1990

REPORT

South African National Land-cover Dataset

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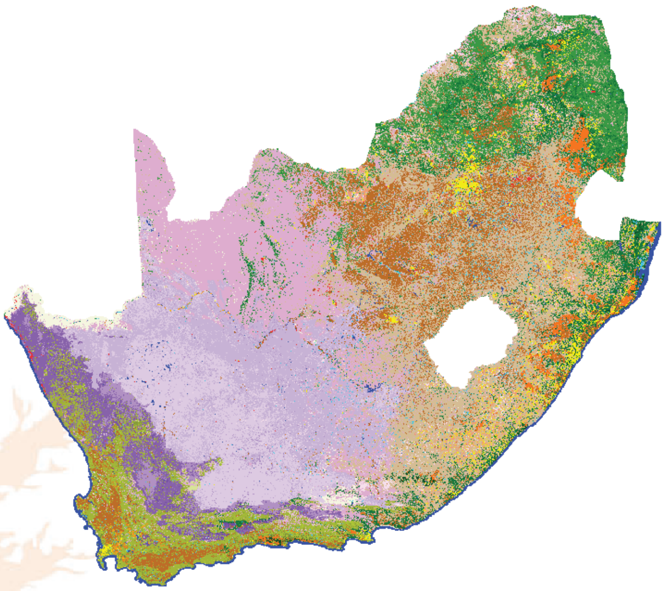
REPORT

GEOTERRA IMAGE

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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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[1] 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

1 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[2] 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.

2 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[3]. 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.

3 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.

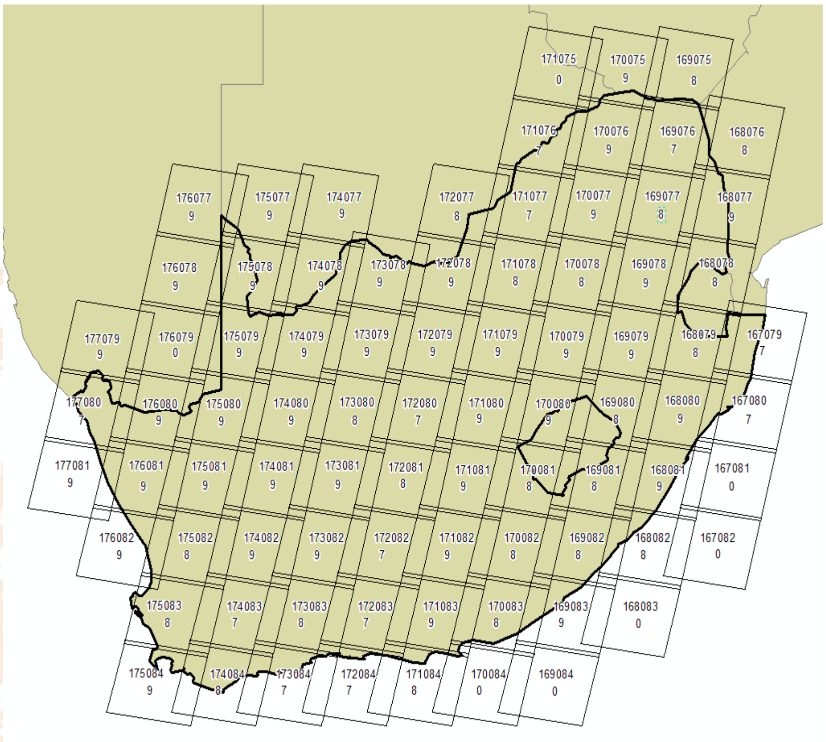

Figure 2 illustrates the date range of the multi-seasonal images used in the processing of each image frame.

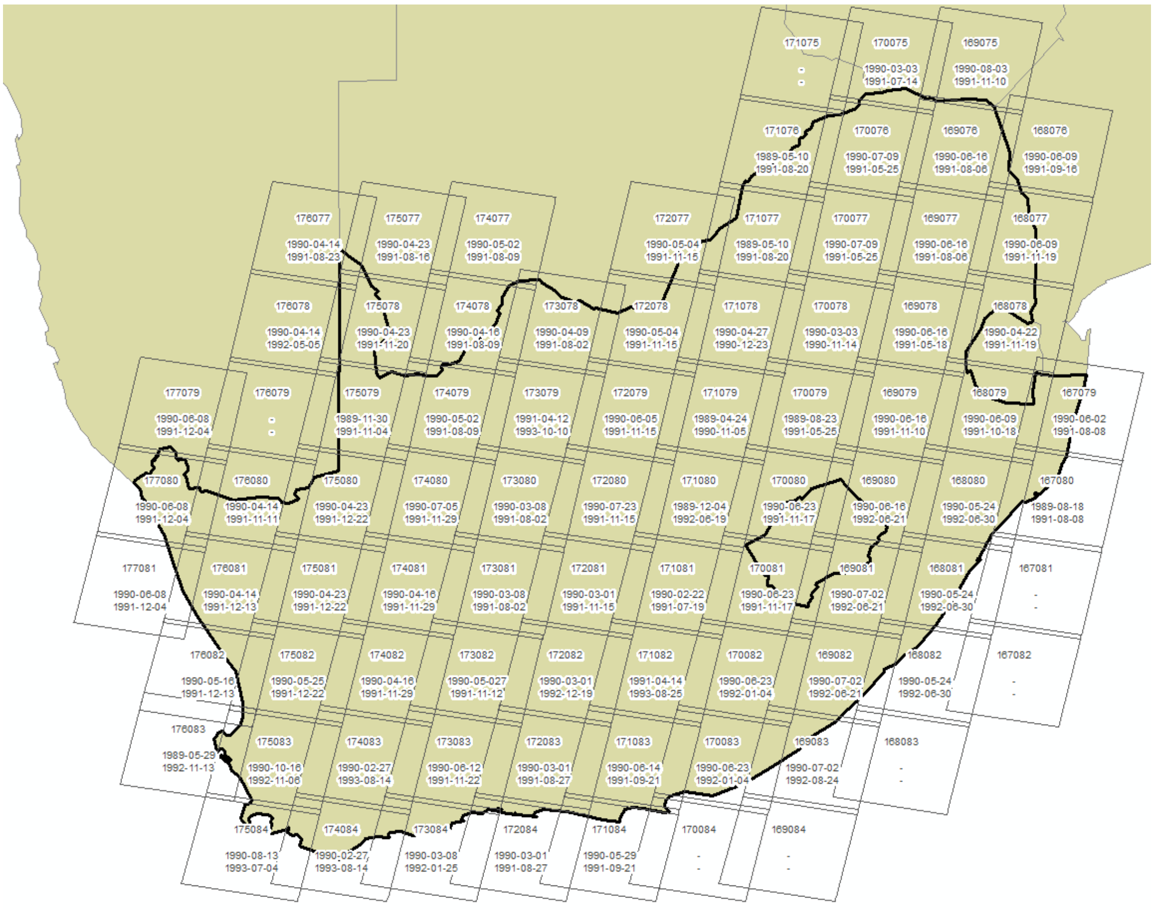

Figure 2. First and last image-acquisition dates used per frame in the production of the 1990 land-cover data.

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[4]. 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).

4 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[5]. 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

5 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/Landsat 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[6], 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[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.

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).

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 spectral bands.

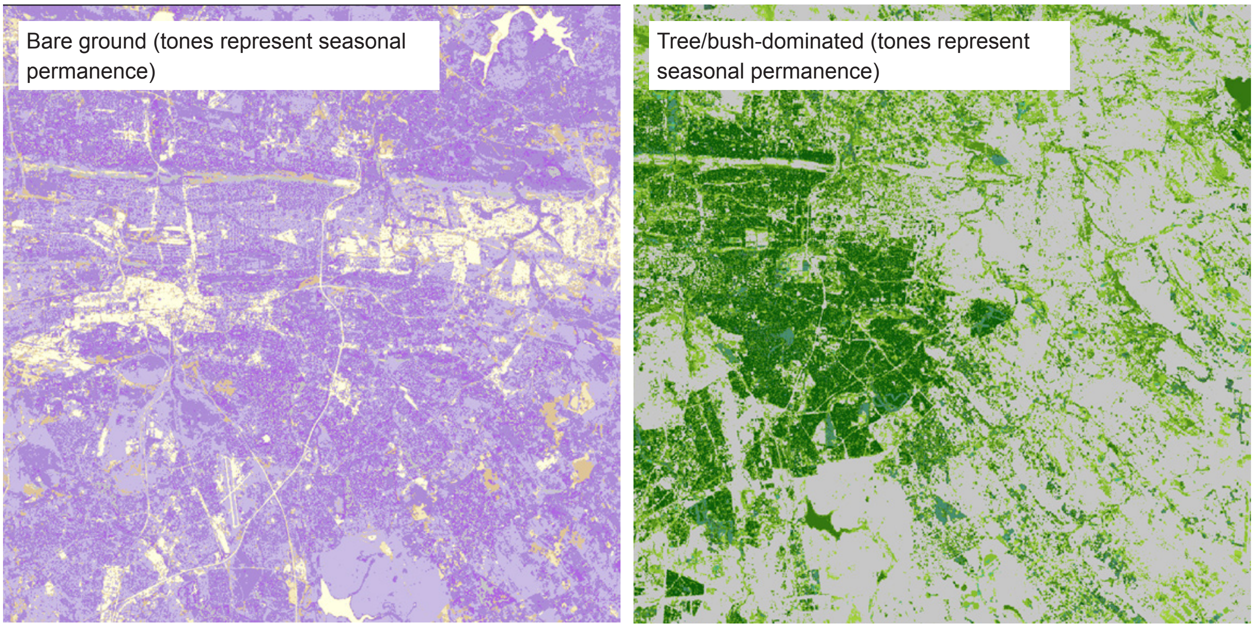

Figure 3. Spectral index-derived model outputs for bare ground and tree/bush-dominated foundation cover classes over eastern Pretoria (frame 170-078).

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[8], 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.

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 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).

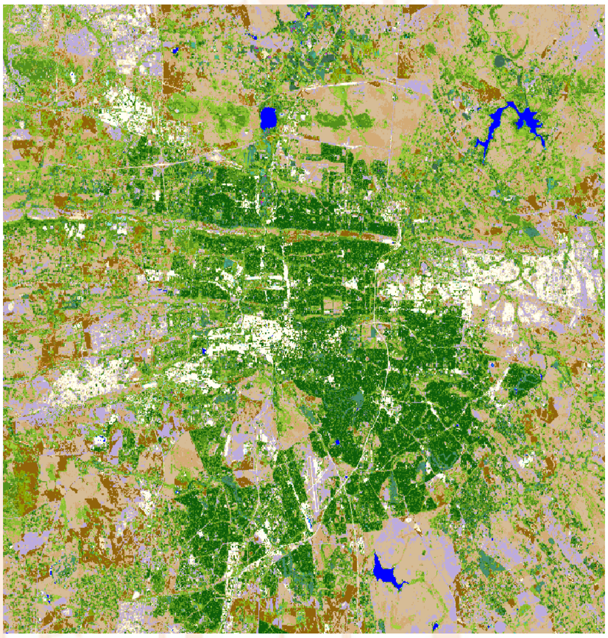

Figure 4. Interim spectral land-cover product after combining all the seasonally defined foundation cover classes (eastern Pretoria, frame 170-078).

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.

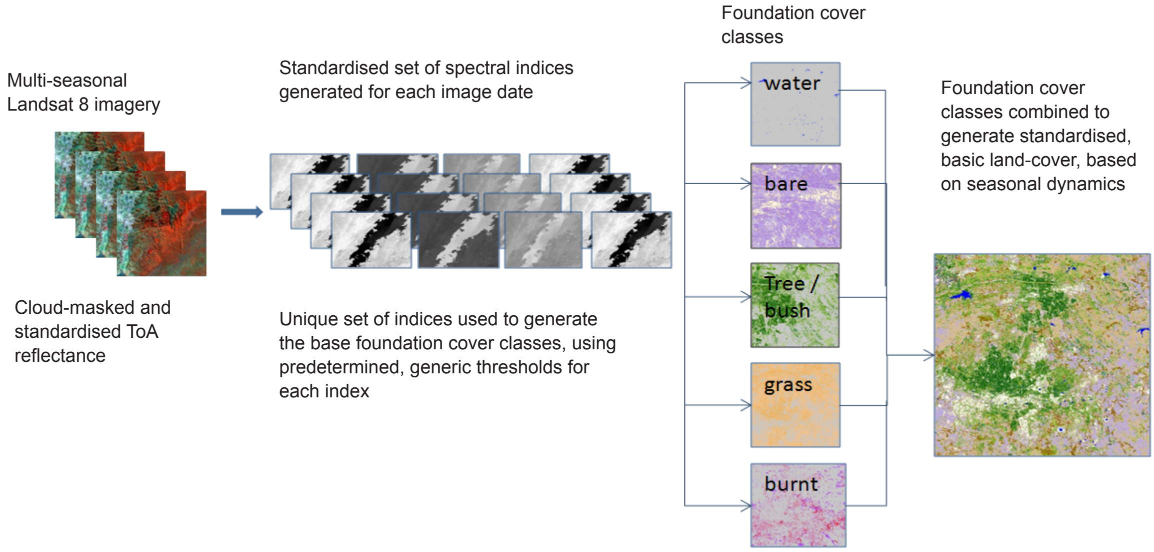

Figure 5. Summary of the full spectral land-cover modelling process.

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.

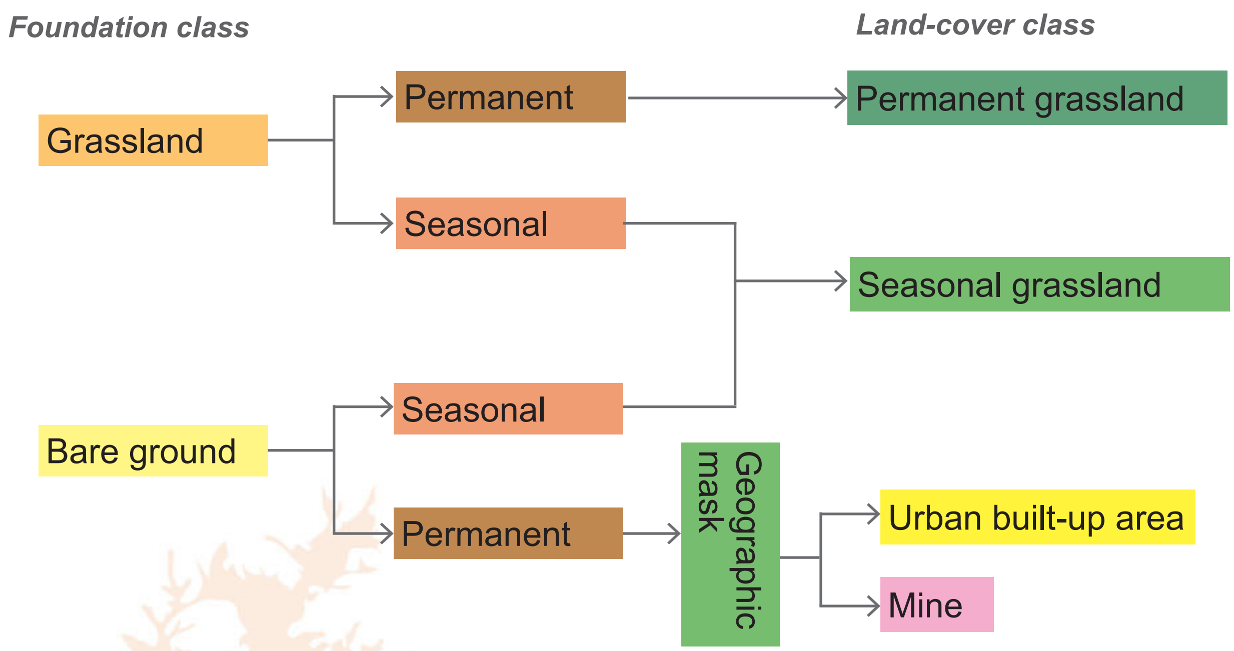

Figure 6. Processing pathways for converting spectral foundation classes to land-cover/ land-use information classes, based on seasonal permanence and shared spectral characteristics.

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[9] 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 the fynbos: low shrubland

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, is often considerably more accurate on a local scale, even down to the nearest 100 m in some cases.

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[10]. 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[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 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

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 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 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[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 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

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 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[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].

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.

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 in 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.

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)

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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 perm		Cultivated commercial perm	313572	3484129
9		Cultivated commercial perm		Cultivated commercial perm	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 bus		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

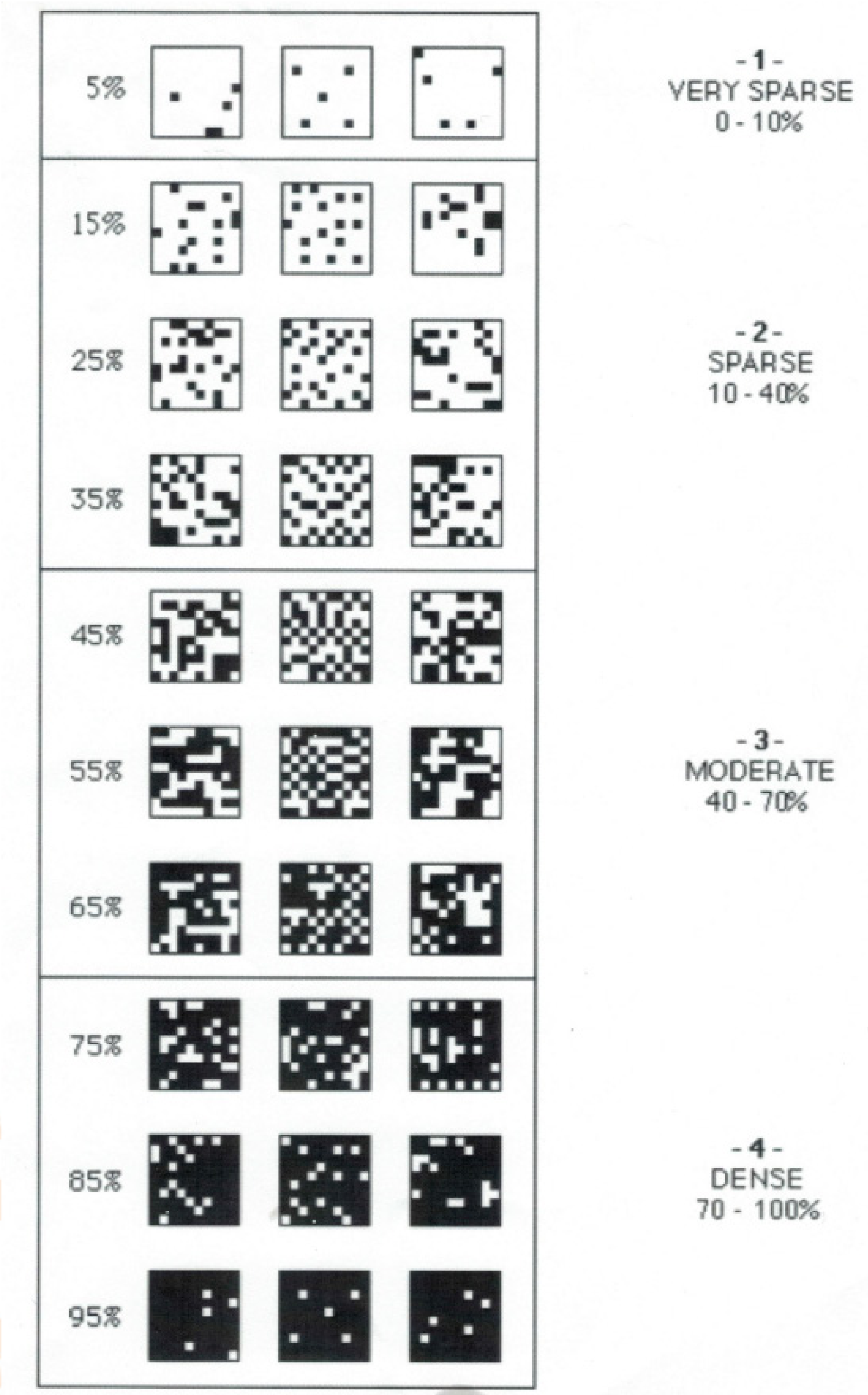
APPENDIX B: List of accompanying documents and files

- 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



GEOTERRA IMAGE

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