and Surname	Organisation	Email Address	Plato Registration	Signature
Mrs Alta Minaar	HATCH GOBA	aminnaar@hatch.co.za	GT1220	
Miss Luna Mjulwa	Department of Public Works	Luna.Mjulwa@dpw.gov.za	G0891	
Mr Mziyanda Mkosana	Department of Economic Development, Environmental Affairs and Tourism	Mziyanda.Mkosana@dedea.gov.za		
*Mr Coster Mmofele	STATISTICS SOUTH AFRICA	costerm@statssa.gov.za		
Mr Neo Benedict Mmutle	Nala municipality	bmmutle@nala.org.za		
Mr Jacob Modiba	Anglo American Platinum	Jacob.modiba@angloamerican.com		
Mr Seakalala John Mojapelo	STATISTICS SOUTH AFRICA	Johnmoj@statssa.gov.za		
Mr Tshegofatso Monama	Square Kilometre Array (SKA)	temonama@ska.ac.za		
* Mrs Marlanie Moodley	DEA	MMoodley@environment.gov.za		
Dr Theunis Morgenthal	DAFF	theunism@daff.gov.za		
Mr Walter Morobe	DAFF	KapengM@daff.gov.za		
Mr Alan Moss	Ilifa Africa Consulting Engineers	a.moss@ilifa.biz		
Mrs Tsatsi Mthimunye	DTPS	emthimunye@dtps.gov.za		
Ms Nale Mudau	SANSA	nmudau@sansa.org.za		
* Miss Sizakele Verona Myeni	DRDLR	sizakeleverona@yahoo.com	GT1509	
Miss Phumla Mzazi	Department of Economic Development, Environmental Affairs and Tourism	phumla.mzazi@dedea.gov.za		
Mr Yogan Naidoo	HERE	yogan.naidoo@here.com		
Mr Mervin Naik	KZN-COGTA	mervin.naik@kzncogta.gov.za		
Mr Mduduzi Ndlovu	GDARD	mduduzi.ndlovu@gauteng.gov.za		
Mr Ronald Nenungwi	DEA	rnenungwi@environment.gov.za		

Name and Surname	Organisation	Email Address	Plato Registration	Signature
Mr Terry Newby	ARC	terry@arc.agric.za		
Miss Dawn Newman	Enterprise Proppeller	newman.dawn@gmail.com		
Miss Sethabile Ngcobo	Emendo Inc	gisoffice@emendo.co.za		
Mrs Bulelwa Ngobeni	DEA	BuNgobeni@environment.gov.za		
Mr Andile Sifiso Nkontwana	KZN Department of Economic Development, Tourism & Environmental Affairs	andile.sifiso@kzndard.gov.za		
Mr Wandile Nomquphu	Water Research Commission	wandilen@wrc.org.za		
Mr Simphiwe Ntozini	Exxaro Resources LTD	simphiwe.ntozini@exxaro.com		
Mr Derick O'Brien	City of Tshwane, Coporate GIS	dericko@tshwane.gov.za	PSL0458	
HUMBELANI MUSWARI	DARDLEA	humbelanibrenny@gmail.com		
CHABALALA JINGISANI	WITS UNIVERSITY	yingisani.chabalala@wits.ac.za		
Tsetsele Motsele	NWPTB	brothusiamuptb.ca.za		
Rashudufhala Kutama	DEA	SKutama@environment.gov.za		
HENRY NKOSI	ESRI SA	hnkosi@esri-southafrica.com		
VUSI MALULEKE	LEDET	Malulekev@ledet.gov.za		
WILLIE MOTHAPO	LEDET	Mothaposw@ledet.gov.za		
Rhulani Mthombeni	LEDET	Mthombenir@ledet.gov.za		
Trevor Mphahlele	LEDET	mphahlelet@ledet.gov.za		
Simon Moloele	DWS	moloeles@dwa.gov.za		
Etienne Louw	TomTom	etienne.louw@tomtom.com		

Completed updated data launch attendance list 2013-14

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Land Cover 2013/2014 Data Launch

Signed attendees: 48

Attendance Register: Surnames P - Z

Date of data launch: *9 June 2015*
Time:

Registration: *09:00 -09:45*
Launch: *10:00 - 12:15*
Technical session: *13h15 – 16:00*

Venue: *Department of Environmental Affairs, Environment House, Corner Soutpansberg and Steve Biko Roads, Pretoria.*

Name and Surname	Organisation	Email Address	Plato Registration	Signature
Mr Robert Parry	STATISTICS SOUTH AFRICA	robertp@statssa.gov.za		
Mr Hugo Paul	MHP Geomatics	hugo@mhpgeo.co.za	No	
Mr Arno Pelser	YB Mashalaba & Associates	arno@ybmac.co.za	No	
Mrs Tankiso Phidza	Gemini GIS and Environmental Services	tankisop@gges.co.za		
Mr Pregan Pillay	DBSA	PreganP@dbsa.org	NO	
Mrs Prenesha Pillay	GISNET	prenesha@gisnet.co.za		
Dr Rajendran Pillay	University of Fort Hare	rpillay@ufh.ac.za		Pillay.
Mrs Erika Pretorius	University of Pretoria	erika.pretorius@up.ac.za	No.	
Dr Rudi Pretorius	DEA	rpretorius@environment.gov.za	no	
*Miss Mittah Raditlhalo	STATISTICS SOUTH AFRICA	mittahr@statssa.gov.za	PGP: 0184	
Mr Tlou Ramaru	DEA	tramaru@environment.gov.za		
Mrs Erine Rawlinson	ESKOM	rawline@eskom.co.za	GT ??	

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Name and Surname	Organisation	Email Address	Plato Registration	Signature
Mr Hadley Remas	Housing Development Agency	hadley.remas@thehda.co.za		
Mr Ernst Retief	BirdLife South Africa	ernst.retief@birdlife.org.za		
Prof Francois Retief	NWU	francois.retief@nwu.ac.za		
Mr Mmuso Riba	DRDLR	Mriba@csg.pwv.gov.za		
Miss Joretha Rossouw	AAM Geomatics	j.rossouw@aamgroup.com	ST 1293	Rossouw.
Mr Imraan Saloojee	SANSA	isaloojee@sansa.org.za		
Mr Ray Schaller	NWPG	rschaller@nwpg.gov.za		
Mr Daniel Sebake	Municipal Demarcation Board	dsebake@gmail.com		
Miss Tumisang Sebitloane	DST	tumisang.sebitloane@dst.gov.za		
Miss Lerato Segooa	Agizo Solutions	lerato.segooa@agizo.co.za		
Miss Mahlogonolo Sekhukhune Sekhukhune	DEA	msekhukhune@environment.gov.za		
Mr Setsoto Sekonyela	YB Mashalaba & Associates	setsoto@ybmac.co.za		
Mrs Bulelwa Semoli	DRDLR - NGI	bulelwa.semoli@drdlr.gov.za	no	
Mr Sydney Shikwambana	DAFF	SydneyS@daff.gov.za		
Mr Sipho Sibanyoni	DEA	ssibanyoni@environment.gov.za		
Mrs Andiswa Silinga	Gemini GIS and environmental services	andiswas@gges.co.za		
Mr Perseverance Sisilana	Rural Development & Agrarian Reform- Eastern Cape	sisilapk@gmail.com	YES	
Mrs Tania Smith	DPW	tania.smith@dpw.gov.za		TSmith
Ms Bettie Souls	DWS	Soulsb@dwa.gov.za		
Mr Robert Stegmann	Department of Economic Development, Environmental Affairs and Tourism	Robert.Stegmann@dedea.gov.za		

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Name and Surname	Organisation	Email Address	Plato Registration	Signature
Miss Heather Terrapon	SANBI	H.Terrapon@sanbi.org.za		
Mr Christopher Thela	DEA	Cthela@environment.gov.za	GT 1180	
Mr Mark Thompson	GeoTerraImage	mark.thompson@geoterraimage.com	FGP0050	
Miss Mandisa Tontsi	Germini GIS and Environmental Services	mandisat@gges.co.za	IN PROGRES	
Mr Garth Truter	Sasol Mining	garth.truter@sasol.com	~~8f~~ YES	
Ms Asiashu Lenette Tshikovhi	DEA	Ltshikovhi@environment.gov.za	ST0796	
Mr Terence Turnbull	South African Air Force	tvturnbull@gmail.com	Yes	
Mr Jan van den Berg	City of Tshwane	Janneman@Tshwane.gov.za		
Miss Cecily van der Berg	DEA	CVDBerg2@environment.gov.za		
Mr Andre Van der Merwe	Dept Environmental Affairs and Development Planning	andre.vandermerwe@westerncape.gov.za		
Ms Chantal van Eeden	DEA	Cveeden@environment.gov.za		
Prof Adriaan Van Niekerk	Stellenbosch University	Avn@sun.ac.za	YES	
Miss Antoinette van Niekerk	Hatch Goba	antoinette.vanniekerk@hatch.co.za		
Mrs Clare Van Zwieten	EE Publishers	clare.vanzwieten@ee.co.za	NO	
Mr Dawie Van Zyl	Manstrat	dawie@manstrat.co.za		
Mr Sindisa Vanda	DEDEAT	Sindisa.Vanda@dedea.gov.za		
Mr Thomas Vanner	Department of Roads and Transport	thomas.vanner@gauteng.gov.za		
Mr Francois Venter	Gauteng Health	francoisv2@gpg.gov.za	yes.	
Mr Jan Venter	DARDLEA	jv16@telkomsa.net		
Mrs Helene Verhoef	STATISTICS SOUTH AFRICA	helenev@statssa.gov.za		

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Name and Surname	Organisation	Email Address	Plato Registration	Signature
Mr Ruan Verster	MHP Geomatics	ruan@mhpgeo.co.za	GT0952	
Mr Bennie Viljoen	DWS	viljoenb@dws.gov.za	6 084 (yes)	
Mr Tom Vorster	DAFF	tomv@daff.gov.za		
Mr Andrew Wannenburgh	DEA-WfW	AWannenburgh@environment.gov.za		
Mrs Lauren Williams	DEA	lwilliams@environment.gov.za		
Mr Alf Wills	DEA	awills@environment.gov.za	G0832	
Miss Elsie Zwennis	GeoTerraImage (Pty) Ltd	elsie.zwennis@geoterraimage.com		
Dr Konrad Wessels	CSIR	kwessels@csir.co.za	—	
Karen Steenkamp	CSIR	~~ksteenkamp~~ ksteenkamp@csir.co.za		
Mr Bongani Machabe	GGES	banganim@gges.co.za		
Ms Dorcas Makoe	GGES	dorcasm@gges.co-za		

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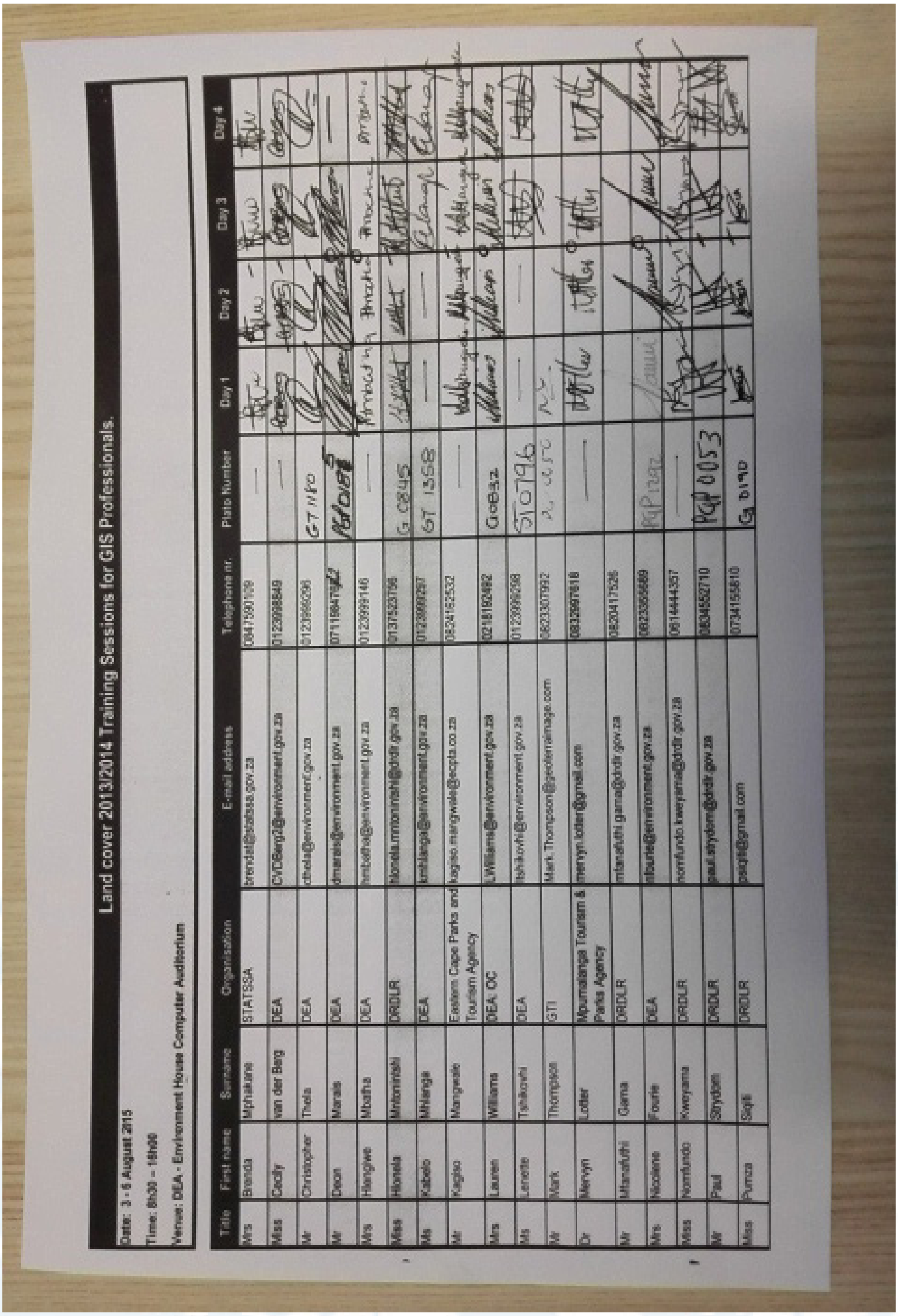
APPENDIX 3: Attendance register for four-day professional GIS data users' training session, DEA offices, 3 to 6 August 2015



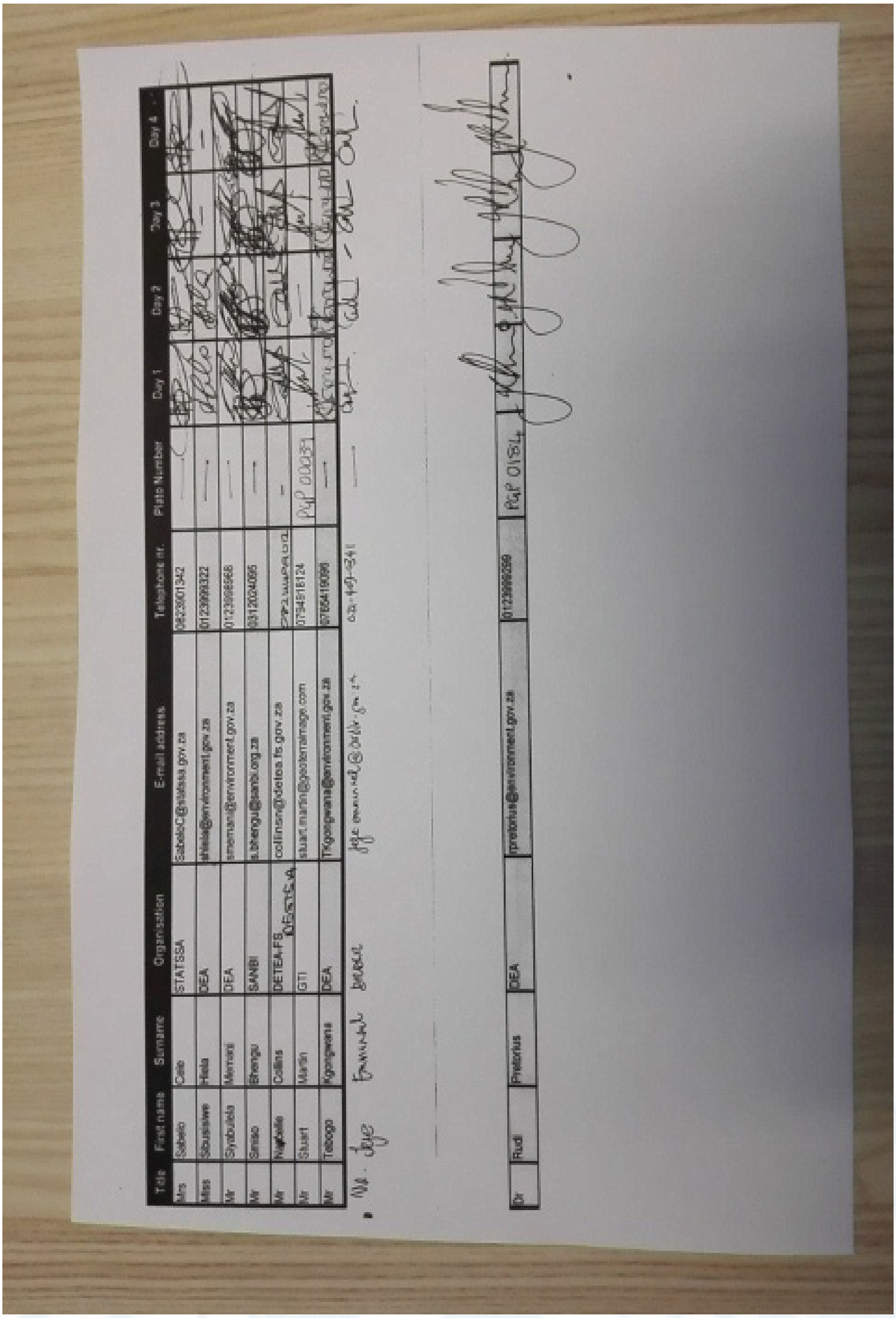
Land cover 2013/2014 Training Sessions for GIS Professionals.

Date: 3 - 6 August 2015

Time: 8h30 – 16h00

Venue: DEA - Environment House Computer Auditorium

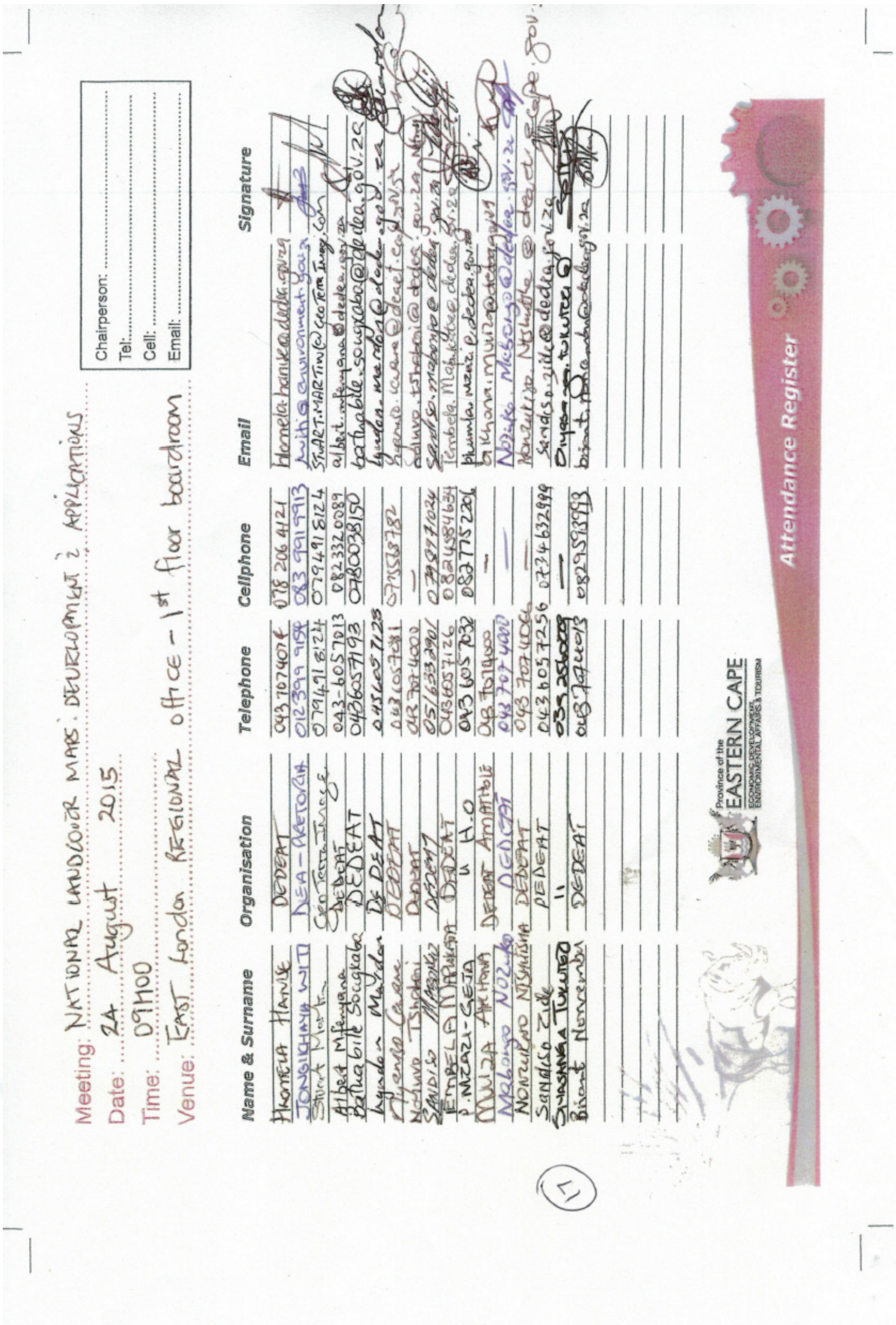
Title	First name	Surname	Organisation	E-mail address	Telephone nr.	Plato Number	Day 1	Day 2	Day 3	Day 4
Mrs	Brenda	Mphakane	STATSSA	brendat@statssa.gov.za	0847590109	—				
Miss	Cecily	van der Berg	DEA	CVDBerg2@environment.gov.za	0123998849	—				
Mr	Christopher	Thela	DEA	cthela@environment.gov.za	0123999296	GT 1180				
Mr	Deon	Marais	DEA	dmarais@environment.gov.za	0711984762	PGP0185				—
Mrs	Hlengiwe	Mbatha	DEA	hmbatha@environment.gov.za	0123999146	—				
Miss	Hlonela	Mntonintshi	DRDLR	hlonela.mntonintshi@drdlr.gov.za	0137523756	G 0845				
Ms	Kabelo	Mhlanga	DEA	kmhlanga@environment.gov.za	0123999297	GT 1358	—	—		
Mr	Kagiso	Mangwale	Eastern Cape Parks and Tourism Agency	kagiso.mangwale@ecpta.co.za	0824162532	—				
Mrs	Lauren	Williams	DEA: OC	LWilliams@environment.gov.za	0218192492	G0832				
Ms	Lenette	Tshikovhi	DEA	ltshikovhi@environment.gov.za	0123999298	ST0796	—	—		
Mr	Mark	Thompson	GTI	Mark.Thompson@geoterraimage.com	0823307992					
Dr	Mervyn	Lotter	Mpumalanga Tourism & Parks Agency	mervyn.lotter@gmail.com	0832997618	—				
Mr	Mtanafuthi	Gama	DRDLR	mtanafuthi.gama@drdlr.gov.za	0820417526					
Mrs	Nicolene	Fourie	DEA	nfourie@environment.gov.za	0823365689	PGP1292				
Miss	Nomfundo	Kweyama	DRDLR	nomfundo.kweyama@drdlr.gov.za	0614444357	—				
Mr	Paul	Strydom	DRDLR	paul.strydom@drdlr.gov.za	0834552710	PGP 0053				
Miss	Pumza	Siqiti	DRDLR	psiqiti@gmail.com	0734155810	G 0190				



Title	First name	Surname	Organisation	E-mail address	Telephone nr.	Plate Number	Day 1	Day 2	Day 3	Day 4
Mrs	Sabelo	Cele	STATSSA	SabeloC@statssa.gov.za	0823601342	—				
Miss	Sbusisiwe	Hlela	DEA	shlela@environment.gov.za	0123999322	—				
Mr	Siyabulela	Memani	DEA	smemani@environment.gov.za	0123998968	—				
Mr	Siniso	Bhengu	SANBI	s.bhengu@sanbi.org.za	0312024095	—				
Mr	Ngubele	Collins	DETEA-FS DESTEA	collinsn@detea.fs.gov.za	[illegible]	—				
Mr	Stuart	Martin	GTI	stuart.martin@geoterraimage.com	0794518124	PGP 000BL				
Mr	Tebogo	Kgongwana	DEA	TKgongwana@environment.gov.za	0765419095	—				
Mr.	Jaye	[illegible]	[illegible]	[illegible]@[illegible].gov.za	012-[illegible]-3241	—				
Dr	Rudi	Pretorius	DEA	rpretorius@environment.gov.za	0123999099	PGP 015L				

APPENDIX 4: Photograph of half-day training session at Geomatics Indaba Conference, 12 August 2015

APPENDIX 5: Attendance register for one-day environmental specialists' GIS data users' training session, East London DEA regional offices, 24 August 2015



Meeting: NATIONAL LANDCOVER MAPS: DEVELOPMENT & APPLICATIONS
Date: 24 August 2015
Time: 09H00
Venue: EAST London REGIONAL office – 1st floor boardroom

Chairperson:
Tel:
Cell:
Email:

Name & Surname	Organisation	Telephone	Cellphone	Email	Signature
Hlomela Hanise	DEDEAT	043 7074074	078 206 4121	hlomela.hanise@dedea.gov.za	
JONGIKHAYA WITI	DEA – PRETORIA	012 399 9159	083 9919913	jwiti@environment.gov.za	
Stuart Martin	GeoTerraImage	079 491 8124	079 491 8124	STUART.MARTIN@GEOTERRAIMAGE.COM	
Albert Mfenyana	DEDEAT	043-6057013	0823320089	albert.mfenyana@dedea.gov.za	
Bathabile Songxaba	DEDEAT	0436057193	0780038150	bathabile.songxaba@dedea.gov.za	
Lyndon Mardon	DEDEAT	0436057123		lyndon.mardon@dedea.gov.za	
Nyameko Cewane	DEDEAT	0436057081	0735568782	nyameko.cewane@deaet.ecape.gov.za	
Noluvo Tshabeni	DEDEAT	043 707 4000	–	noluvo.tshabeni@dedea.gov.za	
SANDISO MABONGO	DEDEAT	051 633 2901	0798971024	sandiso.mabongo@dedea.gov.za	
TEMBELA MAPUKATA	DEDEAT	0436057126	0824584634	Tembela.Mapukata@dedea.gov.za	
P. MZAZI-GEJA	" H.O	043 605 7032	0827752206	phumla.mzazi@dedea.gov.za	
MUIZA AKHONA	DEDEAT AMATHOLE	043 7074000	–	akhona.muiza@dedea.gov.za	
Mabongo Nozuko	DEDEAT	043 707 4000	–	Nozuko.Mabongo@dedea.gov.za	
NONZUKISO NTSHUTSHA	DEDEAT	043 707 4066	–	Nonzukiso.Ntshutsha@deaet.ecape.gov.za	
Sandiso Zide	DEDEAT	0436057256	0734632999	sandiso.zide@dedea.gov.za	
SIYASANGA TUKUTEZ	"	039 2560029	–	Siyasanga.tukutezi@	
Briant Nonyembu	DEDEAT	0437074013	0829593993	briant.nonyembu@dedea.gov.za	

(17)

Province of the EASTERN CAPE
ECONOMIC DEVELOPMENT, ENVIRONMENTAL AFFAIRS & TOURISM

Attendance Register

GEOTERRA IMAGE

The project was funded by the Department for International Development (DFID), UK Government

UKaid from the British people

Department of Environmental Affairs

Environment House
473 Steve Biko
Arcadia
Pretoria, 0083
South Africa

DEA call centre:
+27 86 111 2468