GEOGRAPHICAL INFORMATION SYSTEM FOR INTEGRATED MANAGEMENT OF AGRICULTURE AND THE ENVIRONMENT

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Thesis presented in fulfilment of the requirements for the degree of Master of Sciencein the Faculty of Science at Stellenbosch University.

Pectora roborant cultus recti

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December 2014

DECLARATION

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ABSTRACT

The agricultural sector plays a valuable role in the South African economy. However, agriculture is embedded in the natural environment. The research problem revolves around the lack of an information management system, capable of integrated agricultural and environmental management to promote sustainable agricultural development on farm level. This study aimed to develop a spatial information management system to aid with integrated agricultural and environmental management. The study area consisted of a seven-farm production unit, Howbill Properties, which provided the necessary agricultural and environmental elements for this study.

Spatial data requirements were identified by unpacking the relevant imperatives directing integrated agricultural and environmental management. Data was collected with a recreational outdoor GPS device, digitised from remotely sensed images and obtained from various sources. Spatial data consisted of infrastructure data, such as water pumps, power lines, and fruit orchard boundaries, whereas environmental spatial data consisted of natural resource data, and topographic data.

The study further details the process of selecting the necessary components for an enterprise GIS and building the system. PostgreSQL with the PostGIS spatial extension was selected as the spatial database and QGIS was selected as the desktop GIS application.

It was found that the prototype integrated spatial information system could be effectively applied to assist integrated agricultural and environmental management. The prototype spatial information system was able to serve the needs of novice to advanced users. However, insufficient spatial data were identified as a limitation, and spatial data should be improved and updated regularly.

Key words and phrases: Spatial information management system, GIS, sustainable agricultural development, natural resources, open source software

OPSOMMING

Landbou speel ‘n belangrikke rol in die Suid-Afrikaanse ekonomie. Landbou is egter vervat in die natuurlike omgewing. Die probleem wentel om die gebrek aan 'n geografiese inligtingstelsel wat in staat is om geïntegreerde landbou- en omgewingsbestuur op plaasvlak te bevorder. Hierdie studie het ten doel gehad om 'n ruimtelike inligtingsbestuurstelsel te ontwikkel om die voorafgaande probleem aan te spreek. Die studie area bestaan uit 'n sewe-plaas produksie-eenheid, Howbill Properties, wat die nodige landbou- en omgewingselemente vir hierdie studie bevat het.

Ruimtelike datavereistes is geïdentifiseer deur die relevante internasionale, nasionale, provinsiale, en mark vereistes wat geïntegreerde landbou en omgewingsbestuur rig, te ondersoek. Data is ingesamel met 'n behulp van ‘n GPS-toestel, gedigitaliseer van afstandswaarnemingsdata en ingesamel van verskeie bronne. Ruimtelike data het bestaan uit infrastruktuur data, soos water pompe, kraglyne, en vrugte boord grense, terwyl die ruimtelike omgewing data bestaan het uit natuurlike hulpbron data en topografiese data. Verder behandel die studie die proses van hoe die nodige komponente vir 'n ondernemings GIS gekies was en hoe die stelsel ontwikkel was. PostgreSQL met die PostGIS ruimtelike uitbreiding is gekies as die ruimtelike databasis en QGIS is gekies as die GIS program.

Daar is gevind dat die prototipe geïntegreerde ruimtelike inligtingstelsel doeltreffend toegepas kan word vir geïntegreerde landbou en omgewingsbestuur. Die prototipe ruimtelike inligtingstelsel was in staat om aan die behoeftes van ‘n beginner gebruiker sowel as gevorderde gebruikers te voorsien. Daar was ook bevind dat onvoldoende ruimtelike data die stelsel beperk, en dat data sal voordurend verbeter en opgedateer moet word.

Sleutelwoorde en frases: Ruimtelike inligtingstelsels, GIS, volhoubare landbou-ontwikkeling, natuurlike hulpbronne, oopbron sagteware

ACKNOWLEDGEMENTS

I would like to thank the following people for their support during the process of writing this thesis:

- Mr. Raymond Gibson for his hospitality during the field trip and making available his farm for this study.
- Professor Van Der Merwe for his patience.
- Inge for her support.

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ACRONYMS

CN	CapeNature
CSV	comma separated values
GPS	global positioning system
CARA	Conservation of Agricultural Resources Act
CBD	Convention on Biological Diversity
CDNGI	Chief Directorate: National Geo-spatial Information
CGA	Centre for Geographical Analysis
CPCC	control points and compliance criteria
DEADP	Department of Environmental Affairs and Development Planning
DEM	digital elevation model
EGNOS	European Geostationary Navigation Overlay Service
FAO	Food and Agriculture Organisation
FMDP	(CAPE) Fire Management Data Project
GAP	good agricultural practices
GHP	good handling practices
GISIMAE	Geographical information system for integrated management of agriculture and the environment
GlobalG.A.P.	Global Good Agricultural Practice (International standard for)
GMP	good manufacturing practices
GPS	global positioning system
GPX	GPS exchange
GCBC	Greater Cederberg Biodiversity Corridor
GUI	graphical user interface
IPCC	Intergovernmental Panel on Climate Change
NDVI	normalised difference vegetation index
NEMA	National Environmental Management Act
NEMBA	National Environmental Management: Biodiversity Act
NGI	National Geo-spatial Information
NWA	National Water Act
OGC	Open Geospatial Consortium
PGA	PostgreSQL Admin 3
RMSE	root mean square error

RS	remote sensing
SANBI	South African National Biodiversity Institute
SANSA	South African National Space Agency
SBAS	satellite based augmentation system
SPOT	System Pour l'Observation de la Terre
SQL	structured query language
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
WBFC	Walker Bay Fynbos Conservancy
WCDA	Western Cape Department of Agriculture
WfWP	Working for Wetlands Project
WMO	World Meteorological Organisation
WMP	Wildlife Management Project

CHAPTER 1: SUSTAINABLE AGRICULTURE AND GIS

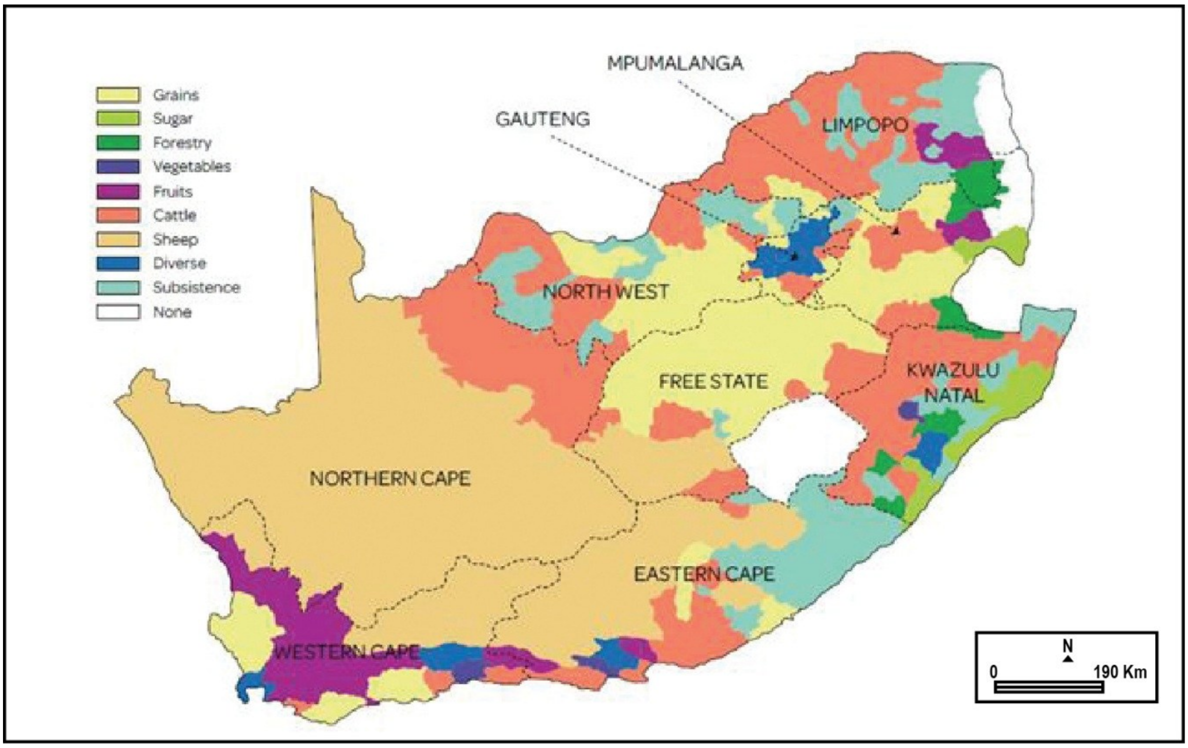
Geographical information systems (GIS) have become ubiquitously applied in a host of management fields dealing with spatially distributed information. However, while GIS have become an accepted vehicle for recording, storing, organising and ordered retrieval of spatially related information, the innovative application of the technology's analytical functionality in particular applied fields to support decision-making and industry operations, have lagged behind. Managing commercial agricultural operations and environmental management in an integrated manner in South African agriculture offers a case in point. In this chapter this challenge is developed into a research problem, followed by the standard research aim and objective formulation, the study area description, an overview of the methodology and project design applied.

1.1 CHALLENGES TO AGRICULTURAL CONDUCT IN SOUTH AFRICA

Conducting agriculture sustainably is determined by its strategic role and importance in a country's economy and the natural and organisational framework within which it is exercised. The next subsections sketch the spatial nature of South African agriculture, the symbiosis with its natural setting, particular challenges inherent to sustainability in this African setting and the management challenges to which spatial technology might contribute.

1.1.1 The spatial nature of South African agriculture

South Africa is located at the southern extreme of the African continent and has an estimated area of 121.9 million ha, of which 81% is used for agriculture. Only 13% of the area is suitable for crop production and 1.3 million ha is under irrigation (Department of Agriculture 2007). Agricultural activities include intensive crop production and extensive livestock farming. Commercial agriculture is responsible for virtually all of South Africa's real agricultural economy, which is produced on less than 40 000 commercial farm units covering an area in excess of 80 million hectares (South Africa 2010). Some eighteen million hectares of agricultural land is divided into smallholder agriculture, subsistence farming and conservation areas. Figure 1.1 shows the general agricultural regions in South Africa. The smaller, intensively farmed (grains, sugar, vegetables, fruit, diverse commodities) areas with high impacts on natural ecosystems contrast with the larger areas devoted to low-intensity extensive livestock farming (sheep and cattle). The Western Cape is largely dominated by the intensive fruit- and grain-producing industries.



Source: FAO (2005: 8)

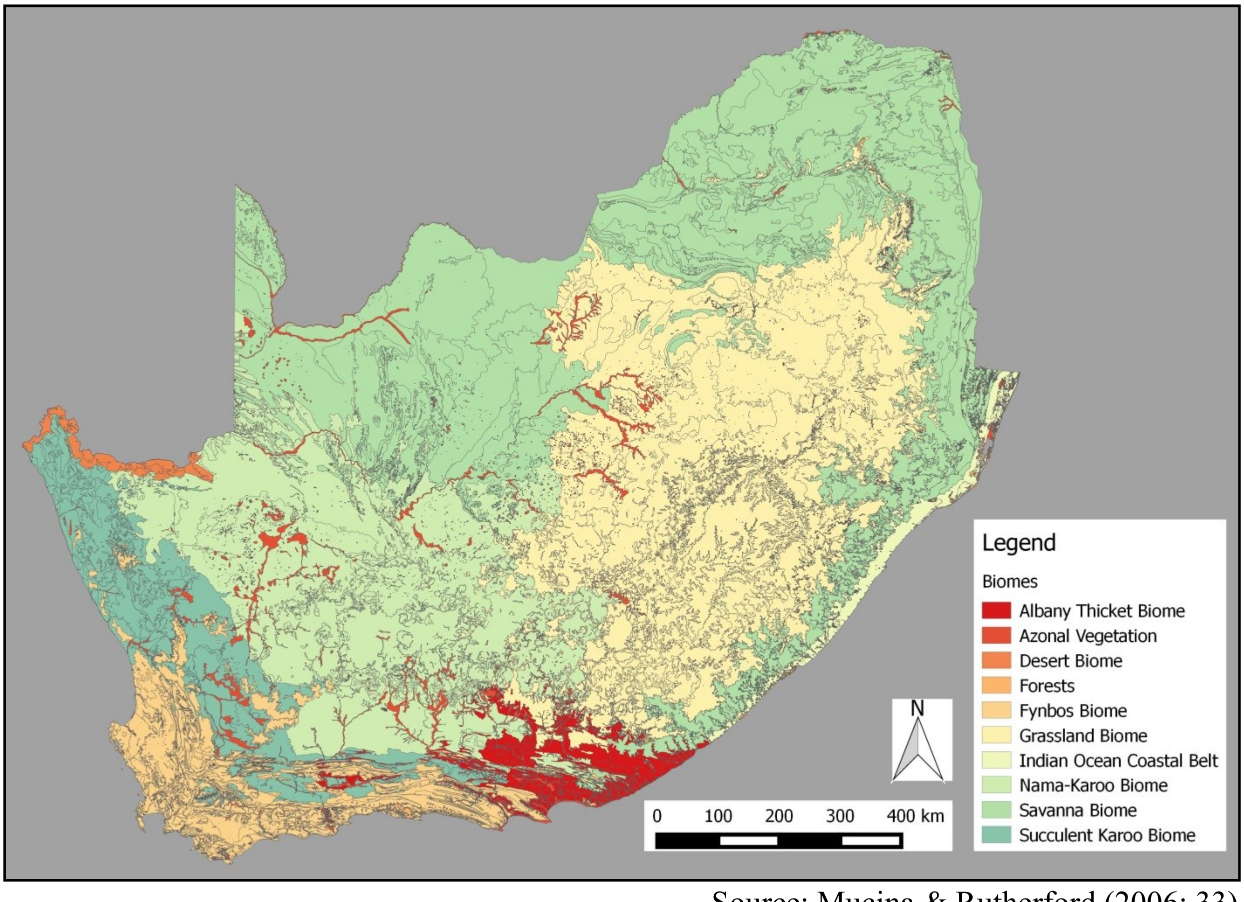
Figure 1.1 Agricultural regions of South Africa

Agriculture is an important industry in the South African economy and for social development, despite its small contribution (less than 3%) to the gross domestic product (GDP) (GCIS ca 2013a). Coupled with value added services and agro-industry, agriculture's combined GDP contribution increases significantly to about 12%. Commercial agriculture in South Africa is also an important earner of foreign exchange, with the top six agricultural sub-sectors contributing a combined commodity (excluding fish and wood products) export value of R54.2 bn in 2013 (Legare 2013).

The largest agricultural export sub-sector for 2013 was fresh fruits and nuts (46%), followed by wines and spirits, yielding 22% of total export value. These commodities originate primarily from Western Cape producers. Furthermore, (intensive) commercial agriculture provides formal employment to an estimated 7% of the South African population (GCIS ca 2013b). It is clear that agriculture is vital to socio-economic development in South Africa and needs to be prudently managed. Its main challenges emanate from agriculture's close relationship with natural resources and environmental processes that, similar to the situation globally, appears to be under constant threat in a modernising world.

1.1.2 Spatial congruence between agriculture and natural environmental resources

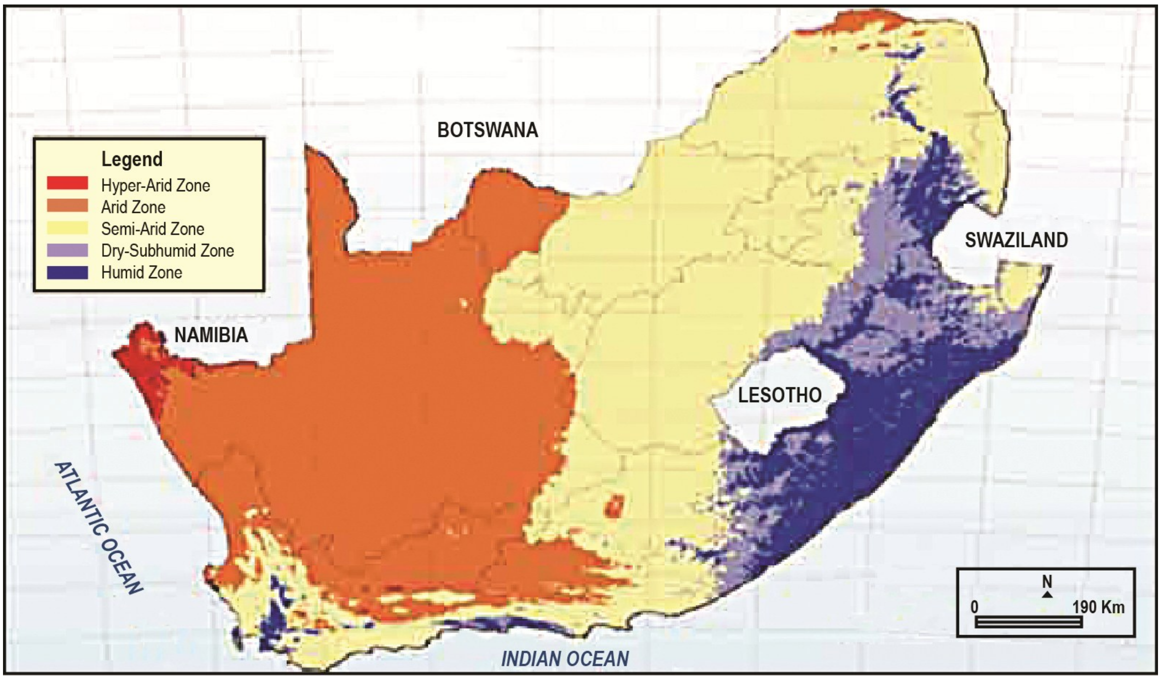
The distribution of the agricultural regions and activities are largely coupled to differences between agro-climatic regions (Benhin 2006). The various South African agricultural regions coincide in geographical space with the major natural biomes, as classified by SANBI (Low & Rebelo 1996; Mucina & Rutherford 2006), and is dependent on the ecosystem services the biomes provide. Many of the plant species within the biomes are endemic to certain regions within South Africa and include a wide range of species classified as threatened (Reyers et al. 2001). Variously known as the Cape Floral Kingdom or the Cape Floristic Region, encapsulated in the Fynbos Biome contains the fifth largest number of plant species in the world (almost 9000 plant species, 69% endemic) but have lost approximately 30% of its primary vegetation (Myers 2000; Rebelo et al. 2006). Figure 1.2 shows the delimitation of biomes of South Africa and shows the precarious grip of the Fynbos Biome on the southern extremity of the continent, and strictly coinciding spatially with the narrow band of intensive agriculture referred to earlier. Clearly, a symbiotic relationship between a growing agricultural industry and its sensitive natural environments is essential to ensure



Source: Mucina & Rutherford (2006: 33)

Figure 1.2 Vegetation biomes of South Africa sustainable resource exploitation.

Water availability is a major limiting factor for South African agriculture (Benhin 2006). Climatic zoning is consequently a serious determinant of agricultural sustainability in South Africa. With an average annual rainfall of about 500 mm, ranging from below 100 mm per year in the west to above 1200 mm in the east, two thirds of the country receives less than the average annual rainfall (GCIS ca 2013a). Figure 1.3 shows that the country can be classified as predominantly (80%) arid according to the United Nations Council on Combating Desertification (UNCCD) index for dry lands. The Western Cape mountain lands appear as precarious spines of high rainfall



Source: FAO (2005: 5)

Figure 1.3 Aridity zones of South Africa

reservoirs of run-off generation. Incidentally, commercial agriculture (often irrigated) consumes more than 60% of South Africa's fresh surface water stock (DWAF 2004), placing a heavy burden on it for constantly improved water management and ever more economical usage.

Soil erosion remains a major environmental concern that influences agricultural conduct and management (Le Roux, Newby & Sumner 2007). An estimated 70% of the country's surface has been affected by soil erosion and the loss of valuable topsoil and appearance of erosion gullies (dongas) is an ever increasing threat to sustainable development all over southern Africa (Pretorius D.J. 1998; Garland, Hoffman & Todd 2000). Soil erosion is accelerated by anthropological activities such as overgrazing and vegetation clearing (Snyman 1999). The loss of fertile top soil is not the only concern, since sediment is deposited in dams and gradually reduces water storage capacity (Boardman, Foster, Rowntree, Mighall & Parsons 2009). Jordaan (1989) calculated an average annual sedimentation rate of 0.5%, which equates to a loss of roughly 150 million m^3 in water storage capacity in South Africa.

Climate change is a now a prevalent concern confounding the fine balance between a functional natural system and agricultural practice in South Africa. The Department of Environmental Affairs (DEA) confirmed that change in rainfall (spatially variable) and increases in mean temperatures and temperature variances have been recorded all over the country (Agriprobe 2007). At the national scale it is predicted that the western parts, including the Western Cape province, are likely to suffer more severe droughts, while the east undergoes more intense rainfall events (South Africa 2011a). The above prediction of climate change effects are likely to result in water shortages and desertification in the western parts with concomitant dire consequences for rural livelihoods, agricultural production and ecosystems. Sustainable agriculture rears as an existential challenge here.

1.1.3 Ensuring agricultural sustainability

From an agricultural industry perspective, the answer to the aforementioned real-world problems facing agriculture is what Morris & Winter (1999) refer to as the third way of farming or sustainable commercial agriculture. Sustainable commercial agriculture integrates the three pillars of sustainable development (environment, economy, society), filling a niche between large-scale commercial agricultural (with its potentially detrimental social, and environmental consequences) and organic farming – however, the latter is unable to produce the appropriate food quantities required for a growing population (IISD 2010). Sustainability is a pivotal concept in international consensus regarding global development pathways foreseen in Agenda 21 of the 1992 United Nations Conference on Environment and Development (UNCED). Chapter 10 stated unequivocally that natural resources are compromised due to the increasing requirements of human and economic activities (United Nations 1993). It further states that achieving sustainability requires methods to overcome conflict between agriculture, environmental needs and natural resource usage, and that integrated planning and management is the answer.

Sustainable development requires multidisciplinary solutions that draw on resources and information integrated across multiple sectors (social, economic and environmental). The Food and Agriculture Organisation (FAO) of the United Nations suggests that spatial information management systems can aid multidisciplinary communication, since databases from various disciplines can be integrated into geodatabases, where spatial data and statistics can be analysed and mapped to solve conflicting goals (FAO 2004). A GIS might be a possible management tool to enable sustainable development in agriculture.

1.1.4 Integrated agricultural and environmental management with GIS

Goodchild et al. (2000) propositions a two-fold argument for studying and managing the environment with the aid of geographic data and GIS. First, the environment is studied directly rather than in controlled environments. Observations are made over time at specific locations and the observations are then compared to other locations and over different time periods. Thus, according to this first argument, creating scientific knowledge is essentially extracting information from space and time – arguably the essence of geography as a discipline. The second argument for the use of geographic data and GIS stem from applying the new information to a specific location for management purposes. This is done by combining scientific knowledge as procedures or models with location and time-specific information contained in a GIS database. Although the above arguments come from an environmental viewpoint, it can also be applied to other applications, such as agriculture or management, where space and time are determining factors.

A GIS is especially suited to the integrated management and planning processes and procedures of agriculture in the environment, since both are essentially geographic in character (Wilson 2005; Goodchild 2003). Agricultural and environmental databases are often large, abstract and generally have a spatial component, with various factors to take into account when analysing and interpreting the data. This is where a GIS can play a valuable and innovative role in managing the data required to support decision-making for agricultural and environmental management. A GIS is capable of integrating, analysing, displaying and storing large amounts of data, acquired from various sources (satellites, field surveys and existing databases), in different formats (images, text and vectors) and tying the data to a geographic location (Kaminska, Oldak & Turski 2004).

1.2 RESEARCH PROBLEM

Specific preparatory (White Paper on Agriculture (South Africa 1995)) documents and national legislation, namely the Conservation of Agricultural Resources Act (CARA) 1983 (South Africa 1984), and the National Environmental Management: Biodiversity Act 2004 (South Africa 2004), set the principles and provide the legal framework to direct the sustainable management and conservation of natural resources (soil, water and biodiversity) for the benefit of agricultural production in South Africa (South Africa 2012a). While agricultural conduct and the maintenance of environmental integrity appears to be in constant tension, the implementation of spatial information systems, a highly efficient planning and management tool at the level of individual producers, is virtually ignored. National agricultural policies and strategic plans make very little provision to promote the use of spatial information management systems at farm level. Spatial analysis is first mentioned in the strategic plan of the Department of Agriculture, Forestry and Fisheries (DAFF) 2012 to 2017 (South Africa 2012a), but still makes no provision for farm level spatial information management to assist with integrated agricultural and environmental management.

The research problem revolves around the lack of spatial information management systems and operational decision support at farm level in South Africa. Specific research questions are how to:

- tailor a spatial information management systems to aid farm-level operational planning and decision-making in integrated agriculture and conservation;
- accommodate the requirements set by new national laws and provincial policies and regulations in spatial management measures at farm level;
- ensure and demonstrate compliance with the commercial requirements set by new international policies and marketing strategies in practical spatial management measures at farm level;
- enable the documentation and archiving of past spatial farm processes and practices, for longitudinal and cumulative recording and retrospective assessment of farm management practices over time.

1.3 RESEARCH AIM

The aim of this study was to perform a requirements and needs analysis for a spatial information system suitable for addressing integrated agricultural operational and environmental management demands derived from local, provincial, national and international demands; to practically populate a prototype system in a mixed farming fynbos environment in the Western Cape; and to demonstrate its planning application.

1.4 RESEARCH OBJECTIVES

To achieve the aim, the following seven research objectives were set as tangible, guiding deliverables for the research task:

1. Determine and unpack relevant international, national and provincial imperatives directing integrated agricultural operational and environmental management at farm level.

2. Determine the farm-level spatial information requirements for agricultural operational planning, decision-making and analysis.
3. Determine spatial information requirements for integrated environmental planning, analysis and decision-making.
4. Build a spatial environmental and agricultural infrastructure database for a case study farm property.
5. Determine the generic technical and operational requirements for the system in an operational format on an operating farm and develop a suited-to-task prototype integrated spatial information system for a case study farm property.
6. Populate the prototype spatial information system from the collected data.
7. Develop demonstration scenarios of the information system for agricultural and environmental management applications for the case study farm property.

1.5 THE STUDY AREA

The study area comprises an integrated landholding under single ownership located in a setting selected consciously for the spatial diversity of its natural and economic characteristics.

1.5.1 Location of the study area

The study area is an 8 276 hectare, seven-farm production unit, Howbill Properties, situated in the Koue Bokkeveld, north of Ceres, in the Western Cape, South Africa. It is situated in the vulnerable Cape Floral Region, in the upper catchment of the Olifants River. Figure 1.4 shows the single farming property unit and boundaries of its seven constituent farms. Table 1.1 lists the spatial dimensions the seven farms as extracted from the GIS database generated in this study. The data

Table 1.1 Spatial dimensions of the Howbill farm units selected for study

Farm name	**Area (ha)**	**Perimeter (km)**
De Kruis	850.10	13.58
Die Hoek	1324.56	22.58
Ebenezer	1253.76	15.66
Kweperkraal	508.77	9.62
Malabar	1062.64	19.48
Molenrivier	2161.43	21.95
Parys	1114.49	16.16

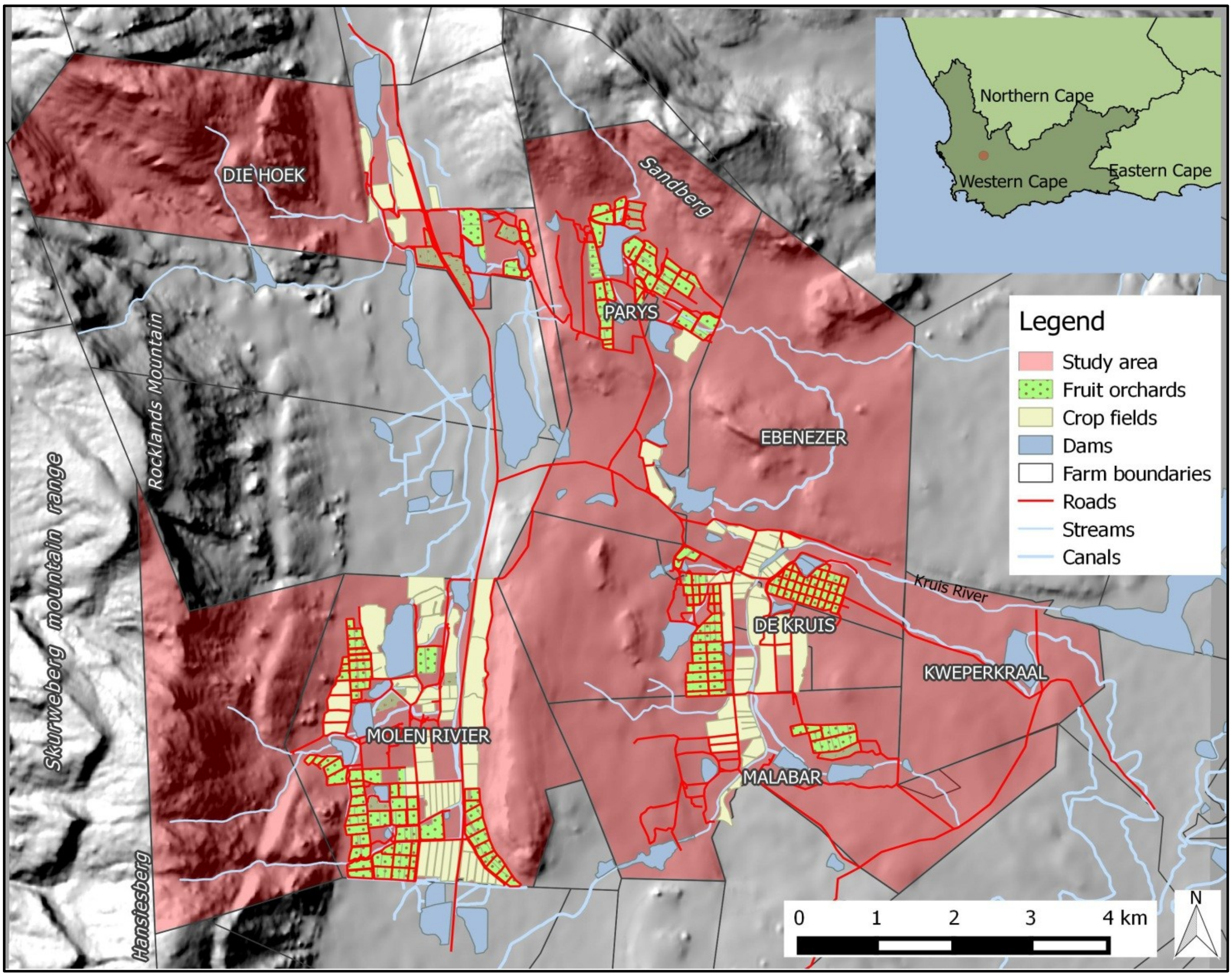


Figure 1.4 Study area

show that each farm unit contains elements of all main land use types (fruit orchards, cropfields, irrigation dams), are linked by infrastructure and hold significant fynbos matrix areas of natural vegetation – a truly mixed-farming-in-fynbos study area ideal for the experimental application of GIS.

1.5.2 The natural environment

The *topography* of the study area varies considerably as Figure 1.4 shows. To the west Hansiesberg and Rocklands Mountain reach heights of 1844 m and 1811 m respectively and form part of the Skurweberg mountain range. To the north Sandberg reaches a height of 1505 m, but to the east and south of the study area the landscape gradients undulate more gently at an average height of some 800m above sea-level. In terms of *geology* (see Appendix A1 for spatial reference), the study unit is unique, having representative underlying groupings from the Cape and Karoo Supergroups within a 7-km horizontal distance from west to east. In the west the Table Mountain sandstones build the higher mountains and is succeeded immediately eastward by the softer Bokkeveld shales underlying the eroded valley stretching north-south. The first ridgeline to the east and the higher-lying mountain and hills to the north and south are formed by Witteberg sandstones. The more level basin in the central eastern area was eroded on the Dwyka and Ecca tillites and shales of the Karoo Supergroup. These underlying geological bedrock types determine the variable soil characteristics and concomitant natural vegetation types, as well as the agricultural suitability exploited for farming purposes. Fractures and faults in the Table Mountain group are considered significant secondary water aquifers capable of yielding high quality underground water (Parsons, Coetzee & Wise 2004). Water drains towards the north into the Doring River, a main tributary of the Olifants River hosting the important Olifants River irrigation scheme.

Natural vegetation in the study area, strictly corresponding to the specific underlying geological groups, forms part of the sensitive fynbos biome. From west to east the vegetation types are Winterhoek Sandstone Fynbos located on the Table Mountain and Witteberg sandstones, Kouebokkeveld Shale Fynbos located on the Bokkeveld shales and Ceres Shale Renosterveld located on the Karoo tillites and shales (see Appendix A2 for spatial reference). The conservation status of the lower-lying Kouebokkeveld Shale Fynbos is listed as endangered and Ceres Shale Renosterveld is listed as vulnerable, but the higher-lying Winterhoek Sandstone Fynbos is listed as least threatened (Mucina & Rutherford 2006).

The *climate* of the study area is typically that of the winter rainfall region of South Africa. It receives about 600 mm per year (Van Niekerk & Joubert 2011). Snow falls periodically on the surrounding mountain tops and occasionally in the valleys. Average minimum day temperatures range from about 2.8°C during mid-winter in July (Elsenburg 2013a) to an average maximum temperature of 28.1°C during February (Elsenburg 2013b). Water resources are replenished during the winter and stored in manmade water reservoirs for irrigation during summer.

1.5.3 Production units and infrastructure

Howbill Properties constitute the seven separate farm production units as well as the central supporting processing plants where vegetables and fruit are held in cold storage and packed for direct marketing on Parys, where the administrative head office is located. Four smaller equipment storage facilities and management offices are located on Molenrivier, Die Hoek, Parys and Ebenezer. A sawmill is situated at the main entrance on Parys, which produces pallets, crates and wood mulch for use as compost. Four chalets, a manor house, camp site and reception hall make up the buildings of the guest farm located on Malabar.

Each production unit has at least one production manager responsible for overseeing a specific production branch. Production managers are housed on the various farm units. Seasonal labourers are contracted as required and sleeping facilities with amenities (running water and electricity) are provided at distributed residential facilities.

Water-related infrastructure on the production units consists of large manmade earth dams, water pumps, boreholes, filter banks, transfer and irrigation pipelines, irrigation risers and manmade surface canals. Water is stored in the reservoirs for use during the dry summer months. Water pumps and irrigation pipelines are used to distribute water between water reservoirs, and from water reservoirs to the various crops as required. Water is pumped through filter banks, which removes debris such as plant material and silt to prevent obstruction in the irrigation pipes. Irrigation risers are located in crop fields and connect sub-surface irrigation pipes with temporary above ground sprinkler systems. Winter runoff water is channelled to water reservoirs via surface canals (see Appendix A3 for spatial reference) and from there via pipeline into the irrigation system as required.

Electricity is supplied by ESKOM via one main power line splitting into secondary lines carried by timber pylons to distribution points where it is required on the farm. Transformers are used to regulate voltage output between the electrical grid and features requiring electricity such as water pumps, industrial electric motors and residential housing.

A network of mostly gravel roads and tracks provide access to crops fields and farm infrastructure. A short section of tarred road connects the main entrance gate and the processing hub on Parys. Where roads intersect streams or surface canals, low bridges span the gap.

1.5.4 Agricultural production branches

There are two main agricultural production branches, namely crops and livestock. Crops consist of perennial fruits and annual vegetables and grain. Livestock consists of sheep and cattle. *Perennial fruit* types comprise deciduous apples and pears as well as stone fruits like nectarines, plums, peaches and olives. Fruit production occurs on roughly 420 hectares across the seven production units. Fruit trees (orchards) are planted in rows and form orchard blocks, typically of the same variety, but sometimes of mixed composition. A block can be defined as a collection of rows, surrounded by or divided by an access road or a collection of rows which consist of a specific fruit type or cultivar. Older orchard blocks contain mixed cultivars or fruit types, whereas the younger orchard blocks contain only one type of fruit and cultivar. Each orchard or block is uniquely identified by a number and cultivars are referenced according to the orchard block number and cultivar name. The cultivar name is shortened to three-letter codes. Production managers refer to the block number and cultivar name as block codes.

Annual crops produced on the farming units consist of various vegetables (mainly onions, some potatoes, squash etc.) and oats harvested for stock feed. Crops are rotationally grown on large open fields ranging in area from two to thirty hectares. Some crop fields are irrigated whereas cereal fields rely on seasonal rain. Crop fields are also code-referenced for identification, the code consisting of uppercase letters (sometimes refer to farm unit names) followed by numbers. *Livestock* are kept in fenced camps during the night and moved to grazing areas during the day.

The study area provides the necessary variety in production and natural environmental features to fulfil the requirements for experimentally designing and applying the spatial information management system aimed for in this study.

1.6 RESEARCH DESIGN

Research methodology consists of the systematic approach to solving problems in the context of a specific field of study and includes the appropriate methods used to do so (Van der Merwe & De Necker 2013). This study looked at solving a practical problem in the agricultural industry and is therefore regarded as applied research. A pragmatic research approach was used, since certain elements in the study were handled in a quantitative manner, such as spatial data collection, and spatial data accuracy assessment, whereas other elements will be approached in a qualitative manner, such as determining imperatives directing sustainable development and spatial data requirements.

Figure 1.5 illustrates the research design in alignment with the research objectives that were reached through four research stages.

The *first stage* entailed the execution of two separate actions. First, the international, national, provincial and market imperatives guiding sustainable development were investigated. Second, the spatial data requirements for the spatial information system from the imperatives identified in part one was determined. This step was performed through conducting the literature survey as reported in Chapter 2. The first stage was crucial to ensure relevance, since without the relevant spatial data the prototype spatial information system would be of no use despite excellent design or capability with regards to computer hardware and software.

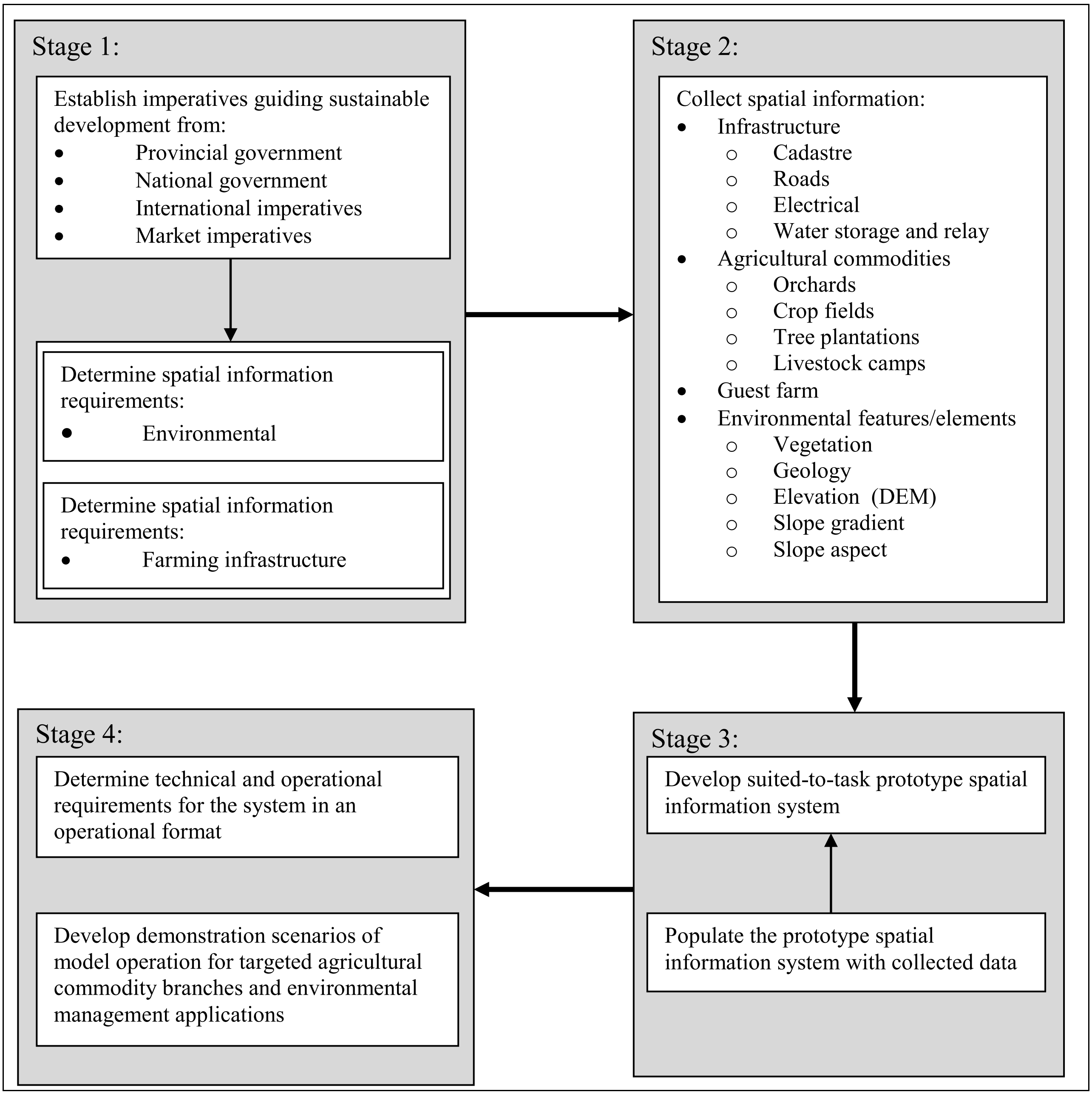


Figure 1.5 Research design

Stage 2 involved compiling the spatial database for features identified in the previous stage and the processing thereof. Primary data regarding farm infrastructure was collected with a global positioning system (GPS) device during five-weeks of field surveying and digitizing from remotely sensed imagery. Secondary data captured generally consisted of environmental features such as vegetation distribution, elevation and geology, and some attribute data related to farm infrastructure. For the data to be useful to the project, it had to be processed. Processing of GPS data consisted of converting the GPS exchange (GPX) files to Arc shapefile format, projecting the data to the relevant projected coordinate system (in this case Lo19), adding attributes to individual shapefiles, cropping sourced spatial data to the study area extent, and correcting satellite imagery for geometric and radiometric errors. Data collection and processing is described in detail in Chapter 3, to facilitate replication of this work by other scientists or system operators.

Stage three comprised the design and development of a suited-to-task spatial information system and populating it with the processed data from the previous stage. Spatial information development incorporated the assessment and selection of suitable GIS software and hardware to meet stipulated requirements. It also detailed how the software components were connected, how the spatial data was uploaded to the database, and how the spatial data are used in the selected software.

The *final stage* entailed the technical aspects of the system required to successfully operate the system. It details a basic geospatial data and system management model to increase system security and data integrity. Demonstration scenarios were also developed to highlight certain functions and features of which the system is capable, to alert users to its potential practical application.

1.7 DATA COLLECTION

Collecting the appropriate spatial data for this study was time-consuming, because little data was available at the micro-scale level required. This section summarises data collected and used to populate the geodatabase, which comprised of spatial and non-spatial data elements.

It is important to know what a spatial dataset (spatial information or spatial data) consist of, since terms related to spatial data is used throughout this report. Spatial data define a location and a spatial dataset consisting of two parts, first a *spatial component* represented by *data models* and, second, *attribute data* (non-spatial data) (Chang 2010). There are two spatial data models, namely vector and raster data, which represent real world features, and is referenced to a location on the earth's surface. Vector data can be points, lines or polygons, and a single dataset can consist of many features of one of the aforementioned data types. Raster data consist of a grid and each cell represents an area on the earth's surface. Vector data is best suited to represent features with discrete boundaries, such as water pumps (points), roads (lines) and enclosed crop field boundaries (polygons). Raster data, on the contrary, is best suited to represent continuous features across a surface such as temperature or elevation variation at regular observation points (Campbell 2006).

Spatial data captured for this research consisted of agricultural infrastructure and environmental features. Spatial agricultural infrastructure data were collected using a handheld consumer-grade GPS device or were digitised from remotely sensed images. Non-spatial attribute data for fruit orchards and crop fields were acquired from Howbill Properties in the form of Microsoft (MS) Excel spread sheets. Additional attribute data for infrastructure features were not readily available during initial data collection, but provision was made to insert attributes at a later stage. Infrastructure data consisted of vectors (points, lines and polygons) as digitized from remotely sensed images. Non-spatial data for fruit orchards and crop fields were acquired from Howbill Properties in the form of Microsoft (MS) Excel spread sheets. Additional attribute data for infrastructure features was not readily available during data collection, but provision was made to insert attributes at a later stage. Infrastructure data consisted of vectors (points, lines and polygons). Table 1.2 summarizes the acquired spatial data features for infrastructure, the data model type and

Table 1.2 Particulars of spatial data for the research

Spatial feature	**Data model type**	**Data source**
Infrastructure		
Cadastre (property boundaries)	Vector polygons	Surveyor General
Buildings	Vector points	Digitised from remotely sensed (RS) images
Roads	Vector polylines	Digitised from RS images and collected with GPS
Road bridges	Vector points	Nodes extracted from intersecting surface canals and roads
Water: reservoirs/dams	Vector polygons	Digitised from RS images
Water: pump stations	Vector points	Collected with GPS
Water: pipelines (below ground)	Vector polylines	Collected in digital format from Spillhaus, Ceres (irrigation engineers)
Water: drainage line/canals	Vector polylines	Chief Directorate: National Geo-spatial Information (CD:NGI)
Electricity: power lines	Vector polylines	Digitised from GPS readings
Electricity: transformers	Vector points	Collected with GPS
Crop field boundaries	Vector polygons	Digitised from RS images
Orchard boundaries	Vector polygons	Digitised from RS images
Plantation boundaries	Vector polygons	Digitised from RS images
Wire fence lines	Vector polylines	Digitised from RS images
Fence gates	Vector points	Digitised from RS images
Open storage facilities	Vector polygons	Digitised from RS images
Natural features		
Digital elevation model (DEM)	Raster (5 m resolution)	Centre for Geographical Analysis (CGA)
Slope aspect	Raster (5 m resolution)	Derived from DEM
Slope gradient (%)	Raster (5 m resolution)	Derived from DEM
Geology	Vector polygons	Digitised from field maps obtained from Council for Geoscience
Water: Rivers/streams	Vector polygons	CD: NGI
Natural vegetation	Vector polygons	SANBI (Mucina & Rutherford 2006)
NDVI	Raster	Derived from RS imagery

the agency the data was sourced from. Vector data processing consisted of projecting the GPS data, grouping the various features collected with a GIS into respective datasets and correcting the spatial data when necessary. Raster data pre-processing consisted of the geometric and radiometric correction of the SPOT 5 scene, and pansharpening of the SPOT 5 scene. Raster data processing consisted of extracting Normalised Difference Vegetation Index (NDVI) from the SPOT 5 scene to aid with biomass estimation and identifying bare soil and rocky outcrops. Slope aspect and slope gradient, in percentage, was extracted from the 5 metre resolution DEM.

1.8 THESIS STRUCTURE

This first chapter provided the required background to the study in exposing the lack of spatial information systems propagation to address the integrated management of farm operations and environmental processes in agriculture as an industry. It provided the research focus through aim and objectives foci, introduced the case study area and explained the research methodology and data. Chapter 2 investigates relevant imperatives directing integrated agricultural operational and environmental management and covers spatial data requirements.

The focus of Chapter 3 is technical in nature and feature the processes carried out for spatial data collection and spatial data processing. In Chapter 4, the prototype spatial information system is developed. It details the process of selecting a suitable spatial information system, putting the system together and uploading the spatial data. It also covers basic geospatial information and system management.

In Chapter 5, demonstration scenarios of GISIMAE are developed to alert users to the salient functions and features of the system. Functions and features were paired with user GIS experience, and the demonstration scenarios were developed accordingly. Chapter 6 provides the generic summary of results, conclusions and recommendations.

CHAPTER 2: IMPERATIVES DRIVING SUSTAINABLE AGRICULTURAL DEVELOPMENT

Chapter 2 serves a two part function. The first part looks at current driving factors which direct integrated agricultural and environmental management internationally, nationally and provincially, such as international treaties and conventions, national legislation and policies, provincial initiatives, and finally international market initiatives. The second function is to identify potential data requirements derived from imperatives required for integrated agricultural and environmental management.

2.1 LEVELS OF GOVERNANCE

Lange et al. (2013) argue that governments are no longer the sole entities responsible for managing sustainable development. Governing sustainable development has become a shared responsibility between nations, markets and civil society (Rhodes 1997; Stoker 1998; Kooiman 2003; Pierre & Peters 2000). This resulted in levels of governance each with a specific responsibility towards sustainable development. Figure 2.1 model-wise illustrates the levels of government responsibility through which integrated agricultural and environmental imperatives are implemented and managed. At the apex is a global source or driver for taking action and

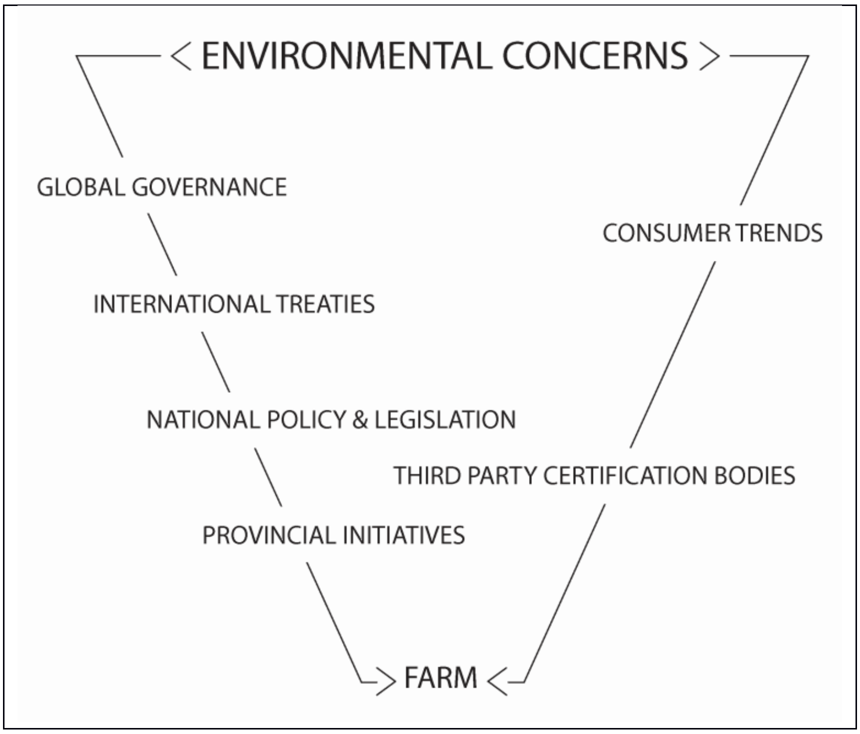


Figure 2.1 Levels of environmental government

implementing sustainable development. For the purpose of this study, these are compelling environmental concerns. Below the driving source, global governing entities are responsible for identifying possible mitigation measures to counter the cause of, in this case, environmental issues and putting measures in place to ensure these mitigations are implemented on national government level. This is done in the form of treaties, which are binding by international law when signed by a member state (Department of Foreign Affairs and Trade 2013). After signing a treaty it becomes the member state or country's responsibility to implement and enforce the required mitigation in the form of national policies and legislation. Policy guidelines are, generally, available from global governing bodies. Implementing and enforcing these policies are, in some cases, the responsibility of provincial government. In addition to policies and legislation, consumer trends and market initiatives also require certain sustainable certified measures to be put in place to satisfy market demands (Sahota 2009; Bredahl et al. 2001), which in turn opens new competitive market opportunities (Busch 2000; Van der Grijp et al. 2005). Ultimately, farms or agricultural production units, at the base of this inverted pyramid, must conform to these regulations and mitigations to avoid legal or financial penalties or even lose access to these markets. Each of the above mentioned levels of governance is discussed below, starting with the global environmental concerns.

2.2 ENVIRONMENTAL CONCERN: CLIMATE CHANGE

Climate change is a major global concern that directly affects the agricultural sector due to a range of its impacting manifestations, like increased frequencies of extreme weather events, droughts and floods (Environment & Energy Publishing 2014), and loss of certain ecosystem services due to habitat change (EPA 2013a). An overview of climate change and the major contributing factor thereof, anthropological induced greenhouse gas emissions, is provided. Also covered are general trend predictions of greenhouse gas emissions, and the effects of climate change.

2.2.1 Driving forces of climate change

Climate change, as defined by the Intergovernmental Panel on Climate Change (IPCC), implies long term changes in the state of the climate that can be scientifically observed or estimated and which is caused either by natural events or due to human activity (IPCC 2007a). Climate change is a significant environmental concern, since it affects all areas of existence on earth due to the intricacy and pervasiveness thereof (UNFCCC 2013a). Environmental issues are by nature interrelated. A change in one facet of nature results in change in other facets of nature. Altered hydrological processes and resources (like run-off reduction or flooding) are prime examples of climate change effects (Bates et al. 2008). Also, climate change affects biodiversity and related ecosystem services due to habitat change and range restrictions (Parmesan & Yohe 2003; Thomas, Franco & Hill 2006; CBD 2009). Agriculture affects biodiversity directly through habitat destruction during conversion of pristine land through ploughing.

According to Thomas & Trenberth (2003), human induced changes in the atmosphere are the major driving force of climate change. They list energy associated emissions as the primary cause, but also indicate that changes in land use is an important driving force. Burning fossil fuels release the greenhouse gasses carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_20) into the atmosphere, which obstructs heat loss, causing a greenhouse effect (Jackson & Jenkins 2013) that drives climatic abnormalities.

2.2.2 Sources of greenhouse gasses

Carbon dioxide constitutes 77% of global greenhouse gas emissions, of which 57% is due to fossil fuel burning, 17% to deforestation and biomass burning, and 3% results from other unspecified sources (IPCC 2007a). Carbon dioxide is released through natural processes such as volcanic eruptions. However, concentrations in the atmosphere have increased profoundly since the industrial revolution in the 19th century and since due to the burning of fossil fuels for energy generation and transportation, and due to deforestation for the expansion of human settlements, agricultural activities and output, all derived through land use changes (IPCC 2007b; Jackson & Jenkins 2013) consuming natural land cover.

Methane comprises 14% of global greenhouse gasses (EPA 2013b) and is produced naturally during the decomposition of plant and animal material. Although wetlands are regarded as one of the largest natural contributors of methane to the atmosphere (EPA 2013c), it is estimated that anthropologic activities generate 60% of global methane emissions (EPA 2013c), of which agriculture contribute 47% (Smith et al. 2007). An important agricultural source of methane production is the ruminant digestive system and decomposition of manure from domestic livestock.

Nitrous oxide constitutes an estimated 8% of global greenhouse gas emissions (IPCC 2007a) and it is also emitted during the breakdown of nitrogen in manure and urine in livestock. However, agricultural soil processing is, globally, the largest source of nitrous oxide due to the breakdown of nitrogen in commercial and organic fertilisers (GMI 2012; Raey et al. 2012).

From a global industry perspective, the energy sector is responsible for 25.9% of greenhouse gas emissions, industry (metallurgical, chemical and mineral transformation) for 19.4%, forestry for 17.4%, agriculture for 13.5%, transportation for 13.1% and 7.9% and 2.8% is contributed by buildings and waste management respectively (IPCC 2007a; EPA 2013b). Although agriculture is one of the bottom four contributors to greenhouse gasses, the sector is still responsible for a significant quantity of greenhouse gas emissions. Origins of greenhouse gas emissions in agriculture are soil management (tilling and fertilisers), livestock, biomass and fossil fuel burning, and deforestation for agricultural expansion or due to veld mismanagement. Sources of agricultural greenhouse gas emissions can be documented and monitored in a spatial information system, so aiding in the reduction of greenhouse gas emissions at farm level.

2.2.3 Spatial data needs determined by climate change concerns

Agriculture is a source of greenhouse gas emissions that contributes to climate change. To reduce greenhouse gas emissions at farm level, it is necessary to document and monitor certain agricultural processes. Table 2.1 lists the potential agricultural processes for which data could be documented and monitored via a spatial information system.

Table 2.1 Spatial data requirements determined by climate change imperatives

Agricultural process	Spatial data or attributes
Crop production	Crop field identification (where)
	Crop type
	Date of planting (when)
	Date of harvest
	Production volume
Tilling	Crop field identification (where)
	Date of tilling (when)
	Mode/depth of tilling
Fertilizer application	Crop field identification (where)
	Date of application (when)
	Quantity applied
	Type or make of fertilizer applied
Veld management: Movement of livestock and grazing intensity	Livestock camp identification
	Livestock type and number (sheep, cattle)
	Date livestock were moved into the camp
	Date livestock were moved out of the camp
Veld management: New field expansion	Previous date land or area was disturbed
	Natural vegetation covering before disturbance
	Date veld was disturbed
Veld management: Fire events	Date of fire event
	Cause/source of fire
	Area burnt (ha)
	Fire path and dynamic
	Duration of fire

The agricultural processes listed above are sources of greenhouse gas emission and contribute to climate change. Identifying the sources and limiting it through improved management measures is the first step in mitigating greenhouse gas emissions at farm level.

2.2.4 Climate change predictions

Although the exact increase quantity is uncertain, there is general consensus on a predicted increase in global greenhouse gas emissions over the next 20 to 30 years (EPA 2011; PBL 2012; EPA 2013b). The nature and extent of expected environmental changes are currently still uncertain (Thomas & Trenberth 2003). However, some of the observed effects of climate change are increased air and ocean mean temperatures (especially in the higher latitudes), melting of glaciers and snow caps, increased intensity in cyclones, and rising average sea level (IPCC 2007a; Jackson & Jenkins 2013). For the Western Cape, increased temperatures and reduced winter rainfalls are predicted, which could negatively affect the deciduous fruit and viticulture industry (DEA 2013). Also, Midgley et al. (2005) predicted that rainfall events will become more irregular and increase in intensity. Sharp (2003) lists potential effects of climate change on the agriculture sector as:

- Increased heat stress to livestock and crops;
- Decline in precipitation in semi-arid regions;
- Reduced soil moisture due to increased evapotranspiration rates;
- Intensified weather events, which could increase soil erosion and alter natural habitats;
- Changes in seasonal rainfall; and
- Reduced food security, due to increased weather events, such as droughts.

Climate change is a global phenomenon that affects all spheres of life including the environment, industry, and economies. Therefore, mitigation measures and adaptions are governed on a global level and constitute a legitimate concern at farm level.

2.3 GLOBAL ENVIRONMENTAL GOVERNANCE

This section highlights international mechanisms which aim to cooperatively contribute towards lowering environmental impacts and improving conditions by addressing sector related environmental issues across national boundaries. There were no data requirements that stemmed directly from this section. However, the background given in this section will help to comprehend the origin and significance of national policies, legislation and programmes, directing sustainable development.

2.3.1 The United Nations

Global governance refers to the management of international affairs. No single global government exists and therefore global governance consists of bodies with voluntary member states (countries) as signatories and international organisations (World Health Organization 2013). The role of global governance is to coordinate and respond to general crises collaboratively through formal (treaties, laws or norms) or non-formal (practices or guidelines) measures (UNIHP 2009).

The UN is the largest international governing body and is responsible for a number of environmental institutions and mitigations. The UN was established by 51 countries in 1945 with the primary aim to maintain international peace, promoting human rights, and develop affable relations between countries (UN 2013). South Africa was a founding member of the UN. Currently, the UN has 193 member states and, in addition to the main body, consists of various institutions, specialised agencies, councils, programmes, committees and working groups. The various entities of the UN provide information bases and strategy guidelines for countries and governments to develop their own policies to ensure a global standard of related policies that take specific regional aspects into consideration. For the purpose of this study, only environmental and sustainable development UN entities are reviewed. Table 2.2 list UN institutions, specialised agencies and treaties directly related to environmental protection and agriculture (Stakeholder Forum 2004).

Table 2.2 Global governance responses to environmental concerns

Entity	**UN entity name**
Institutions	United Nations Environment Programme (UNEP)
Specialised agencies	World Meteorological Organization (WMO)
	Intergovernmental Panel on Climate Change (IPCC)
	Food and Agriculture Organisation of the UN (FAO)
UN Treaties	The United Nations Framework Convention on Climate Change (UNFCCC)
	Kyoto Protocol
	UN Convention to Combat Desertification (UNCCD)
	Convention on Biological Diversity (CBD)
non-UN treaty	Ramsar Convention (on wetlands of international importance especially as waterfowl habitat)

The above mentioned UN environmental entities and treaties are briefly summarised in the following subsections.

2.3.2 United Nations environmental institutions

A UN institution is an overarching organisation responsible for dealing with a specific topic, such as trade, health or the environment. UNEP was founded in 1972 and is responsible for promoting and facilitating environmental management for global environmental sustainability (UNEP 2013). Their goals are to:

- Provide information to environmental decision and policy makers to achieve environmental goals; and
- Facilitate the implementation and enforcement of environmental policies in member states (UNEP 2010).

Specialised agencies conduct research or provide information on key areas within the general scope of overarching institutions.

2.3.3 United Nations specialised agencies

The primary role of the World Meteorological Organisation (WMO) is to monitor the state and behaviour of global meteorological processes, the interaction between these processes and the oceans, the climate in general, and resultant water distributions (WMO 2013). The Intergovernmental Panel on Climate Change (IPCC) was established by UNEP and the WMO in 1988. The primary role of the IPCC is to review and provide scientific information related to climate change (IPCC 2013). The Food and Agriculture Organisation (FAO) aims to increase global food security and food nutrition, reduce malnutrition and rural poverty while facilitating sustainable agriculture (FAO 2013a). Apart from financial aid, this aim is achieved by providing a knowledge base from which countries can devise food security policies, agricultural policies and best agricultural practices for natural resource conservation (FAO 2013b).

2.3.4 International treaties

Treaties are multilateral agreements between countries to reach or maintain one or more specified goals, which is binding by international law (Department of Foreign Affairs and Trade 2013). Therefore, if a country is a signatory member of an agreement, the country is responsible for implementing the necessary policies or legislation to reach the specified goals within a set period. A treaty is not a set of exact rules which should be followed to the letter, but rather a framework to be used as a guide to create new, or strengthen existing, national policies and legislation to reach specific goals set out in the treaty (Moore & Goldberg 2010). In some cases a country's current policy or legislation could already be in line with treaty goals and little to no changes are necessary.

2.3.4.1 United Nations treaties

The following treaties relate to environmental conservation and sustainable management. The United Nations Framework Convention on Climate Change (UNFCCC) is an international agreement established in 1992 to cooperatively deliberate limiting climate change and adapt to inevitable environmental impacts (UNFCCC 2013). The goal of the UNFCCC is to limit global warming to 2°C relative to pre-industrial levels. The Kyoto Protocol was put in effect in 2005 to strengthen the UNFCCC by legally binding member states to reach greenhouse gas emission reduction targets within a set period (UNFCCC 2013b). The UNCCD is the only legally binding international agreement which link sustainable land management to the environment and development (UNCCD 2012a). The convention developed a ten year strategy to strengthen the convention and to implement united regional and sub-regional action programmes (UNCCD 2012b). The Convention on Biological Diversity (CBD) was put in effect in 1993. The main objectives of this convention are the conservation of biodiversity, sustainable use of biodiversity components, and sharing benefits from resource use (CBD 2013a). Some of the strategic targets set in 2010 for the period 2011 to 2020 are to minimise loss of natural habitats, conserve 17% and 10% of terrestrial and marine areas respectively, and to recover a minimum of 15% of degraded natural habitats through conservation efforts (CBD 2013b).

2.3.4.2 Treaties not affiliated with the United Nations

The Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention for short) is a multilateral agreement but is not affiliated with the UN. The Ramsar Convention was founded in 1971. The aim of the convention is to maintain the ecological character of important wetlands and to implement sustainable management practises for all wetlands within a member country's territory (Ramsar 2013). South Africa is a signatory member of all of the mentioned agreements.

No specific spatial data requirements were determined from global governance imperatives, since global governance responses only provide a base from which regional and national policies can be developed to cooperatively mitigate environmental issues. As mentioned above, international agreements are binding by international law, and being a signatory member requires active national changes through implementing policies and legislation aligned with the outcomes of international agreements. By agency these measures drive many national imperatives that do require and generate spatial management variables at the farm level.

2.4 NATIONAL IMPERATIVES GUIDING SUSTAINABLE AGRICULTURE

This section investigates national policies, legislation and programmes which guide integrated agricultural and environmental management. It also underscores the necessity of a spatial information system for integrated agricultural and environmental management, and help with identifying potential data requirements for the spatial information system.

2.4.1 National policies and programmes

Examining older initiatives allows managers to identify trends (management focus points) with regard to integrated agricultural and environmental management at farm level. In turn, these trends could aid with predicting future management focus points for integrated agricultural and environmental management, which could ultimately provide insight to spatial data requirements.

According to DAFF's 2012 Integrated Growth and Development Plan, the 1995 White Paper on Agriculture is a key framework document for agricultural policy making (South Africa 2012b). Previous DAFF strategic plans, and agricultural policy discussion documents (South Africa 1998a) also specify national initiatives which guided integrated agricultural and environmental management (South Africa 2001; South Africa 2011b; South Africa 2012a; South Africa 2012b; South Africa 2013). The following is a short list of some of the important initiatives developed by national government to align agricultural and environmental policies with international agreements:

- The 1995 White Paper on Agriculture;
- Working for Water programme;
- LandCare programme;
- The 2001 Strategic Plan for South African Agriculture;
- 2012 Integrated Growth and Development Plan.

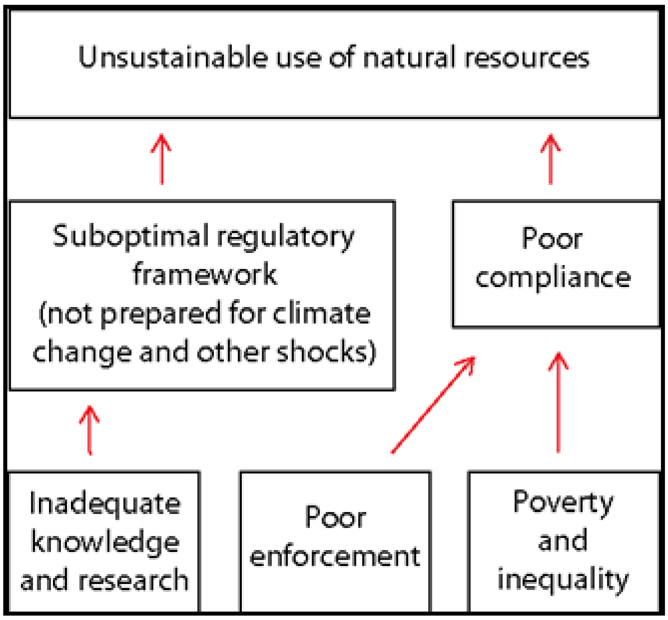
The 1995 *White Paper on Agriculture* serves as a policy framework, which guide policy making in the agriculture sector. Section 4 makes provision for the use of natural resources in a sustainable manner (South Africa 1995), opening the need for proper spatial planning based on accurate spatial information about natural resources at farm level.

The *Working for Water* programme was established in 1995 and was designed to incorporate all three pillars of sustainable development, namely economic success, social development of workers and the broader community, and maintaining an ecologically healthy and biodiverse environment (UNEP 2007). The essence of this programme is the removal of alien invasive plant species. From a water use perspective alien invasive plant species tend to extract large amounts of water from its surroundings. Removing alien invasive plants increase water resources for both indigenous plant species and for anthropological applications. From an economic and social perspective the programme provides work and learning opportunities which contribute to improved rural economies and societies. Programme requirements open the need for proper spatial planning based on accurate spatial information about the occurrence of alien invasive plant species at farm level.

The *LandCare programme* was introduced in 1999 with the aim to optimise natural resource management through implementing sustainable practices for both commercial and small communal farmers. The programme is guided by the UNFCCC, UNCCD, and CBD, and is also aligned with Chapter 10 of the UN's Sustainable Development Agenda (South Africa 1999). The programme is largely community based, meaning communities are required to use their own initiative in identifying and managing sustainable projects, while the government will provide or source funding for the projects. The three main conservation themes are soil care, water conservation and natural veld management (South Africa 1999). Programme requirements open the need for proper spatial planning based on accurate spatial information about the occurrence of all natural resources like soils, vegetation and water sources at farm level.

In 2001 the *Strategic Plan for South African Agriculture* introduced a fundamental turning point for sustainable development in agriculture when the plan was accepted by national government and the agriculture sector. In addition to ensuring fair access to natural resources and to improve global market opportunities, the plan also makes provision for sustainable utilization of natural resources in agriculture (South Africa 2001). Focus is placed on preserving natural biodiversity, promote sustainable water use and to protect and improve soil by implementing supporting programmes. Naturally, these programme foci open the need for proper spatial planning based on accurate spatial information about the occurrence of all natural resources like vegetation water sources and soils at farm level.

The 2012 *Integrated Growth and Development Plan* is a long-term strategy for growth and development in the South African agriculture, forestry and fisheries sectors. The document mentions that environmental sustainability is a key challenge to be addressed (South Africa 2012b). Figure 2.2 illustrates the challenges faced with regards to sustainable use of natural resources in lieu of this document's objectives. Poor compliance from land owners, poor enforcement from government, a suboptimal regulatory framework and inadequate research are regarded as the main causes contributing to unsustainable use of natural resources. Clearly, compliance requirements with resource-directed regulations necessitate knowledge based on accurate spatial information about all natural resources to be at the disposal of farm-level managers.



Source: South Africa (2012b:50)

Figure 2.2 Reasons for unsustainable use of natural resources

Section 4 of the *1995 White Paper on Agriculture* specifies that all citizens are custodians of South Africa's natural resources and a land owner is held accountable for the sustainable management of the natural resources located on their properties. Also, the 2012 *Integrated Growth and Development Plan* specifies the need for integrated spatial planning in agriculture, since the lack of integrated spatial planning is restricting sustainable growth in agriculture (South Africa 2012b). Taking into account the aforementioned and that environmental management is by nature a spatial endeavour (Goodchild 2000), this is where a spatial information system holding accurate and detailed farm-level information on natural resources for integrated agricultural and environmental management can play a valuable role, since such a system could aid with sustainable planning and management of farming activities and sustainable utilisation of natural resources. Such a system could also potentially be used to prove compliance once government has improved legislative enforcement.

This section gave a brief overview of national sustainable agricultural and environmental programmes in existence, and which are aligned with international agreements. Next, legislation is investigated which specifically supports integrated agricultural and environmental management.

2.4.2 National legislation

National legislation plays an important role in governing environmental issues and preserving natural resources. Section 24 of the *Constitution of South Africa* forms the legislative base for environmental legislation in South Africa (South Africa 1996) and states that every citizen has the right to an environment that is not harmful to their well-being, and ensures that the environment is protected for present and future generations, through equitable legislative and other measures that

- prevent pollution and ecological degradation;
- promote conservation; and
- secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.

This proviso reiterates the conservation and sustainable management of natural resources (soil, biodiversity and water) as national prerequisites. Legislation guiding integrated agricultural and environmental management in South Africa is highlighted regularly in all annual strategic plans for agriculture, forestry and fisheries (South Africa 2001; South Africa 2011b; South Africa 2012a; South Africa 2013). The list of acts is extensive and also includes acts related to forestry and fisheries. Van der Linde (2006) emphasises CARA and NEMBA as important acts promoting sustainable use and management of natural resources in agriculture. For the purpose of this study only those acts related to agriculture and the environment from which spatial data requirements could be identified were included. These acts were the:

- Conservation of Agricultural Resources Act (43 of 1983) (CARA);
- National Environmental Management Act (107 of 1998) (NEMA): (South Africa 1998b);
- National Water Act (36 of 1998c) (NWA); and
- National Environmental Management: Biodiversity Act (10 of 2004) (NEMBA).

CARA upholds the conservation of South Africa's natural agricultural resources, which include the conservation of soil, water and plant biodiversity, to ensure the production potential of the land is preserved. The Act also governs the controlling of invasive plants, weeds and bush encroachment. It is enforced by DAFF and it is the responsibility of the land owner to ensure compliance. The regulations specificity of CARA seems to be especially suited to be managed through a spatial information system, and aiding the identification of potential spatial data requirements. Therefore, focus in this discussion was placed on CARA regulations, and less so on other environmental legislation. However, where appropriate, mention was made to supporting legislation. An overview of CARA follows, with bulleted summaries of CARA's regulations numbers two to sixteen specifying farm-level management directives.

- *Virgin land*, that has *not been cultivated within a 10 year period*, may not be cultivated (cultivation means any act which disturbs the top soil mechanically), except by written consent of the regulating authority (Regulation 2). NEMBA further specifies that virgin land of three hectares, or larger, or any size land within an endangered ecosystem (listed in terms of Section 52 of NEMBA) may not be disturbed or cultivated without conducting an environmental impact assessment and obtaining the required permit. This includes the removal of indigenous vegetation for the purpose of creating firebreaks, reservoirs or roads with the aid of a mechanical machine (bulldozer or ripper) or by manual labour. Failure to comply can result in a jail sentence, or a fine of up to five million Rand, or both penalties can be upheld (Overberg Lowlands Conservation Trust 2010).
- *Land with a slope of more than 20%* (or 12% if in an area with specific soil types as listed in the CARA regulations) may not be cultivated, without written consent of the regulating authority (Regulation 3).
- *Cultivated land* must be protected against water and wind erosion, and must also be protected against water logging and salinisation (Regulation 4, Regulation 5 and Regulation 6).
- A *vlei or marsh* (defined as wetland) may not be cultivated or drained without written consent from the regulating authority (Regulation 7).
- *Land within 10 metres* (horizontally) *outside the flood zone* of a stream or river, may not be cultivated (Regulation 7).
- *Vegetation within a flood zone or marsh* (defined as wetland) may not be used if it could result in the degradation of soil, water or vegetation (Regulation 7).
- *Vegetation within a river or stream* (defined as wetland) must be removed to an extent to prevent flooding from causing soil erosion (Regulation 7).
- *Water diversion* from one stream or river into another stream or river without written consent from the regulating authority is prohibited (Regulation 8). The NWA also prohibits the *diversion of water between catchments* without the appropriate licence. Additionally, run-off water must be returned to the water source, after use, from which the water was taken (South Africa 1998c).

- *Natural veld* located on farm units must be protected against any damage or degradation (Regulation 9).
- The *natural veld grazing capacity* may not be exceeded, except if adequate veld protection methods have been put in place (Regulation 10 and Regulation 11).
- *Natural veld* may not be burnt or grazed after burning without written consent from the regulating authority (Regulation 12).
- *Land* that has *undergone excessive soil loss* due to soil erosion must be restored and further soil loss prevented (Regulation 13).
- *Disturbed* areas of vegetation and soil must be rehabilitated (Regulation 14).

Regulation 15 of CARA governs actions regarding *weeds and invasive plants*. NEMBA also have a section dealing with alien and invasive species that correlate with CARA. Regulation 15 of CARA groups (and lists for reference purposes) invasive alien plants into three categories. Category 1 plants are classified as weeds and may not occur on any land and must be removed by land owners or land users, unless written permission is granted by the executive officer. Plant species were included in the first category for reasons that they:

- Can cause human or animal health related issues;
- Result in financial losses;
- Degrade natural veld; or
- Use more water than the surrounding indigenous flora.

Category 2 plants pose a significant invasive risk, but still serve a commercial or utility purpose and may therefore only occur on demarcated areas or biological control reserves. Plant species grouped as Category 1 and 2 plants, which occur commonly in the Western Cape, include *Pinus*, *Populus* and *Eucalyptus* tree (plantation) species. The land owner or land user must control the spread of Category 2 plants outside demarcated areas. Only the executive officer can demarcate an area to cultivate Category 2 plant species. According to Section 21 of the National Water Act (South Africa 1998c) a water use licence is required, since the cultivation of Category 2 plants qualifies as a water use action. Category 3 plants are mostly ornamental or shade-providing plants that will take a long time to replace if removed. The planting or propagating of plants in Category 3 is prohibited but existing plant species may be retained if not in breach of other regulations. Both Categories 2 and 3 plant species may not grow within 30 metres of the 1:50-year floodline of a stream, river, dam or wetland. The rest of Regulation 15 stipulates mechanical, biological and chemical measure to remove or control the spreading of the plant species in the three categories.

Regulation 16 of CARA governs actions of bush encroachment. Bush encroachment refers to stands of specified indigenous flora where the individual plants are closer than three times the average crown diameter from each other. Bush encroachment is regarded as a sign of poor land management and Regulation 16 requires the land owner or land user to take appropriate precautionary measures to rectify the problem. Failing to comply with CARA regulations can result in a fine of up to R5 000, or up to two years imprisonment, or both for a first conviction. With the appropriate data, a spatial information system can aid planning and veld management to remain compliant with these regulations.

NEMA provides a framework for much subsequent environmental legislation. Section 23 of NEMA specifies the general objectives of the act, which, in summary, are to promote integrated environmental principles, take into consideration all impacts (positive and negative) on the environment and socio-economic conditions, and make decisions according to sound environmental principles (South Africa 1998b). This again highlights the importance for a spatial information system capable of documenting, storing and analysing spatial data on resources and infrastructure for integrated agricultural and environmental management.

NWA involves matters related to the use, protection, development, conservation, management, and control of water resources in a sustainable manner. The act is enforced by the Department Water Affairs (DWA). *NEMBA* promotes the conservation of biodiversity and the soil and water it depends on – the very resources determining successful agricultural practices – especially in the intensively farmed areas of the Western Cape.

2.4.3 Data requirements determined from national imperatives

This subsection highlights the data requirements determined from national imperatives directing sustainable development – mainly related to conservation and sustainable use of natural resources. In addition, examples of features to capture as spatial data requirements were listed in the national government's 2012 *Integrated Growth and Development Plan* as existing infrastructure (roads, electricity), land use, land cover, and available arable land (South Africa 2012b). However, there was no mention of the scale of the spatial information (farm level, regional or national scale) that should be met as the spatial data requirements. Assuming it is at national or provincial scale, the listed spatial data requirements could still be gathered and used for integrated agricultural and environmental management at farm level, since these features also occur at that level. Table 2.3 lists potential spatial data requirements which were determined from national imperatives.

Table 2.3 Spatial data requirements based on national imperatives

Data theme	**Spatial data features**
Natural resource features	Soil type
	Water sources
	Natural vegetation
Man-made infrastructure	Land use or land cover
	Transportation infrastructure
	Water storage and transfer
	Electricity delivery
	Buildings and related open facilities

CARA regulations, especially, call for a spatial information system to aid regulations compliance, and aid with farm planning and environmental management. Table 2.4 summarises the data requirements identified from interpreting demands based on CARA regulations. It confirms

Table 2.4 Spatial data requirements determined from CARA regulations

Data theme or feature	**Spatial data attribute**	**CARA regulation**
Vegetation	Veld age	2
	Temporal NDVI data	9, 14
	Vegetation type, biome, conservation status	9
Vegetation	Veld grazing capacity	10, 11
	Veld fire events	12
	Alien, invasive vegetation	15, 16
Water	Water drainage lines	4, 5, 6
	Wetland location	7
	River and flood zones	7
	Catchment boundaries	8
	Surface canal and water pipe lines	8
Topography	Elevation above sea-level	3
	Slope gradient	3
Land use and land cover	Establishment date of crop field, orchard	2
Soil	Soil type	13
	Erosion status	14

that the conservation of natural resources (soil, water, natural vegetation) has been earmarked as one of the primary goals of national agricultural policies, programmes and legislation. Enforcement of national legislation is delegated to provincial departments and hence enterprise-level (farm level) management has to ensure compliance in all agricultural practices.

2.5 WESTERN CAPE PROVINCIAL IMPERATIVES

The Western Cape Department of Agriculture (WCDA) and CapeNature (CN) are the main regulating role players in promoting sustainable agriculture and environmental conservation in the Western Cape. The WCDA is responsible for managing the LandCare programme and CN is responsible for implementation, management and enforcement of environmental conservation and legislation in the Western Cape (DEADP 2011; Western Cape 2000). Each role player has launched a number of initiatives to facilitate sustainable management and conservation of natural resources in the Western Cape. This section provides a brief overview of each initiative to indicate how provincial government promotes aligned national legislation, as mentioned in the previous section, through programmes in addition to enforcing legislative regulations. The main objective of this section was nevertheless to determine potential spatial data requirements for use in the spatial information system.

2.5.1 Western Cape Department of Agriculture: LandCare services

The Western Cape Department of Agriculture (WCDA) is responsible for managing the LandCare programmes in the Western Cape. The aim of the Western Cape LandCare programme is to improve and preserve the natural resources in the Western Cape by promoting sustainable practices to land owners. The provincial LandCare programme stem from the national LandCare programme and consists of four subprogrammes which focus on different aspects of promoting and implementing agricultural and environmental sustainability (Western Cape Department of Agriculture 2011). Three of the four programmes will be briefly overviewed, since these programmes and services are aligned with CARA and could aid with spatial data requirements. The three subprogrammes are Farm Planning, LandCare projects, and Areawide Projects.

The aim of the *Farm Planning* subprogramme is to ensure the implementation of CARA and focuses primarily on implementing soil conservation mechanisms and improved biodiversity (Western Cape Department of Agriculture 2007a). The subprogramme consist of four focus groups namely soil drainage mechanisms, soil protection mechanisms, veld utilisation mechanisms and flood repair mechanisms.

- Drainage mechanisms ensure soils do not become waterlogged and is especially of interest in the deciduous fruit sector.
- Soil protection mechanisms prevent soil erosion through implementing water flow control mechanisms.

- Veld utilisation mechanisms promote sustainable veld use to prevent degradation of this natural resource and enhance stock production.
- Flood repair works provide assistance to land users to repair damage caused by flooding.

LandCare Projects assist in erecting farming infrastructure within previously disadvantaged communities and aims to teach sustainable resource practices to new farmers. *Areawide Projects* empower communities to implement their own sustainable projects to prevent degradation of natural resources by taking into consideration local integrated development plans and allowing communities to contribute to mapping and planning future land use in their areas (Western Cape Department of Agriculture 2007b). Table 2.5 lists the spatial data needs determined from Western Cape LandCare service sanctions.

Table 2.5 Spatial data requirements determined from Western Cape LandCare

Data theme or feature	**Spatial data attribute**
Vegetation	Veld age
	Temporal NDVI
	Vegetation (type, biome, conservation status)
	Veld grazing capacity
	Veld fire events
	Alien, invasive vegetation
Water	Water drainage
	River and flood zone
	Flood damage extent
	Surface canals
Soil	Soil type
	Erosion status of soil

The spatial data requirements determined from Western Cape LandCare services are similar to data needs determined from CARA regulations, thereby emphasising the range of farm-level compliances that may be controlled for from and supported by a well-designed and populated spatial resource database.

2.5.2 CapeNature programmes

CapeNature (CN) hosts a number of environmental programmes and projects. Some of the larger projects include the Working for Wetlands Project (WfWP) (CapeNature 2013a), CAPE Fire Management Data Project (FMDP) (CapeNature 2013b), Wildlife Management Project (WMP) (CapeNature 2013c), The Walker Bay Fynbos Conservancy (WBFC) (CapeNature 2007a) and the Greater Cederberg Biodiversity Corridor (GCBC) (CapeNature 2007b). The programmes are aligned with environmental legislation, policies and treaties, but in some cases also rely on the voluntary participation of landowners.

The *WfWP* enables rural job creation and skills development through sustainable wetland management, wetland rehabilitation and wetland protection. The project is a joint initiative by the Department of Environmental Affairs (DEA), DWA and Department of Agriculture, Forestry and Fisheries (DAFF) and the South African National Biodiversity Institute (SANBI). The project is also aligned with national policies and the Ramsar Convention. In terms of spatial application, it might be as simple as mapping areas with differing severities of alien vegetation infestation, mapping the extent of wetlands, and monitoring the state of the veld with regards to alien vegetation.

The CAPE *FMDP* hosts a spatial dataset with historical fire information of all areas managed by CapeNature (SANBI 2007). The aim of the project is to facilitate on-going analysis of veld age and fire frequencies as indicators of veld health. Capturing veld fire data on production units could aid with preventing unwanted veld fires and reduce the risk of veld degradation.

According to CapeNature (2013c) the Cape's wildlife is under continued threat from anthropological development and the *WMP* aims to integrate ecological and socio-economic objectives for management. The project includes the protection of natural habitat, monitoring wildlife populations and providing guidance on managing certain wildlife mammal species, such as baboons, jackal and black backed caracal. Monitoring wildlife and wildlife movement on production units could aid with implementing mitigation measures to protect crops and livestock, and to manage wildlife optimally.

The *WBFC* is a co-operative, off-reserve, voluntary conservation effort by landowners in the Walker Bay area that may serve as a good example of private management initiatives. Land owners are encouraged to contribute their resources, and are guided in conservation management by CN, in an effort to conserve fauna and flora with the benefit of developing sustainable business opportunities. According to the WBFC (2010) legislation to strengthen such conservancies are being investigated. Well-managed natural fauna and flora could foster additional business opportunities in the realm of ordinary or ecotourism.

The aim of the *GCBC* is to establish extensive corridors of natural vegetation to conserve endangered habitats and facilitate the movement of indigenous fauna and flora between these habitats. The corridors are also in preparation to protect and plan for habitats subject to the vagaries of climate change, and should facilitate the migration of fauna and flora as their habitat changes (CapeNature 2007c). Thomas, Franco & Hill (2006) have highlighted the importance of planning to counter the loss of biodiversity due to habitat change and range restrictions. Spatial planning could aid with the creation of wildlife corridors to facilitate the migration of fauna. Table 2.6 list potential data gleaned from the application requirements of CapeNature programmes. The spatial data requirements determined from Western Cape LandCare services are similar to data needs determined from CapeNature projects, thereby once more emphasising the range of farm-level

Table 2.6 Spatial data requirements determined from CapeNature programmes

Data theme or feature	**Spatial data attribute**
Vegetation	Veld age
	Temporal NDVI
	Vegetation (type, biome, conservation status)
	Veld fire events
	Alien, invasive vegetation
	Wetland extent
Wildlife	Wildlife type
	Wildlife sightings
	Migration patterns

measures that may be controlled for from, and supported by, a well-designed and populated spatial resource database. Next, market imperatives guiding integrated development are investigated.

2.6 MARKET-DRIVEN INITIATIVES FOR SUSTAINABLE AGRICULTURE

Over the last decade there has been a significant global increase in the demand for safe and nutritious foods grown in a sustainable manner (Sahota 2009). This demand, in turn, created a need for third-party food safety and good practice certification bodies able to assure the quality of agricultural products and to assure that agricultural products are produced sustainably (Bredahl et al. 2001; Hatanaka, Bain & Busch 2005). Ultimately, such standards can be applied to constrain market access, which inevitably force suppliers to adhere to regulations and environmentally beneficial production principles (Busch 2000; Van der Grijp et al. 2005; Fulponi 2006; Havinga 2006). Therefore, from a market and financial growth perspective, it would make sense for producers to acquire certification from a leading food safety and good practices certification body.

The FAO classifies food safety and good practice certification schemes into two groups, namely good agricultural practices (GAP) and good manufacturing or handling practices (GMP or GHP) (Lui et al. 2007). GAP standards are aimed at farm level practices, whereas GMP and GHP standards focus on the processing and treatment of agricultural and other produce. For the purpose of this study only GAP standards are covered, since they deal directly with farm-level practices.

2.6.1 Good agricultural practices: GlobalG.A.P.

Good agricultural practices (GAP) standards and regulations focus on what occurs on the farm during pre-harvest, in-harvest and post-harvest produce processes, up to the stage where the produce leaves the farm. GAP standards and regulations are built on assurance of the social wellbeing of workers, effective natural resource management and economic growth to ensure food safety and quality – the three pillars of sustainable development. The GAP concept serves as a reference when deciding on the best farming practices that are socially acceptable and environmentally sustainable. Potential benefits of being GAP-certified include the opening of new market possibilities which can increase economic growth, and reduced risk of unintentional results from incidental non-compliance with national and international regulations resulting in financial penalties or, at worst, legal sanction. GlobalG.A.P. is a global third-party certification body that sets voluntary certification standards and regulations related to GAP and claim to be the leading farm assurance programme (GlobalG.A.P. 2013a) internationally. The following is an overview of its certification process, requirements and assessments.

2.6.2 GlobalG.A.P. certification

GlobalG.A.P. certification aims to increase consumer confidence in food safety and product traceability while maintaining acceptable social and sustainable practices (GlobalG.A.P. 2012). GlobalG.A.P. requirements are extensive and specific regulations are not discussed in detail here. Its certification covers all agriculture, aquaculture, livestock and horticulture production and its certification is valid for 12 months, after which a third party audit is required once more. In addition to an annual audit, unannounced inspections are also conducted by accredited certification bodies. The certification process consists of five steps, namely:

- the applicant to register with a GlobalG.A.P. approved assurer;
- an internal assessment that has to be completed and the applicant having to comply with the requirement;
- an announced inspection of the production unit by the certification body;
- an intermediate step if non-compliance was detected involving a warning issued and the producer given three months to resolve the issue. If after three months the issue is not resolved a full inspection is mandatory;
- the certification body issuing GlobalG.A.P. certification within 28 days if all requirements were met.

There are three assessment modules, which consist of control points and compliance criteria (CPCC) (GlobalG.A.P. 2013b). The first module is a general set of CPCCs for all producers, regardless of commodity, which involves information regarding site history, site management and worker welfare. The second module deals with CPCCs related to the different food production sectors, namely crops, livestock and aquaculture. The third module involves testing compliance with CPCCs regarding a subgroup of the food production sectors mentioned and their supply chains. There are three categories of CPCCs, namely major must, minor must and recommended (GlobalG.A.P. 2013b). All major must CPCCs must be met unconditionally. Ninety-five per cent of minor must CPCCs must be met, while initial non-compliance of all the recommended category CPCCs are allowed, unless required by national legislation particular to a host country.

GlobalG.A.P. certification does not only open potential international market opportunities for South African producers, but also potential national market opportunities. Some of the well-known European retail chain stores that accept GlobalG.A.P. include Tesco, Sainsbury Supermarkets, Spar Austria, Superunie B.A., and Marks and Spencer. South African retail chain stores that accept GlobalG.A.P. are Pick-n-Pay, Woolworths, and Shoprite Checkers' Freshmark.

2.6.3 GlobalG.A.P spatial data requirements

GlobalG.A.P. has four CPCCs which are listed under the environment rubric, of which three are only recommended, and one is a minor must. However, there are other CPCCs which could be stored as spatial attribute data. Table 2.7 lists potential data which could aid producers to obtain GlobalG.A.P. compliance and hence certification.

Fuchs, Kalfagianni & Havinga (2009) lament that, inherent to private food assurance primarily revolving around protecting the interests of retailers, a clear discrepancy is evident between the many and varied concerns and measurement variables assuring food safety and product traceability compared with the very limited and even inconsequential number of environmental variables involved in these certification instruments. Nevertheless, a spatial information system would be instrumental in proving compliance with CPCC's related to product traceability. The bottom-line remains that land owners are responsible for the sustainable management of the natural resources located on their land. Failing to do so, land owners render themselves subject to severe legal and financial penalties.

Table 2.7 Spatial data requirements determined from GlobalG.A.P. standards

Data domain	**Data features**	**Spatial data and attribute data**
Site history and management	Production unit	Georeference or identification system for each crop field, orchard, livestock camp
		Property cadastre
Worker welfare	Residential housing	Location of housing and amenities
	Access to facilities (e.g. toilets)	Facility locations
Fruit, vegetables	Planting, sowing, harvesting schedule	Crop type
		Production dates
	Crop rotation	Crop type
		Production dates
	Fertiliser and plant protection product application	Unit (field or orchard) identification
		Date of application
		Fertiliser type
		Application quantities
		Application mode
		Name of applicator
Livestock	Movement	Dates into and out of camps
		Number of animals moved
		Composition of animal numbers
	Access to resources (e.g. water)	Locations of sources and dispensers
	Enclosure infrastructure (fencing)	Images of enclosure types (e.g. electric, wire)
		Location of electricity feeds
Environment	Conservation status	Conservation boundaries; Stand locations
	Land productivity /suitability	Location and rating of production areas
	Natural resources	Locations of erosion prone areas
		Wetland extents, locations and types
		NDVI for indication of veld degradation, biofuel load
		Location of water sources and consumption volumes

This chapter focussed on unpacking relevant international, national and provincial imperatives determining relevant spatial data requirements for the spatial information system through which spatial management at farm-level can be driven. The next chapter summarises data acquisition matters for a spatial management database by relating what data was gathered and how this was practically achieved.

CHAPTER 3: DATA COLLECTION AND PROCESSING

This chapter details data collection and data processing. It also covers an accuracy assessment of the GPS device to determine the accuracy of the data collected with it. Commencing from a summary of the database structure, the discussion of data collection is divided according to raster and vector data types. Following the general summary, the gathering of raster data types are addressed first, since certain vector data was subsequently digitised from it.

3.1 SUMMARY OF SPATIAL DATA REQUIREMENTS

The spatial data requirements that were determined from imperatives directing integrated agricultural and environmental management in the previous chapter were fairly extensive and in many instances overlapped. Also, obtaining certain datasets might prove challenging or time consuming to acquire. Therefore, for this study, it was decided to collect at least the basic spatial data regarding natural resources and agricultural infrastructure (see Appendix C). Table 3.1 is a simplified physical data model, which summarises the basic spatial data requirements to support decision-making to attain integrated agricultural and environmental management identified for operational purposes of this research exhaustively.

Table 3.1 Database design with data sets, features and attributes

Schema	Dataset	Attributes
Transportation infrastructure	Bridges	Primary key
		Farm
		Width
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date
Transportation infrastructure	Gates	Primary key
		Farm
		Width
		Height
		Construction material
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date

Continued overleaf

Table 3.1 continued

Schema	**Dataset**	**Attributes**
Transportation infrastructure	Roads	Primary key
		Road type
		Farm
		Section length (m)
		Estimated width (m)
		Condition
		Feature type
		Geometry type
		Editor
		Edit date
Buildings and open storage facilities	Field lavatories	Primary key
		Farm
		Lavatory type
		Image path
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date
Buildings and open storage facilities	Fire equipment storage	Primary key
		Farm
		Image path
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date
Buildings and open storage facilities	Industrial buildings	Primary key
		Farm
		Floor area
		Image path
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date
Buildings and open storage facilities	Manager accommodation	Primary key
		Farm
		Occupant
		Floor area
		Image path
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date

Continued overleaf

Table 3.1 continued

Schema	Dataset	Attributes
Buildings and open storage facilities	Work force housing	Primary key
		Farm
		Floor area
		Image path
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date
Buildings and open storage facilities	Open storage facilities	Primary key
		Facility identification number
		Farm
		Area (square metre)
		Feature type
		Geometry type
		Editor
		Edit date
Production banch unit boundaries	Crop field boundaries	Primary key
		Field name
		Farm
		Area ha
		Feature type
		Geometry type
		Editor
		Edit date
Production banch unit boundaries	Livestock camp boundaries	Primary key
		Camp name
		Farm
		Area ha
		Feature type
		Geometry type
		Editor
		Edit date
Production banch unit boundaries	Orchard boundaries	Primary key
		Block code
		Block nr
		Farm
		Area ha
		Fruit type
		Cultivar
		Plant year
		Feature type
		Geometry type
		Editor
		Edit date
Production banch unit boundaries	Plantation boundaries	Primary key
		Plantation id
		Farm
		Area ha

Continued overleaf

Table 3.1 continued

Schema	Dataset	Attributes
Production banch unit boundaries	Plantation boundaries	Tree type
		Feature type
		Geometry type
		Editor
		Edit date
Production banch unit boundaries	Farm boundaries	Primary key
		26digitkey
		21digitkey
		Parcel type
		Parcel_num
		Area (hectare)
		Province
		Maj_region
		Maj_code
		Portion
		Farm name
		Farm name abbreviation
		Circumference (km)
		Feature type
		Geometry type
		Editor
		Edit date
Production banch unit boundaries	Wire fencing	Primary key
		Fence type
		Farm
		Section length
		Feature type
		Geometry type
		Editor
		Edit date
Electricity infrastructure	Electricity transformers	Primary key
		Farm
		Type
		Make
		kW
		Construction date
		Service date
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date
Electricity infrastructure	Power transmission lines	Primary key
		Farm
		Section length
		Voltage
		Service date
		Feature type
		Geometry type

Continued overleaf

Table 3.1 continued

Schema	**Dataset**	**Attributes**
Electricity infrastructure	Power transmission lines	Editor
		Edit date
Environmental features	Natural vegetation	Polysqkm
		Bookcode
		Name
		Constrgt
		Protctd
		Remaining
		Cnsrvtnstt
		Vtypesqkm
		Mapcode
		Booksequ
		Biomecode
		Biome
		Groupcode
		Group
		Brgncode
		Bioregion
		Vegtypeid
		Biomeid
		Groupid
		Brgnid
		Polygonid
		Prtctnstts
		Pdfname
		Toclegend
		Legend
Environmental features	Geology	Formations
		Form code
		Subgroup
		Group
Environmental features	Buffer zone	Primary key
		Farm
		x-coordinate
		y-coordinate
		Feature type
		Geometry type
		Editor
		Edit date
Environmental features	Slope gradient	n/a
Environmental features	Slope aspect	n/a
Environmental features	DEM	n/a
Environmental features	NDVI	n/a
Guest farm	Guest farm buildings	Primary key
		Cottage id
		Area
		Construction date
		Feature type
		Geometry type
		x-coordinate

Continued overleaf

Table 3.1 continued

Schema	**Dataset**	**Attributes**
Guest farm	Guest farm buildings	y-coordinate
		Editor
		Edit date
Remotely sensed imagery	Spot 5 panshapenend image	n/a
	Aerial images	n/a
Water infrastructure	Boreholes	Primary key
		Farm
		Pump make
		Kw
		Depth
		Construction date
		Image path
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date
Water infrastructure	Filter banks	Primary key
		Farm
		Filter make
		Amount
		Construction date
		Image path
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date
Water infrastructure	Irrigation pipes	Primary key
		Section length
		Material
		Diameter
		Pressure rating
		Feature type
		Geometry type
		Editor
		Edit date
Water infrastructure	Risers	Primary key
		Farm
		Construction date
		Image path
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date

Continued overleaf

Table 3.1 continued

Schema	**Dataset**	**Attributes**
Water infrastructure	Rivers	Primary key
		Tag
		Feat_type
		Geom_type
		Mapsheet
		Row_status
		Version_nu
		Create_dat
		Source_ver
		Source_pro
		Capture_in
		Editor
		Edit date
Water infrastructure	Drainage lines/canals	Primary key
		Section length
		Construction date
		Feature type
		Geometry type
		Editor
		Edit date
Water infrastructure	Water fill points	Primary key
		Farm
		Construction date
		Image path
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date
Water infrastructure	Water pumps	Primary key
		Farm
		Pump make
		Kw
		Mobile
		Image path
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date
Water infrastructure	Water reservoirs	Primary key
		Name
		Farm
		Area ha
		Perimeter
		Volume
		Wall height
		Construction date

Continued overleaf

Table 3.1 continued

Schema	Dataset	Attributes
Water infrastructure	Water reservoirs	Feature type
		Geometry type
		Editor
		Edit date
Water infrastructure	Water tanks	Primary key
		Farm
		Capacity
		Construction date
		Image path
		Feature type
		Geometry type
		x-coordinate
		y-coordinate
		Editor
		Edit date

It serves as a reference list for the practical application unfolding in later chapters. The column caption *Database* refers to the primary, overarching database, Howbill Properties, created within the spatial database programme PostGIS, in which all the data is stored. *Schemas* are smaller organisational constituent units within the PostGIS database. The datasets and attributes were covered overarchingly in Chapter 1 and are not revisited in detail here, save to declare that all subsequent applications in the following chapters elaborate on its application.

3.2 DATA COLLECTION: RASTER DATA

Collected raster data consisted of aerial images, a DEM, a scanned geology map, and a SPOT 5 panchromatic and multispectral satellite image covering the study area. What follows is an abbreviated description of each of the spatial raster datasets.

Aerial images and *cadastre* data were sourced from the Department of Rural Development and Land Reform. The latest aerial images available were captured in 2010, with a spatial resolution of 0.5 metres and a root mean square error (RMSE) of 2.0 metres. In addition to the 2010 aerial images, aerial images from a previous period were also collected. The reason for the additional images will become apparent during the discussion of the primary data collection procedure. At the time of writing, the available cadastre data were included in the database. Attribute data included land parcel type, land parcel number, parcel area, province in which land parcel is located, major region, major parcel code, portion number (if land parcel had been subdivided), land parcel name and land parcel perimeter length.

A panchromatic (2.5 metre resolution) and multispectral (10 metre resolution) SPOT 5 scene was acquired from the South African National Space Agency (SANSA) through the good offices of the Centre for Geographical Analysis (CGA) at Stellenbosch University. The SPOT 5 scene was received as a level one A/1A SPOT 5 scene which had been corrected for differences in detector sensitivity. Geometric, radiometric and atmospheric corrections as well as pansharpening of the SPOT 5 scene were applied and are discussed further under data processing.

A digital elevation model (DEM) was acquired from the CGA as well. The Stellenbosch University DEM (SUDEM) has a resolution of 5 metres and was one of the highest resolution DEMs available commercially (Van Niekerk 2013). Slope gradient and slope aspect were extracted from the DEM and the method is explained under data processing. A 25 metre-DEM was also available from the CD:NGI at no cost for South African citizens.

A hard copy geology map (De Beer 1998) of the area was obtained from the South African Council for Geoscience. The hard copy geology map was scanned and georeferenced. Afterwards, the geology dataset was digitised for the study area from the georeferenced geology map and attributes added manually. Attributes included were formations, formation code as listed by the Council for Geoscience, group, and subgroup.

3.3 DATA COLLECTION: VECTOR DATA

Vector data consisted of cadastre data, a vegetation map and agricultural infrastructure spatial data. This subsection describes the various vector datasets, starting with environmental data themes and concluding with the capture of human-made infrastructure and land use features.

3.3.1 Environmental data capture

A *natural vegetation map* was sourced from the Biodiversity GIS website (Biodiversity GIS 2007). The vegetation map was published in 2006, covering 440 vegetation types for the whole of South Africa (Mucina & Rutherford 2006). The accuracy of the extract from the original large-scale map at national scale made for this research at farm-level, is to some extent questionable, since fine-scale, localised discrepancies were identified during primary data collection. Discrepancies are due to the 1:50 000 scale at which the original data was digitised. However, local vegetation types and boundaries can still be documented and refinements can be made to the dataset to improve the accuracy. Feature attributes were left unchanged and some of the important attributes, as identified in spatial data requirements above, are area, vegetation type, conservation status, biome and biome region.

Drainage canals and rivers were sourced from the CD:NGI. It was unclear which data capturing method was used to create the source data, since no metadata accompanied the original dataset. However, it is assumed that the natural drainage lines were digitised from aerial images.

Spatial locational data on some rather vital environmental features could unfortunately not be acquired during this research endeavour. Examples are fire pattern maps, current fire breaks, soil data, land cover disturbance dates, veld grazing capacity, wildlife population data and invasive alien species data.

3.3.2 Farming infrastructure data capture

Infrastructure data and production branch data was collected directly during a five-week field survey period on the study farm units. The three methods used to obtain spatial information on infrastructure were manually collecting coordinate readings with a consumer grade GPS device, digitizing infrastructure from remotely sensed images, and extracting information with the aid of some of the datasets. Data collected with a GPS device is covered first, followed by data that was digitised from secondary datasets. Extracting information with the aid of some of the datasets is covered under data processing. GPS data was collected per production unit, meaning all data were collected for a production unit before continuing with GPS data collection for the next production unit. Each feature type was given a descriptive GPS reference code which identified the feature and the production unit on which it was located. Features locations captured via a GPS device were water pumps, boreholes, filter banks, water fill points, water tanks, irrigation risers, roads, orchard lavatories, transformers, and pylons where power lines changed direction or diverged (i.e. line nodes). Buffer zones (conservation zones abounding orchards) were also documented with a GPS device (point data), since these areas are only formally indicated by pegged point signs in the field.

Regarding *irrigation infrastructure, water pumps, boreholes, filter banks, transformers, orchard lavatories and buffer zones,* locations were recorded and documented first, with a production manager as guide. This procedure saved time, since the production managers knew where the aforementioned features were located and how to access them. Production managers could often not supply requisite attribute information for the features, however. Much irrigation pipe data were acquired in computer aided design (CAD) format from Spilhaus, the engineering company whose engineers designed the various irrigation systems on the holdings. Collecting irrigation riser location coordinates were time-consuming as each riser had to be documented individually – despite in principle being regularly interspersed on underground pipelines, the distance between risers were found to vary considerably. Water tanks were documented when encountered and the locations were confirmed by production unit managers during post-capture reviews.

For *power transmission lines*, pylon locations were recorded with the GPS device, where power lines either diverged into two or more lines or changed direction, as point locations. Vector lines were automatically created from the GPS location points using the *Points2One* function in QGIS. The newly created line shapefile represented the power transmission lines. This method reduced time spent in the field.

Roads were recorded while driving the routes by activating the GPS device's tracking feature, which was set to record a GPS reading every 10 metres. This feature proved valuable for mapping roads from both an accuracy and time-saving perspective. Attributes recorded were road type, width, and condition. Processing of the GPS track is discussed further in the data processing section. *Gates* on fences were recorded when encountered. Attributes recorded were height, width, and construction material. Photographs of these features were taken with the GPS unit's built-in camera. The images were visually of sufficiently good quality and were also automatically geo-tagged by the GPS unit.

3.3.3 Land use data capture

The capture of *land use* feature information was crucial. The high resolution aerial images made it possible to accurately digitise features. It would have been possible to extract the fruit orchards, and crop fields using object-orientated image analysis and the SPOT 5 pansharpened image. However, this method was not chosen, since about 70% of the fruit orchard blocks consisted of more than one cultivar and would be classified as a single block. Therefore, additional time would be required correcting the data manually. Data that were digitised from remotely sensed imagery were reservoirs and surface canals, buildings, fences, plantations, crop fields, livestock camps, and fruit orchards. Plantations were digitised as polygons to include, where possible, only original plantation plots and exclude propagating saplings. Attribute information regarding plantation plots were tree species and area. Age of plantation plots could not be verified. Reservoirs were digitised as polygons according to the high water marks, as it was regarded as the maximum water storage capacity. Not all the reservoirs were at or close to maximum capacity on the 2010 aerial imagery, therefore older aerial imagery were used. Surface canals were digitised as line features from the aerial images. Buildings were digitised as points and classified during processing according to worker housing, manager housing, guest farm accommodation, warehouses, and fire fighting equipment storage units. Fences were drawn on printed aerial images and then digitised.

Provision was made for fence type and height, since it was not always possible to access fences. Livestock camps, crop fields and fruit orchards were digitised as polygons. Bridges were captured by extracting the nodes where surface canals and roads intersected.

In addition to the above mentioned, the latest farm management information was acquired from central farm databases in the form of MS Excel workbooks. Each farm unit had a separate workbook containing relevant fruit and crop attribute information aligned with the requirement list demanded in Section 3.1.

At the end of the five-week field survey, a one-hour meeting with each production manager in charge of a specific commodity on each farm unit was arranged. The production managers cleared up uncertainties and provided attribute information for all captured spatial features, such as reference numbers for fruit orchards, crop fields and livestock camps. In mixed cultivar blocks, rows were counted and marked on the high resolution 2010 aerial imagery for capture in the spatial databases to ensure accuracy and comprehensive cover. The managers conducted accuracy assessment of captured spatial land use information at the same time.

3.4 DATA PROCESSING

Data processing was necessary to prepare the data for importing to the database by saving data as shapefiles fit for GIS manipulation. It also included the addition of fit-to-purpose attribute columns for features. Raster data pre-processing and raster data processing are discussed first, followed by vector data processing.

3.4.1 Raster data pre-processing and processing

The SPOT 5 satellite scene was supplied with only level 1A processing applied and required geometric radiometric and atmospheric correction. Geometric correction is the process of rectifying systematic and non-systematic distortions introduced during image acquisition (Campbell 2006). The result is an orthorectified image from which distance and area measurements can be made. Radiometric correction rectifies errors caused by sensor response, sun angle, and topography. Atmospheric corrections remove haze caused by water vapour and dust in the atmosphere. Rectifying radiometric errors and atmospheric effects allow for comparing satellite images recorded by the same sensor at different time intervals, or comparing satellite images recorded by different sensors. PCI OrthoEngine was used to correct geometric and radiometric error corrections. The method used for geometric corrections and pansharpening were detailed by PCI Geomatics (2006). The Atmospheric and Topographic Correction (ATCOR) module in PCI Geomatica Focus was used to remove haze and correct for topographic effects, following the processing described by PCI Geomatics (2013). PCI Pansharp was also used to pansharpen the SPOT 5 scene. Pansharpening involves fusing the low resolution multispectral image with the high resolution panchromatic image. The result is a high resolution multi-spectral image. The Spot 5 scene was orthorectified first, followed by radiometric and atmospheric correction and lastly pansharpening was applied. Extracted data consisted of NDVI, slope gradient, and slope aspect. NDVI processing is covered first followed by slope gradient and slope aspect.

NDVI was derived from the SPOT 5 pansharpened image. NDVI is calculated using the near infrared and visible light reflected by vegetation. Healthy or green vegetation absorbs visible red light and reflects most infrared light. The opposite is true for unhealthy or sparse vegetation, infrared light is absorbed and red light is reflected. The NDVI ratio (Carlson & Ripley 1996) is calculated by the equation:

$$NDVI = \frac{Near\ infrared\ radiation - Visible\ radiation}{Near\ infrared\ radiation + Visible\ radiation}$$

NDVI was calculated in PCI Geomatica Focus. The result was an image with pixel values ranging between negative one and one. A value of negative one to 0.1 indicated barren areas or water, a value between 0.1 and 0.3 indicated shrubs or grassland with a lower leaf density, and values higher than 0.3 indicate tropical rain forests (Weier & Herring 2000) or, in the case of this study, healthy irrigated fruit trees and crop fields (see Appendix B for spatial reference). The SPOT 5 image was captured in December 2012, which is during the dry summer season. Therefore, the natural vegetation might not be as green as during the wet winter months.

The 5 metre DEM was re-projected to the Lo19 coordinate reference system using the *Raster Warp* function in QGIS. *Cubic* was selected as the resampling method. Slope, aspect and contour lines were extracted from the DEM using the *Raster Terrain Analysis* Plugin in QGIS. Slope was extracted as percentage and reclassified to include 12% and 20% (as determined from CARA regulations). Slopes with a percentage of more than 20% where reclassified as 100% to signify non-cultivation. Also, the aspect dataset was simplified by reclassifying the data according to the four major wind directions, north, east, south and west.

3.4.2 Vector data processing

Vector data processing was done after collecting all the necessary GPS data and digitised features. GPS data processing was done in QGIS. First, the GPS exchange (GPX) files were converted into shapefiles in order to add attributes and to assign a coordinate reference system. Second, the individual shapefiles were *merged* into a single shapefile and the GPS codes were checked for spelling mistakes that could have occurred while entering the codes on the GPS. Merging the shapefiles resulted in all the features collected from all the production units becoming accessible in one file. This procedure made it easier to correct, *select* and *extract* features to individual datasets. Third, the merged dataset was *projected* to the appropriate projected coordinated system, in this case the South African coordinate reference system (Lo 19) (Parker 2011; Parker 2012). This was done to ensure that the data were geographically correctly located and to ensure that accurate measurements could be made. Lastly, the data was sorted into individual shapefiles using the *Select by expression* function in QGIS R (Thiede, et al. 2013). A structured query language (SQL) expression was formulated to select the relevant data and the selected data was then saved as individual feature datasets. The compiled SQL expression reads as follows:

"Name" LIKE '%*GPS_code*%'

Where "Name" is the column header in which the appropriate attribute data is stored;.

LIKE is an SQL operator used to match a character pattern;

% indicates any arbitrary character; and

GPS_code signifies the feature codes in the "Primary_key" column.

The resultant output shapefiles were given descriptive dataset names and, finally, the individual datasets were reviewed and feature locations were corrected if necessary.

Individual GPS track recordings were also converted to shapefiles, merged into a single shapefile and projected to the Lo 19 South African coordinate system. The tracks were recorded as points and had to be converted to lines. This was done using the *Points2line* function, which resulted in a single line feature describing roadlines. Roads that were not recorded with the GPS track feature were digitised from aerial images and the SPOT 5 pansharpened image. Single-line features, such as roads, were split at intersections using the *v.clean.break* GRASS module. Unnecessary line features were removed. Bridges were extracted as nodes from line datasets from intersecting surface canals and roads using the *Line Intersections* tool.

The necessary attribute data for each dataset was created in MS Excel and linked with the respective dataset using the GPS code as unique identity for each feature. Table 3.1 lists the attributes added to each dataset. The *primary key* is uniquely coded for each feature, not required by the spatial database, but aid users in identifying an individual feature and the specific feature group that the feature belongs to (Petrenko 2012). Primary keys are also used to link tables with related feature attributes. Only the necessary and available attributes were added to spatial datasets. Supplementary data, in table format such as MS Excel tables, can be joined to the spatial dataset temporarily using key constraints. This was done to avoid spatial datasets becoming congested with attributes. As an example, the fruit orchard spatial dataset of a production unit (farm) only contains basic attribute data as listed in Table 3.1. All other information related to fruit orchards are stored in existing MS Excel spread sheets (current management data) and can be joined temporarily with the orchard spatial dataset when required for spatial display or manipulation.

3.5 SPATIAL DATA ACCURACY ASSURANCE

Testing the accuracy of the collected GPS and digitised data was difficult, since a differential GPS device was not available to take accurate location readings and quantify location errors. Positional accuracy was determined by calculating the RMSE (Campbell 2006).

Aerial images and the SPOT 5 pansharpened image had an RMSE value of 2.0 metres (automatically calculated during pre-processing). Therefore, it was assumed that digitised data would have about the same positional accuracy (at least 67% of data would be within less than 2 metres of the actual position). The accuracy and precision of collected GPS data was determined by performing an accuracy assessment of the GPS recorder-unit. It should be noted that this only applies to the GPS device used to collect the data. Accuracy may differ between GPS devices and accuracy also depends on specific conditions at the location of individual features, such as overhead cover or large structures close by.

The method that was used to estimate positional accuracy of the GPS device was adapted from Weih et al. (2009). The modified method can be considered fairly crude due to the lack of accurate reference coordinates. It consisted of selecting 20 small features from the aerial images and creating a reference location point-shapefile of these features. The coordinates of the 20 points were uploaded to the GPS device and navigated to in the field. The same spatial reference settings were used for the reference point-shapefile and the GPS device. A GPS reading was taken when the GPS device indicated 0 metres from a reference location (i.e. precisely on target). Each feature was visited five times over a period of five days, giving a total of 100 points. The GPS readings were added to QGIS, projected to Lo 19 and the latitude and longitude locations in metres were exported as comma separated value (CSV) files. Also, the linear distance between each collected point was determined. In MS Excel the RMSE of the collected GPS readings were calculated to determine an estimated positional accuracy (Chang 2010), and the average distance between collected GPS points were calculated as an indication of precision. An RMSE of 3.24 metres was obtained, whereas the precision was calculated as 2.03 metres. It should be noted that the relatively small sample size could have significantly affected precision due to random variation. However, the time lapse between coordinate readings should have adequately countered errors due to random variance and, therefore, the sample size was deemed sufficient to ascertain accuracy.

This chapter detailed the procedures followed during spatial data acquisition and data processing for this project. The next chapter forms part of stage three in the research design diagram of

Figure 1.5 and addresses the development of prototype spatial information system for application to the case study farming unit.

CHAPTER 4: THE PROTOTYPE SPATIAL INFORMATION MANAGEMENT SYSTEM

This chapter deals with the design and development of a suited-to-task integrated spatial information system and the technical and operational requirements to successfully operate it. Throughout this chapter the approach adopted is to partly address technical system matters generically, but to also inform task-specific case study (i.e. Howbill system decisions) and general enterprise decisions that inform system implementation. Also, reference is made to relevant technical decisions pertaining to the application of the geographical information system for integrated management of agriculture and the environment (GISIMAE) developed for this case study application. The chapter details the process followed to select the required GIS software and hardware, and it also covers basic spatial information system management and training recommendations, often in a user manual format.

4.1 DEFINING THE PROTOTYPE INFORMATION MANAGEMENT SYSTEM

This section gives a brief generic overview of the components of a GIS, to understand what GIS components were needed to develop the prototype spatial information management system, and concludes with a description of each of the required components.

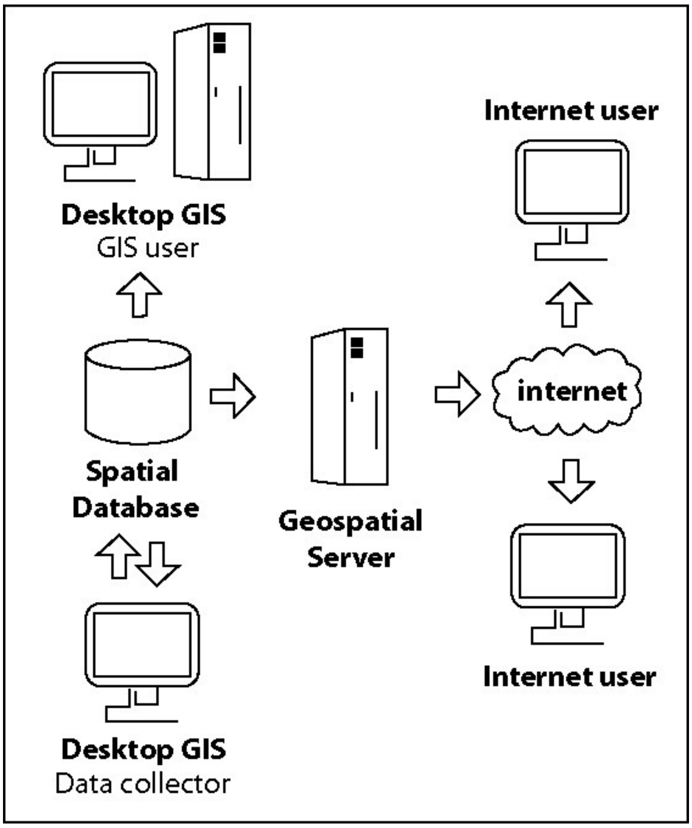
4.1.1 Selecting the type of spatial information system

In this subsection GIS systems are generically defined, a process Abdalla & Niall (2007) refer to as logical design. Chang (2010) defines a GIS as a computer based system which incorporates different processes, data and software to store, manage, display and analyse spatial data. This is a fairly broad definition, and GIS can be subdivided into desktop GIS and enterprise GIS. ESRI (2013a: 1) defines a desktop GIS as “Mapping software that is installed onto and runs on a personal computer (PC) and allows users to display, query, update, and analyse data about geographic locations and the information linked to those locations.” An enterprise GIS is defined as “A geographic information system that is integrated through an entire organization so that a large number of users can manage, share, and use spatial data and related information to address a variety of needs, including data creation, modification, visualization, analysis, and dissemination.” (ESRI 2013b: 1). The main difference between the two types of GIS is that an enterprise GIS provides the ability to share, or access the same spatial data concurrently, between multiple users, whereas a desktop GIS is focused more towards serving the needs of a single user.

For the purpose of this study, developing an elementary enterprise-type GIS is focused on for three reasons. First, multiple users (in this case the Howbill Properties managers) require concurrent access to spatial data. Second, a desktop GIS forms part of an enterprise GIS. Therefore, a desktop GIS will inherently be covered as well. Third, an elementary enterprise GIS can also run on a single PC – a prerequisite for local farm-level application. The following subsections detail the development process of an enterprise GIS and the components required to do so.

4.1.2 Defining the components required for an enterprise GIS

An enterprise GIS consists of various components and Figure 4.1 provides a simplified illustration of what an enterprise GIS might look like and the components it might consist of. The



Source: Steiniger & Bocher (2009)

Figure 4.1 Enterprise GIS infrastructure

diagram sketched the process whereby spatial data is collected by a data collector and uploaded to a spatial database, where the data is stored. GIS analysts can access the data in the spatial database and use it for various applications. The spatial database can be connected to a geo-server to serve data over the internet to users.

Each component serves a specific purpose and it is necessary to understand the purpose of each component and what is currently available, since components has to be integrated when designing and implementing a GIS in order to fulfil the needs of the user (Somers 2005). Longley et al. (2006) and Chang (2010) list the basic components of a GIS as software, hardware and data, and each enterprise GIS component is summarised next.

4.1.3 Software

Basic software requirements for an enterprise GIS consists of a Desktop GIS application and a spatial database. Desktop GIS software serves as a front-end (user interface between user and spatial database) for the spatial database, which provides relatively easy data viewing, editing, and analysing functionalities. The Desktop GIS software must be able to connect to the spatial database in order to retrieve the necessary data.

A spatial database, or spatial data management system, is software that securely stores and organises spatial data, and regulates access to the data. The spatial database forms the foundation of the spatial information system. In essence, the spatial database is a single computer directory or computer file which serves as a container that securely stores all the spatial and non-spatial data, and ensures data integrity. The spatial database operates as a background computer process and is rarely operated directly by users, except for data and database maintenance. Users access the database via a front-end application, which could either be a desktop GIS application or a user interface specifically designed for the spatial database.

4.1.4 Hardware

Software requires hardware to operate on, which could consist of a computer server, or a PC (including a monitor, a mouse and a keyboard). Defining a server is relatively complex, and can be especially confusing for users with little or no computer background. The term server may refer to both hardware and software or just the software performing certain services (web services, or data storage services) (PCMag 2014). Therefore, a server can either be a purpose-built server computer system (or multiples thereof), or a server can be software installed on a PC, which provide a specific service such as data storage. However, the focus here is on computer hardware. Additional equipment consist of a router for internet access (some functions of desktop GIS software requires an active internet connection), and access to a network in order to retrieve data from the database if the database is located on a server (a separate computer system in this case). Supplementary hardware includes GPS devices, printers, and cameras. Minimum hardware requirements depend on the GIS software's minimum hardware requirements and can only be identified once the GIS software has been selected. Without data, software and hardware are of little productive use, but data types, data requirements and data collection were covered in previous chapters.

The components required for an enterprise GIS are a spatial information management system (spatial database), a desktop GIS application and hardware. The process of selecting software and hardware is referred to as the physical database design process (Abdalla & Niall 2007), and is covered next. Specific hardware requirements are dealt with after selecting the software.

4.2 SOFTWARE SELECTION FOR AN ENTERPRISE GIS

There are a number of GIS software platforms currently available. However, functionality and cost vary greatly between them. This section details the process of selecting the necessary software for the prototype spatial information system.

4.2.1 Selecting the spatial database

It was decided to select the spatial database first, since the spatial database was seen as the foundation of the information system. This subsection highlights some of the available spatial database options, and the process of selecting a spatial database.

4.2.1.1 Spatial database software selection criteria

Longley et al. (2011) listed cost of GIS implementation versus benefit of GIS to the company as one of the key questions a business is likely to consider. This means that if the cost involved to implement and manage the spatial information management system is too high with regards to potential benefits, a company is likely not to implement a spatial information management system. Therefore, the first criterion was minimum cost to company, which include both minimum initial implementation cost and on-going management costs. Potential benefits of implementing a GIS for integrated agricultural and environmental management were highlighted in previous chapters, so, aside from cost, the spatial information management system also had to meet the following criteria:

1. Must support vector and raster data types, since both raster and vector data were acquired;
2. Must allow for potential future expansion of the spatial information system, such as serving data to users over the internet, which enables user access to data in the field;
3. A cross-platform database, meaning the database should be able to work on Windows, Linux, and Macintosh operating systems (OS), would be advantageous, since the system would then be

compatible with the current OS used in the company, thereby eliminating the cost and time to convert to a new OS to accommodate the new spatial information management system.

4.2.1.2 Spatial database software review and final selection

Boundless (2014) gave an extensive overview of available spatial databases and some salient issues capturing the essence of each of these spatial databases are highlighted here. Available spatial database options were:

- SQL server 2012 with Spatial
- Oracle relational database management system (RDBMS) with Spatial or Locator
- PostgreSQL with PostGIS
- ArcSDE and
- SpatiaLite.

Oracle RDBMS, *SQL Server* and *PostgreSQL* are all highly capable relational database management systems and spatial support is added through an extension in each case. An extension can be defined as an additional software package that is added to existing software, in this case a database programme, to add additional functionality (like spatial management functions).

Microsoft developed *SQL server 2012* with *Spatial*, as the follow-up version of SQL Server 2008 with Spatial. It is a relatively new spatial database that follows simple features SQL (SFSQL). SFSQL was developed by the Open Geospatial Consortium (OCG) and defines standard spatial functions and data types used in spatial databases. Therefore, implementing SQL Server with Spatial is quite similar to other SFSQL products. An advantage of SQL Server 2012 with Spatial is the fully functional spatial extension available for all editions of SQL Server, including the free Express edition. However, there are three major disadvantages of SQL Server with Spatial. First, it is only available for Windows servers, second, coordinate reference system transformations are not supported and, third, SQL Server's spatial extension uses an older multi-level grid index, which could seriously limit a database with very large data sets.

Oracle RDBMS has two spatial extension options. Spatial is the spatial extension with full spatial functionality available only for the Oracle Enterprise Edition database. The Oracle Enterprise Edition database is expensive, which ultimately limits the user base of the Oracle Enterprise Edition. Locator is a free spatial extension, with limited functionality, available for all Oracle database editions, including the free Oracle XE database. The foremost disadvantage of Locator is the limited functionality. Buffer, union, intersection, centroid point generation, and calculate area or length functions cannot be used due to licence constraints. Also, raster data types are not supported by Locator, which means DEMs and aerial images cannot be stored in the database.

PostGIS is the spatial extension for *PostgreSQL*, and is the most advanced open source database currently available (the term PostGIS refers to the PostgreSQL with PostGIS extension). Advantages of the PostGIS database are fairly extensive, but the following are indispensable:

- PostGIS is open source software, which means it can be acquired, used and distributed at no cost to the user;
- PostGIS has a large, active user base, from which aid with development and improvement of new PostGIS versions can be expected;
- Vector and raster data types are supported by PostGIS;
- PostGIS can be installed on Windows, Linux or Mac OS; and
- PostGIS follow OGC and SFSQL spatial specifications, implying that users familiar with IBM and ESRI databases would be able to easily convert to a PostGIS database environment.

ArcSDE is not a spatial database, but is intermediate software which provides database-independent spatial functions to relational databases for use by ESRI client software (such as ESRI ArcGIS). *SpatiaLite* is also a relatively new and very basic spatial database, based on SQLite, but it is not suited for a server environment where data is shared between multiple users concurrently (Furieri 2011).

Following the considerations highlighted above, Table 4.1 summarises the spatial database selection criteria pertinent to operational decision-making in this research. PostGIS emerged from the criterion comparison as a clear winner and was selected as the most suitable spatial database for the prototype spatial information system GISIMAE and its Howbill application (see Appendix C). As open software it is freely downloadable from the Internet (PostgreSQL 2013a), can handle both types of spatial data, can be expanded, runs on the three dominant OSs, and has added potential functional abilities. This decision naturally raises the question which desktop GIS to select – answered in the next section.

Table 4.1 Spatial database selection criteria

	Selection criteria				
Spatial database software	**(Cost) Free**	**Data type support**	**Potential expansion capabilities**	**Supported OS**	**Additional functionality**
SQL server 2012, with Spatial	No	Vector and raster	Yes	Windows	Limited
SQL server 2012 Express, with Spatial	Yes	Vector and raster	Yes	Windows	Limited
Oracle, with Spatial	No	Vector and raster	Yes	Windows, Linux and Mac OS	Yes
Oracle, with Locator	Yes	Vector	Yes	Windows, Linux and Mac OS	Limited
PostgreSQL, with PostGIS	Yes	Vector and raster	Yes	Windows, Linux and Mac OS	Yes
ArcSDE	No	Vector and raster	Yes	Windows	Limited
SpatiaLite	Yes	Vector and raster	Limited	Windows, Linux and Mac OS	Limited

4.2.2 Selection of desktop GIS software

The desktop GIS for case study application were selected using a similar approach as for selecting the spatial database. First, a set of criteria were identified, and a list of potential desktop GIS software were reviewed and compared against the criteria.

4.2.2.1 Desktop GIS software selection criteria

Criteria for selecting a desktop GIS application were slightly different than for the spatial database. Cost was again an important consideration for the same reason as for spatial databases. However, at this stage the spatial database was already selected and therefore it was more important that the desktop GIS could connect to the spatial database.

The criteria for selecting a desktop GIS required:

- Ability to connect to the *PostGIS* database, since PostGIS was already selected as the spatial database;
- Having a range of spatial functions for both vector and raster data types;
- Preferably having a point-and-click graphical user interface (GUI), in order for users to easily identify functions, and being able to see results relatively quickly;
- Ability to work on Windows, Linux, and Mac OS;

- Affordable cost; and
- Limited need for user experience.

Having formulated these criteria, available software could now be measured for best fit against them.

4.2.2.2 Desktop GIS software review and selection

The following are some of the major desktop GIS software platforms that were listed by Obe & Hsu (2011) and Obe & Hsu (2012) as being capable of connecting to a PostGIS database:

- ESRI ArcGIS (ArcGIS) with *ArcSDE* license;
- QGIS;
- Geographic Resources Analysis Support System (GRASS) GIS;
- User-friendly Desktop GIS (uDig); and
- Generalitat Valenciana, Sistema d'Informació Geogràfica (gvSIG).

ArcGIS is a commercial GIS software package which provides a comprehensive range of spatial analysis functions for both vector and raster data types. However, the primary limitation of the ArcGIS package is cost, since the package is fairly expensive (Lowry 2006). Most of the functions available in ArcGIS will not be used very often or not at all by most entry level GIS users, including most GISIMAE users. Therefore, from a cost versus benefit point of view, the functionality of ArcGIS, with regards to GISIMAE, far exceeds the user needs and cost of acquisition cannot be justified. Also, ArcGIS currently only operates on a Windows OS.

QGIS is relatively similar to ArcGIS in terms of functionality and user interface. However, QGIS is an open source application and is freely available to users. An organisation may acquire and use as many QGIS software copies as required without breaching any licence stipulations. The GUI of QGIS is, to some extent, easier to navigate and remember than ArcGIS, due to the number of large shortcut icons (critics might argue differently). QGIS can also operate on Windows, Linux and Macintosh's OS X. Coordinate reference systems are also well defined and supported in QGIS, a function vital for accurate spatial analyses and queries.

GRASS GIS was developed by various governmental and educational institutions of the United States of America (USA) for use in research (Steiniger & Bocher 2009). The prime disadvantage of GRASS GIS is its complexity. However, GRASS GIS is incorporated into QGIS and can be used when users require more advanced functions and analyses.

uDig prides itself on developing GIS software capable of viewing and editing data directly in databases and over the Internet. However, execution of certain functions is likely to be too complex for novice GIS users.

gvSIG was developed by the Regional Council for Infrastructures and Transportation (CIT) of Valencia (Spain) to replace ESRI's ArcView in their organisation. The GUI of gvSIG is straightforward, and provides a host of GIS functions. Table 4.2 summarises the criteria for selecting a desktop GIS with reference to the performance of the five GIS software platforms listed and discussed above on six salient criteria. The criterion in the last column requires further consideration before a decision can be made and for that purpose Table 4.3 lists categories of user experience and GIS operating skills of users, in order of increasing experience, as formulated in Steiniger & Bocher (2009).

Table 4.2 Desktop GIS selection criteria

	Criteria					
Desktop GIS software	**Able to connect to PostGIS?**	**Support vector and raster data types and functions?**	**Graphical user interface?**	**Supported operating system**	**Cost: user/computer per license**	**Minimum user proficiency**
ArcGIS 10.1 (Current version)	Yes, via ArcSDE	Raster and vector	Yes	Windows	About R10 000+ per user license	All users
QGIS	Read and write	Raster and vector	Yes	Windows, Linux, Mac	Free	All users
GRASS	Read and write (limited)	Raster and vector	Yes, via QGIS	Windows, Linux, Mac	Free	Experienced, expert, researcher
uDig	Read and write	Raster and vector	Yes	Windows, Linux, Mac	Free	All users
gvSig	Read and write	Raster and vector	Yes	Windows, Linux, Mac	Free	All users

Table 4.3 Levels of GIS user proficiency

Categories of user proficiency	**GIS operating skill**
Novice	View spatial data and print maps
Experienced	Edit data, execute queries, perform basic spatial analysis
Expert	Perform advanced spatial analyses
Researcher/Developer	Scripting and programming

The GIS experience and GIS proficiency levels required of GISIMAE users is expected to range from novice to experienced, or at most (eventually) expert, but always according to task. It is also highly likely that in time user proficiency will increase and advance through categories with continued use of the GIS. Therefore, the desktop GIS software must at minimum be able to fulfil the needs of all user levels from novice to experienced user, and allow for user experience to improve with time.

Based on criteria performance, QGIS, uDIG, and gvSIG were determined to, in theory, be equally good choices as desktop GIS applications to use for GISIMAE. Ultimately though, QGIS (see Appendix C) was selected as the desktop GIS application, since the GUI seems to be better orientated towards novice users, and therefore it might be easier for users to get familiar with the platform – even for experienced and expert users. However, it would also be possible to substitute QGIS with some other desktop GIS application tabled above if required.

Having reached a decision regarding the most suitable GIS software platform, hardware components for GISIMAE enterprises had to be selected.

4.3 SELECTING COMPUTER HARDWARE FOR AN ENTERPRISE GIS

This section covers hardware requirements for an agricultural enterprise GIS (like GISIMAE). Hardware includes server hardware, desktop GIS hardware, and peripheral or supplementary equipment which support data capturing. Selecting hardware for a GIS system can justify a study on its own. There are many factors to consider and each enterprise will set its own system requirements. However, selecting suitable hardware is vital and contributes to the success of a GIS in an enterprise (Longley et al. 2011). It should be noted that this section does not claim to be a sure hardware selection and implementation guide – professional guidance is advised.

4.3.1 Enterprise hardware requirements and selection

Numerous literature sources broadly outline considerations for implementing an enterprise GIS system, but few detail how to go about determining hardware requirements for such a system, especially on a smaller scale involving fewer than fifteen concurrent users as in the case of Howbill Properties. Therefore, determining hardware requirements focused on a limited number of basic questions to consider. The basic model emerging when determining enterprise hardware requirements for implementing server systems seems to centre on the purpose of the system, as well as user requirements (HP 2013; Gann 2012; IBM 2012). To determine a company’s hardware needs, the following questions, suggested by HP (2013), should be answered:

1. What is the purpose of the system? In the Howbill case it is assumed to be a spatial database server.

2. How many employees would access the system? In the Howbill case the assumption is that a small user base (probably less than 10) users would do so.

3. What is the frequency at which users will access the system – often (three or more times per week), or occasionally (less than three times per week).

4. How many users will work on the system concurrently?

The decision on hardware selection can be tailored to fit three logical model options for potential combinations of hardware and database types to consider:

- Combination option 1 – Single, medium- to high-end personal computer (PC) with spatial database and desktop GIS installed.

- Combination option 2 - Entry level server with client (user) computer connection via a local area network (LAN).

- Combination option 3 - Medium to high end server with client (user) computer connection via a LAN.

Table 4.4 summarily lists a range of possible recommended solutions matching the user requirement questions with one of the three options for potential hardware combinations.

Table 4.4 User computer hardware requirements

Number of users	Frequency of use	Potential concurrent connections	Hardware combination options
1-5	Often	Yes	Option 2
		No	Option 1
	Occasionally	Yes	Option 1 (with time roster)
		No	Option 1
6-10	Often	Yes	Option 2 or 3
		No	Option 2
	Occasionally	Yes	Option 1 (with time roster)
		No	Option 1
11-15+	Often	Yes	Option 3
		No	Option 2
	Occasionally	Yes	Option 1 (with time roster)
		No	Option 1 or 2

To determine specific hardware requirements for a desktop (client or user) GIS computer, an enterprise has to determine the purpose the computer system has to serve. Limited-specification computers (Option 1) would suffice to meet the needs of a novice user (see Table 4.3), since the purpose of the computer would only be to view spatial data. A higher-specification computer would be required for an expert user typically performing advanced spatial queries and analyses. It should be noted that user experience may increase rapidly, and it might be prudent to acquire a higher-specification computer from the outset, to avoid costly upgrades early on.

A further consideration would be software-specific. QGIS developers specify no standard minimum or ideal GIS workstation requirements for operating QGIS software. Their rule of thumb is compatibility; if the user's current computer hardware is able to run one of the operating systems listed on the QGIS download page (see Table 4.2), then it should be able to run QGIS. However, while the hardware might be able to run QGIS, it might take too long to open large datasets or complete certain analyses. Therefore, in the Howbill case, the system requirements were determined to meet proprietary GIS software system requirements. Table 4.5 lists the minimum and ideal hardware requirements for a desktop GIS computer as stipulated for ArcGIS (2014) use. Note that professional advice would be required should an enterprise require a server, to address the additional server hardware considerations not covered here. A medium-specification GIS computer system meets a mixture of minimum- and high-end computer hardware specifications. Table 4.6 combines and compares user experience (from Table 4.3) with computer hardware requirements (from Table 4.5), to further aid users in determining the appropriate computer system to acquire.

Table 4.5 GIS computer specifications

Computer system component	**Minimum system requirements**	**High-end system requirements**
OS	32-bit OS	64-bit OS
CPU	Dual core CPU	Advanced dual core or quad core CPU
CPU speed	2.0 GHz	3 GHz or more
RAM	2-4 GB	8 GB or more.
Display	16-Inch with 24-bit colour depth	≥ 20-Inch with 24-bit colour depth
Screen resolution	1024x768 at 96 dots per inch (dpi)	1024x768 at 96 dots per inch (dpi)
Hard drive install space	2-5 GB	2-5 GB
Data storage space	320 GB	320 GB - 1 TB
Video or graphics adapter	64 MB with OpenGL 2.0 and shader	1 GB with OpenGL and DirectX support.
Networking hardware	LAN card or wireless (WIFI) card.	LAN card or wireless (WIFI) card.

Table 4.6 Categories of user experience versus computer specification

Categories of user experience	**Minimum Computer hardware requirements**
Novice	Minimum-specification computer hardware
Experienced	Minimum- to medium-specification computer hardware
Expert	Medium- to high-end computer hardware
Researcher	High-end computer hardware

Applying the criteria encapsulated in Tables 4.3-4.6, the hardware recommendation for Howbill implementation of GISIMAE would be to initially acquire or provide a computer meeting minimum system requirements in line with Option 1 expectations. Depending on system experience and the standard of currently available hardware, the system can then be upgraded as the sophistication of use and user proficiency grows.

Computer hardware is only one facet of GIS. Supplementary hardware could add additional functionality and application possibilities to the spatial information system and its management support function, which is attended to in the next section.

4.3.2 Supplementary hardware components

Supplementary equipment consists of components that can be used to enhance the functionality and application of software like GISIMAE. Supplementary equipment consists of immediate, connected peripherals like printers and external devices like GPS units and cameras. Peripheral hardware are integral components of GIS, but, unlike software, without cost-free (gratis) options. Hence, enterprises would be well advised to consider the determining factors in the next section to aid decisions regarding purchase of appropriate peripherals to limit initial acquisition costs.

4.3.2.1 Printers

Printers are necessary devices to print hardcopy paper field maps and maps for reporting documentation. Field maps are required when large amounts and various types of information are to be displayed relating to specific (normally outdoor) locations. Typically functionaries would require such printouts to take into the field for locational reference during infrastructure maintenance or upgrade operations, or to record new spatial locational data. Consumer-grade GPS devices are sufficient for mapping point and track (line) features, but fail in situations where large amounts of polygon data or raster-type data are generated in the field. Furthermore, budgetary limitations may prohibit GPS device purchase, allowing printed field maps to substitute. Users should determine the maximum paper size (A4 to A0), printing delivery mechanism (inkjet or laser) and colour (mono or colour) option requirements. Users should also take into account that larger format printers are more expensive to acquire, maintain and operate than smaller format printers. Laser printers generally print more pages per minute than inkjet printers but can be costly especially with colour printer capabilities. A colour printer would be recommended, since colour and texture is used to signify features on maps.

4.3.2.2 GPS devices

GPS units are used for navigation and data collection. GPS units can be grouped into three application categories, namely recreational units, mapping grade units, and survey grade units (Kamiak Environmental 2014). Recreational GPS units are further divided into automotive and recreational outdoor types. Automotive units are optimised for vehicle navigation along road networks, usually have large screens which allow for easy viewing, are voice enabled (audible navigation), have a limited battery life and limited off-road navigation and limited data capture features. Automotive GPS units are not recommended for data capture, since the units were not designed for that purpose and therefore do not have appropriate data capture abilities and features.

Recreational outdoor GPS units are used mostly for off-road navigation (hiking and cycling). Generally, they are smaller than automotive GPS units, are more rugged (dust and waterproof), and have a longer battery life. In most cases these units allow users to capture waypoints, which make it cost effective for data capture. Positional accuracy of these units range between 2 to 15 metres, depending on the quality of the GPS signal receiver, and the environmental conditions (e.g. cloud cover, proximity to buildings or tree cover) of the user area (Weih et al. 2009). The use of recreational outdoor GPS devices for data collection has become more popular over the last decade, due to increased accuracy and reduced unit cost (GPS World 2009).

Mapping and survey GPS units are optimised for data capture and have a high positional accuracy ranging between 10 to 50 centimetres after post-processing, which is considerably better than recreational devices. However, the cost of these units can be substantial as becomes evident from Table 4.7 summarising the characteristics of the various GPS device types.

Table 4.7 Summary characteristics of GPS device types

GPS type	**Application field**	**Positional accuracy**	**Estimated cost**
Automotive	On-road navigation	10-30 m	R1 000-R3 000
Recreational outdoor	Off-road navigation and data capture	2-15 m	R1 200-R5 000
Mapping and survey	Data capture	2-50 cm	>R10 000

With reference to GISIMAE implementation at Howbill and similar enterprise level, an affordable recreational outdoor GPS unit would be sufficient for mapping most features significant for the management of agriculture (new water pumps, electric transformers, field boundaries) or the environment (e.g. soil type boundaries, unique vegetation stands, species finds, fire tracks). Also, multiple recreational outdoor GPS devices can acquired for the price of one mapping grade GPS unit. Should features require mapping at sub-metre accuracy, such as individual fruit tree stands, or underground irrigation pipes, it might be more advisable and cost effective to employ professional services.

4.3.2.3 Cameras for visual data capture

Cameras can be used to record photographic images as records of target features, and the image directory can be added as an attribute to a feature in the GIS database. This would provide a visual reference for most captured features listed in Table 3.1. Cameras with *geotag* capabilities would be advantageous, since the location of images are simultaneously recorded allowing effortless image location mapping. A low-cost, compact digital camera would be sufficient for recording images of features, but GPS devices equipped with a camera function obviates the purchase of an additional camera. Modern cellular phones (smart phones) are now equipped with both GPS and camera functions, which open up a whole new realm of compact multi-functional devises serving most of the external device functions required for data capture.

4.4 ASSEMBLING THE GISIMAE SYSTEM PARTS

Having decided in Section 4.2.2.1 on PostgreSQL with PostGIS as the spatial database of choice for GISIMAE implementation, the exact software version had to be located for installation. Specifically, PostgreSQL 9.2 with PostGIS 2.0 was selected to serve as the spatial database. This section highlights how the spatial database was set up and should provide users with a basic understanding of setting up PostGIS and the PostGIS graphical user interface (GUI). The filing structure of the collected data within the spatial database is also covered.

4.4.1 Setting up PostGIS

This subsection covers the setting-up of the PostGIS database. It is recommended that the initial PostgreSQL and PostGIS database be installed and set up by a professional on a server system, since it is relatively complicated. Users should also consult the detailed PostgreSQL (PostgreSQL 2013b) and PostGIS (PostGIS 2013) installation documentation before and during installation.

PostgreSQL is a client-server based system and consists of two processes. First, is the server process (back-end), responsible for managing database files and connections from client applications. The server process (database server program) is Postgres. Second, is the front-end application, which is used to perform database operations. PostgreSQL Admin three (PGA) is an example of such a front-end application. Client and server applications can be located on different hosts and requires a LAN network connection to communicate.

PostgreSQL is installed first, followed by installing the spatial extension PostGIS. The installation distribution package used for installation will depend on the OS (Windows, Linux or Macintosh). It is also recommended to install PGA as a front-end to allow for easy database access and basic database maintenance via a GUI. Connection and authentication settings are stored in the *pg_hba.conf* file located in the *data* file directory of PostgreSQL installation location. Specific connection and authentication settings depend on the system setup and will likely differ between user enterprises. A super user account is created when the database is installed. A super user account avoids all permission checks performed by the database, and is allowed to change all aspects of the database. The following subsection describes the default PostGIS file structure.

4.4.2 PostGIS default file structure

PGA is a graphical open source administration and development platform (front-end application) for PostGIS, which supports most PostGIS functions, ranging from executing simple SQL queries to creating complex databases. This subsection describes the file structure of PostGIS and is important to understand, since users will have to navigate the database in order to retrieve data, view data, manage the database, or upload new data to the database. Figure 4.2 is an anchor graphic showing a screen capture of the PGA object browser window which lists the PostGIS database file structure leading treewise to objects. Each node in the tree is termed an object. Technical reference in the following subsections refers to these nodes and objects and may require recurrent consultation of this graphical structure.

4.4.2.1 Server groups and nodes

The first node at the top in the object browser shown in Figure 4.2 (*Server Groups*) lists all servers available to the user by name and number available. Servers (software) could be located on the same computer or on a different computer system. However, the number of servers in the server group and their locations are unimportant, only the server on which the spatial database is located is important and this device location will be enterprise-specific. Individual servers form the second node in the tree and list the available server(s) (in this case, PostgreSQL - software providing a database service, as described at the beginning of this chapter). This is the server software, and should be the same on a user's system. The host name and port number are displayed next to the respective servers. The host name refers to the particular system from which the service is

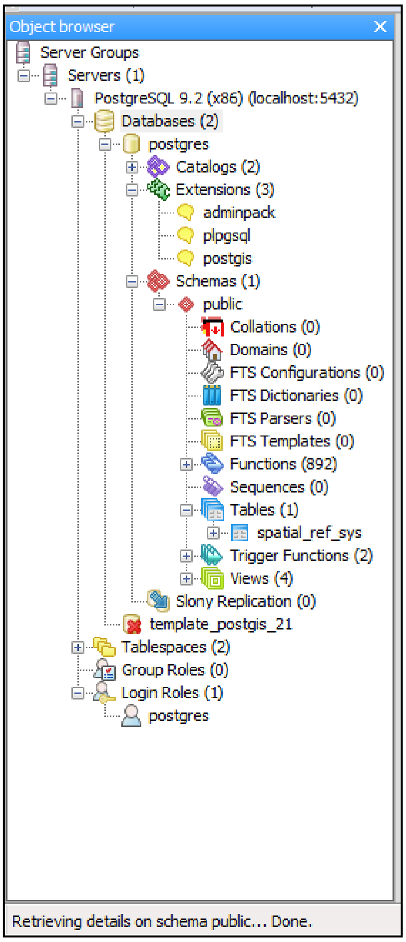


Figure 4.2 Screen capture of PGA object browser window

run, or hosted on. The port number refers to a specific communication channel through which information (database connections, data and queries) is sent between the client computer (user PC) and the server. The host and port number is configured during the installation of PostGIS. Four objects are listed under the individual servers (PostgreSQL 9.2 as illustrated in Figure 4.2). However, only the *Databases*, *Group Roles* and *Login Roles* are important nodes to note. These nodes are detailed separately below.

4.4.2.2 Database and login roles node

PostGIS can contain multiple databases and they are listed under the *Databases* node. To access the database a user requires an authorised login account activated through a uniquely assigned username and password. User accounts are created and recorded under the *Login Roles* node (second branch, bottom). *Group Roles* are used to manage a number of user accounts at the same access restriction level without having to change user accounts individually.

Extensions and *Schemas* (third branch level) are important objects listed under the *Databases* node. *Extensions* add additional functionality to the database. In this case, the PostGIS extension enables the database to accommodate and manage spatial data. Extensions must be enabled separately for each database listed under the *Databases* node. *Schemas* can be regarded as databases within a database, with the benefit of being able to interlink datasets and move datasets between schemas. It is not possible to link datasets between two databases, though. Schemas were used to group related datasets (e.g. all water related features were grouped in a schema named Water). The *public* schema is created by default by PostGIS when a new database is created. Under each individual schema there are 12 default objects, of which only the *Tables* object is important to GISIMAE users.

4.4.2.3 Tables node

Individual datasets are stored as tables and can be found under the *Tables* object (fourth branch). Tables have a typical spreadsheet structure made up of columns and rows. A row represents a specific feature and a column represents an attribute of that feature. It should be noted that once a table with more than one column (attribute set) is created, the order of the columns cannot be changed unless a new table is created with the columns rearranged. Therefore tables should be carefully and thoughtfully constructed. However, this proviso does not affect the functionality of the data. Column headers will vary between datasets, since each dataset is, generally, unique in terms of attribute data. There are five objects listed under each *table*s node, but these are not relevant at this stage – they become important during advanced database management actions.

4.4.3 GISIMAE database design

Database design, in this case, refers to the process of planning how the data should be lodged or filed within the database, and determines the relationship between the various datasets, or tables, in the database. The database design process for GISIMAE was relatively straightforward. The main principle governing the design process was to group features or tables with similar themes and to avoid unnecessary data duplication. This rudimentary design was selected to make it as readily accessible and simple as possible for the user group foreseen (mostly novice users).

The database development consisted of four steps: creating a database in PostGIS, enabling the spatial extension, creating and defining schemas (data groups) and uploading actual spatial data (Obe & Hsu 2011). First, and very simply, a new database was created and named Howbill Properties. Second, the PostGIS spatial extension was enabled. Third, eight schemas were created which would eventually group the various datasets into predefined categories. The categories are transportation infrastructure, buildings and open facilities, production branch unit boundaries, electricity infrastructure, environmental features, guest farm infrastructure, remotely sensed imagery, and water infrastructure. Categories provide structure within the database. Each data category contains a number of datasets under each schema as comprehensively listed in Table 3.1.

The fourth step was to implement the physical data model (see Table 3.1) which involved uploading data into the database. Implementing the physical data model resulted in the operational database (Petrenko et al. 2012). Datasets were loaded into the database using three different methods as described by Obe & Hsu (2011). The method used depended on the type of data – requiring dedicated coverage of each type in the next three subsections.

4.4.4 Loading vector data into PostGIS

The PostGIS shapefile loader is a graphical plugin supplied with PostGIS version 2.0 and higher. A shapefile stores geometry and non-spatial data coupled to locational co-ordinates suitable for GIS use (ESRI 1998). The shapefile loader is accessed through the plugin menu on the menu bar in PGA. Figure 4.3 holds a screen capture GUI of the shapefile loader and the discussion refers to its content elements throughout this subsection.

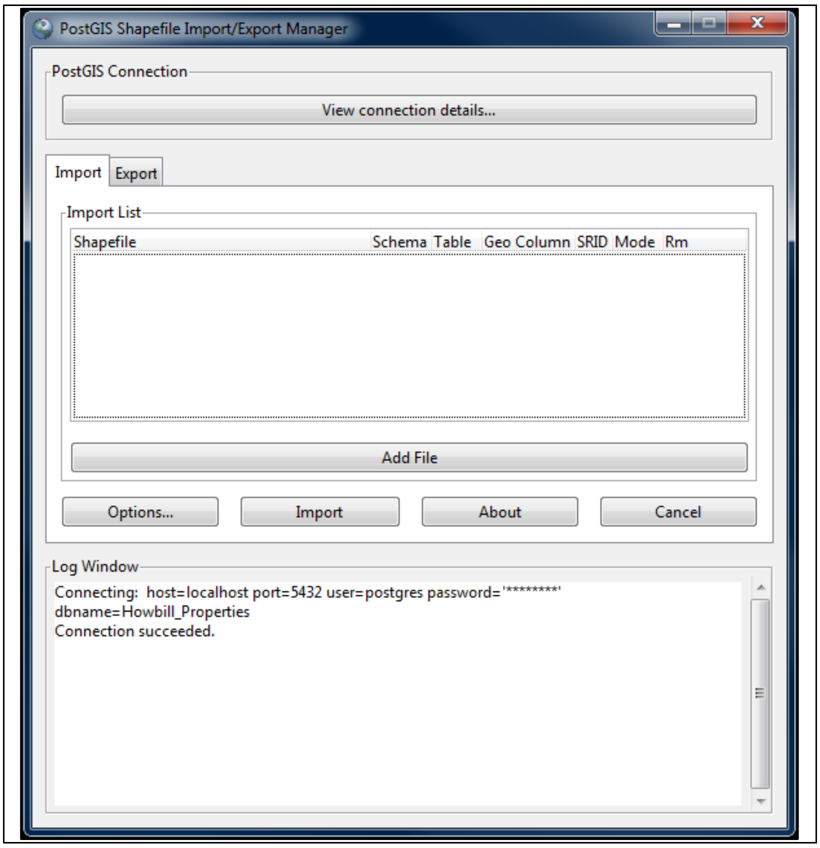


Figure 4.3 PostGIS Shapefile loader

All vector data was loaded at the same time, by following the four-step method described below.

First, a connection was established with the database, by selecting the *view connection details* button, and providing the required database and user account information (port number, host name, username, and password). Only an account with write access can load data into the database. Second, shapefiles were added using the *add file* button, which opened the *Import List* window. All vector data listed in the window were selected. Third, information regarding each dataset was provided in the appropriate column in the *Import List* window. In the *Schema* column, the respective schema names (data group name) for the datasets were typed. Each dataset was given a name in the *Table* column. The *Geo Column* (*Import List* in the Shapefile loader, Figure 4.3) indicates the header name of the column (created when the spatial data is imported) and was left as the default name, since certain GIS software (e.g. QGIS) expect the column header of the spatial dataset to be named *geom*. The spatial reference identifier (*SRID*) is a unique standardised code which indicates the spatial reference system of the data being imported. The spatial reference system used for the study area was *SRID 2048,* which refers to the Lo 19 coordinate reference system. The *create* option was then selected in the *Mode* column, since new datasets were generated in the database. *Rm* removed redundant shapefiles from the *Import List*. Lastly, the shapefiles were imported by clicking the *Import* button. After all the data had been imported, the data was inspected in the database to ensure it was imported correctly and lodged in the correct schema.

4.4.5 Adding raster data to PostGIS

Loading raster data to the database was more complex than loading vector data, since, at the time of writing, there was as yet no GUI for adding raster data and the *windows command processor* was used to add raster data. Raster data were loaded into the database using the *raster2pgsql* executable which is located in the *bin* folder under the PostgreSQL install directory. The *raster2pgsql* programme is operated using a command prompt in this case the *windows command processor* was used. In the command line interface the following command template was used:

raster2pgsql -s (SRID) -f -I -C -Y (raster_location) > (file_name).sql psql -h (host_name) -U (username) -d (database_name) -f (file_name).sql

Where

raster2pgsql	=	the application used to load raster data into PostGIS
-s	=	SRID
-f	=	default column name for rasters (‘rast’)

-I	=	create a generalised search tree (GiST) index in the raster column
-C	=	applies raster constraints, such as SRID and pixel size to ensure the raster is correctly registered in the raster column
-Y	=	copies the file, rather than insert the file
(raster_location)	=	file location and file name with extension to be loaded into the database
>	=	indicates the file should be loaded into the database
(file_name).sql	=	SQL file to be created in the bin folder before loading it into the database
-h	=	host server on which the database is located
-U	=	specifies the username of the user account
-d	=	the database into which the file should be loaded
-f	=	the SQL file used to load the raster to the database and is the same SQL file specified in (file_name).sql

After executing *raster2pgsql*, a password is requested. When successfully completed, 'COMMIT' appears in the command line window.

After importing each raster, the dataset was reviewed in the database to ensure that the raster was imported correctly. Raster data was imported into the public schema and had to be moved to the correct schemas, since no schema was specified during the import process.

4.4.6 Importing non-spatial data to PostGIS

PGA was used to import non-spatial tabular data. Adding tabular non-spatial data to PostGIS, through PGA, was experienced as a tedious process, since PostGIS does not accept files in MS Excel format, and these data files had to be converted to comma separated values (CSV) files first.

This step was performed in MS Excel by saving each MS Excel document as a CSV file. In order to subsequently import a CSV file it is required to create a table in PostGIS with the same column header names, column order and data type (string, integer or float) as the CSV file being imported. Using PGA, a new table was created in PostGIS. On the *properties* tab, each table was given a name and the appropriate schema was selected. Columns were created under the *Columns* tab. In addition to creating new columns corresponding with the CSV file columns, a *GID* column was also created, as is required by PostGIS. As mentioned before, column order cannot be changed after its formal creation. The primary key was selected under the *constraints* tab. The CSV files were then imported by right clicking on the corresponding table in PostGIS and selecting *import*. On the *file options* tab in the *import data* window, the CSV file was selected and CSV selected as the format. The columns to be imported were nominated on the *columns* tab. Finally, on the *miscellaneous options* tab, the checkbox *header* was ticked, since the CSV file had column headers, and *comma* was selected as delimiter.

After import completion, the data in the tables were reviewed to ensure their correct importation. After creating the database and importing data into the database, QGIS could be used to connect to the database and to graphically view the datasets onscreen.

4.5 SETTING UP THE DESKTOP GIS: QGIS

After the database was set up, and the data uploaded to the spatial database, the desktop GIS, QGIS, was installed and set up as sequenced in the following sections. The downloading of spatial data to QGIS from the PostGIS database is also reported.

4.5.1 Installing QGIS and adding functionality through plugins

This subsection details the setting-up process of QGIS and reviews some plugins that provide additional functionality to QGIS. Acquiring and installing the latest version of QGIS is relatively easy and, not including internet use fees, cost free. QGIS can be downloaded from the official QGIS website (QGIS 2014). Binary packages are available for Windows, Macintosh and various Linux distributors. To install QGIS in a Windows OS, the user starts by opening the install package and subsequently follows the on-screen instructions. Additional installation information is obtainable from the official QGIS website.

QGIS is installed with a range of included functions used for viewing, editing, processing and analysing data. However, in instances where additional functionality is required, these can be added as plugins. Plugins can be downloaded and installed from within the QGIS GUI. An overview of seven salient plugins with their functionalities (deduced from their names) that might be useful is provided in the next subsections. They are *OpenLayers*, *MMQGIS (*no mention was made of what *MM* signifies*)*, *Walking time*, *Advance viewshed analysis*, *Generaliser*, *LatLonGrid*, and *Photo2Shape*. Some plugins have multiple functions but only the essential functions are highlighted here.

4.5.1.1 Openlayers plugin

The *OpenLayers* plugin provide the option to add OpenStreetMap maps, Google maps, Bing maps, or Yahoo maps as a layer to the QGIS map canvas. This plugin can be used to improve visual reference for vector data by incorporating the layer as a background image. It is important to note that Google maps, Bing maps and Yahoo maps do not permit users to digitise features from their maps. An internet connection is required to enable using this plugin, since map data is downloaded from the respective repositories directly.

4.5.1.2 MMQGIS

MMQGIS provides additional vector manipulation functions to QGIS. Some of the more notable functions enable the user the ability to:

- Create buffers at specified distances around defined features;
- Export attribute values to external CSV files;
- Perform searches for specific spatial features or attributes in the database; and
- Delete duplicate geometries.

Some of these functions are already included in the core QGIS installation. However, the functions mentioned also provide additional options for specified functions. First, the *buffer* function in *MMQGIS* allows users to create buffers of various shapes, such as triangles, squares, and diamonds, whereas only rounded buffers can be created using the buffer function in QGIS. Second, the *export attributes to CSV files* function only export the attribute data without geometry data. This is useful to simplify the exporting and viewing data processes in a spreadsheet application such as MS Excel. Third, the *search* tool provides an easy-to-understand and -use interface for browsing features which match specific criteria. Selecting a feature in the results window automatically centres the map canvas on the selected feature. This is not the case when a feature is selected in the attribute table of QGIS. Lastly, *delete duplicate geometries* removes identical geometries from a spatial layer and save it as a new shapefile which saves time as users do not need to manually remove each duplicate feature. Other functions also contained in the *MMQGIS* plugin may be of use and users are encouraged to explore them.

4.5.1.3 Walking Time plugin

The *Walking Time* plugin provide a means to calculate the walk-time duration along a line, path or track, accounting for the particular slope traversed. The plugin is based on Tobler's hiking function and it can be a useful tool for application in hiking or cycling trail design and construction. Consequently, the plugin is recommended for use in guest farm management in the Howbill constellation to perform automatic calculations regarding experimental and alternative trail designs across real landscapes.

4.5.1.4 Viewshed Analysis plugin

The *Viewshed Analysis* tool provides advanced visibility analysis functionality to create cumulative viewsheds and to extract visibility horizons in QGIS. The plugin allows observer height, view radius and target height or area to be set. As such, the tool can be used to calculate best locations for scenic hiking trails for a guest farm, or to determine the least visually intrusive locations for specified infrastructures. Minimising the visual impact of existing or new infrastructure in the natural landscape of the Howbill properties would be the proper environmental management response to recommendations by Fourie (2005) in her experimental visual impact evaluation of this same area.

4.5.1.5 Generaliser plugin

Spatial line features can be simplified, generalised or smoothed with various algorithms provided by the *Generalizer* plugin. Changes are saved to a new layer, removing the risk of accidentally affecting unwanted changes to the original dataset. Also, the plugin has a batch process option, which enables the processing of multiple-line datasets with different algorithms. This plugin is useful to create visually aesthetic line features on maps from roughly digitised line datasets and serves to enhance visual display during management communication.

4.5.1.6 LatLonGrid plugin

The *LatLonGrid* plugin adds vector latitude and longitude gridlines at specified intervals across a spatial image. The gridlines are added as a layer in the layers window and can be deactivated when required. Gridlines are useful reference features on maps, for remote areas and in cases where background imagery is not available.

4.5.1.7 Photo2Shape plugin

Photo2Shape creates a point shapefile from the feature locations of geotagged images. This plugin can be applied in situations where an agricultural infrastructure feature, such as a road pothole or broken fence, requires identification for repair or similar attention. For environmental management application, the location of new or threatened vegetation species stands provides an example. A photograph can be recorded by cellular phone (with geotag capability) of the particular feature and sent to the appropriate responsible manager charged with an action. The requisite manager would plot the target location in QGIS, assess the damage from the image and navigate to the feature with the tools or parts required to perform the prescribed management task. This procedure would not only expedite the repair process, but also place the action on controllable record.

QGIS plugins are user solutions to practical problems that originate in the various user application industries. New plugins and updates are added frequently and active users are encouraged to keep track of new plugins to enhance the functionality of QGIS continually to plan or perform specific analytical or management asks as the need arises.

4.5.2 Connecting QGIS and PostGIS

Operationalising the entire spatial management system requires the GIS software and the target database to be operationally integrated. This subsection details how QGIS (the software) is connected with PostGIS (the database). Loading data into QGIS requires the connection between QGIS and PostGIS to be established through a four-step process reported as it was executed in this research. First, the *add PostGIS layers* shortcut function in QGIS was selected. This action opened a new window in which program connections were managed. Second, *new* was selected to establish a new connection. This action opened the *create new PostGIS connection* window. Third, information was provided regarding the database to which a connection had to be established. In the *name* field a descriptive name for the connection was given, *Service* was left empty and Localhost was specified as *host*, since it refered to the name of the server on which PostGIS was accommodated during the installation process (this name would differ for other installations). *Port* referred to the host's communications endpoint, which is signified by a number. In this case the default PostGIS port, *5432*, was used. The name of the database to connect too was entered in the *database* field, *SSL mode* was set to *allow,* and an authorised username and password were entered into the respective fields before the connection details could be accepted.

Finally, in the a*dd PostGIS tables* window a connection between QGIS and PostGIS was enabled by selecting *connect*. If the connection is successful, available schemas are listed and can be expanded by selecting the dropdown menu. QGIS saves connection information for future use and setting up a connection is only required once.

4.5.3 Adding spatial and non-spatial data to QGIS

Data was loaded into QGIS using four different methods, depending on the data source and format. The four methods, according to data source are:

- Loading spatial and non-spatial data from the PostGIS database;

- Opening shapefiles;
- Adding MS Excel sheets; and
- Importing GPS files (in GPX format).

PostGIS data was loaded into QGIS using the *add PostGIS layer* shortcut function. As described before, schemas are listed in the *add PostGIS tables* window after establishing a connection between QGIS and PostGIS. Spatial data were added by navigating to, and selecting the desired spatial dataset, and clicking the *add* button. Non-spatial tables were loaded by, first, enabling the *list no geometry tables* radio button, and second, following the same steps as described for adding spatial datasets.

Shapefiles, MS Excel sheets and GPX files were added using the *add vector layer* shortcut function. In the *add vector layer* window, the *file* radio button was selected and the *encoding* set to *system*. Using the *browse* function, the desired file (or multiple files) was selected and opened. In some instances, multiple files were added by dragging and dropping the files into QGIS.

4.5.4 Viewing data in QGIS

Data was viewed in QGIS using two methods, one having very limited viewing options and only used to view data stored in the PostGIS database without having to add the data to QGIS. The second method requires the data to be added to QGIS. To view data stored in the PostGIS database, the *Database Manager Plugin* was used. *PostGIS* and *SpatiaLite* database options are loaded by default. To view spatial or non-spatial data, the user navigates to the desired dataset and selects one of the three tabs (*info, table* or *preview*) depending on the desired action. General information about a dataset was viewed under the *info* tab. Attribute data was viewed under the *table* tab, and a preview of the dataset was viewed under the *preview* tab if the dataset had a spatial component.

Data was also viewed in QGIS by adding spatial data to the layers window and displaying spatial data on the map canvas. This procedure enables the user to navigate to specific features by zooming in or out and panning across the dataset. Figure 4.4 is a screen capture of the QGIS GUI with the three *shortcut bars* at the top, the *layers* window on the left and the *map canvas* on the right.

To view the attributes of a dataset, the *open attribute table* shortcut was activated. In the *attribute table* window, attributes of features were viewed, selected using Boolean operators, and edited as and when these actions were required. MS Excel files with additional attributes were also temporarily joined to vector spatial datasets for the purpose of viewing specific information regarding features that were not included in the attributes of the particular spatial dataset. This was done by opening the *properties* window of the spatial feature in question, and selecting the *join* option. To create a new join, the *green plus sign* (+) was selected and the appropriate join *layer*, join *field* and target *field* selected. *Join field* was the requisite attribute layer. *Join field* is a unique feature identity in the attributes layer that corresponds to a target field, also with a unique feature identity, in the spatial dataset. The added attributes were viewed using the Open Attributes Table shortcut function.

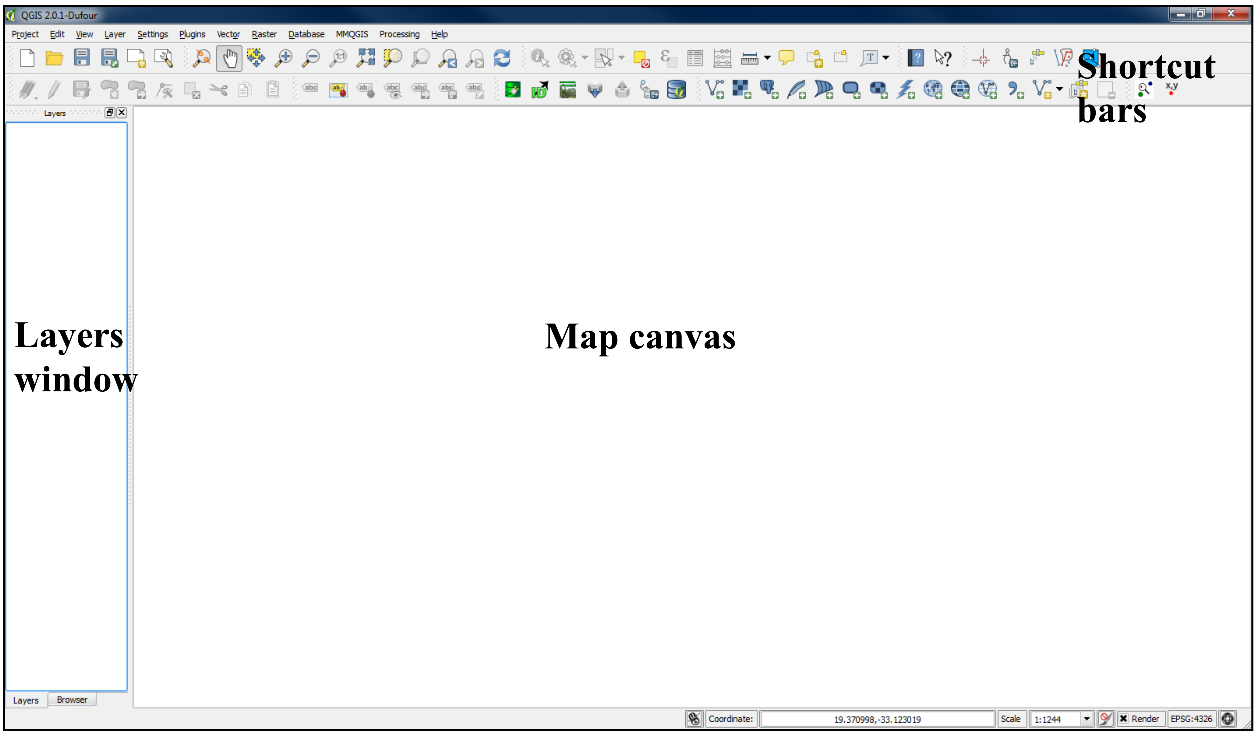


Figure 4.4 Screen capture of QGIS GUI

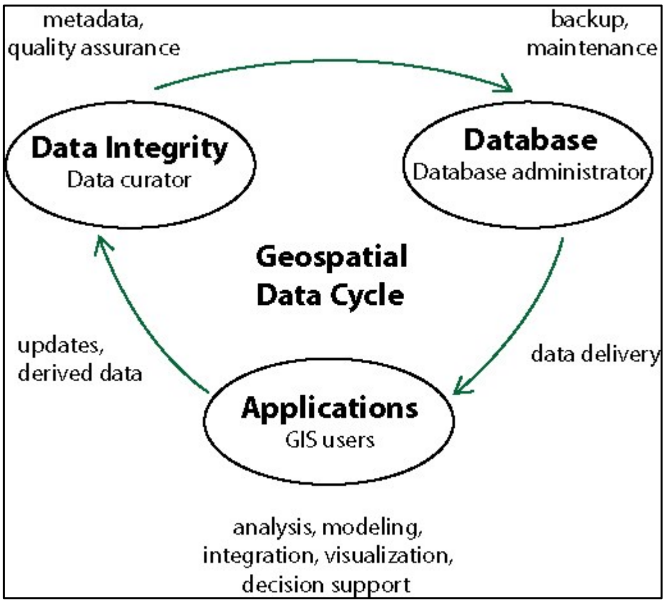
It is possible to link datasets on a more permanent basis in PostGIS using key constraints, based on a primary key and a foreign key. The advantage of linking the attributes of spatial data is that, when a new feature is added or removed in a spatial table, the same feature will also be created or removed in the linked table. However, if users are unfamiliar with the procedure to create and remove constraints from a dataset, it might become difficult to move datasets between schemas or remove tables from the system. Therefore, it was decided not to add constraints in the GISIMAE prototype.

4.6 GEOSPATIAL INFORMATION MANAGEMENT

Geospatial information management is crucial to ensure data security and integrity, however it is often neglected (Keating, Rich & Witkowski 2003). This section highlights some basic geospatial information management.

4.6.1 The geospatial data cycle

Geospatial information management can be perceived as a cyclically connected, sequential event of geospatial information management (Keating, Rich & Witkowski 2003), as illustrated in Figure 4.5. It shows spatial data stored in the spatial database, from where users access



Source: Keating, Rich & Witkowski (2003; 28)

Figure 4.5 Geospatial data cycle

and extract spatial data to view, edit, or analyse it. Updated spatial data is subsequently sent to a data curator who reviews the changes made to the spatial data and certify the accuracy, quality and integrity of the updated data. After certifying the quality and integrity of the spatial data, it is uploaded to the database, and the cycle is closed or repeated. At each of the three cyclical nodes, measures can be put in place to aid with data security, quality, and integrity.

4.6.2 Administrative measures for data security, quality and integrity

A spatial information management system requires efficient administrative measures to be emplaced. Longley et al. (2011) list system administration, system security, and data backup as key management tasks and suggest that a detailed system management plan regarding each should be drawn up to ensure the information system is capable of delivering a high level of service. Smith

(2010), Obe & Hsu (2011), Obe, Hsu & Blanchette (2012) and PostgreSQL (2013c) provide a detailed description of proper procedures to create, set up and manage a PostgreSQL and PostGIS database. The measures discussed in the next paragraphs could be put in place to aid with key management tasks.

Good administration allows all spatial data users, especially novice users as in the Howbill case, read access only to all spatial data in the database. Users have to save required working data to their private computers in a valid spatial format, such as a shapefile, in order to edit or perform any analysis on the data. It is recommended to have only one super user account and to create an additional system access role with permission to create databases, create roles, and which is used to perform routine database maintenance tasks. This will ensure that unintentional changes are not made to the database. A designated functionary affects these changes to the central database. This measure should eliminate unwanted or accidental permanent changes to be made to the central spatial database. It would be good practice to provide an attribute column with the name of any person who has made the last changes to the dataset and the date on which these changes were made. This measure will ensure accountability for changes made to the data.

After changes had been made to a dataset the spatial data and a description of the changes made should be sent to the designated functionary (a data curator) who should review and approve all changes made to the dataset before committing the changes to the database. The data curator should also create or update the metadata for the dataset. Metadata (information about data) provides overarching descriptions about a dataset, such as the method or mode by which the data was captured (see Appendix D for example of a metadata form). If the suggested changes are not approved for any reason, the curator should return the data to the prospective dataset editor, accompanied by directives for improvement and the process is repeated until accurately completed.

Database maintenance tasks can be automated using Cron scripts or Window’s Task Scheduler. The database integrity workflow might seem elaborate and tedious but it is worth the effort, and the importance becomes evident if compared to the cost and time spent to collect and process data (spatial and non-spatial). The assumption is that the original database constructed had been efficiently executed, so subsequent updates would be of fairly limited extent and be spread over time. It should be borne in mind that end users are rarely to blame for poor data integrity. In some cases software or hardware failures, due to a normally limited product lifetime, can result in the loss of data. Therefore it is important to maintain database backups.

4.7 GIS USER TRAINING RECOMMENDATIONS

Ultimately, the success of the information system depends on the users' ability to utilise it, and to some extent that will depend on their experience with or training in the use of the GIS. This section reviews some training recommendations proffered by Steiniger & Bocher (2009) in a user experience classification already elaborated in Table 4.3 (Section 4.2). It is assumed throughout this section that users are computer literate (defined as having the ability to perform basic tasks on a computer).

Novice users, if they are to remain at that proficiency level, require very little training, since their basic skill-level requirement is to view and print data. The following abilities are assumed at this level:

- Connecting to the spatial database in order to access the data;
- Loading data from the spatial database to the desktop GIS;
- Symbolising spatial data;
- Labelling spatial data;
- Viewing attribute tables; and
- Creating maps (including the use of basic map elements).

Training to enable the performance of the above-mentioned tasks should require between half a day and a full day, depending on users' grasp of the relevant concepts. Except for connecting to and loading data from the database, numerous free online tutorials introducing some remaining novice training topics are available.

Experienced user-level training would require the above-mentioned novice tasks abilities (if not already familiar with) as a basis, as well as training to perform the following additional tasks:

- Knowledge about data types and when to use each type;
- Skill to edit, digitise and save spatial and attribute data;
- Skill to convert spatial data between different file formats;
- Skill to create and execute simple Boolean queries on the database;
- Ability to use basic geo-processing tools, such as to perform buffer, clip, and intersect functions; and
- Ability to use a GPS for data collection.

Depending on the individual learning capacity of users, experienced users' training might take between one to two days. Expert- and research-user experience training would be considered a formal qualification.

The suited-to-task prototype integrated spatial information system called GISIMAE and the technical procedures to establish and maintain it, was described in this chapter. It was determined that an enterprise GIS would be the most appropriate system. PostGIS was selected as the spatial database, and QGIS was selected as the desktop GIS application. A process for selecting the necessary hardware was also outlined. The procedures to set up and connect software components and upload the spatial data were described. Basic operational guidelines were established to increase system security and data integrity. The next chapter demonstrates some of the functions and features of the spatial information system in operational format.

CHAPTER 5: DEMONSTRATION SCENARIOS OF THE PROTOTYPE GISIMAE

This penultimate chapter demonstrates some examples to showcase the abilities of GISIMAE for application. The demonstration scenarios were developed to determine if GISIMAE could be effectively applied to integrated agricultural and environmental management, and to highlight its functionality to prospective users. To prove its mettle, selected demonstration scenarios were presented to upper management of Howbill Properties. Topics covered here consist of the demonstration design process, followed by practical demonstration of six scenario types.

5.1 PRINCIPLES OF DESIGN PROCESS DEMONSTRATION

This section describes how the demonstration scenarios were decided upon. Turner (2013) suggested the following basic guidelines to entice maximum interest in an information technology (IT) product in a presentation, namely to:

- Include senior management, since they are the driving force behind an organisation;
- Highlight only key features, functions, and advantages, which could improve business performance; and
- Where possible, avoid using industry specific terms unfamiliar to the audience.

The demonstration design process consequently endeavoured to adhere to these principles and encompassed four basic steps, namely to:

- Identify key elements to promote a successful and engaging presentation to the prospective users;
- Cover a range of features and functions in scenarios that would alert potential users to the possibilities for application of the system;
- Link the functions used for demonstration scenarios to the level of likely user experience; and
- Include data and demonstrations related to imperatives discussed in the preceding chapters.

The demonstration scenarios focused largely on demonstrating features and functionalities of the system, and less so on the actual practical examples, since it was not possible to include every possible demonstration scenario. Still, the demonstration scenarios still had to be relevant to the application environment it was developed for. Therefore, the selection of features and functions to demonstrate was informed by firstly linking user experience categories (from Table 4.3), with the classification of spatial analysis techniques according to their conceptual framework derived from Longley et al. (2001). Thereafter examples relevant to the imperatives determined in Chapter 2 were selected and demonstrated where possible. This approach promoted a range of features and functions, ensured that all levels of user experience were addressed, and that relevant examples were demonstrated.

GIS functions and techniques can be classified according to the conceptual framework derived in Longley et al. (2001) and listed in Table 5.1. The visualisation task class was added and

Table 5.1 Conceptual framework for the classification of GIS techniques

Feature and function class	**Function description**	**Minimum user experience level**
Visualisation	View and print data	Novice
Simple data query	Return existing results	Experienced
Spatial measurement	Measure distance, length, area	Experienced
Spatial transformation	Create new feature from existing features	Experienced
Descriptive summary	Compute summary statistics for collection of features	Experienced to expert
Optimisation	Identify new results from user-defined objectives (e.g. optimum location analysis)	Expert
Hypothesis testing	Statistical analysis	Research

aligned with the associated categories of user experience and proficiency as defined by Steiniger & Bocher (2009) for each function level. It was decided not to include demonstrations of hypothesis testing, since such examples are inevitably highly technical and time-consuming, defying Turner's (2013) basic IT presentation guidelines. Some of the six demonstration scenarios constituted more than one classification, and demonstrations were grouped according to the highest classification.

5.2 DEMONSTRATION 1: VISUALISATION

Visualisation demonstrations were aimed at all levels of user experience, and illustrated some of the basic to more advanced data viewing and symbolising functions in QGIS. It is considered a given that users at all levels of proficiency would at the very least need to view database elements for various purposes and that data symbolisation and labelling are therefore basic application features requiring demonstration.

5.2.1 Symbolising spatial data for thematic mapping

This demonstration illustrated how to create basic thematic maps using the symbolise functions in QGIS. Crop field data, with attributes of the dates when crops were planted, were added to QGIS to run the demonstration off. Under *style* in the *layer properties* window, the appropriate *column*, was selected, namely the crops *classified* according to the *crop types*.

Figure 5.1 shows the crop fields symbolised according to crop type in the QGIS GUI.

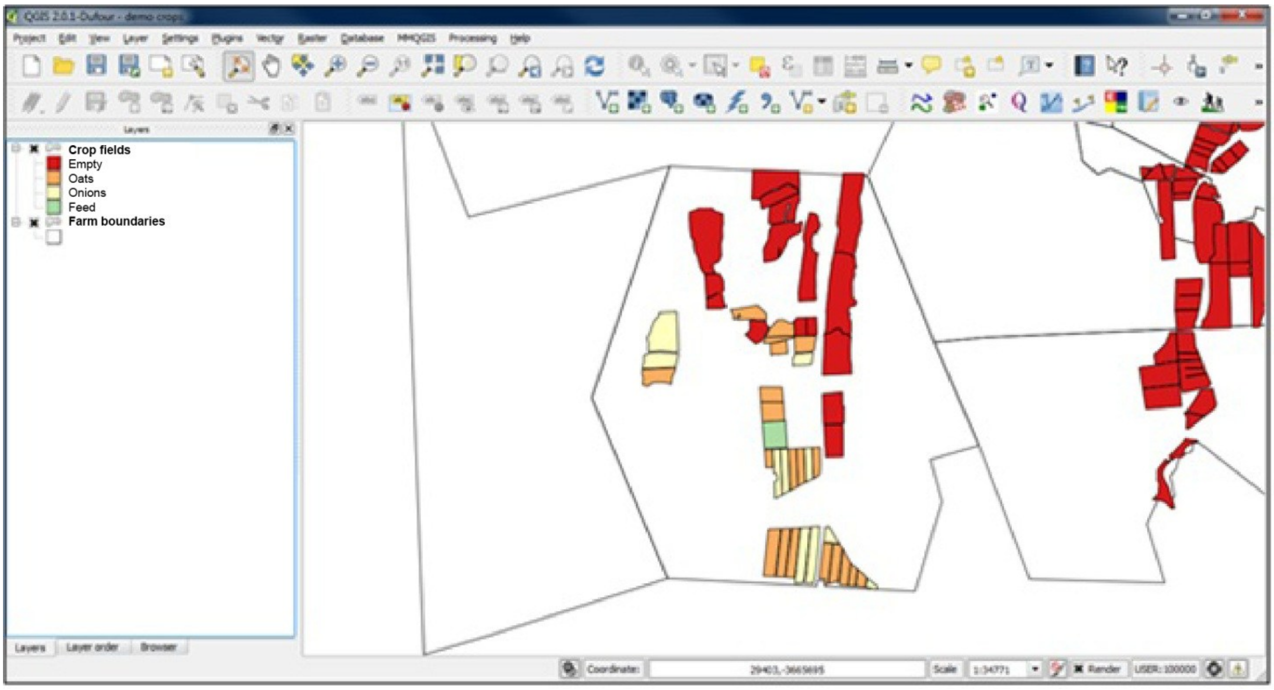


Figure 5.1 Screen capture showing display of symbolised crop fields

Symbolising spatial data according to attributes can be quite useful to quickly distinguish between different features, or attributes. It was mentioned that the same method as described above could be used to symbolise other spatial information and attribute data, for example cultivars in fruit orchards. This demonstration was relatively simple and quick to construct and execute successfully.

5.2.2 Labelling features

This demonstration was inspired by the need to prove that a GlobalG.A.P. control points and compliance criteria (CPCC – see Section 2.6.2) check can be performed via the system. The CPCC requires that all crop fields, orchards, and livestock camps must have reference or code numbers. This demonstration showed how to add labels to features for the purpose of easy reference to crop fields, orchards, and livestock camps.

For this demonstration, crop fields, livestock camps and fruit orchards were added from the spatial database into QGIS. Features were labelled by opening the *labelling options* window, and activating the *show labels* option. The appropriate column, with reference number information (in this case *name*), was also selected from the dropdown list. Figure **5.2** shows the *layer labelling settings* window, with the labelling settings applied.

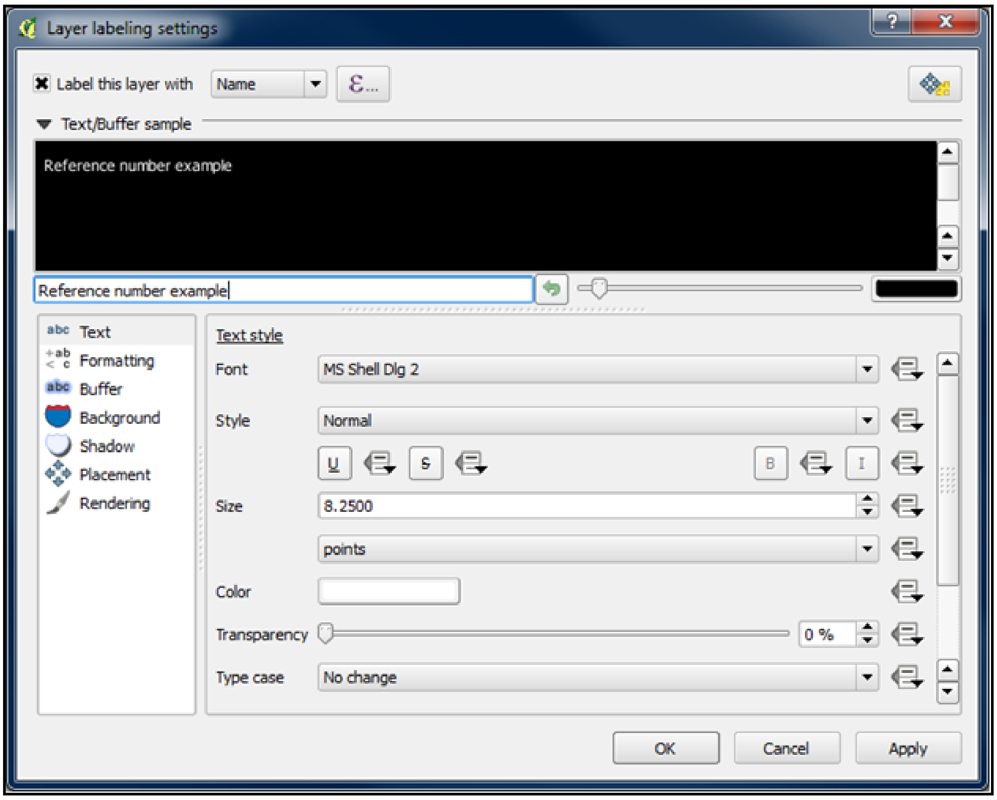


Figure 5.2 Screen capture showing display of label settings window

Additional label options were also demonstrated. Label font colours for crop fields were changed from black to white by selecting the *colour* setting and selecting white as the colour. A white display 'halo' or buffer was added around the labels of the fruit orchards to improve ease of reading. Each dataset had slightly different labelling settings applied to it. Figure 5.3 shows the final label application results in the resultant map display. Like the previous visualisation exercise, this demonstration was still relatively simple and quick to construct and execute successfully, but it does demand a little more execution skill.

5.2.3 Viewing photos of features in QGIS

This demonstration illustrated how to view a photographic image of a feature from within the QGIS GUI. Before the demonstration commenced, an image (in .jpg format) of a water pump motor was recorded and the path where the image was stored on the computer was saved in the water pump attribute column. For demonstration purposes, the Water pumps spatial layer was added to QGIS. In order to view the image, it was necessary to specify the image format and programme to open the image with. This was set in the *configuration* tab of the *eVis Event Browser* window (accessed from the *Database* menu on the *menu* bar).

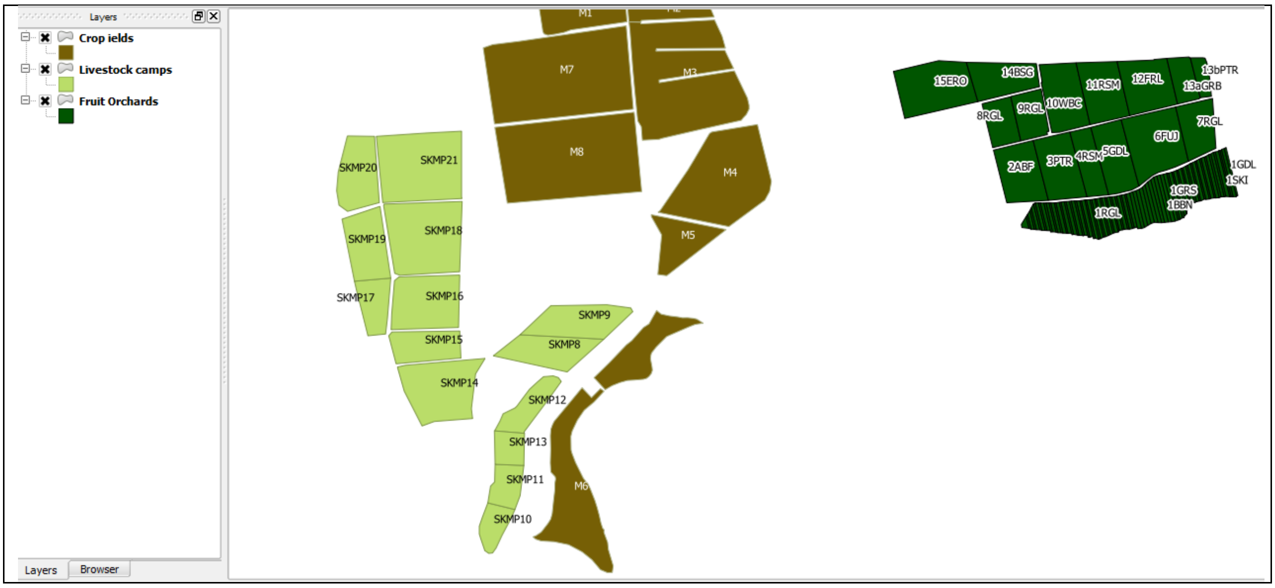


Figure 5.3 Screen capture showing display of labelled crop fields, livestock camps and fruit orchards

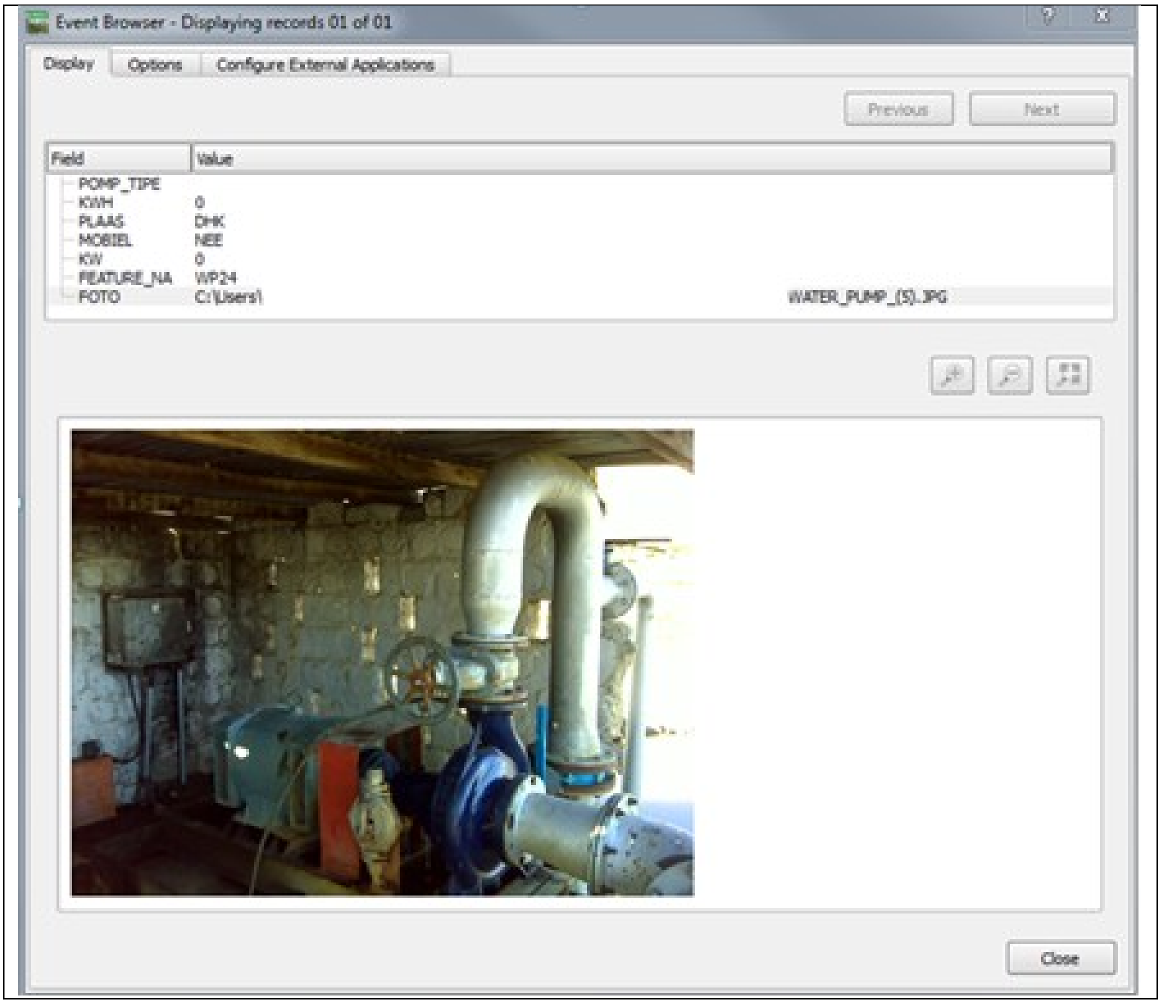


Figure 5.4 Screen shot showing display of event browser window with image of water pump

Under the options tab, the attribute column containing the image path was selected from the dropdown list. Also, it was specified that the image path was relative. Finally, the water pump feature in question was located on the map canvas. Using the *eVis Event ID* tool, located under the *database* menu on the *menu* bar, the particular water pump to be displayed was selected. Figure 5.4 shows the *eVis Event browser* window with the photo display of the water pump. Double clicking on the image path in the *values* column opens the photo in an image viewer, which can be used to enlarge or print the image. Obviously, the quality and detail focus of the original image will determine what information can be gleaned from the display. Like the previous two visualisation exercises, this demonstration was still relatively simple and quick to construct and execute successfully.

5.3 DEMONSTRATION 2: SIMPLE DATA QUERY

The purpose of this demonstration was to highlight the ability of QGIS to handle MS Excel data, create a temporary link between the data in the MS Excel sheet and a spatial dataset, query the data, and finally present the results visually. The end result would be a display of harvest data for the 2013 season symbolised according to predefined ranges of tonnages of fruit (apples in this case) yielded per orchard. This demonstration was aimed for application toward experienced GIS users.

The demonstration consisted of three steps: Adding the required data to QGIS, joining the MS Excel data and spatial dataset, and finally querying and symbolising the data. First, the required data was loaded into QGIS. Data consisted of fruit harvest figures recorded for 2013 in MS Excel format, and spatial fruit orchard data (polygons) loaded into QGIS. Second, a temporary attribute join between the two datasets was performed. The appropriate MS Excel sheet was selected as the *join layer*. The MS Excel *Block code* column was selected as the *join field*. The *Block code* column (located in the attribute table of the spatial dataset) was selected as the *target field*. The option to *create a temporary join* was enabled. Opening the attribute table of the spatial dataset revealed the newly added attributes from the MS Excel sheet. Third, features were queried and symbolised according to specific criteria. For this demonstration, apple orchards were selected and symbolised according to tonnes of apples harvested from each apple orchard coded as unit. *Style* was selected in the spatial dataset's *layer properties* window. *Single symbol* was changed to *rule-based* in the dropdown list and a new rule added by clicking the green plus sign (+). Figure 5.5 shows the layout of the style properties window with the above-mentioned settings applied. Notice the Boolean queries in the *rule* field, which was

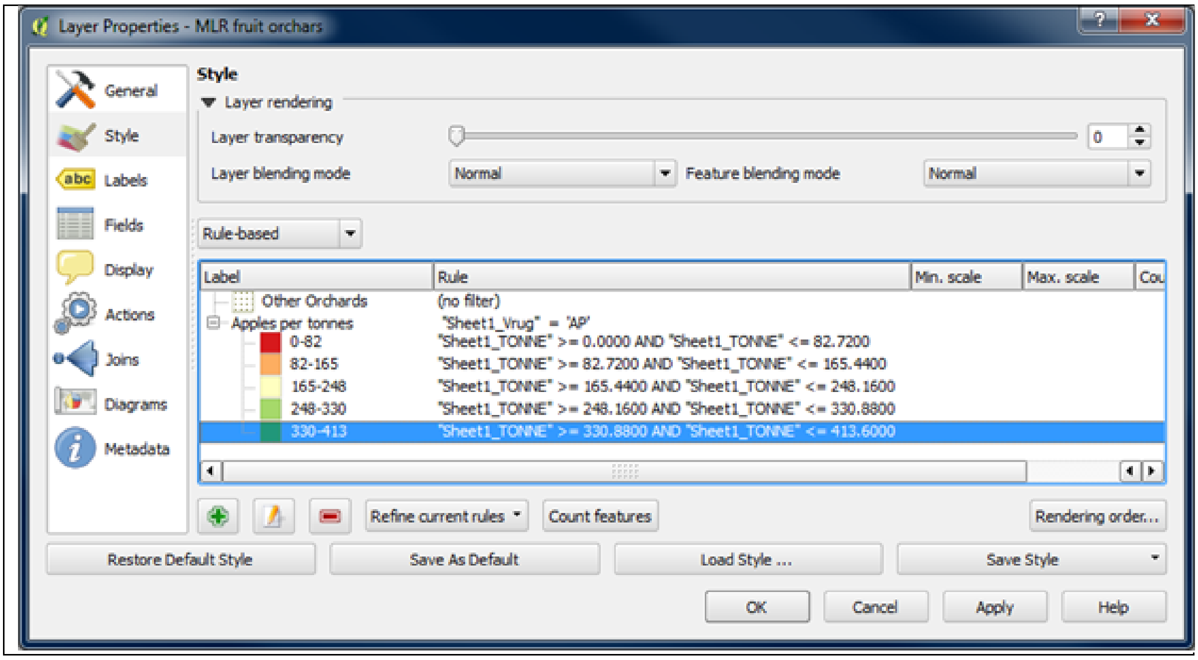


Figure 5.5 Screen capture showing display of layer properties window

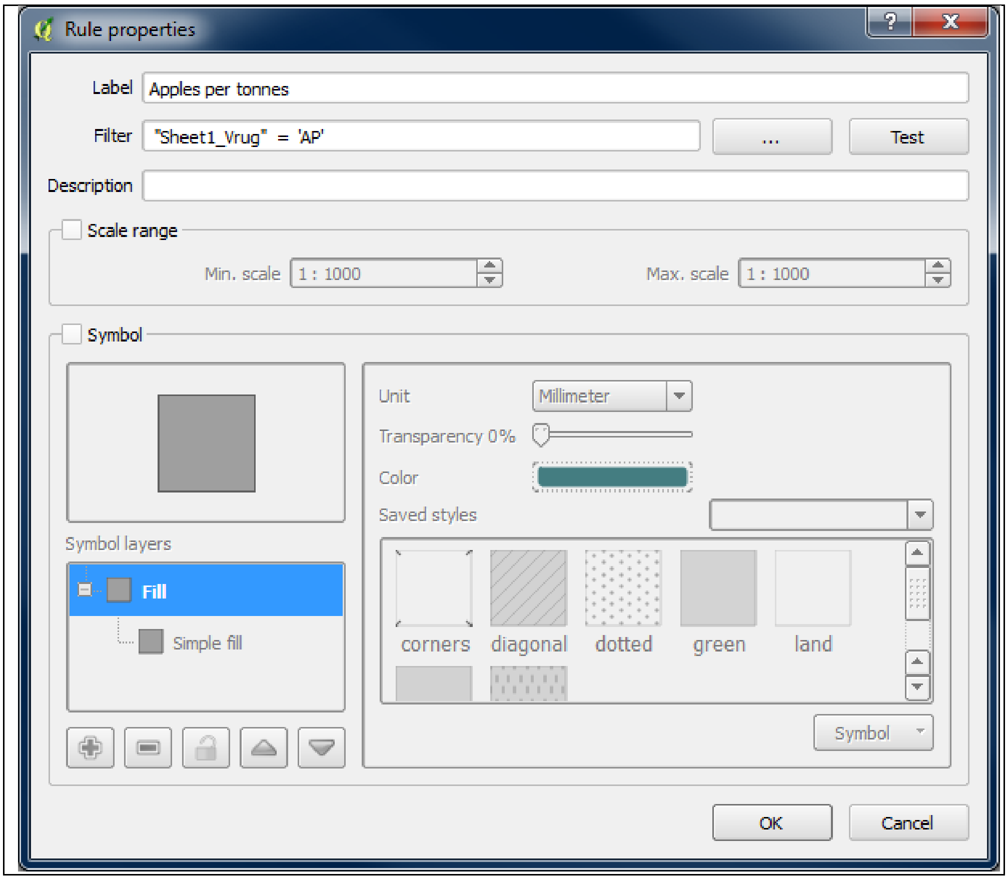


Figure 5.6 Screen capture showing display of rule property window

used to select apples, and define the required value ranges. In the rule properties window, a *label* (name) was provided and *apple orchards* were selected by applying the Boolean expression reading as follows:

"Sheet1_fruit" = 'AP'

Where

"Sheet1_fruit"	the column header of the attribute table, fruit type
=	a Boolean operator signifying same as, or equal to
'AP'	a value in the fruit column, which refers to apples

Figure 5.6 displays a screen capture of the *rule properties* window with the *label* and *filter* that were used to name and query the data. In the *dropdown list* next to the *red minus sign* (-) in the *layer properties* window, *add ranges* were selected. This action opened a *refine a rule to ranges* window, which enables the user to customise rule symbols and ranges. The appropriate *column* (*tonnes*) were classified according to *five equal interval* classes (to simplify the data) and symbolised with the *red, yellow and green colour ramp* (specific class values and different labels can be entered as required). Figure 5.7 shows a screenshot of the window with range settings applied. After classification was completed, cadastre, road and reservoir spatial information were added for orientation purposes. The screen capture displayed in Figure 5.8 is the final view of the results in the QGIS GUI.

A Google satellite background was also added using the Open Layers Plugin, and a printable map was created by means of the print composer.

5.4 DEMONSTRATION 3: SPATIAL FEATURE MEASUREMENT

This demonstration involves the planning of a route for a new main irrigation pipeline. It demonstrates how to digitise a new feature and how to calculate the length of that feature. This information can be used to compute the length of pipe needed to complete the new pipeline, and calculate the estimated cost of the project. Typically, various path scenarios will be generated and the various results compared to identify the best or most economical solution. The scenario required the completion of four operational steps. The first step was to add water pump and crop field spatial

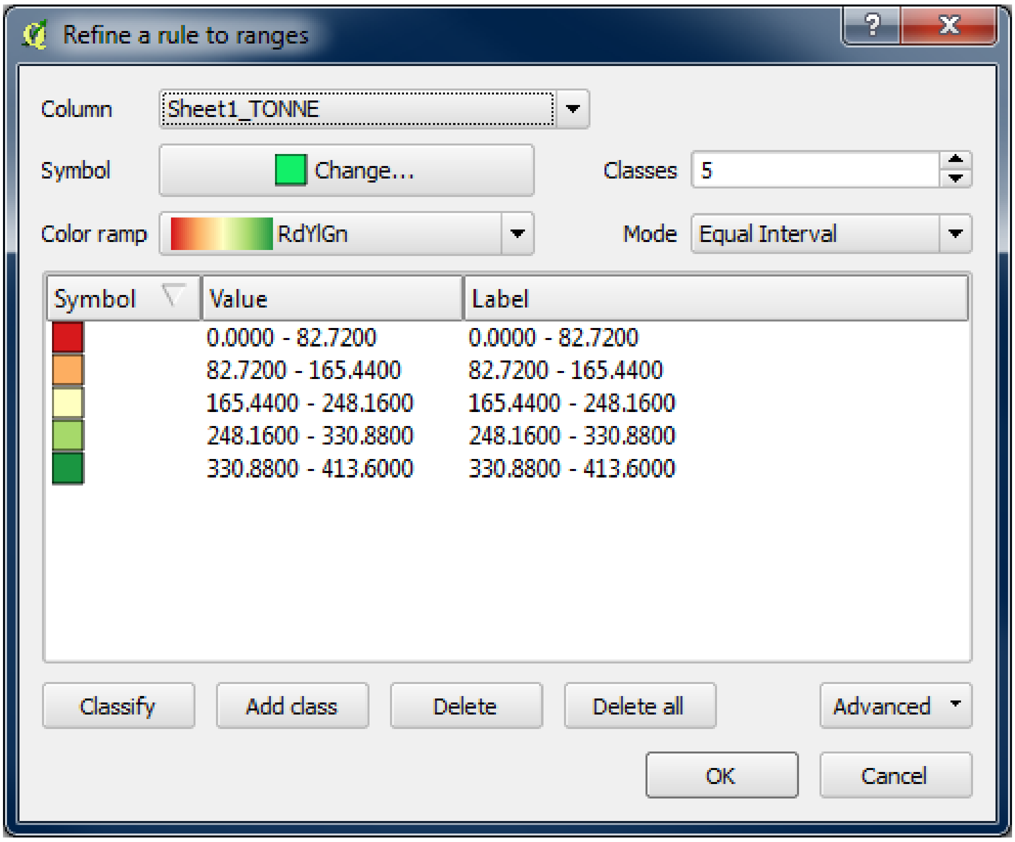


Figure 5.7 Screen capture showing display of define ranges window

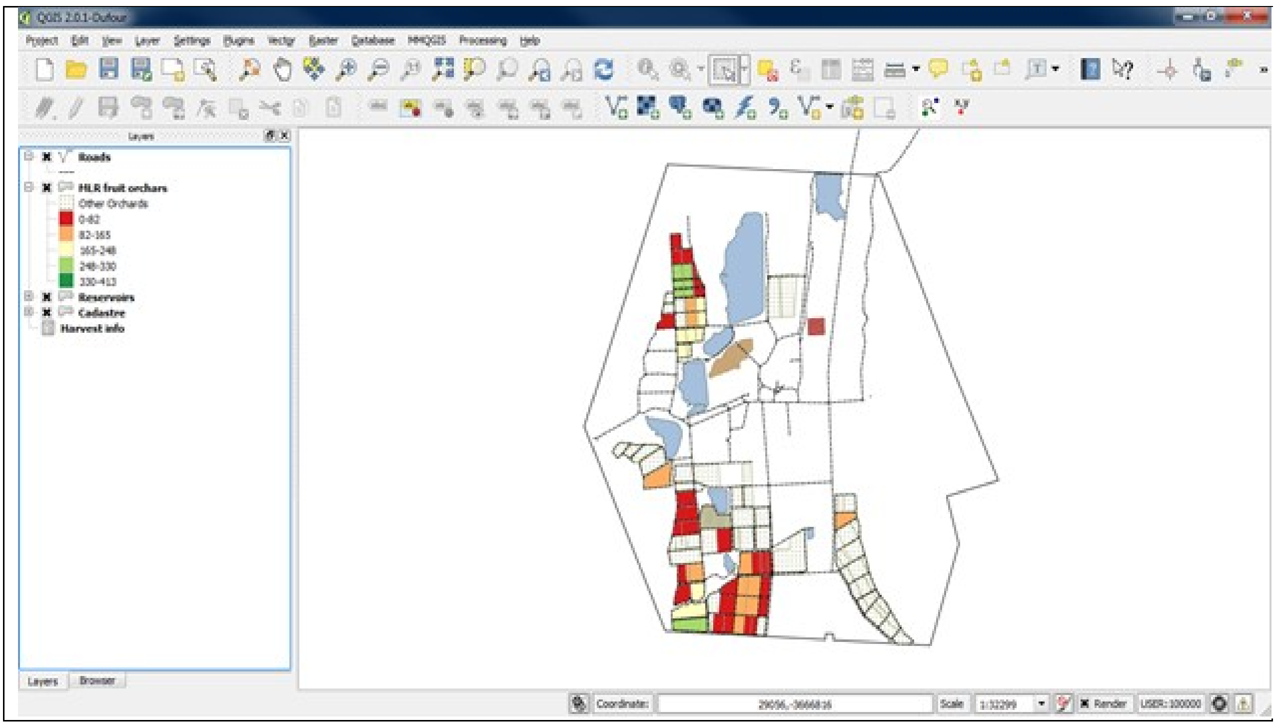


Figure 5.8 Screen capture showing display of yield per apple orchard

data from the PostGIS database into QGIS. The second step was to *create a new line shapefile* with a Lo 19 coordinate reference system. To clarify, the dataset must be *projected* to the correct coordinate reference system in order to calculate distances accurately and in metres. Third, was to *digitise* the new main irrigation pipeline. This was done by enabling *editing* for the newly created shapefile. *Snapping* was enabled for the crop fields and water pumps spatial layers, since the requirement was that the new irrigation pipeline should be located as close as possible to the crop field intended for irrigation.

Figure 5.9 shows the QGIS GUI with the new irrigation pipeline path in yellow. The irrigation pipe runs from source at the water pump and terminates at the lower end of the crop field. Lastly, the length of the new pipeline was calculated to enable estimation of the construction cost of the pipeline and to inform the product order of the required length of piping. In the new irrigation pipeline's *attribute table*, with *editing* still enabled, the *field calculator* was opened and *create a new field* was activated. The *output field name* was *length* and *decimal number* selected as *field type*. In the *function list*, *length* was selected under the *geometry* option.

Figure 5.10 shows the *field calculator* window with the settings applied as described above. Note that the length of the pipeline is given at the bottom of the display window next to output preview. Length is reported in metres, since the new irrigation pipe database layer was assigned the Lo 19 coordinate reference system. Figure 5.11 shows the *attribute table* window of the new irrigation pipeline with the newly added *Length* column and calculated distance. Additional attribute fields such as cost of pipeline per metre can also be created. The *field calculator* could then be used once more to calculate the total cost of the new irrigation pipeline by multiplying the total length of irrigation piping with the value in the cost per metre column.

Similar demonstrations could be prepared where area or perimeter of a livestock camp is calculated, to estimate carrying capacity of the camp, or to calculate the length of fencing wire required to fence off the camp area. Area can be calculated in hectares by dividing the area reported in square metres by 10 000 in the field calculator.

5.5 DEMONSTRATION 4: FEATURE TRANSFORMATION

Transformation techniques constitute the procedures followed in creating new features from existing features, and experienced users should be able to perform such tasks. The two demonstrations provided are both geared to determine spatial management and planning problematic related to accessibility to or distance from infrastructure or natural features.

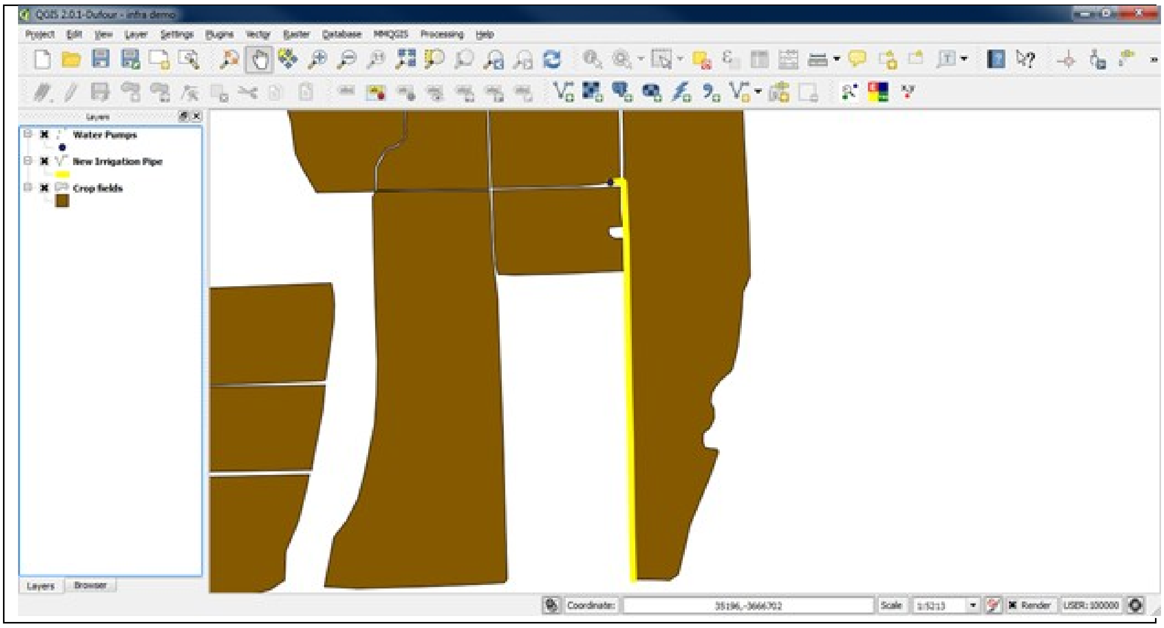


Figure 5.9 Screen capture showing display of new route for irrigation pipe

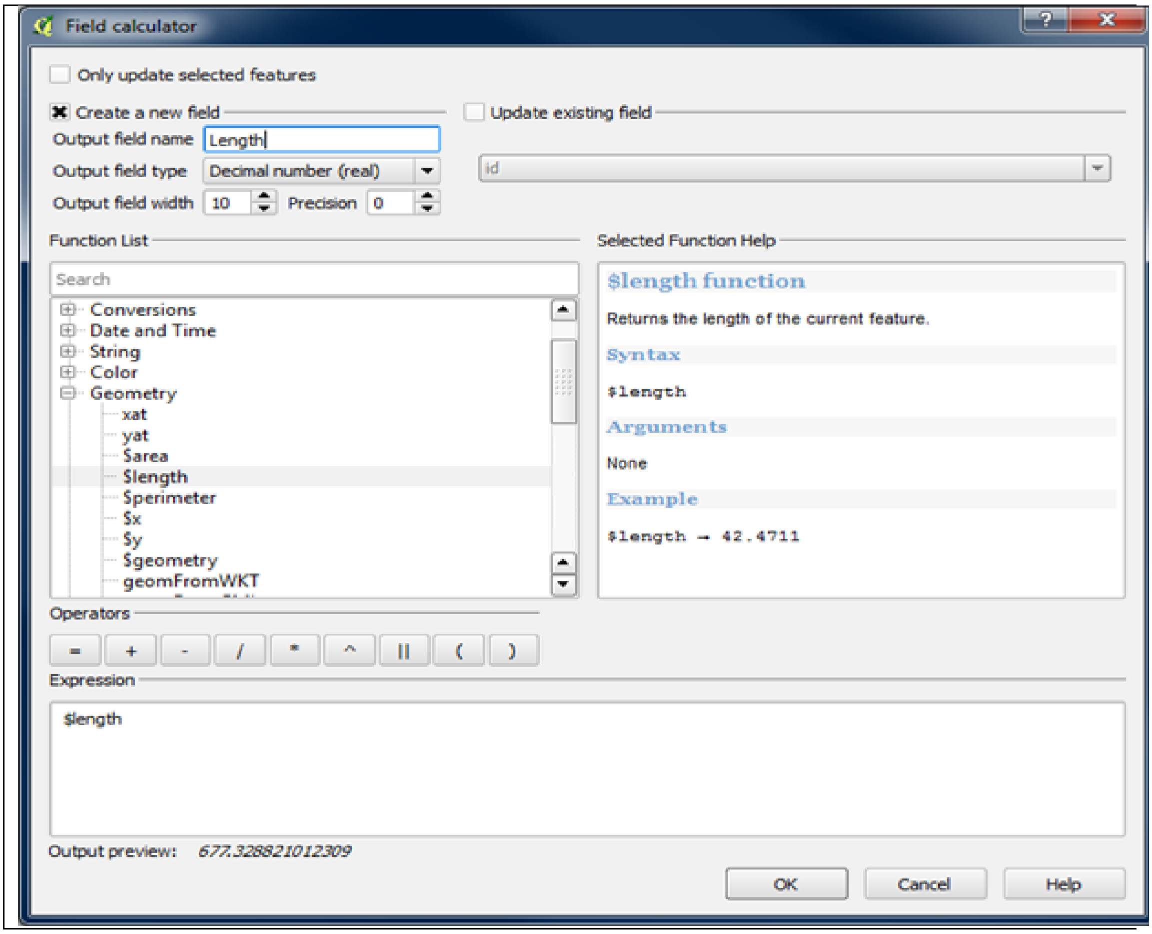


Figure 5.10 Screen capture showing display of field calculator

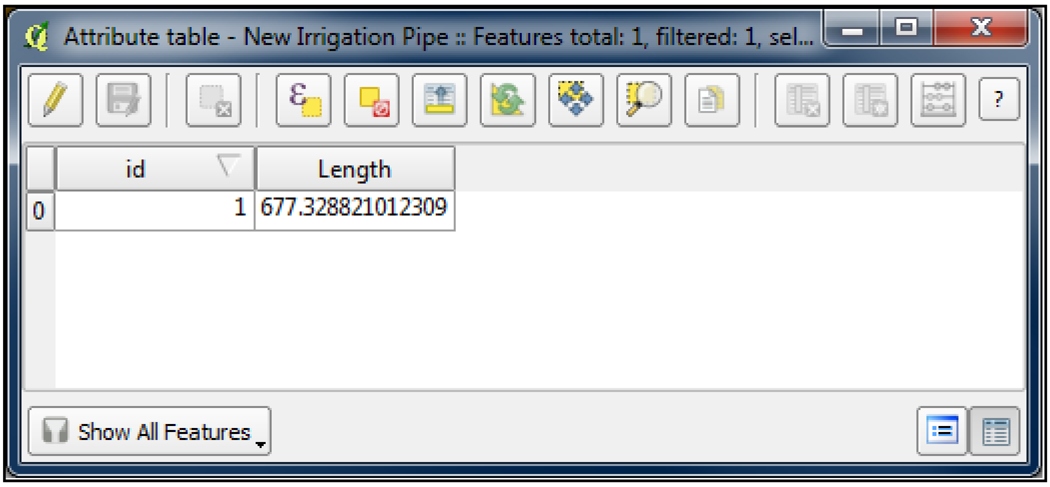


Figure 5.11 Screen capture showing display of new length field

These are the types of planning issues arising in farm management regularly and may also be used to prove compliance with regulations and industry standards to be met for modern market access certification.

5.5.1 Crop field located within a specified stream distance

The demonstration scenario originated from one of the CARA regulations which specifies that land within 10 metres of a stream flood zone, may not be cultivated. The demonstration therefore aimed to define and spatially demarcate the zone forbidden from cultivation. In this instance, spatial data in the form of mapped flood zones were not available and mapped spatial stream (line) data was used instead. Nevertheless, it is the principle of the demonstration scenario that is important and the same method could be applied using flood zone data when available.

The demonstration consisted of the completion of a three-step process. Step 1 involved downloading of digital spatial cadastre, surface canal and crop field data to QGIS. Cadastre data (farm boundaries) was only added for orientation purposes. In Step 2 distance buffers were created. The *input vector layer* was *rivers* and the *buffer distance* specified as 30 metres. A 30 metre buffer was used rather than a 10 metre buffer to exaggerate the final resulting demarcated zone somewhat, since rivers were digitised as a (sub-metre) line feature in the centre of the stream and not as a polygon allowing the realistic stream width of the whole stream area. This procedure assigns a 10 metre width to the stream channel and adds 10 metres on both sides of it – a realistic solution that can be manipulated to reflect reality as demanded.

The final step entailed selection of digitised crop field areas falling within the 30 metre buffer limit and saving the identified crop fields as a separate dataset. This was done with the *spatial query* *function*. The crop field dataset was set as the *features to be selected*. *Intersect* was selected as *selection criteria*, and the 30 metre buffer dataset was selected to be used at a later stage as reference data. Figure **5.12** shows the screen capture of the *spatial query function* window with the settings applied as described above.

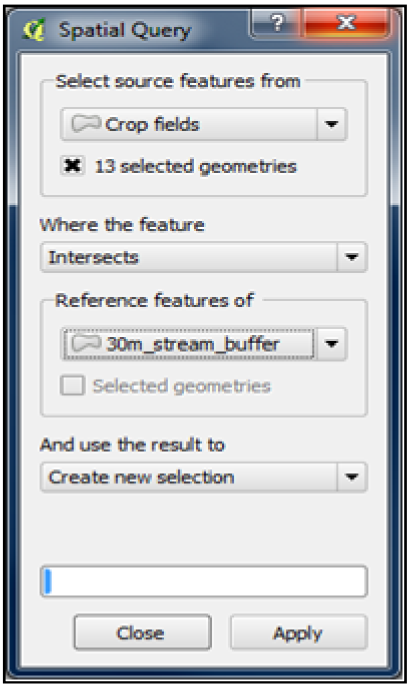


Figure 5.12 Screen capture showing display of spatial query window

Figure 5.13 shows the results in the QGIS GUI. The thin dark blue line symbolises the river dataset, whereas the surrounding light blue shading depicts the 30 metre buffered zone prohibited from cultivation. The green polygons were crop fields not intersecting the 30 metre buffer and the yellow polygons those crop fields intersecting the 30 metre buffer. Consequently the latter fields were those cultivating some prohibited land and an intersect operation would be able to determine exactly how much of each field was involved and could be targeted for corrective action to maintain agricultural compliance with land use regulations – as required for marketing certification.

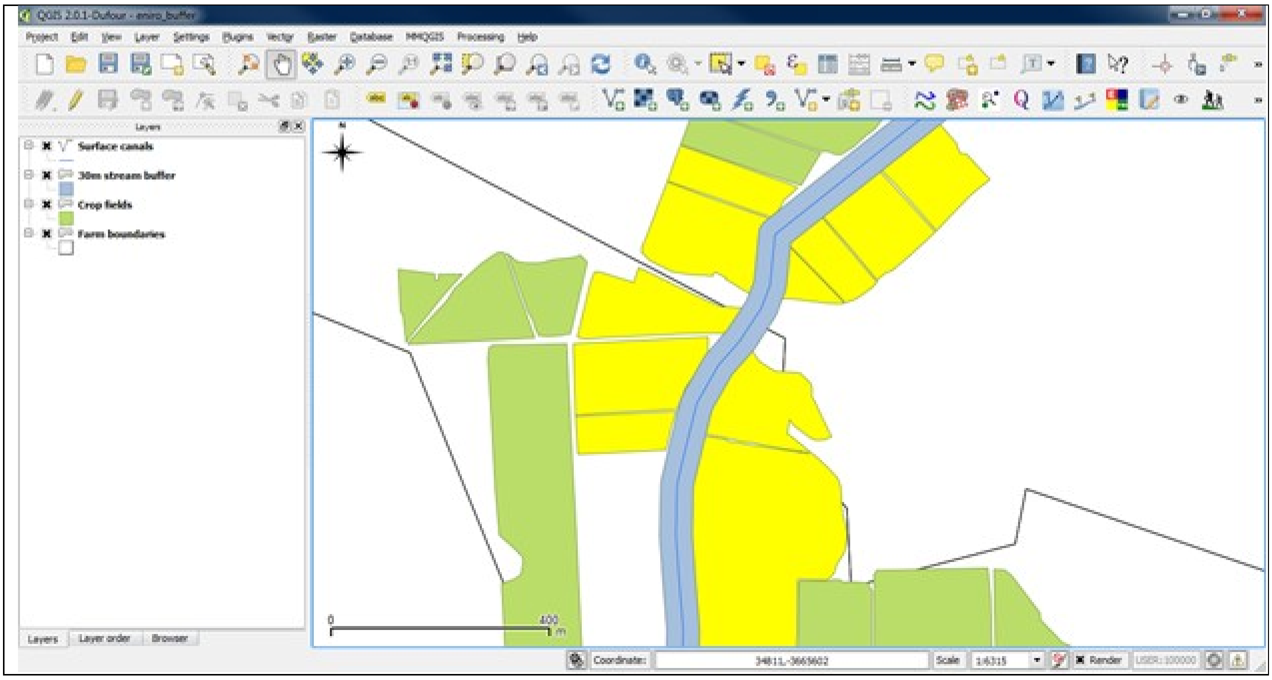


Figure 5.13 Screen capture showing display of crop fields within 30 metres of a stream

The selected crop fields were *saved as* a separate shapefile. This information could now be used to implement the necessary changes and the shapefile containing the selected crop fields could be used as a reference after changes were affected.

5.5.2 Determine access to field lavatories facilities

This second demonstration shifts to an accessibility issue and originates from a GlobalG.A.P. CPCC. GlobalG.A.P. requirements specify that workers must have access to lavatories close to where they work and the lavatories must be within 500 metres, or 7 minutes' walk from the work area. This demonstration illustrated how the system can determine whether current facility locations conform to GlobalG.A.P. prescriptions. The demonstration consisted of three steps. The first step was to add spatial orchard data (polygons) and spatial field lavatory location data to QGIS. Spatial orchard data was added since it represents the working area. Secondly, a 500 metre buffer was created around the point locations of orchard lavatories, using the *buffer geoprocessing* tool. The option to *dissolve intersecting buffers* was also selected. In step three a *spatial query* was used to determine which orchards were outside the prescribed 500 metres distance from a lavatory. The spatial query consisted of selecting orchard areas falling within the 500 metre buffer distances.

Figure 5.14 shows the screen capture of the graphics window depicting orchards which are within (yellow) and outside (green) the 500 metre buffer (blue) distance. Management might

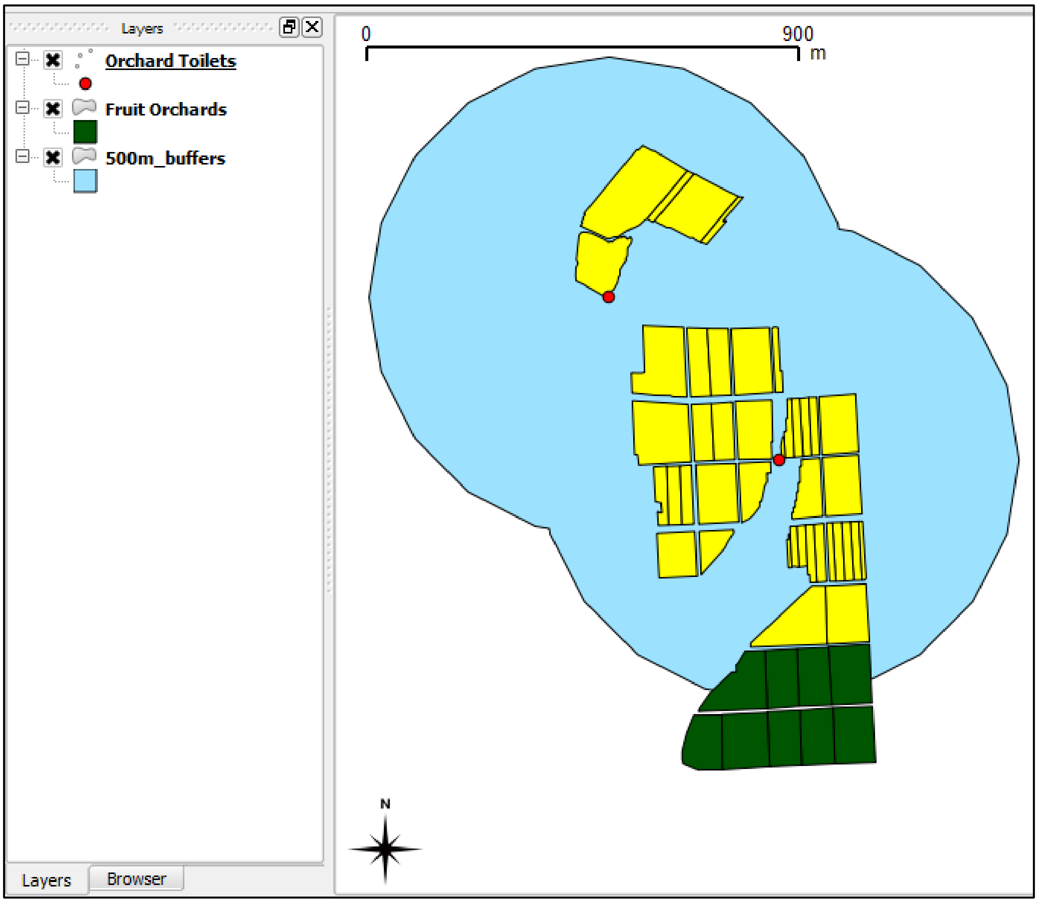


Figure 5.14 Screen capture showing display of orchards within 500 metres of a toilet

use this information twofold: to select locations for additional lavatories to service previously unserviced work areas and, secondly, to provide documentary proof of GlobalG.A.P. compliance. It should be noted that some of the lavatories actually captured in the database were removed from it for demonstration purposes. This exercise could also be applied to identify vulnerable features such as sensitive vegetation stands or water sources located within a specified distance from hazardous substances such as fuel tanks or fertiliser storage.

5.6 DEMONSTRATION 5: COMPILING DESCRIPTIVE SUMMARIES

This penultimate scenario was compiled to illustrate a basic management application and involved selection of a set of target spatial features and computing summary statistics for them. Concerning application skills level, experienced to expert users should typically be able to perform such spatial analytical tasks in GISIMAE. The demonstration consisted of specifically selecting roads in need of repair and then calculating the feature length of the affected line. The results obtained can be used to determine cost of repairs in terms of labour, equipment, materials and machinery committed as well as the time it would take to complete the task. The record particulars of this management and maintenance intervention would be committed to the GSISMAE database for future reference.

The procedure entailed, first, that road spatial data was downloaded to QGIS. Second, the symbology was changed to represent the different road conditions (this step is not required to obtain results, but it again highlights the functions of symbology use). In this case three classes of road conditions were assigned, namely good, fair, and bad (more is possible). Under *style* in the road layer's *property* window, *single symbol* was changed to *categorised* and *condition* selected in the column *dropdown list*. The *red, yellow, and green colour ramp* was selected to represent the three categories.

Figure 5.15 shows the screen capture of the road layer's *property* window with the foregoing settings applied.

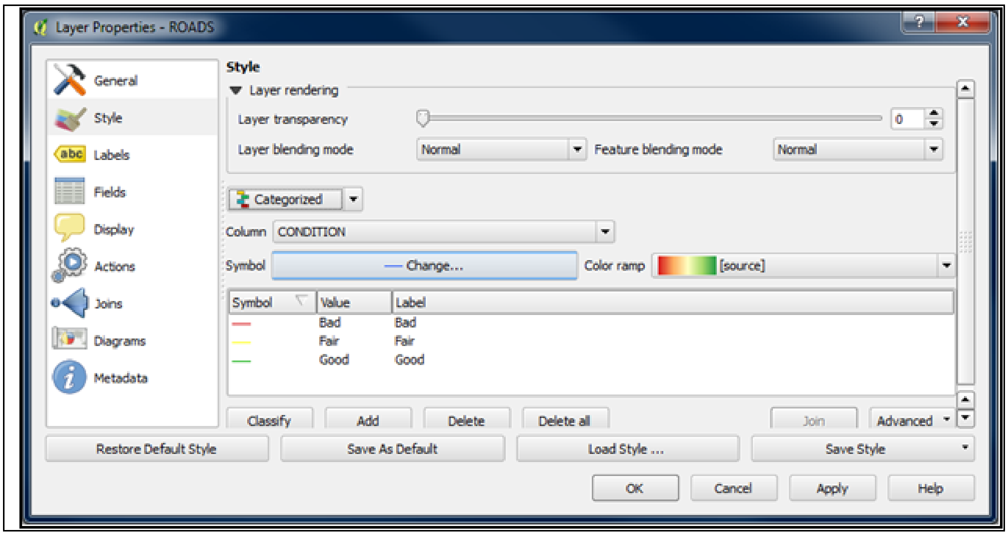


Figure 5.15 Screen capture showing display of layer properties window

In the third step, road sections in need of repair were selected and the total road distances to be repaired calculated. The following Boolean expression was formulated and used to select road sections in a bad condition:

"CONDITION" = 'Bad'

Where

"CONDITION"	refers to the column header
=	a Boolean operator signifying same as or equal to
'Bad'	a value in the condition column, which refers to the state of the road

The sum of the road lengths were calculated using the *basic statistics* function under *vector*, *analysis tools* on the *menu bar*. *Road*s were selected as the *input vector layer* and the *use only selected features* tick box checked. *Length* was selected as the *target field* to be summarised. The screen capture for the *basic statistics* window, with the summarised statistics of the length field already calculated, is shown in Figure 5.16 in the *Value* column. To illustrate interoperability between QGIS and MS Excel, the selection was also saved as a CSV file and opened in MS Excel where the information could be prepared for use in a report document.

5.7 DEMONSTRATION 6: LOCATION OPTIMIZATION

The final demonstration addresses slightly more advanced application features and functions suitable for expert users. It involves a locational optimization demonstration in which the most suitable site or sites that meet previously stipulated locational requirements are to be found. The

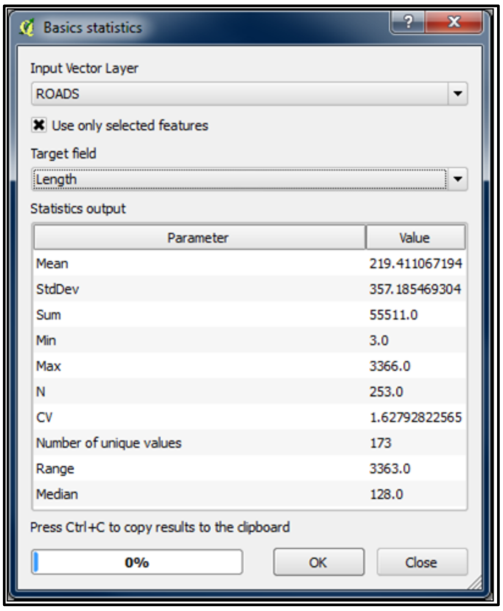


Figure 5.16 Screen capture showing display of basic statistics window

assumption is that user defined criteria for the site location had been formulated as part of the normal enterprise operational or planning activities. This demonstration scenario was judged to be relatively complex and computer resource intensive. However, it provided a suitable illustration of what integrated agricultural and environmental management decision support could entail. The analysis involved selection of a location most suitable for the establishment of a new fruit orchard according to a set of predefined user criteria for ideal orchard conditions. The criteria for the new site required that the (virgin) terrain:

- Must be facing north, in order to receive maximum radiation (amount of sunlight);
- May not have a slope gradient exceeding 8%;
- Must be covered in vegetation with least threatened conservation status; and
- Must be between two and three hectares in size.

The demonstration involved the execution of seven operational steps. The first step required the download of four necessary datasets from the PostGIS database to QGIS: slope gradient, slope aspect, vegetation and the land unit cadastre.

Step 2 consisted of selecting all areas with slopes facing in a northern direction, i.e. slope direction (aspect) values between 45 and 315 degrees. This was done with building and executing an expression in the *raster calculator*, located under *raster functions* on the *menu* bar. The expression read:

"Aspect" <= 45 OR "Aspect" >= 315

Where

"Aspect"	name of the dataset containing slope direction information;
<= 45	signifying the lower aspect value limit (45 degrees) to be selected;
OR	Boolean operator; and
>= 315	signifying the higher aspect value limit (315 degrees) to be selected.

The selection was *saved as* a new raster file, in a GeoTIFF format. The newly created aspect raster was automatically added to QGIS and consisted of a black and white image with a value of zero or one. A value of one (1) indicated a North-facing slope and a value of zero (0) represented all slopes not facing due north.

Step 3 involved selection of all areas having a slope gradient value of less than or equal to 8%. The *raster calculator* was used once more to execute the expression formulated as:

"Slope" <= 8

Where

"Slope"	the name of the dataset holding gradient information; and
<= 8	signifying the maximum aspect value limit (8 degrees) to be selected.

The selection was *saved as* a GeoTIFF file and automatically added to QGIS. Layer values were either zero (0) or one (1), with one indicating gradients of 8% or less and zero indicating gradients values above 8%.

In Step 4 the two newly created raster layers were converted to vector format all features with a value of one were extracted. The *polygonise function* located under the *raster functions* on the *menu* bar was used to convert both raster files to polygon shapefiles. Polygons with an attribute value of one (1) were *selected with an expression* and the selections *saved as* shapefiles.

The fifth step involved the extraction from aspect and gradient shapefiles of areas where the selected critical values overlapped. The *intersect geoprocessing* tool was used to locate the overlapping areas, and the result was *saved as* a new shapefile. The slope shapefile was selected as the *input vector layer* and the aspect shapefile selected as the *intersect layer*.

In Step 6 locations were identified where the intersected slope/aspect layer overlapped areas with the least endangered vegetation class. Least threatened vegetation features were selected using an expression. The *intersect geoprocessing* tool was then used again. The intersected slope layer (created in Step 5) was set as the *input layer* and the vegetation layer was selected as the *intersect layer*. Also, for the vegetation layer, only *selected features* were used during the intersect process.

Step 7 consisted of clipping the cadastre and the above mentioned vegetation and slope intersect layer. This was done using the *clip geoprocessing* tool. This final step furthermore involved calculating the areas of the clip layer, and selecting all the sites with an area covering between two and three hectares. *Editing* was enabled for the clip layer and the *field calculator* opened. A new *decimal column* was created in which area in hectares was calculated. After saving the edits made to the clip layer *an expression was used to select* sites with an area between two and three hectares. **Error! Reference source not found.** shows the screen capture of the window isplaying final suitable site locations as shaded polygons.

The final sites might already be cultivated or unfeasible for cultivation, but it would be possible to identify actual sites accurately. However, the demonstration was already complex and would only become more complicated if additional criteria were to be added. This chapter endeavoured to develop a number of scenario demonstrations of the GISIMAE functionality as applied to Howbill Properties, the study area. Six analyses exercises were shown to be feasible for application by a range of user proficiency levels. These demonstrations were thematically tailored to give effect to conceptual, legal

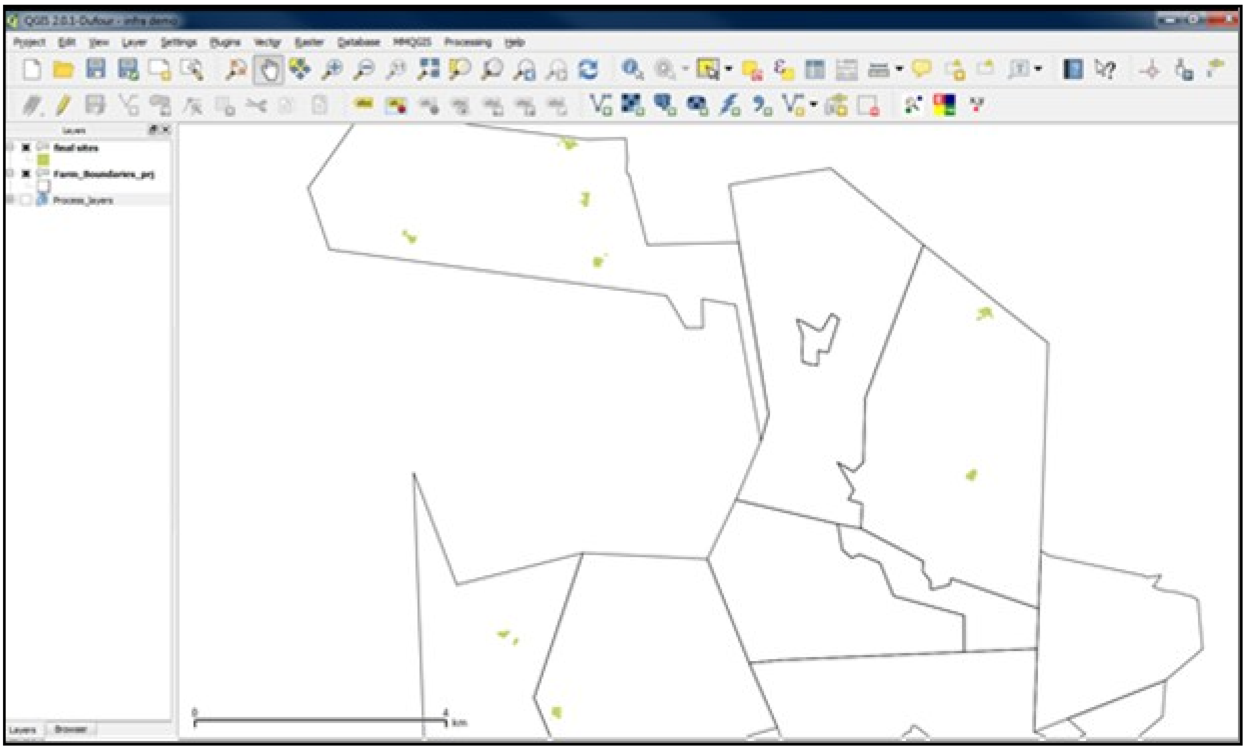


Figure 5.17 Screen capture showing display of final sites for new fruit orchard

and management prerequisites for the conduct of agriculture in a sensitive natural environment in the Western Cape. These demonstrations met the goal set as the final research objective in Chapter 1, leaving only the task to formally conclude the research in a final summary chapter.

CHAPTER 6: SUMMARY AND CONCLUSIONS

In line with the directives provided in Van der Merwe and De Necker (2013), this final chapter ties together the research in a concluding, concise summary of all that has been done, highlights the significance of results and points the way to future research. The aim of this study was to perform a requirements and needs analysis for a spatial information system suitable for addressing integrated agricultural operational and environmental management demands derived from local, provincial, national and international demands and to practically populate a prototype system in a mixed farming fynbos environment in the Western Cape and to demonstrate its planning application. This aim has been met as will become evident from revisiting each research objective separately and determining the success with which each one has been realised.

The chapter is crafted to succinctly restate the developments of the previous chapters and sections and the important findings. It starts by revisiting the aim and seven stated objectives set out in the introductory chapter and summarises the results in line with them in six initial subsections. Conclusions are substantiated by evidence presented on both the theoretical and practical implications of the results. Some reflections on the value and contributions of the research and its limitations lead to recommendations for improving farm-level management as well as further research.

6.1 IMPERATIVES FOR INTEGRATED FARM-LEVEL MANAGEMENT

The first objective of the research was to determine and unpack relevant provincial, national and international imperatives directing integrated agricultural operational and environmental management at farm-level. The objective was addressed by reporting in Chapter 2.

It was found that imperatives directing integrated management arose and were concerns at various levels of governance, starting at international level and cascading through national to provincial governing levels and impacting at farm-level in management demands. The driving concern to the problematic of this study was found to be climate change which is a global threat naturally leading to management forcing at the farm-level. In our local context each level of governance has a specific responsibility. Global solutions to environmental issues are monitored and determined and policy guidelines are drawn up by international bodies like the UN and its statuary environmental and specialised agencies (like UNEP, WMO, FAO) and delegated to member states for local action. Member states are expected to comply with international agreements and formal treaties (e.g. UNFCCC, Kyoto Protocol, and CBD) by implementing the required compliance policies and legislation at the national level. In South Arica's case these are reflected in various White Papers, legislation (e.g. NEMA, NWA, CARA, NEMBA), agriculture industry strategies, and programmes like Working for Water and LandCare. This legislation contains regulations directly binding on the conduct of agriculture. In certain instances, stipulated by the Constitution, enforcement of national legislation and programmes is delegated to provincial departments, which implement programmes to promote legislation adherence, in addition to law enforcement. Examples directly concerning farm-level action are Farm Planning, LandCare projects, Areawide and various CapeNature Projects (e.g. WfWP, FMDP, WMP, GCBC).

Perhaps the most important, it was found that market-driven initiatives have now become paramount in enforcing compliance with international concerns by farm-level management. Good agricultural practices (GAP) and specifically in case if the research target, GlobalG.A.P., now demands third party certification bodies to demonstrate compliance with food safety and traceability standards. These standards, despite a stronger focus on food safety and traceability, do make provision for mitigating environmental issues at the level of the individual farm-production units. Clearly, the world of agricultural production has come of age and now demands a sophisticated level of management practice to be instituted at the level of the individual farm to ensure long-term competitiveness and access to national and international markets.

6.2 FARM-LEVEL SPATIAL INFORMATION REQUIREMENTS

Ultimately, the statutory and market-driven imperatives directing integrated agricultural and environmental management at farm-level determined the data requirements for the spatial information system developed in this research. Objective 2 therefore set out to determine the spatial information requirements for agricultural operational planning, decision-making and analysis, and Objective 3 to determine the same for environmental planning, analysis and decision-making. Of course, the central notion here was to ideally enable a fully integrated approach. The two objectives were realised in parts of Chapters 2 and 3.

Data requirements from national imperatives were determined and tabled in Section 2.4.3; mostly they were gleaned from specifications in national CARA regulations and concerned both the man-made (land use, water, transportation and water storage) and a range natural (landscape structure, soil, water and vegetation) environmental issues. All of these imperatives found their way into provincial regulation, policies, and programmes.

Market-driven data requirements emanating from national and global (specifically from GlobalG.A.P.) agencies (specifically retailers) certification standards were determined and tabled in Section 2.6.3. Salient items concerned production site management history, worker welfare provisions, specifics on livestock crop production (schedules, chemical applications) the man-made (land use, water, transportation and water storage). Environmental concerns were found to be somewhat oblique, incidental and perhaps token in nature. Of concern here was the low level of compliance demanded.

The two main themes of data requirements that were determined nevertheless drove operational data assembly for the research in terms of an exhaustively list of data summarised in Section 3.1 and listed in Table 3.1. It encompassed eight data schemas and 37 item datasets on natural resources (soil, water and natural vegetation) as well as agricultural infrastructure to be gathered.

6.3 CASE STUDY DATABASE

Objective 4 required the collecting and building a database of spatial environmental and infrastructural data relevant to application to the case study farm property. The process of gathering and manipulation of the database is reported in the majority part of Chapter 3. The discussion separates data matters by data type – first raster data, followed by vector data. Most data were collected during a five-week field survey using a recreational outdoor GPS for smaller individual features, such as water pumps and electrical transformers. Larger features such as orchard boundaries and buildings were digitised from aerial images. In addition, spatial delimitation of classified natural vegetation, geology and elevation data (DEM), aerial images, and a SPOT 5 scene were sourced from the SANBI, Council for Geoscience, CD:NGI and the CGA in-house data store. Not all the required spatial data could be obtained, and there is still a need for certain spatial datasets, such as soil data, as well as attribute data for a range of features in the existing spatial datasets which could not be obtained at the time, to be added to the library.

Spatial data accuracy was determined to be between 2 and 3 metres for digitised datasets, and 3 to 4 metres for data collected by means of the GPS device. For most agricultural production features, such as crop field boundaries and water pumps, the spatial accuracy is deemed sufficient. However, for features such as underground water pipe-lines, or individual fruit tree locations, a sub-metre spatial accuracy would be preferable and in some cases a necessity.

6.4 TECHNICAL AND OPERATIONAL SYSTEM REQUIREMENTS

Having established the imperatives for having a spatial management system and having built the requisite database, Objective 5 set the task to determine the generic technical and operational requirements for the operational spatial management system (GISIMAE) in a format suitable for an operating farm and develop such a suited-to-task prototype integrated spatial information system. This task was fulfilled in the first half of Chapter 4, where several sets of tabled selection criteria are lodged for easy reference. Departing from theoretical and operational guidance obtained from literature, the task was met by considering both system type and its components. It required a choice to be made between a single user desktop GIS system, and an enterprise GIS. An enterprise GIS was selected as the most suitable setup, since it could serve the need of a single user or the need of more than one user. It was determined that an enterprise system typically consists of a three components: a desktop GIS application, a spatial database, and hardware.

A review of the functions and features of currently available enterprise GIS software components revealed that PostGIS would best serve the role as a spatial database, and QGIS was selected as the desktop GIS software. System cost versus system benefit was the main criterion guiding the software choice for the spatial information system. Furthermore, it was determined that, among a range of criteria, the software components must allow efficient database connection, must be able to handle vector and raster data, and offer a range of GIS functionalities. User experience with GIS was paired with the functions and features of the spatial information system and it was found that the system could potentially be utilised by all four categories of user experience (novice, experienced, expert, and research). This spatial information system also provides a platform to expand as the need arises at a later stage to serve spatial data over the internet to users in the field.

The goal to determine technical and operational requirements for the system in an operational format on an operating farm was also reached. This required technical requirements in terms of computer hardware and supplementary equipment for enterprise type GIS to be determined. Computer hardware decisions were resolved by considering the software's minimum system requirements and coupling with the user experience level with GIS. Novice GIS users would only require a computer to view spatial data, and therefore do not need a high-end computer. Supplementary hardware included printers, GPS devices and cameras. To summarise basic system requirements: on the computing side, minimum- to medium-specification computer hardware is recommended, the operator should have access to fairly basic printing facilities (preferably colour), a recreational outdoor GPS device would suffice for data capture purposes, and some form of digital camera equipment from which feature imagery can be downloaded to computer is necessary.

6.5 SPATIAL SYSTEM INFORMATION POPULATION

Objective 6 was directed to populate the prototype spatial information system with collected data and the description of this process occupies the second half of Chapter 4. The database design was fairly straightforward, and the main drive was to group relevant data together in a default file structure, that PostgreSQL terms, schemas. The data was divided tree-wise into groups with similar themes, such as water, transportation and electricity, and then uploaded it into the relevant schema. Uploading vector data into PostGIS turned out to be easy and the process steps could be sketched out for ready application by would-be users. Vector data manipulation can be performed through using a range of installed plugins to carry out analyses involving inter alia, spatial buffering, calculating walk-time duration, viewshed analysis, smoothing and gridding. However, uploading raster data and importing existing tabled data into the database proved more difficult and requires more than basic knowledge of computer systems and databases. The structuring of a command template to perform this function might prove to be a source of difficulty if the appointed database administrator (or user) does not have the required knowledge or experience.

Also, adding tabular non-spatial data to PostGIS, through PGA, was experienced as a tedious process, since PostGIS does not accept files in MS Excel format and these basic data files had to be converted to comma separated values (CSV) files first. General database maintenance tasks can be automated and is recommended in installations lacking a dedicated database administrator without the relevant experience. The chapter concluded with directives to help administer the GISIMAE system, including such measures as assuring data security, quality and integrity and recommends a schedule for user training to operate the system at various proficiency levels.

6.6 SCENARIO DEMONSTRATIONS

The final objective required the development of demonstration scenarios of the information system GISIMAE for agricultural operational and environmental management spanning as much as possible of the application functionalities. This task was completed successfully in all of Chapter 5. Following the principles of design process demonstration gleaned from literature, six GIS techniques capturing a range listed in Table 5.1, were demonstrated in as many subsections. This placed the focus on the functions and features of the system, instead of focusing on a single application, thereby, alerting potential users to the possibilities of such a system.

The demonstrations commenced by showing the user how to visualise data through creating a thematic map of crop fields as example of polygonal display and also how to label feature in such displays. Being a tool for infrastructure management in an agricultural setting, the visualisation of infrastructure features (e.g. water pumps installed in particular locations) was demonstrated. Beyond visual display, the system's ability to allow queries of all contents – spatial and non-spatial – through rule based classification was shown. Demonstration of the measurement of spatial features in the database through shapelier overlaying followed. The fourth demonstration moved somewhat beyond the realm of the novice user into that of the more experienced by showing some transformation techniques by which new spatial features are generated from existing features by employing buffering geoprocessing tools. The penultimate scenario demonstration was compiled to illustrate a basic management application and involved selection of a set of target spatial features and computing summary statistics like costing for planning repairs to or maintenance of infrastructure. It moved the application skills level to experienced and expert users. The final demonstration addresses slightly more advanced application features and functions suitable for expert users. It involved a locational optimization demonstration in which the most suitable site or sites that meet previously stipulated locational requirements – in this case the best location for new orchards – are to be found by means of GISIMAE.

The six demonstration scenarios delivered the unforeseen advantage that it highlighted data limitations of the currently developed system. Demonstration scenarios were hindered by data shortcomings – both level of detail and simply in terms non-availability. As an example, very little spatial analysis-type demonstrations could be performed for orchards, since orchard boundaries were the only available data for this feature type. Having the locations of individual fruit trees would significantly improve the capability of the system. While possible to calculate from existing data, it would require time beyond that available for this research to accurately map features at the micro level required to really inform production decision-making. Ultimately, the system will be of limited use if appropriate data is not generated and updated on a regular basis.

6.7 VALUE AND LIMITATIONS OF THE RESEARCH

The research represents a novel and innovative application of GIS and related technologies as a broadening of its application scope. Revisiting the forceful arguments built to reveal the international, national and local pressures piling up on the conduct and management of high-intensity commercial agriculture in a pristine Western Cape fynbos environment, they appear convincing. System demonstrations were thematically tailored to give effect to conceptual, legal and management prerequisites for the conduct of agriculture in a sensitive natural environment in the Western Cape. It must be clear to all role-players in agricultural conduct and development in the modern agricultural industry that the pressures emanating from international organisations with global mandates to diminish the contribution to and impact of industry on a vulnerable global environment is set to increase relentlessly. The influence on industry of consumers driven by such perceptions of imminent catastrophe derived from climate change, channelled through the retail industry determining certification of benevolent modes of production, is unavoidable. GISIMAE provides a means by which integrated agricultural operational processes and thoughtful environmental management can be supported in a demonstrable way. This research offers a potential tool in the hands of management to do so in an affordable manner.

Like all research, this endeavour could not fully avoid smaller pitfalls and suffered certain generic limitations. Finding the solution pathway through the problem field sketched in Chapter 1, was hampered by a dearth of similar work previously published elsewhere from which experience-based pointers could be acquired. While attesting to its innovative and relatively novel nature, it meant that the approach had to be relatively original. More specific limitations unveiled, concerned the way in which regulating mechanisms were being applied. The absence of real and innovative enforcement of environmental concerns in GAP implementation comes to mind, which leads to a certain lack of urgency in compliance with regulations by certified agricultural enterprises. Still, it does not mean that these environmental requirements are not set to become ever more stringently conditional for market access.

Operationally, the implementation of GISIMAE is hampered by the nature of local spatial data availability. While hugely improved over the past decade, severe limitations are still experienced – in terms of data range, fine-scale data resolution, data accuracy, resources to effect regular revision and scope to encourage input from users themselves. Despite excellent national coverage on themes like soil type and natural vegetation, data resolution at 1:250 000 scale is inadequate for application at farm-level locally. Consequently, the GISMAE demonstrations that were developed lack an innovative environmental management application due to lack of comprehensive fine-scale data.

6.8 RECOMMENDATIONS

The recommendations made in this final section of the thesis maintains a narrow focus on the application and further development of GISIMAE in operational settings and suggests some salient avenues for further research – both in terms of system development and in terms of practical environmental management actions through GIS support.

From the operational requirements constituting a geo-spatial data cycle, that were determined from literature, come recommendations for the improvement of spatial information system integrity. Clearly, coarse-scale datasets for and knowledge and understanding of a range of natural resources (geology, terrain type, soils, vegetation distribution, species composition and variety, geology-vegetation association, agriculture-environment interaction) must be refined to fine-scale renditions for application at enterprise level. While much of this can be accomplished by government sponsored service delivery through prominent agencies like DWA, DA, SANBI and other research bodies, private and especially local enterprise-based sponsorship of fine-scale analysis and resource mapping must be promoted. This needs statement opens a prominent avenue for research, whereby individual researchers at various qualification levels might focus their output goals to build a fine-scale, locally focussed but eventually wall-to-wall spatial coverage that spans all intensively farmed regions of the Western Cape province – or elsewhere in targeted high-sensitivity regions. The prototype spatial information system developed in this study would be able to facilitate fine-scale integrated agricultural and environmental management provided that appropriate data become available. Research might generate the requisite spatial data.

Developing a spatial information management system was only the first step. Properly implementing and managing the system is now of utmost importance for the success of this spatial information management system. Future research should be focussed on more innovative GAP implementation concerned with spatial environmental issues currently glossed over in certification processes. In that way research might contribute to encourage technology adoption beyond what GISIMAE may have achieved in this research exercise. The current lack in environmental compliance enforcement must be circumvented by demonstration of what becomes possible through innovative spatial management applications. While not properly enforced at present, the principle inherent to GlobalG.A.P. implementation and conditional certification at present is at least that temporal improvement (i.e. improvement every year over the previous year's performance) must be proven, and that can be the driver of enhanced application.

The system can, in theory, be utilised by a broad range of users with different levels of GIS experience. Further development and research on the system should therefore target enhanced ease of operation – finding more intuitive and less technically demanding operational procedures to encourage wider adoption of the technology. From a technical point of view, the prototype system has much room for improvement, and for expanding, such as automated data gathering, or expanding system operation to the internet, which would enable users to access data in the field or add data directly from the field.

In the final analysis, however, “in a society that seems to value only what illustrates a profit on a balance sheet” (Ashwell et al. 2006: 153) it has become incumbent upon commercial agriculture and entrepreneurs, as resource users, to attach real value to the retention of ecological services rendered by natural landscapes from which they derive their lifeblood. GISIMAE adoption offers a first step towards reaching that lofty goal.

[35 509 Words]

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APPENDIX A

Figure A1 Geology map indicating the various geologic formations

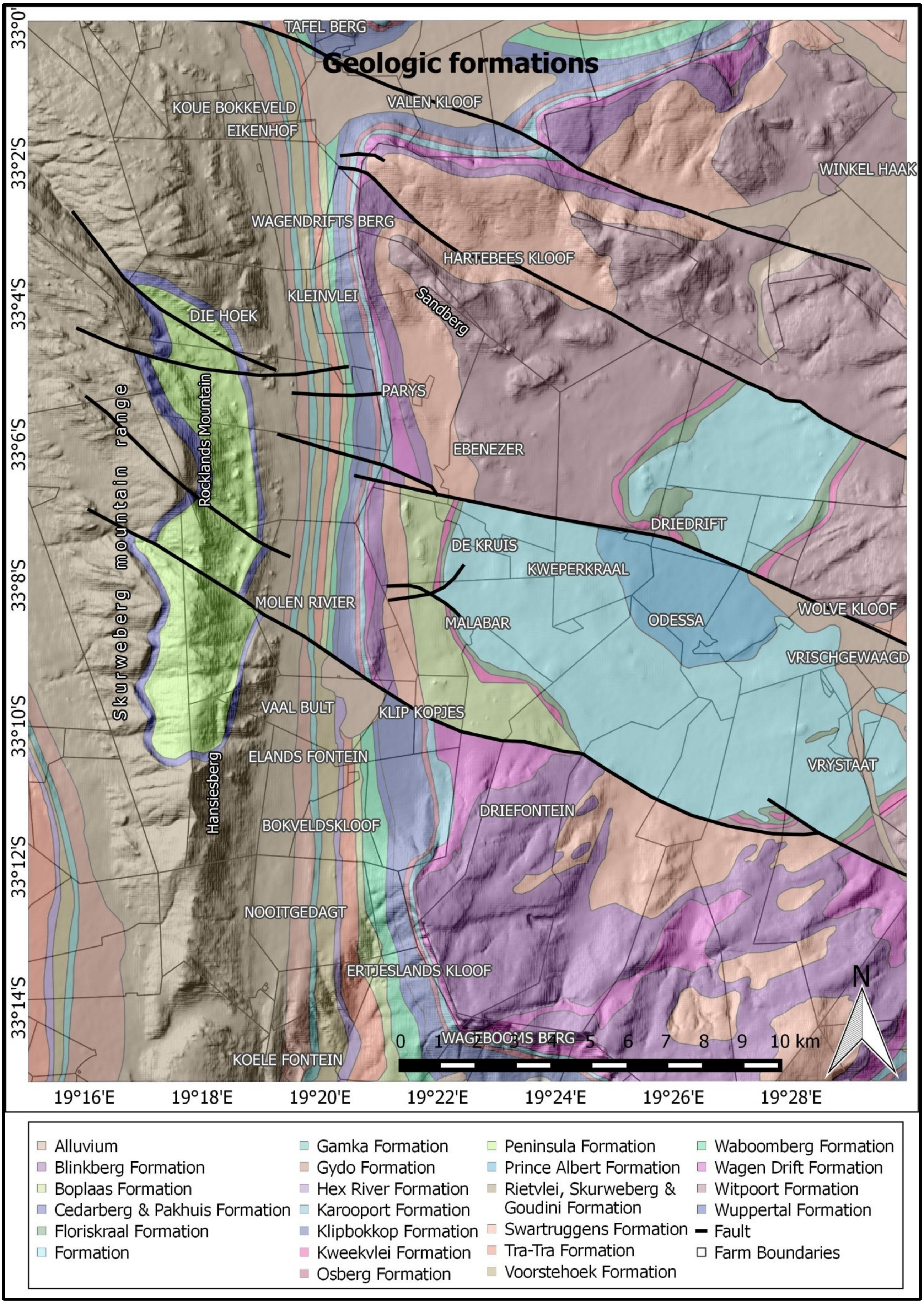

Geologic formations
TAFEL BERG
VALEN KLOOF
KOUE BOKKEVELD
EIKENHOF
WINKEL HAAK
WAGENDRIFTS BERG
HARTEBEES KLOOF
KLEINVLEI
Sandberg
DIE HOEK
PARYS
Rocklands Mountain
Skurweberg mountain range
EBENEZER
DRIEDRIFT
DE KRUIS
KWEPERKRAAL
MOLEN RIVIER
MALABAR
ODESSA
WOLVE KLOOF
VRISCHGEWAAGD
VAAL BULT
KLIP KOPJES
ELANDS FONTEIN
VRYSTAAT
Hansiesberg
DRIEFONTEIN
BOKVELDSKLOOF
NOOITGEDAGT
ERTJESLANDS KLOOF
WAGEBOOMS BERG
KOELE FONTEIN
0 1 2 3 4 5 6 7 8 9 10 km
N
33°0'
33°2'S
33°4'S
33°6'S
33°8'S
33°10'S
33°12'S
33°14'S
19°16'E
19°18'E
19°20'E
19°22'E
19°24'E
19°26'E
19°28'E
Alluvium
Blinkberg Formation
Boplaas Formation
Cedarberg & Pakhuis Formation
Floriskraal Formation
Formation
Gamka Formation
Gydo Formation
Hex River Formation
Karooport Formation
Klipbokkop Formation
Kweekvlei Formation
Osberg Formation
Peninsula Formation
Prince Albert Formation
Rietvlei, Skurweberg & Goudini Formation
Swartruggens Formation
Tra-Tra Formation
Voorstehoek Formation
Waboomberg Formation
Wagen Drift Formation
Witpoort Formation
Wuppertal Formation
Fault
Farm Boundaries

Figure A2 Vegetation map that show the various indigenous vegetation in the study region

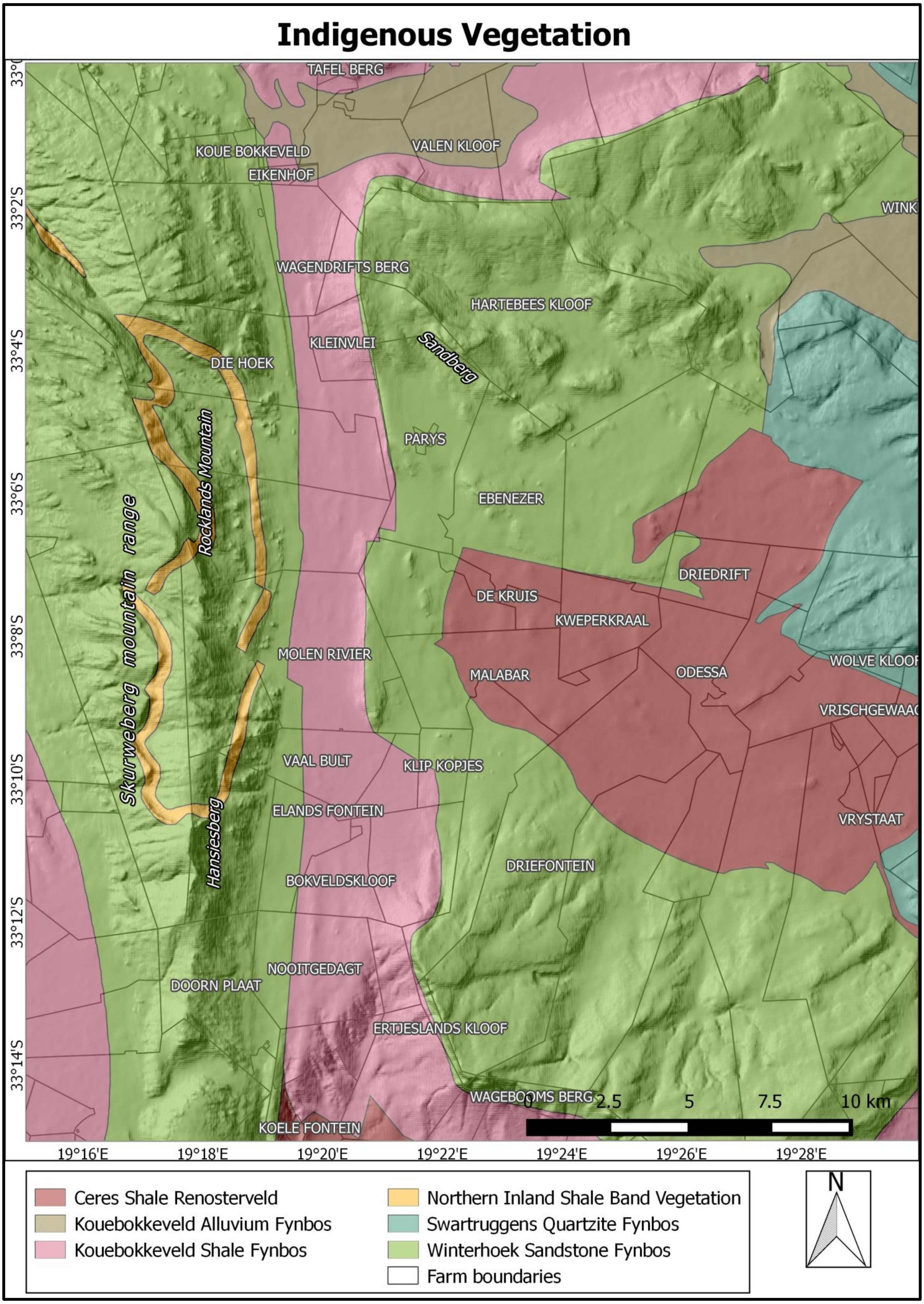
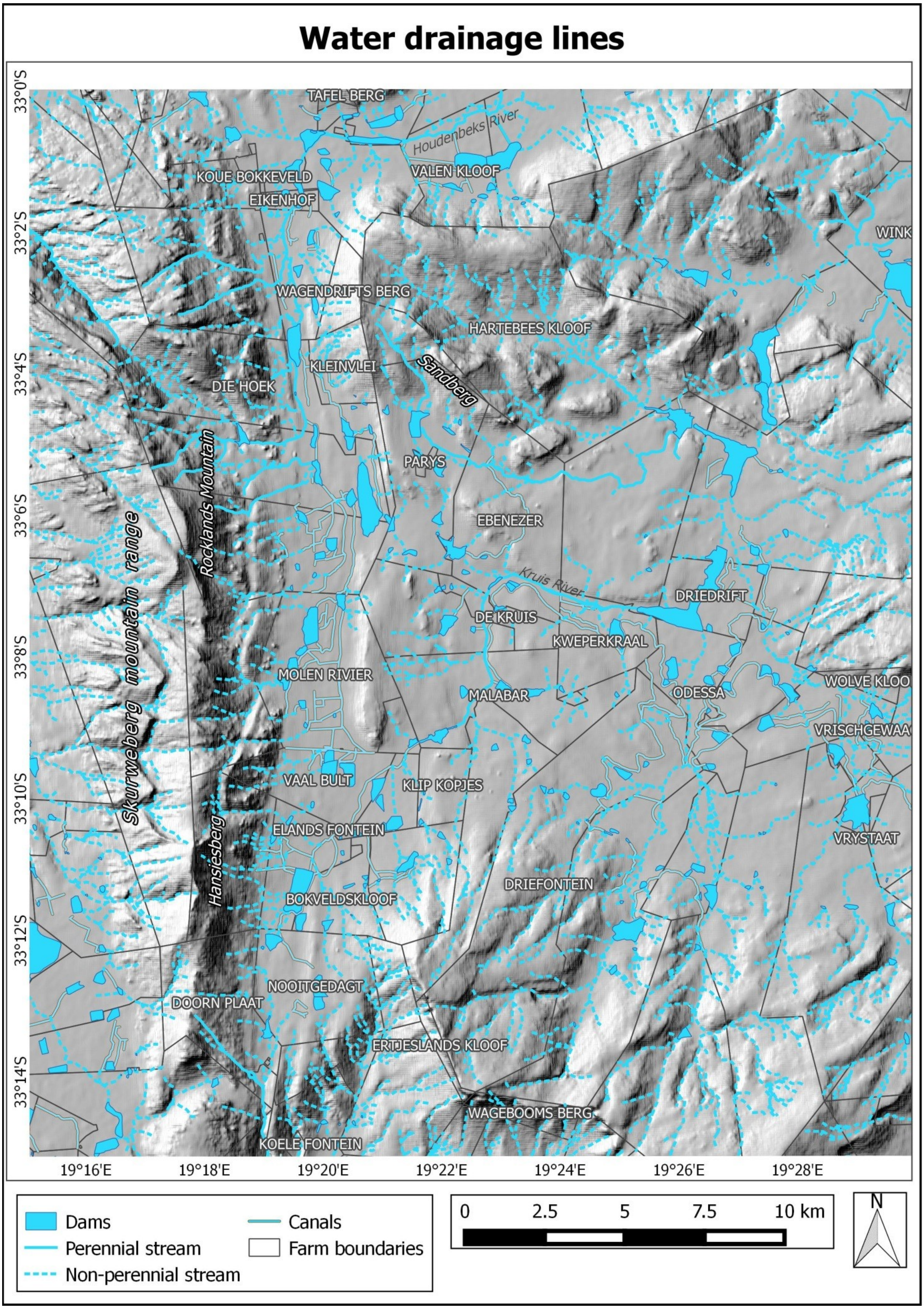
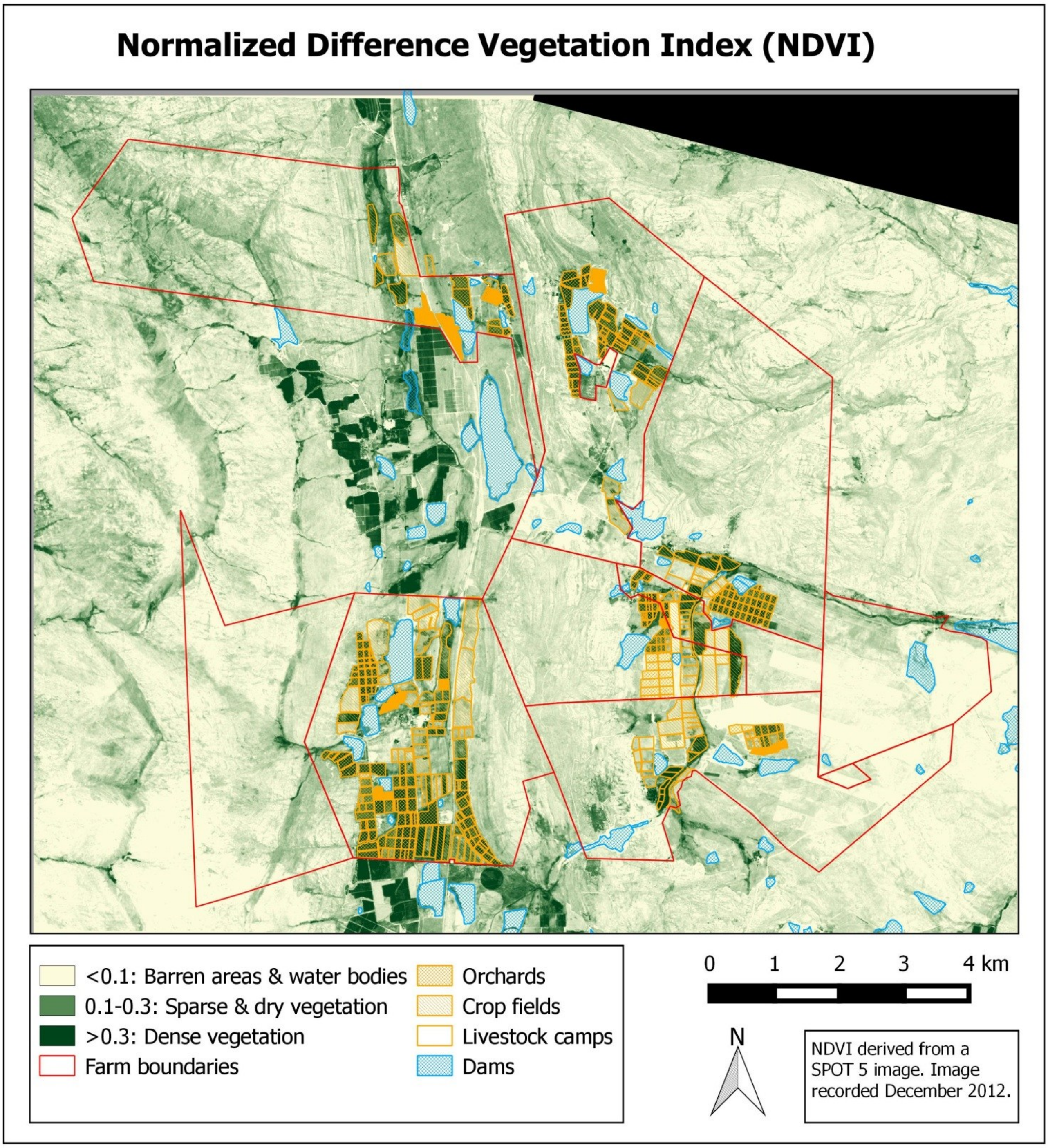

Indigenous Vegetation
TAFEL BERG
KOUE BOKKEVELD
VALEN KLOOF
EIKENHOF
WAGENDRIFTS BERG
HARTEBEES KLOOF
KLEINVLEI
Sandberg
DIE HOEK
Rocklands Mountain
PARYS
EBENEZER
Skurweberg mountain range
DRIEDRIFT
DE KRUIS
KWEPERKRAAL
MOLEN RIVIER
MALABAR
ODESSA
WOLVE KLOOF
VRISCHGEWAAG
VAAL BULT
KLIP KOPJES
ELANDS FONTEIN
Hansiesberg
VRYSTAAT
DRIEFONTEIN
BOKVELDSKLOOF
NOOITGEDAGT
DOORN PLAAT
ERTJESLANDS KLOOF
WAGEBOOMS BERG
KOELE FONTEIN
WINK
0 2.5 5 7.5 10 km
33°2'S
33°4'S
33°6'S
33°8'S
33°10'S
33°12'S
33°14'S
19°16'E
19°18'E
19°20'E
19°22'E
19°24'E
19°26'E
19°28'E
Ceres Shale Renosterveld
Kouebokkeveld Alluvium Fynbos
Kouebokkeveld Shale Fynbos
Northern Inland Shale Band Vegetation
Swartruggens Quartzite Fynbos
Winterhoek Sandstone Fynbos
Farm boundaries
N

Figure A3 Drainage lines in the study region


Water drainage lines
TAFEL BERG
Houdenbeks River
KOUE BOKKEVELD
VALEN KLOOF
EIKENHOF
WINK
WAGENDRIFTS BERG
HARTEBEES KLOOF
KLEINVLEI
Sandberg
DIE HOEK
PARYS
Rocklands Mountain
EBENEZER
Skurweberg mountain range
Kruis River
DRIEDRIFT
DE KRUIS
KWEPERKRAAL
MOLEN RIVIER
WOLVE KLOO
MALABAR
ODESSA
VRISCHGEWAA
VAAL BULT
KLIP KOPJES
ELANDS FONTEIN
VRYSTAAT
Hansiesberg
DRIEFONTEIN
BOKVELDSKLOOF
NOOITGEDAGT
DOORN PLAAT
ERTJESLANDS KLOOF
WAGEBOOMS BERG
KOELE FONTEIN
33°0'S
33°2'S
33°4'S
33°6'S
33°8'S
33°10'S
33°12'S
33°14'S
19°16'E
19°18'E
19°20'E
19°22'E
19°24'E
19°26'E
19°28'E
Dams
Perennial stream
Non-perennial stream
Canals
Farm boundaries
0
2.5
5
7.5
10 km
N

APPENDIX B

NDVI and impervious surface map



APPENDIX C

CD C1 contains the spatial data (farm infrastructure and environmental features in shapefile and TIFF format), spatial database programme (PostgreSQL 9.2 and PostGIS 2.1) and the desktop GIS software (QGIS 2.4).

CD C2 contains aerial images of the study area.

APPENDIX D

Geospatial metadata form

GIS METADATA : DETAILED REPORT

FILE NAME:	
Full Path	
Description (detailed)	
Copyright Holder	
Data Origin	
Capture Source	
Scale Digitised at	
Date Captured	
Data Copyright	
To be distributed	

DATA INFORMATION AND METADATA INFORMATION	
Owner Organisation	
Contact Person	
Position of Contact Person	
Contact Address	
Contact Number	
Contact Email	

LEGEND PROPERTIES	
Legend Title	
Feature Type	
Scale Parameters	

PROJECTION	
Projection Name	
Central Meridian	
Upper Parallel	
Lower Parallel	

DATUM	
Name	
Semi Major Axis	
Semi Minor Axis	
Inverse Flattening	

DETAILED NOTES
Purpose: Methodology:

ATTRIBUTE FIELDS		
Field Name	Description	Alias