AN INVESTIGATION INTO USING GIS IN ELECTRIFICATION AND NETWORK PLANNING IN RURAL KWAZULU-NATAL

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Abstract

The South African Government has set a target of universal access to basic electricity by the year 2012. Free basic electricity is defined as the amount of electricity sufficient to provide basic lighting, media access, water heating and ironing with on-grid electricity; or basic lighting and media access for a non-grid system. Eskom Distribution, in conjunction with local municipalities, is responsible for the outstanding electrification predominantly in rural areas. In KwaZulu-Natal, mountainous terrain and scattered settlement patterns of communities complicate the achievement of this goal. This study was aimed at using GIS to address the urgent need to plan electrification, firstly by identifying areas that need electrification and secondly by prioritising those areas according to set principles. Electrification areas were effectively identified and prioritised from both a need and capability of supply aspect. The study then aimed at designing the shortest networks from the grid to those identified electrification areas.

To determine electrification areas spatially, electoral areas (EAs) demarcated as rural during the run up to the 1994 elections were used to identify rural areas; and Ethekwini Metropolitan Municipality, current electrification projects, reserves and a buffer zone around existing transformers excluded. Household point data was used to polygonize the remaining area, and those polygons were aggregated on their calculated area to create future rural electrification areas (FREA). A points and weighting system; based on one initially used in Namibia and further developed in an electrification planning model by RAPS Consulting, CSIR and DME to prioritise villages for electrification; was applied to calculate point scores for each FREA and other criteria such as distance from a network with capacity considered to determine a prioritised list of FREA that can be electrified immediately.

Roads, land cover, household positions and slope were used to design the shortest path from the grid to the three highest scoring FREA. Each layer was reclassified, ratings applied and the layers combined to successfully determine the final path in terms of the criteria used.

Interest in using GIS for spatial planning has led to a GIS Initiative Group (GISIG) being formed at Eskom Distribution in Eastern Region to address data collection, co-ordination of planning, tools written previously but never implemented being re-evaluated and, more recently, new tools being designed. However, much is still needed in terms of research, resolving of data quality issues, testing of points and weighting systems, and for functionally independent sections to work together on making changes to age-old system structures and processes before any of the recommendations resulting from this study can be effectively implemented.

Declaration

I declare that this dissertation is my own unaided work. It is submitted in fulfillment of the requirements for the degree of Master of Environmental Science at the University of KwaZulu-Natal, Pietermaritzburg, and it has not been submitted before for any other degree or examination at any other university.

Declared by: Supervised by:

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Ms J.B. Barnard Dr F. Ahmed

On this ______________ day of ______________, 2006

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List of Acronyms and Abbreviations

ABB	Asea Brown Boveri
AM/FM	Automated Mapping / Facilities Management
AMIS	Analytical Minimum Impedance Surface
ASER	Agence Sénégalaise d’Electrification Rurale
BELCO	Bermuda Electric Light Company Limited
CAD	Computer Assisted Design
CSD	Commission on Sustainable Development
CSIR	Council for Scientific and Industrial Research
DBSA	Development Bank of South Africa
DEC	Department of Education and Culture
DEM	Digital Elevation Model
DIMS	District Information Management System
DME	Department of Minerals and Energy
DMS	Distribution Management System
DSM	Demand Side Management
DTLGA	Department of Traditional and Local Government Affairs
EA	Electoral Area
EDL	Electricité Du Liban
ENS	Electricity Network Schematics

EPRI	Electrical Power Research Institute (USA)
ESRI	Environmental Systems Research Institute, Inc.
FREA	Future Rural Electrification Area
FSA	Field Service Area
GE	General Electric
GIS	Geographic Information System
GISEL	Geographic Information Systems Electricity of Lebanon
GISIG	Geographic Information System Initiative Group
GPS	Global Positioning System
HELP	Housing and Electrification Program
HOMER	Hybrid Optimization Model for Electric Renewables
HV	High Voltage
ICT	Information & Communications Technology
IDP	Integrated Development Plan
IVM	Integrated Vegetation Management
KZN	KwaZulu-Natal
LV	Low Voltage
MV	Medium Voltage
NDA	National Development Agency
NDP	Network Development Plan

NER	National Electricity Regulator
NERC	North American Electric Reliability Council
NERI	National Energy Research Institute
NRECA	National Rural Electric Cooperatives Association
NREL	National Renewable Energy Laboratory (USA)
NYPA	New York Power Authority
PNM	Public Service Company of New Mexico
PPGIS	Public Participation Geographic Information System
RAPS	Rural Area Power Solutions
RDP	Regional Development Plan
RED	Regional Electricity Distributor
REN21	Renewable Energy Policy Network for the 21st Century
ROW	Right of Way
SARERD	South African Renewable Energy Resource Database
SCADA	Supervisory Control And Data Acquisition
SCHOOL	Substation / Circuits History of Operational Loads
TAMIS	Transmission Asset Management Information System
TIN	Triangulated Irregular Network
UAP	Universal Access Plan
UN	United Nations

UNEP	United Nations Environment Programme
USA	United States of America
USAID	United States Agency for International Development
WWF	World Wildlife Fund

On May 21 2004 President Thabo Mbeki stated in his address to the first joint sitting of the third democratic Parliament, Cape Town

"… We also need to achieve further and visible advances with regard to the improvement of the quality of life of all our people…

…Through our integrated system of government, with a strengthened local government working with our state enterprise, ESKOM, we will, within the next eight years, ensure that each household has access to electricity…

... Let us get down to work in a people's contract to build a better South Africa and a better World."

(President Thabo Mbeki, 2004)

Eskom's Vision:

"Together building the powerbase for sustainable growth and development"

(Eskom Distribution, 2006)

Chapter 1: Introduction

1.1 Overview

Internationally electricity companies have realized the benefits of using GIS for the running of their day-to-day business and this has led to the installation of an AM/FM GIS largely to manage outages and mapping requirements (Meehan, 2005). Connecting databases across an electricity company has facilitated new activities in some companies such as customer analysis to develop marketing strategies (Newhouse *et al*, 2004), comparison of billed electricity and actual use to find illegal connections (Marmar, Undated, Rajopadhyay *et al*, 2002), asset management of equipment and network maintenance (Bush, 1999), and combining company data with external datasets in order to prioritise and plan new connections (Baumann, 2003, Glasgow *et al,* 2004). Growing awareness of the capabilities of GIS analysis has started to evolve into a number of GIS projects being researched and initiated in developing countries such as Uganda, Burkina Faso, Cameroon, Mali and Niger in Africa where rural electrification is low, to perform electrification and network planning (UNEP, 2005, Kaijuka, 2006).

Eskom is the principal electricity supplier in South Africa and is divided into three separate functional entities providing for generation, transmission and distribution. Electricity is generated in Power Stations by Eskom Generation through a number of methods, primarily through coal (80% of generated electricity) due to the massive reserves of coal from sediments in the Karoo region, but also through other fuels such as natural gas (currently under 2% but increasing), hydroelectric power and other renewables (close to 10%) and nuclear (Koeberg Power Station, approximately 7%) (Lynch R, 2002). Electricity is transmitted by Eskom Transmission along high voltage networks and Eskom Distribution then distributes the electricity to Metropolitans, certain municipalities and also direct to the general public in rural areas and smaller towns.

Eskom Distribution regional offices capture engineering location and basic equipment data into Smallworld (GE Energy, 2006), which has been developed primarily for facilities management, and limited automated mapping purposes. The engineering data is replicated into Oracle manually on a daily basis where it can be linked to customer data, plant information (detailed equipment specifications) and fault management system databases for scheduling of outages and maintenance. Other applications currently in use are for the phone-in centre and for the plant department who monitor electrical performance on the networks. Although available and used in other countries, GIS analysis capabilities have not yet been implemented in Eskom as part of the Smallworld (GE Energy, 2006) package; and it can currently perform only very limited basic queries and no real spatial analysis which has been the general trend in the implementation of GIS in utilities worldwide (Meehan, 2005). This has resulted in substantial advances in technology such as Computer Assisted Design (CAD) and GIS applications not being realized as being fundamental to the needs of the business. Furthermore the Oracle database is not spatially enabled, which drastically limits the use of spatial analysis in any area of the business. Any request for this functionality has to be addressed through the implementation of an alternative GIS package at great expense, and huge amounts of data have to be converted from Smallworld (GE Energy, 2006) and Oracle into formats that are usable by a robust GIS. Obviously by the time any analysis is run, the data is already out of date.

As new functionality is developed for Smallworld (GE Energy, 2006), such as is currently being achieved to create schematic diagrams of the networks (Electricity Network Schematics (ENS)) and replacing the Supervisory Control and Data Acquisition (SCADA) system, changes have had to be made to data structures; as shortcomings are found in the existing structure. For instance, primary and secondary technologies on transformers were not captured and are now having to be added for over 50 000 transformers, and look up tables for cable and conductor types which are essential for planning have not yet been finalized and when they are, extensive work will have to be done in order to update over 109 000 sections of line already in the database. Adjustments needing to be made have a far-reaching effect in terms of data collection, capture and verification each time a problem is found, when instead an enterprise wide GIS data model should be created that incorporates all facets of the business.

To compound this issue, unlike many businesses who maintain data within the division it is created, all network and internal substation data is maintained only by the Land Development division. This means that where draughting staff previously needed to capture surveyed data into CAD drawings of each network for the purpose of printing maps, they are now required to capture all electrical equipment and attribute data into Smallworld (GE Energy, 2006) for use across the business. Differences in naming conventions of fields and the data itself between previously independent databases such as the equipment schematic databases and network drawings have also made data interoperability difficult.

Efficient business decisions can easily be made based on the output of an information system but only if data structures are sound, existing data has been verified and a sustainable process implemented for ongoing maintenance to ensure quality of the data used. Using GIS for electrification and network planning would completely revise current methods used and result in viable planning for network extensions where there is still currently spare capacity.

The promise of universal access for all to electricity by 2012 and subsequent subsidies by the government for free basic electricity means that all communities not yet electrified must now be considered for electrification. In 1994, the South African Government committed itself to promote access to basic electricity to improve health and help ease poverty, increase opportunities for business and improve living standards (DME, 1998). Between 1996 and 2001, an intense Electrification Program run by Eskom saw an increase in household access to electricity from 32% in 1996 to 70% in 2001 (Cassim et al, 2004), electrifying more than 2.8 million homes (UNEP, 2000), well in excess of the set target of 450 000 per year; and including a number of schools and clinics.

Rural electrification in South Africa was estimated to be approximately 51% by 2004 (WBCSD, 2006). Many of these connections included urban areas and borderline rural areas, and were also within reach of existing networks and capacities of substations, and these factors together with advances in the development of innovative technology meant that costs could be kept to a minimum (WBCSD, 2006). Most remaining rural settlements needing electrification are characterized by population growth, the need to find more grazing for livestock and availability of fuel in the form of natural vegetation (Van Der Post, 2004). Several acts and white papers released by parliament - such as the National Development Agency Act (Act 108 of 1998) and the White Paper on the Energy Policy of the Republic of South Africa 1998 (DME, 1998) have emphasized the need to improve service delivery, accountability, transparency and good governance. Planning is essential for effective long-term management of the electrification program in order to meet targets, optimize resource allocation and keep costs to a minimum.

However, while the customer base, costs and environmental requirements are increasing, supply is reaching capacity (Carter-Brown, 2004) and the network infrastructure is aging. Combined with this, the remaining households to be electrified with at least basic electricity are predominantly far off the existing grid and settled at low densities in mountainous areas. At this time a number of strengthening projects are being planned and implemented together with the building of new high voltage (HV) substations and, while Eskom reconsolidate on capacity, less electrification has been done in the past 12 months compared with previous years. Eskom CEO Thulani Gcabashe estimates that 65 000 MW of power will be needed by 2024 to meet the growing demand and stated that alternative sources of power were being researched (Creamer, 2006). Previous estimates were considerably lower as they were based on an expected growth rate of 4% (Creamer, 2006).

It is vital therefore that Eskom do more to conserve power for instance by identifying areas of electricity theft, misuse of electricity and renewable energy alternatives in order to source additional supply to continue with the electrification program. GIS could be used effectively to identify, target and monitor areas of concern for more intensive investigation and to assess the ongoing effectiveness of different marketing strategies.

To complete the electrification program by 2012, an alternate interim method for electrifying villages far off the existing grid is to use renewable energies such as hydro, nuclear and solar energy and, biomass fuels (Abdullah, 2005). In 2002, South Africa's energy-related carbon dioxide emissions were 377.6 million metric tons, which represent 1.5% of the world's output (Johnson, 2005), and is the highest in Africa. Coal reserves are only estimated to last a further 40 to 50 years at the current rate of extraction (Lynch R., 2002). South Africa, (although regarded as a developing country and excluded from censure), may need to start complying with the Kyoto Agreement as early as 2012 by reducing fossil fuel emissions (Gullberg *et al*, 2005); just as electrification targets of 100% are intended to be reached (NER, 2005). A combination of energy supply is often beneficial where there is extreme poverty; for instance solar cells for lighting and modern fuels such as paraffin for heating and cooking (Clark *et al*, 2002). Other practices include embedding small generators in a distribution network which improves efficiency, and net metering where customers can generate to and use electricity from the grid – paying (or being paid) for the net difference in consumption (Christensen *et al*, 2006).

The National Electricity Regulator (NER) is responsible for overseeing the electrification process and delivery of free basic electricity to all South Africans by 2012 (NER, 2005). To meet this target, it is vital that Eskom determines now exactly which areas it can electrify on the grid, and then meets with contractors currently working on off-grid electrification to allocate clearly demarcated areas to them for electrification until such time as those communities can be connected to the grid after 2012.

Electrification planning needs to seriously consider using both internal and external criteria in a more structured approach to prioritise areas for electrification. Working in reaction to demand from municipal managers and communities has led to overloaded networks and wastage in time and money as projects are planned, put aside due to others more urgent and then the original projects need to be replanned a year or so later due to changes both on the networks and on the ground (Bunge, 2005).

Electrification and network planning departments should identify areas for connection to the electricity grid, prioritise those areas according to factors such as nearest network capacity, size and household density of the area, number of schools, medical facilities, small businesses and agricultural concerns and determine the most optimal route to those areas. Recently the South African Government committed itself to poverty alleviation by advising that municipalities focus on the poorest areas within their boundaries and this requirement needs to be built into the electrification plan. Community participation with extensive information sharing, perhaps facilitated by an external party, has been found to be extremely beneficial to the success of any electrification project and should also be considered (Holland *et al*, Undated). In June 2003, at the South African Growth and Development Summit held in Johannesburg, electrification was listed as one of eight projects that have the most potential for job creation, mainly through the development of small enterprises (Mason, 2003, SARPN, 2005). Implementing a GIS could prove vital in terms of identifying and prioritising those areas for electrification.

Network planning is currently done by qualified electrical engineers who work off aerial photography and maps of an area usually on paper but sometimes as tables, in CAD or in GIS format. The engineers need to evaluate all factors available to plan a route from an existing network. Putting all the available information together manually is a slow process and when the project is sent for survey or environmental impact studies it can be returned for replanning due to relevant criteria being unintentionally overlooked.

This study attempts to use GIS to identify and prioritise the delivery of electricity to rural communities located close to the grid in KwaZulu-Natal. The study also focuses on analyzing the constraints to delivery of electricity to those areas to determine shortest paths.

1.2 Aim and Objectives

The aim of this study is to demonstrate the value of using GIS in a utility company in electrification and network planning taking the rural areas of KwaZulu-Natal as a case study.

The specific objectives for electrification planning will be to:

- Identify the areas that constitute rural KwaZulu-Natal
- Determine which parts of rural KwaZulu-Natal need electrification by excluding Ethekwini Metropolitan Municipality, current and planned electrification projects, nature reserves, and transformer zones
- Identify future rural electrification areas (FREA) by polygonising household positions and dissolving boundaries based on density values.
- Prioritise those FREA by use of a points and weighting system. (Based on the points allocation process formulated during the Namibia Electrification Master Planning exercise in 1999 and further enhanced for an Electrification Planning Model Tool developed between 2000 and 2003 for Eskom Distribution).
- Create a final list of FREA ordered on household density, the existence of schools and medical facilities, nearest network capacity, and distance from the nearest 22.00 kV substation.

The main objective for network planning will be to use spatial analysis techniques and apply constraints in terms of:

- Roads,
- Land cover,
- Households, and
- Slope;

to determine the shortest path to a central point or points within the three highest scoring FREA on the final list.

1.3 Structure of Thesis

Chapter 2 provides a literature review where the use of GIS in electricity utilities is discussed in more depth, with cases of the use of GIS for electrification planning and modeling. Examples are provided where GIS and cost weighting for route planning will be used to determine the shortest path.

Chapter 3 describes the materials and methods and includes a description of the study area, which is defined as the rural areas of KwaZulu-Natal. The materials (criteria and data) and methods used in this study are outlined. Methods include determining the study area, exclusions from the study area, determination of future rural electrification areas (FREA), prioritisation of those FREA by applying a points and weighting system and then short-listing FREA according to supply constraints. Finally, cost-weighted methods will be used to determine the shortest path from an Eskom network to a central point in three of the short-listed study sites, these being Mjila, Mqatsheni and Shayilanga / Kamlenze; and details and maps of these areas are included.

The results of the analyses for the case study area and each study site together with discussions of the results are in Chapter 4.

The conclusions of this study and the relevant recommendations are described in Chapter 5.

Chapter 2: Literature Review

2.1 Introduction

In countries such as the United States of America (USA), electricity and other utility companies compete for areas of supply and have therefore been forced to improve their use of Information Technology to support their business. The most significant realization is that it is not what technologies can do in isolation within a company that is important, but to look at what they can all do together (Juhl, 1998) in an enterprise wide system that shares information in a central database (Wilson, 1998, ESRI, 2006a). Such integration allows essential information about customers, assets, facilities, maintenance, and external information to be shared in an enterprise resource across different departments to ensure that management is informed, supply is optimized, equipment maintained, existing customers are better looked after and new customers can be aggressively targeted. In utility companies GIS is being used by some as a strategic technology that facilitates the integration of the entire business process relating to the delivery of electricity (Bush, 1999, Kumar *et al*, 2004).

GIS is an acronym for 'Geographic Information Systems'. This refers to a tool now used widely across many fields for comparing the spatial co-incidence of objects in order to support decision-making. It is important to understand that a GIS can do more than just retrieve data for a map – it can also produce new information by combining existing data. A 'working definition' of GIS is: *"A geographical information system is a group of procedures that provide data input, storage and retrieval, mapping and spatial analysis for both spatial and attribute data to support the decision-making activities of the organization"* (Grimshaw, 1996). Spatial analysis identifies patterns and the relationship between objects in space at the same point. Earlier spatial queries used topology to answer questions involving density and distribution of objects, network analysis, 2.5 and 3-dimensional analysis and spatial comparisons. The future could include 4-

dimensional analysis (analysis of change over time), virtual reality, internet interaction, and interoperability with other systems and data.

A GIS has the ability to overlay maps and ‘summarize’ coinciding features (Berry, 2004). For example, it is simple to run a query to identify where steep slopes with high rainfall, few people, within a temperature range and with a certain soil type exist in order to identify sites where a certain endangered plant might thrive, considerably reducing the research area and thereby saving costs. Added to this each requirement can be weighted according to its importance by experts in each field (Glasgow et al, 2004).

A GIS/GPS workshop was held to discuss applications and developments for planning, design, operation and management of electric utilities (EPRI, 1999) and it was found that while there are a number of automated applications that would be extremely useful, a significant number of those utilities present had not yet implemented them due to the risks involved in identifying the most suitable technology to use, the costs involved and identifying the benefits of such a system. Accuracy and quality of data collected and data structures were also found to be an issue and to move to an Electric Powerline data model such as that proposed by ESRI (Harder, 1999) that incorporates all processes from planning to maintenance and fault management, and which has been developed in consultation with many of its customers, would possibly - in some cases - involve recapturing all electrical data.

Due to the deadlines imposed by the South African Government of the year 2012 for access to basic electricity for all, there is no time to radically change data structures and recapture data. Using the current structures and data already collected within Eskom Distribution, existing information must be put together to formulate a plan for all outstanding electrification.

In KwaZulu-Natal planning is sometimes difficult due to the mountainous terrain and scattered nature of settlements. This is further complicated by the creation of 21 new municipalities in 2000 (now a total of 64), consideration of the requirements of traditional authorities and the pressures of complying with several new Acts such as the Public Finance Management Act, 1/1999 (DBSA, 2005). At the same time there are numerous instances of support in the form of programs for development and training of municipal staff, and plans at different levels for implementation of services all of which need to be synchronized. Benefits have been substantial for those communities that have been electrified (Banks *et al*, 2004) and it is feasible that delivery on rural electrification on a large scale would have a positive impact on the economic growth in South Africa overall.

2.2 GIS in Electricity Utilities

At Duke Energy, USA, the focus has been on better availability of data for staff and in 1997, it published its network plans on the company intranet. After basic training staff could access, download and analyze network data on their office PCs. This has grown to include other departmental databases, transportation networks, hydrologic features, demographics, electric generation facilities, electric grids and competitor networks. The next step for Duke Energy was to take GIS information out to the field – the vision was that building or maintenance changes would be redlined and downloaded to the engineering system via the Internet at the end of each day – thereby maintaining the as-built database live on a daily basis (Corbley, 2000). In March 2002, Duke Energy linked maps to individual work orders for display in the field on handheld tablets, with the added functionality of being updateable through redlining (Duke Energy, 2002).

In Bermuda, after Hurricane Fabian destroyed approximately half of Bermuda Electric Light Company Limited's (BELCO) 150 mainline circuits in 2003, they used GIS to organize the restoration of power within three weeks. To reduce data entry duplication, accurately model networks and to maintain customer and facility data needed for outage management, BELCO had already implemented a GIS to replace databases kept across the business. By then linking a GIS-based damage assessment tool designed by OneGIS Incorporated, they collected information on damaged poles, networks, and equipment; which assisted management in quickly demarcating and prioritising areas for the work teams.

The company has now purchased redlining software for field users in preparation for future disasters, to allow the GIS to be updated with notes from the field (ESRI, 2006a).

Burbank Water and Power in California is combining a field operating system in the field with GIS and wireless geodatabase connectivity, to ensure a paperless system of updating data (ESRI, 2003). Field workers can sketch in changes and additions to the data – such as making notes about a specific location, highlighting features perhaps where editing is needed, and mark the sites of damaged assets or conditions, using a digital pen. Redlining is saved as a layer into the geodatabase and quality checked through by engineers, who then update the relevant GIS layers.

The Public Service Company of New Mexico (PNM) was listed as one of the top five utilities leading the way to the 21st century (Bush, 1999) and has implemented a number of GIS applications across its company. Applications are continually being rolled out that shorten processes and further develop the information system to improve decision-making within the business. One of these applications is a 3-dimensional distribution substation design application which, due to equipment standardization agreements met with providers and the new application, has resulted in substation design being reduced from 3 months to an average of 3 hours. Another application in use at PNM is their Transmission Asset Management Information System (TAMIS), which was developed from a right-of-way application into a comprehensive operational asset management tool. Staff who find it useful include field personnel who can use it to access information such as to determine where maintenance is needed, environmental constraints and landowner restrictions, quickest routes in mountainous or difficult terrain, and also to procure the nearest equipment. In response to a query from the field, engineers can work on a solution in the office and get it back to the site electronically, enabling the work to be completed. PNM base their applications (developed using software tools from a number of companies) on a sound database and believe that investing in computer-based technology is contributing to moving the company forward (Bush, 1999)

PacifiCorp (based in Portland, Oregon, USA), is an electricity utility with 1.5 million customers who are currently using GIS through an internet-based system for outage management, daily outage reporting, load historian and power-quality monitoring, and have also tested internet-based planning software in a pilot study. Analysis tools include a viewing tool set up to dynamically colour-code substations according to peak transformer usage. Currently, only 50% of their substations are equipped with SCADA equipment or other automated methods of recording load, and therefore they have recently developed a Substation / Circuits History of Operational Loads (SCHOOL) which is envisaged to improve or even eliminate manual processes for load studies and forecasting primarily used for planning. Other studies for new applications include reliability improvements, equipment maintenance, and planning (Williams *et al*, 2003).

In India, the Info Tech Enterprise Limited in Hyderabad undertook to identify where theft of electricity was taking place – mainly on the Transmission and Distribution networks (Rajopadhyay *et al*, 2002). Up to 40% of all power generated was found to be unaccounted for and a detailed study of their system was essential. The first step was to link their GIS to the billing system and compare the total power given out by a substation with the total power billed to the customers – taking into account the normal technical losses. The results were then plotted in the GIS and any substation with abnormally high differences could be further investigated at station level. Also monitored were month to month readings – drastic variances were flagged for physical checks. A decision was also made to install electronic meters to certain customers to interface with the SCADA system – set up to monitor the load and detect possible tampering, which would instantly alert a team to investigate.

Electricité Du Liban (EDL) in Lebanon has modelled its electrical system infrastructure using GIS since 1993 (Geographic Information Systems Electricity of Lebanon (GISEL)) and recently enhanced it to identify network losses, caused predominantly by unsystematic network extensions and illegal connections. The new application has two levels, primary feed to distribution transformers to highlight which should be inspected, and distribution transformers to end customers, where billing is compared to actual usage. Teams can then be sent out to specific areas to disable illegal connections. The system is also now designed to assist with new connections and reinforcing existing connections. A network planner will enter electrical data such as the required new load, and a buffer distance in which to search for a power source. The application then runs a load flow analysis to calculate voltage drop for any number of scenarios, after which the planner chooses the best option and draws in the projected route. A report is then generated which includes a map of the site and network, and all calculated electrical factors. In addition, the application can offer recommendations for optimising line configuration by moving loads between networks and rerouting lines (ESRI, 2006a).

On August 14, 2003, midwest and northeast America, and Ontario Canada suffered one of the worst blackouts in history with over 50 million people affected – some for two days. The blackouts continued intermittently for a week before the grid was restored. Both governments investigated the causes and one of the principal origins was found to be the growth of trees onto the networks. (ESRI Energy Currents, 2004) This highlights one of the most important practices of an electricity utility to maintain quality supply - the need for regular line-clearing – management of which can be done using GIS. An example is the New York Power Authority (NYPA) who manage approximately 16 000 hectares of Right of Way (ROW) in their Integrated Vegetation Management (IVM) program which has now set a standard followed by the rest of the United States. Initially digital ortho-photos were used to verify and adjust records converted from paper maps and ROW limits were captured. Field crews then traced vegetation sites as polygons into the GIS using portable GIS and added attribute data from lookup tables built into the database.

The application can then run queries on request that will not only take into account ROW boundaries and vegetation, but data can also be analyzed in conjunction with wetlands, landowner data, issues and agreements, site access information, relevant legal documentation, security and dangerous tree trimming sites and generate work orders. The vegetation data also contains information such as cultural, physical, biological and chemical tactics used to control, for instance, tall growing tree species. Lower growing vegetation is encouraged. All maintenance and contract information is documented in the system and inspections are carried out a year ahead of schedule to ensure control. Implementing the system has also resulted in changes in processes such as a reduction in the use of herbicides, and a need to only clear parts of lines resulting in saving a significant amount in costs.

After using meter readers to capture the pole number of all transformers servicing customers, Allegheny Power in the USA 'connected' the data to their customer database for their Outage Management System (OMS) and found that they had an 80% connection rate – which they felt was inadequate (Newhouse *et al*, 2004). Initial errors found were data entry errors, which could be fixed using automated methods and this brought the match up to 88%. Further issues included blank or invalid pole numbers in the Customer Database, missing lines or transformers in either database, delays in maintenance of the data, and lack of support from the field staff. A team was assembled comprising technology and field staff, who then visited each Service Area to discuss non-connected customer issues. With the support of the entire business, especially from management, the connection rate was brought up to 98.97% (Newhouse *et al*, 2004).

To further increase the customer to network link percentage all new lines are now being designed in the GIS System and not in stand alone CAD drawings, constructors are communicating the transformer numbers directly to the administration department for entry into the system as soon as the new structure is built, and meter readers are now verifying transformer numbers. Customer analysis is being done by mapping information about customers – for instance occurrences of excess usage of electricity are targeted with energy saving marketing and in some countries utility companies are crediting customers for disruptions in service. By plotting customer data such as type of account, average electricity usage, and credit history patterns can be revealed that enable marketing staff to identify and target areas of concern more effectively (Bradbury, 2005).

Choosing the most appropriate technology for electricity networks can also be simplified by using GIS (Amador *et al*, 2005). In 1999, the Council for Scientific and Industrial Research (CSIR) developed the South African Renewable Energy Resource Database (SARERD). At a resolution of 1000 metres, SARERD contains layers of information such as biomass, wind and micro-hydropower possibilities across South Africa. The National Renewable Energy Laboratory (USA) developed a GIS System for the CSIR in South Africa – the Hybrid Optimization Model for Electric Renewables (HOMER) (CSIR, 2004). HOMER evaluates and models a range of both conventional and renewable energy technology options. In a joint initiative between the CSIR, Eskom, and the Department of Minerals and Energy (DME), data was extracted from SARERD and interfaced with HOMER to create HomerGIS. The proposed output is to suggest hybrid systems that could be implemented for villages far off the grid. In 2005, further data including income statistics, was collected and the tool developed to include the requirements of the Renewable Energy White Paper (DME, 2004) which sets a target of 4% of all electricity to be supplied by renewables by the year 2013 (ERC (Energy Resource Centre), 2004). The tool was completed in December, 2005 and has been sent to the CSIR, Eskom and the DME for use and evaluation by June 2006 in order to be officially launched later in 2006 (REN21, 2005). When available, it could be used to identify off-grid electrification areas which need to be contracted out as soon as possible.

Ideally asset management should not only record and track assets but also manage them in such a way that performance and reliability are improved resulting in cost savings. Layers should be added to a company's GIS to keep track of assets such as equipment, property records, customers, marketing and technology spatially. For instance in an electricity utility, if a query is run on grouping equipment by age, network reliability and efficiency can be improved when the life cycle of equipment is considered - instead of reacting when problems start, problems are avoided altogether by replacing (or at least more closely monitoring) assets whose life cycle is calculated to be over. Only by integrating all business data and applications spatially can utilities optimize the management of their assets (Kumar *et al*, 2004, Igbokwe *et al*, 2005).

2.3 Rural Electrification Planning

Electrification will not initiate development but it can stimulate and support development that is already taking place (Holland *et al*, undated). In their campaign for access to electricity, ABB Consulting (a company that specializes in distribution information systems) joined forces with WWF in a pilot program to measure that electrification supports development in Ngarambe, Tanzania. Positive results include night classes held at the local school with an increase in the number of pupils, the installation of a water pump in the centre of the village saving time in the daily collection of water, plans to build a sawmill, and cheaper and cleaner electricity and the number of connections and improvements to the village since electrification have been measured (WBCSD, 2005).

A 20-year electrification plan has been developed for the Kingdom of Bhutan, situated in the eastern Himalayas, where approximately 75% of rural households still needed to be electrified (Tshering, 2005). Bhutan is mountainous and villages are described as isolated and scattered, and, as the area was one of the highest consumers of firewood, it was felt that electrification was important to reduce greenhouse gas emissions and soil erosion. Also important were the benefits to socio-economic development, less dependence on imported fossil fuels and minimizing rural to urban migration. (Tshering, 2005, Appleyard, 2005)

Alternatives considered for rural electrification included on-grid extension, and off-grid renewable energy options such as small-scale hydro, solar photovoltaic, bio-fuels (produced by energy plants such as maize, sugarcane and soya), and wind (DME, 2006). GIS was used to identify details of non-electrified villages and further to identify which should be on-grid (88%) and which off-grid (12%).

In Cambodia, Lao PDR and Vietnam, a rural electrification project was initiated in June 2003 to examine current planning tools and methods that mainly limit themselves to technical and economic issues and expansion of the existing networks. The intention was to overlay local development and related infrastructure using GIS so that planners would be more informed as to available options, and thereby make better decisions for planning. Results from three different case studies done in each country were compared and decisions made to first structure a comprehensive database for rural electrification that includes national census data, existing and planned data for roads, agriculture, health and education, and also energy-related data, including existing networks, and potential and existing renewable energy sources. A decision was also made to strengthen the existing GIS capacities of staff. The first version of a GIS tool (REDEO 1.0) is now operational and compares the electrification of village points from four potential sources, including diesel gensets, biomass installations, hydropower turbines and the existing networks. Future development on the GIS tool will enable the planner to compare features and costs of available technologies in terms of production, transport and distribution (REDEO, 2004).

The Sahel, a region in Senegal, has a population of around ten million of which approximately 55% live in rural areas. Only 8% of those rural areas have been electrified. The Agence Sénégalaise d'Electrification Rurale (ASER) is using GIS for planning electrification projects in the hope that it will accelerate electrification to achieve a target of 70% in the next 15 years (Baumann, 2003). Initially, 18 electrification districts were demarcated and 3 selected for pilot studies in order to develop an appropriate electrification model. Data standards, modeling, analysis, and visualization capabilities are being built into the system for running the projects and easy access to information by management.

ASER states that all constraints and demands on the electricity grid need to be assessed in conjunction with one another, making the use of GIS ideal. Data on issues such as number of village inhabitants, proximity to the grid, infrastructure, assessment of demand and relative wealth of the village is being collected. Once combined with technical and economical data, the type of connections and a schedule for implementation would be determined. It is also felt that electrification planned in consultation with the villagers, will greatly contribute to reducing poverty levels, improve communication and stem migration to more affluent areas (Baumann, 2003).

Up until 2002, electricity reform programs in India focused on installing meters, reducing subsidies, unbundling supply, and privatisation of electricity generation and distribution. However, in 2002, senior officials from the Departments of Energy and of Rural Development colluded to develop a new joint approach which would be consumer-based and decentralized. Participatory Rural Energy Services for Karnataka (PRESK) was a pilot program for this initiative that worked closely with village councils and farmers, and addressed rural electrification together with improvements in farm management, ground water depletion issues and other aspects of rural development and GIS was used to integrate data and identify areas of concern. The pilot program was then transferred to a reconstituted Mahatma Ghandi Regional Institute for Rural Energy Development and was expected to be central to the operation of its overall program in 2005 (USAID SARI, 2004).

One of the outcomes of the pilot study was that working together on co-management and planning of energy, water and agriculture was extremely productive – these three services are irrevocably interlinked as one third of India’s electricity is dedicated to pumping water from the ground water supply for agriculture. Other departments such as Forestry and Health are now being considered for integration into the project to provide a bigger picture of the problems facing rural electrification.

Another outcome was the importance of interaction and sharing of information between PRESK and rural communities. Resource Centres and a website were set up as sources of information and a basic understanding of electricity supply and customer needs assisted the farmers and electrification planners in making decisions. Informative and motivational films, videos and booklets were distributed, and lectures and training courses were run at the Resource Centre (USAID SARI, 2004). Public participation in rural planning initiatives including electrification has proven successful where instituted and serves to empower communities as they take control over their future. This includes the establishment of energy service businesses and independent co-operatives to supply an array of energy resources such as paraffin, solar power, revenue collection and includes customer education (Banks *et al*, 2004 b, Ilskog *et al*, 2005).

In developing countries there is a high backlog of rural electrification and in Africa, there are currently a number of ongoing initiatives investigating the use of GIS to accelerate and manage electrification projects. Burkina Faso, Cameroon, Mali and Niger have recently joined forces with partners from France, the Netherlands, and the Ivory Coast in order to develop a GIS for their rural electrification programs, the aim being to promote sustainable development and poverty reduction. Each country will work on a pilot area and identify areas with development potential in order to create a priority list for electrification (UNEP, 2005).

In South Africa, the District Information Management System (DIMS™) Tool was created by Intermap for Uthungulu District Municipality for the identification and prioritization of their water projects in rural areas (Intermap, 2005, De Laborde, 2005). DIMS™ is a tool that interfaces with existing systems over the internet and provides step by step information to users to easily enter data and extract reports and the same principles could be used to develop a similar tool for planning of other services such as electricity to rural areas.

Village boundaries were created from Eskom household data (which Intermap updated), and, with the help of consultants and local leaders, improved it further by confirming the village outlines and making adjustments where necessary – and this formed a base map for prioritization. Data was collected on each village in terms of the current water supply and this was combined with data relating to disease areas (such as malaria), population density and other criteria relating to the need for access to water and costs were calculated per village. An algorithm was then applied to the villages and a prioritization number allocated to each village within the Uthungulu District Municipality. Taking into account the projected annual water budget for the next 5 years, projects were assigned a number (1 to 5) which would denote which year the project would take place. Clusters of projects were reviewed and their allocation changed manually to make them coincident. Any change to a criterion would result in the model being rerun and results displayed immediately.

Currently DIMS™ is accessible over the internet to registered users in a complete Management System from planning to completion of building the asset (water project). A contractor working on a project is allocated a password and can access his project in order to update progress and add step-by-step details. Only when certain details are updated, is the contractor paid. Any manager can easily extract reports, graphs and maps on the progress of any project or see overall progress at any stage of the financial year. Changes in budgeting and prices or in any other data can be made to the data when they happen - which will immediately cascade through the system and be evident in the reports. In this way, the system is extremely dynamic, and at any time during a financial year progress can be checked and monitored. (Intermap, 2005)

DIMS™ is a worthy example of how GIS can be used to implement a system for overall management of a business. Managers do not need to be GIS experts and are therefore not intimidated by the system and, as the onus is on contractors to enter details of their progress, this alleviates the need for the company to continually monitor progress of all its projects.

In 2005, the Provincial Government Information Technology Council commissioned the development of a GIS for each province, (in the Office of the Premier) in order to monitor poverty, growth and development, to understand which areas need services and to support decision making on the allocation of resources to have maximum impact (KZN, 2005). The GIS has already been used to map poverty by overlaying the lack of services, income level, and the incidence of HIV and AIDS and preliminary results are being used to prioritise service provision. The GIS, now known as the ‘Nerve Centre’ of each province, is set up next door to parliament in KZN, where members of the executive committee and other officials can now adjourn to an interactive viewing room whenever necessary in order to clearly visualize issues under discussion. At this stage, there are no plans to use the GIS to co-ordinate or collect data on future planning between service providers, although this may be considered at a later stage (Office of the Premier, KZN, 2006).

In Eskom, the process of electrification starts in Electrification Planning with the identification of projects and preliminary planning in conjunction with the relevant municipality; and then goes through Network Services (design, costing, ordering of materials and survey), Commercial (procurement – tender document compilation and approval process), Capital Program (materials purchased, construction done and as-built drawings submitted) and Field Services (commissioning and adding customers to the customer database) before a customer is connected (Burt, 2005). Each department uses any number of external resources. Keeping records within each department is time consuming and monitoring overall progress at any time is complex. Meetings are also held weekly by management with all role players and management to check progress of all projects and discuss problems and issues.

Implementing a GIS for planning purposes was first addressed in 1996 when the Department of Housing and Local Government and Eskom worked with MegaSub Nadia Pty (LTD) to collect data for the Housing and Electrification Program (HELP) in KwaZulu-Natal. This data included the positions of households, villages, schools, medical facilities, and police stations and was intended to be used in conjunction with network data for more effective spatial planning of rural electrification and also as a basis for developing a 5 year forecast model to assist with making valid business decisions for electrification. Planning departments within Eskom Distribution Eastern Region have long realized the potential benefit of using GIS but struggled to put it into operation due to constraints imposed by the National Office, a lack of GIS expertise, and data compatibility and maintenance issues.

An electrification planning model was developed by Rural Area Power Solutions (RAPS), in conjunction with a number of partners between 2000 and 2003, on behalf of the Department of Minerals and Energy, Eskom and the Development Bank of South Africa (DBSA) (Banks, 2000). Based on a point allocation system, the model uses the HELP data and the aim is to prioritise electrification projects by identifying grid and off-grid areas, and assess financial costing and load estimates (Banks *et al*, 2000). A base score for each village is calculated by adding points together as allocated from a look-up table and that score is then modified by applying weighting factors.

When implemented in 2000, households, medical facilities, schools (primary, secondary and tertiary), and police stations were part of the model. In 2002, the Nuon-RAPS Utility researched KwaZulu-Natal to find sites suitable for off-grid electrification and used this tool. However, one of their findings was that the settlement patterns in KwaZulu-Natal were such that the Electrification model developed by RAPS could not be used for Electrification purposes without extensive further modification (Banks *et al*, 2004a).

Towards the end of 2005, a small group of representatives from Information Management, Land Development and the Electrification and Network Planning Departments formed a GIS Initiative Group in Eastern Region. Frustrated by the unsuccessful implementation of various GIS initiatives started previously from a national level, and realizing the potential benefits of a successful GIS, their intention is initially to support and drive the use of GIS for planning purposes in Eskom's Eastern Region (which incorporates KwaZulu-Natal and parts of the Eastern Cape, Mpumalanga and the Freestate).

A tool was recently developed that uses network data and household points overlaid on aerial photography to identify and record electrification areas. An electrification planner can draw in an electrification polygon, which is then allocated an id number and written to the database. It was quickly realized that the household point data being used was now ten years out of date and could not be used to give reliable results. As very little funding had been allocated to

Eastern Region for its maintenance, the Network Planning Manager allocated funds from his budget to recapture the household data for Umhlabuyalingana Municipality as a pilot project. It was hoped that the contrast between new and old data would make clear the need to recapture all the HELP data as soon as possible. The pilot project was finished early in 2006 and the household count in that area had increased by over 70% when compared with the households digitized in 1996. This led to the allocation of funds and the recapture of household data for the entire region, which was found on completion, to have doubled overall.

2.4 Network Planning

In order to determine the shortest path for a new electricity network, a number of factors are usually taken into consideration. Common concerns are gradient or slope, land usage, roads, households and other requirements may include a need to site a line so that it is not visible from certain areas (Berry, 2005). All these requirements can be considered by using printouts of maps and aerial photographs and working between them to determine the shortest path. The more factors considered, the longer it would take to evaluate the maps and determine the shortest path manually. Electricity utilities and other route planners are therefore turning more and more to using GIS as an effective alternative (Williams *et al*, 2003, Glasgow et al, 2004).

Using GIS a model can be created to overlay any number of requirements into one multi-criteria map which is created and reclassified with relevant scores which are then joined together spatially using a mathematical operator. In the case of an electrical network, ideally the best route would run along the least slope, avoid forests, wetlands and other ecologically sensitive areas, be routed near to roads and avoid households, while going near to densely populated areas in order to supply them with electricity. In the GIS model these criteria would have zero points allocated while ecologically sensitive areas or steep slopes would be allocated the highest points. Planners, engineers and environmental scientists need to determine a standard points system for each layer in such a model (Glasgow et al, 2004). Points could then be allocated to the pixels in each layer according to such a system, the layers overlaid and the points added together. Where the resultant combined suitability raster has pixels with a combined rating equal or near to zero, this will identify the best path for an extension or new network.

The Electrical Power Research Institute (EPRI) is working on a GIS tool for Georgia Transmission Corporation (GTC), that overlays satellite imagery with layers of GIS datasets. The tool, developed in consultation with engineers, and professionals from historic and regional planning, community development, homeowner organizations and natural scientists; largely looks for corridors for placement of transmission lines that consider housing, wetlands, and cultural, ecological, topographical and physical features. In January 2004, engineers and scientific experts from 10 Utility companies met to discuss the tool and agreed that its methodology was sound and far exceeded current practices. Most were also interested in a macro corridor analysis technique whereby corridors identified could be further enhanced by the collection of more detailed data – for instance buildings were weighted equally in the tool and it was found that the differences between residential, commercial and industrial areas needed to be distinguished for weighting purposes. Overall though, such a tool still depends on the skill and expertise of professionals who design and use it (Glasgow *et al*, 2004).

In the USA, it has become difficult to plan routes for roads that are in compliance with various acts and to also satisfy the requirements of all stakeholders concerned. Transportation Corridor Agencies (TCA) has developed a tool that accesses the data held within a GIS and this has resulted in reducing planning time through use of 3D models and templates, and builds in costs for easy calculation of different scenarios. The tool was first developed in 2002 after two years of planning alternative routes for a 16km stretch of toll road, TCA were no closer to agreement between the different stakeholders. The tool converts the Digital Terrain Model (DTM) into a database and integrates that with data such as habitat areas, geology, cultural resources, rivers, stream, road, rail, urban areas, land-ownership, utilities, floodplains, etc. The tool considers issues such as avoidance of wetlands, cultural resources and other key environmental issues; and incorporates Engineering Standards such as minimum horizontal and vertical curve radii and maximum slope, as well as costs for excavation and structures. Consensus on the route corridor defined after running the program was relatively quick when it was realized that all possible criteria and constraints had been considered. The use of this tool saved an estimated further 6 to 12 months in planning, reduced impact to wetlands and sensitive species, reduced landslide risks, minimized impact on existing utilities and cut forecast construction costs by $100 million and is now being successfully applied on further road and rail projects (Bettes, undated).

The North American Electric Reliability Council (NERC) is now using GIS to define the shortest practical path for planning new routes. Although GIS had been implemented, it was still seen by many as a visual aid to automate map production and GIS was used to locate features and produce preferred options to the public on maps or plots. The merits of an integrated spatial analytical system were largely ignored. NERC has now taken this a step further by developing a methodology based on GIS (Analytical Minimum Impedance Surface (AMIS)) that overlays all issues, such as physical, environmental and socio-economic factors, into one raster 'decision landscape'. Standards for weighting those issues were agreed upon by a number of professionals over a period of 6 months. In its first release, AMIS was used to create optimal corridors with comparisons between scores to assist in choosing the best path for a new network. The system has allowed for a more standardized approach which is transparent to the public and flexible to allow the addition of further data should it be required (Bailey *et al*, 2005).

Uganda has committed itself to long-term electricity planning with the establishment of a rural electrification fund, agency and board. On-grid electrification in rural areas is currently 2% and the aim is to increase that to 10% (400 000 new consumers) by 2012. A master plan is being drawn up to discern between on and off grid electrification, analyze and prioritise projects in terms of a cost / benefit analysis and to select technology to suit each set of conditions. GIS will be used to identify ‘energy demand centres’ such as schools, medical facilities, village trading centres and small business enterprises, and also to compare demand (such as census information) and supply (costs, renewable energy options) issues in order to create a priority list. Planning is envisaged to follow roads, especially in rural areas, and densely populated areas far off the grid will be considered as suitable for off-grid electrification (Kaijuka, 2006).

In 2004, AgileWorks PTY (LTD), South Africa, developed an Electrification Modeling Tool based on the RAPS scoring, but also incorporating an affordability ‘budget’ according to the possible income they could generate (based on village size, density and income levels) - which indicates whether the village can ‘afford’ to be connected. Again, the main aim is to simplify high level planning of electrification and after identifying suitable rural villages it then defines how these villages could be connected spatially and in which order. Delauney Triangles and weighted Minimal Spanning Tree Algorithms are used to connect villages to existing networks. Villages are prioritised, costs applied and estimates calculated for the new networks (AgileWorks, 2005). The tool requires village centroids, and unlike other regions, Eastern Region has collected individual household points and now need to polygonize that data before it can be used. Based on the results in this study, it has now been decided to use voronoi polygons to polygonize the new household data and thereby identify settlements in order to test the tool developed by AgileWorks PTY (LTD) by the end of August, 2006.

Even though the intention is for this tool to be used at a high level, once figures have been calculated there may be a tendency by some planners and management to adopt them as fairly accurate estimates. Criteria such as roads, slope and land cover are not taken into consideration in this model which results in straight lines from the network and between villages. Disregarding these criteria could result in cost estimates being unrealistically low and questioned when more detailed planning is done and costs increase.

GIS simplifies the comparison of any number of different network planning concerns such as the position of roads and households, and environmental issues. Currently the network planners work manually, using maps and ortho-photos in order to design routes for network extensions. Three areas (later identified in this study as Mjila, Mqatsheni and Shayilanga / Kamlenze) will be chosen from the final list of electrification areas in order to demonstrate how GIS can be applied in planning an extension from the nearest network to the schools within those areas.

2.5 Summary

From the literature reviewed in this chapter, it can be seen that using GIS in utilities is becoming a practical option worldwide. In addition to AM/FM, utilities in many countries are now integrating databases and using the analytical capabilities of GIS for a range of applications such as using redlining to update or amend data in the field, managing the restoration of power on a large scale after a natural disaster, asset management, finding and removing illegal connections, vegetation management, customer administration, as well as electrification and network planning.

In South Africa, the government has set a target date of 2012 for a universal access plan (UAP) to be completed, supplying every household with at least a basic level of electricity. This is defined as the amount of electricity sufficient to provide basic services to a household and includes basic lighting, media access, water heating and ironing on grid or basic lighting and media access for a non-grid system (Eskom Distribution, 2005). Currently most areas for electrification are in rural areas and are being identified by municipal managers and communities who request connection to the grid. Time is often wasted in planning those connections only to discover that nearby networks already have too many customers or that the area is too far from an existing network, and plans are then put aside.

GIS tools have been partially developed to assist with both electrification and network planning, and it is vital that those tools are now enhanced and implemented. In KwaZulu-Natal, one of the restrictions to implementation has been in the availability of a village dataset, difficult to create due to the scattered nature of the settlements in the province. It is important that all areas for electrification be identified and prioritised as soon as possible in order to build the UAP for electrification. Using a GIS to do this will adopt a standard approach that can consider issues of both supply and demand. The planning of networks to those electrification areas can also be done using GIS to replace the current manual process to overlay and calculate the shortest path between a network and community by taking all relevant issues into consideration.

Chapter 3: Materials and Methods

3.1 Introduction

In order to demonstrate how GIS can be used in electrification planning, the full extent of the rural areas of KwaZulu-Natal as determined by the Demarcation Board will be refined by excluding Ethekwini Metropolitan Municipality, reserves, current electrification projects, and transformer 'zones' (estimated to be 550 metres from existing transformers.) Household positions from 1996 will be polygonised and grouped to identify areas where the density is greater than 30 households per square kilometer, and the RAPS scoring applied to those areas to identify areas where demand is highest. To prioritise the list from a supply perspective, the initial list will only contain areas within the required distance of a substation, in descending order of household density, containing one or more schools and within 2 kilometres of the existing electricity grid. Once those areas have been electrified, the next pass should remove a criterion such as the presence of a school, or change another, for instance increasing the distance from the grid to 5 kilometres and the process repeated until all areas have been prioritized for electrification.

A planned approach to electrification and network planning must be developed that considers the needs of the people in the rural areas of KwaZulu-Natal in conjunction with Eskom's ability to address those needs. GIS can be used to develop such a process that identifies and prioritises rural areas that need electrification, and then further to that, plans the most optimal route from the electricity grid to those areas allowing for a far more stable system.

The materials needed for this study and the methods used for analysis are described below.

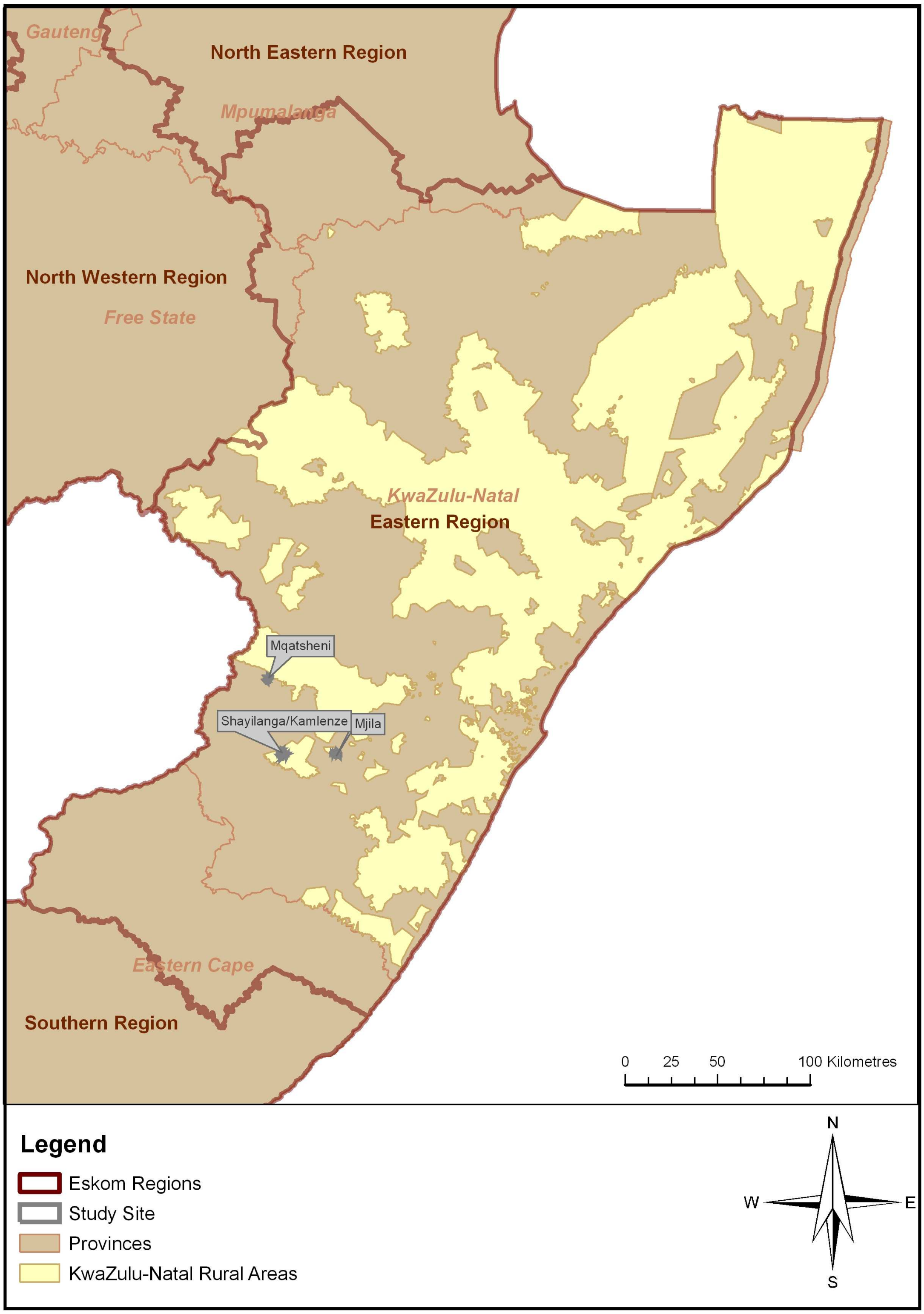
3.2 Case Study Area: Rural Areas requiring electrification

Access to electricity has been identified as one of three main indicators of poverty and basic needs within communities, and in rural areas with no access to electricity, forest biomass fuels are the main source of energy for cooking, lighting, boiling water and heating for most households. (Sepp, 2002) Time spent on collecting firewood and other fuels has an adverse economic affect as less time can be spent on developing agricultural and small-scale businesses. Overall there is a shortage of forest biomass fuels in most parts of South Africa and deforestation in some areas has led to ecological damage such as erosion and decreasing biodiversity. Another important issue is the serious health problems caused by indoor pollution from the various types of wood fuel used.

Electrification and network planning is compounded by the settlement patterns of its people in rural areas of KwaZulu-Natal scattered over the predominantly mountainous terrain rather than close together in definite settlements. Current methods of prioritising areas for electrification allow for political interference as municipal managers are relied on to give details of their electrification needs, and as each municipal manager is naturally biased in terms of his or her municipality, it is proving difficult to prioritise those needs fairly. Economic viability of projects can no longer be considered of prime importance as in the past as all areas now need to be considered for electrification on a social basis (Gaunt, 2005). There is a struggle to meet the constant current demand and priorities change often, causing time to be wasted in planning projects that are postponed and reshuffled and then have to be replanned at a later stage (Bunge, 2005).

The boundaries of rural areas in KwaZulu-Natal were determined to define the outline of the study area (See Map 3.1) where it is estimated that electrification of households is only 51% complete (WBCSD, 2006). As the study concentrates on electrification in rural areas, those that are electrified or being electrified, urban, or within a reserve, need to be excluded to create the case study area.

Within the case study area clusters of households must be identified that can be electrified. A scoring system applied to those household clusters prioritises them for electrification and from that list, a further selection process follows to determine a list of electrification areas that could be planned for electrification immediately.



Map 3.1: Case Study Area: Rural Areas of KwaZulu-Natal showing approximate positions of the case study sites: Mjila, Mqatsheni and Shayilanga / Kamlenze

3.3 Materials

The data used in this study relate directly to the criteria (or constraints) applied in electrification and network planning. The data was available in GIS format and include the list shown in table 3.1.

Table 3.1: List of Data used in the study

Description	***Format***	***Year***
Rural areas of KwaZulu-Natal	ReGIS *.fea file	1996
Ethekwini Metropolitan Municipality boundary	Shape File	2005
Current electrification projects	Shape file	2005
Nature Reserves	Shape file	2005
Eskom medium voltage (MV) stations	Shape file	2005
Eskom transformers (link to Eskom medium voltage (MV) stations)	Spreadsheet extracted from Oracle	2005
Eskom customers (calculate count of current customers per transformer)	Spreadsheet extracted from Oracle	2005
Housing and electrification program (HELP) data – household positions	Shape file	1996
Schools	Shape file	2001
Medical facilities	Shape file	2005
Eskom medium voltage (MV) networks	Shape file	2005
Roads	Shape file	2000
Land cover	Shape file	2000
DEM	ASCII file	2005

3.3.1 Rural Areas of KwaZulu-Natal

The electoral area boundary dataset was created using ReGIS and AutoDesk World and defined in a joint project by the Demarcation Board, Africon, and the Department of Land Affairs in 1996 for the 1999 elections in South Africa and was used as a basis to create a set for the rural areas of KwaZulu-Natal. The vector polygons were divided into 4 categories – informal rural and urban (boundaries captured by contractors) and formal urban and rural (as derived from cadastral boundaries). The rural informal polygons are needed to define rural areas in KwaZulu-Natal.

3.3.2 Ethekwini Metropolitan Municipality

Ethekwini Metropolitan Municipality Electricity Department is responsible for the distribution of electricity within the metro boundary and the area defined by the boundary of Ethekwini Metropolitan Municipality needs to be excluded from the study area. The boundary was obtained in shape file format from the municipality dataset supplied with the Census 2001 data from STATSSA.

3.3.3 Current Electrification Projects

Electrification project areas are currently maintained in MicroStation by each Field Service Area (FSA) drawing office in Eskom Distribution. However, due to the pressure of other priorities such as data maintenance of networks, not all the drawings are current or accurate. However, for the purpose of this study, this data will be used to exclude the boundaries of 335 complete, current and planned electrification projects defined in the drawing files as these areas need to be excluded from the study area.

3.3.4 Nature Reserves

Nature reserve boundaries were obtained from the Department of Traditional and Local Government Affairs. Nature reserves were excluded from the study area as they are protected areas in terms of the National Environmental Management: Protected Areas Act (Act 57 of 2003) and no development or construction may take place in a protected area without prior permission from the management of that nature reserve. These areas should therefore be avoided wherever possible.

3.3.5 Transformer Zones

Current customers must be excluded from the case study area but only approximately 40% of the more recent customer data stored in Oracle has a reliable spatial context. Ninety percent of customers fall within 550 metres of a transformer (Eskom Distribution, 2000) and this measure was used to create a transformer zone where it was assumed that all households that fell within the zone were already electrified.

In Smallworld (GE Energy, 2006), transformers are part of an "internal world" – which means that their geographic location is defined by the pole that they are attached to. To define transformer zones, transformers (extracted from Oracle with customer counts as a spreadsheet and exported to a dBase table) were linked to the station positions (extracted from Smallworld (GE Energy, 2006) as a shape file).

However, stations contain mainly one or more switches, or a transformer or both. In an attempt to isolate stations with customers, the station data was linked to the customer data and all stations with a customer count greater than 1 were extracted - this resulted in 40940 out of 89998 stations being selected. On closer inspection, it was found that there was no relative value in the customer spreadsheet for some of the stations where there should have been and they had not been selected. Therefore, it was decided to rather select all stations of the type 'Pole Mounted Transformer Bays' as they do contain transformers for the purpose of supplying customers – this resulted in 49161 out of 89998 stations being selected – and the latter result was used for this study.

These stations were then buffered by 550 metres to create transformer zones which must be excluded from the case study area to exclude current customers.

3.3.6 Household positions

In the past electrification planning has focused on areas where the household density is over 70 households per square kilometre and an important factor taken into account has been the costs of connection (Carter-Brown, 2004). As many of those areas are now electrified, that position has recently been re-evaluated and densities over 30 households per square kilometre are now being prioritised for electrification and importantly, as all households need to be electrified by 2012 (SA Government, 2004), cost can no longer be regarded as being of prime consideration when prioritising electrification.

The HELP data was collected in 1996 and stored in shape file format in order to assist the Department of Local Government and Housing and Eskom in planning services to rural areas. Household positions are vital to this study as they are needed for the following reasons:

- To identify rural electrification areas inside the case study area based on the relative density of those households.
- For prioritization of rural electrification areas. A count must be done for each polygon.
- To identify areas where groupings are over the most recent definition of suitability for on-grid electrification which is a density of 30 households per square kilometer.

3.3.7 Schools and Medical Facilities

The schools dataset released in 2000 in shape file format with SA Explorer (Demarcation Board, 2005) was used. The most recent medical facility dataset, also in shape file format, was sourced from the Department of Health in 2005.

During the electrification drive schools and medical facilities were considered a priority and providing electricity to these vital services has continued to be the focus in the past few years. Schools and medical facilities were considered at two stages:

- Points were allocated to schools and health facilities that fell within FREA and added to the total points scored by each FREA.

- Rural electrification areas that contain schools or medical facilities were given a higher priority.

3.3.8 Medium Voltage Substations

Eskom Distribution distributes energy from high and medium voltage substations through medium voltage networks predominantly to the general public, farms and industry. The main criterion to be considered here for distribution of power from a substation containing a transformer where the secondary voltage is 22.00 kV, is that it not be distributed for more than 30 kilometres from that substation (or 15 kilometres from a substation containing an 11.00 kV transformer). The positions of those 22.00 kV substations were extracted from Smallworld (GE Energy, 2006) in shape file format and buffered to identify the limit of the area where network extensions can take place.

3.3.9 Medium Voltage Networks

The most important measure to be considered here is that the total number of customers per network should not exceed 3000 connections and this total needs to be calculated for each network. To determine which networks can be extended to new customers the following was done:

- All medium voltage networks were extracted from Smallworld (GE Energy, 2006) in shape file format as lines and then dissolved on the Standard Label field (network name) to create networks.
- Customer data was extracted from Oracle and a count done of number of customers per transformer.
- A spatial join between stations (transformers) and networks summed the customer count per network.

3.3.10 Roads

In many cases electricity networks are planned along roads as, for instance, constraints such as slope and environmental issues have already been considered during route planning for the road and vegetation will have been cleared during its construction. In addition, roads are needed to transport equipment and ease access for line monitoring and maintenance (Eskom Distribution, 2003). Roads data is therefore needed for network planning to extend the grid to new electrification areas, and the dataset captured by the Directorate of Surveys and Mapping in the Department of Land Affairs was obtained in Microstation format for analysis in this study.

3.3.11 Land cover

Land cover is used to determine the costs of clearing areas of dense vegetation and to consider environmental concerns, for instance to avoid indigenous forests or water bodies. The land cover dataset released in 2000 by the CSIR was used to identify land cover in and around study sites so that an optimal route can be designed.

3.3.12 Digital Elevation Model (DEM)

Building a new line straight to a customer down a very steep slope could cost more than if a longer route is taken at a gentler slope. DEM data obtained by Eskom in point (ASCII) format from the Directorate of Surveys and Mapping in the Department of Land Affairs was converted to a TIN for each study site and a slope dataset derived for consideration in identifying the most effective route from a network to a FREA.

3.4 Methods

Identifying and prioritising rural areas for electrification requires a systematic approach in order to arrive at a reliable result which depends not only on the availability of relevant data, but also on the methods used. This section describes the analytical methods used for electrification and network planning.

3.4.1 Defining Rural KwaZulu-Natal

The boundaries of the 1996 informal rural enumerator areas in vector polygons were dissolved to create polygons of rural areas which together formed the basic case study area.

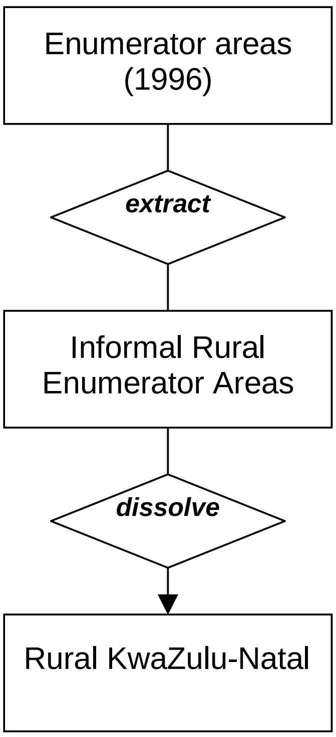


Figure 3.1: Definition of Case Study Area: Rural KwaZulu-Natal

3.4.2 Rural areas requiring electrification

As Eskom is not responsible for the distribution of power to any households within Ethekwini Metropolitan Municipality, and only to the metro itself, Ethekwini Metropolitan Municipality was excluded from the case study area. Existing and already planned rural electrification project areas were excluded from the case study area. Nature reserves were excluded from the case study area as protected areas should be avoided wherever possible. Lastly, as the assumption can be made that 90% of customers are within 550m of a transformer (Eskom Distribution, 2000); households within those 'transformer zones' were excluded as being already electrified. Medium voltage (MV) stations with transformers were buffered by 550 metres to create a transformer zone for each MV station. Excluding all of these areas determined the final overall case study area.

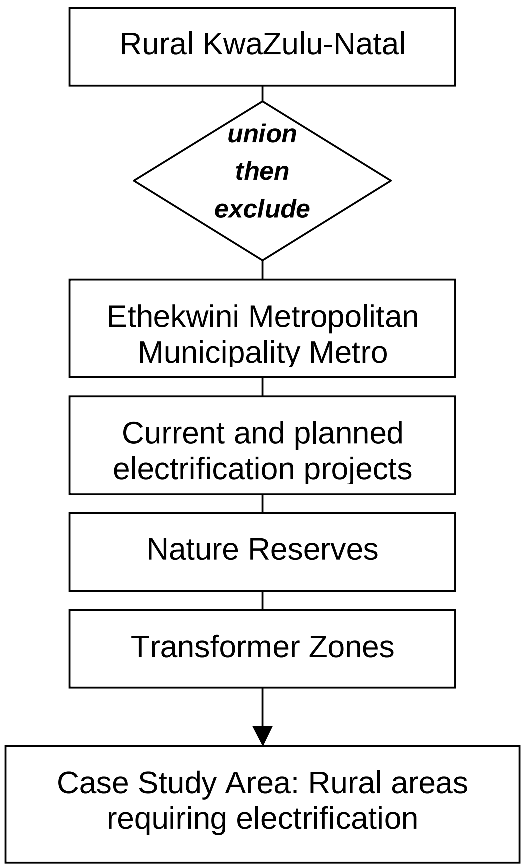


Figure 3.2: Definition of Case Study Area: Rural Areas requiring Electrification

3.4.3 Identification of FREA

To identify rural electrification areas, clusters of households were identified within the case study area by polygonising the case study area using Voronoi Polygons. (Ahmed, 2005) Voronoi polygons assume the sphere of 'influence' of a point to be half-way between itself and the next point, and so doing can build up logical polygons around point data (ESRI, 2004).

Households clustered with a density of less than 30 households per square kilometre are currently considered to be suitable for off-grid electrification and therefore only those FREA with a density of over 30 households per square kilometre were considered. The figure of 30 households per square kilometre can be substituted by instead identifying polygons or 'properties' of 3.3 hectares or less as being suitable for electrification and merging those 'properties' to create FREA (30 households per square kilometre equates to 1 household occupying 3.3 hectares). These are informal settlements of people and there are no actual boundaries demarcating properties.

- Voronoi polygons were created from the household point data using ArcView GIS 3.3 (ESRI, 2006b) (see example in Map 3.2).
- The process creates raster polygons which were converted to vector polygons and clipped to the study area boundary determined in 3.4.2 above. A pixel size of 50 metres was used.
- In ArcMap 8.2 (ESRI, 2006b), an area calculation and household count was achieved for each polygon, and then the area divided by the number of households to calculate an average area. (If two or more household points had the same density, then one voronoi polygon was created and the areas for these polygons had to be divided by the number of households they contained in order to calculate an average area per household.)
- Rural FREA were created by dissolving all voronoi polygons with an area calculation less than 3.3 hectares.

Figure 3.3 demonstrates the steps followed in identifying polygons for electrification.

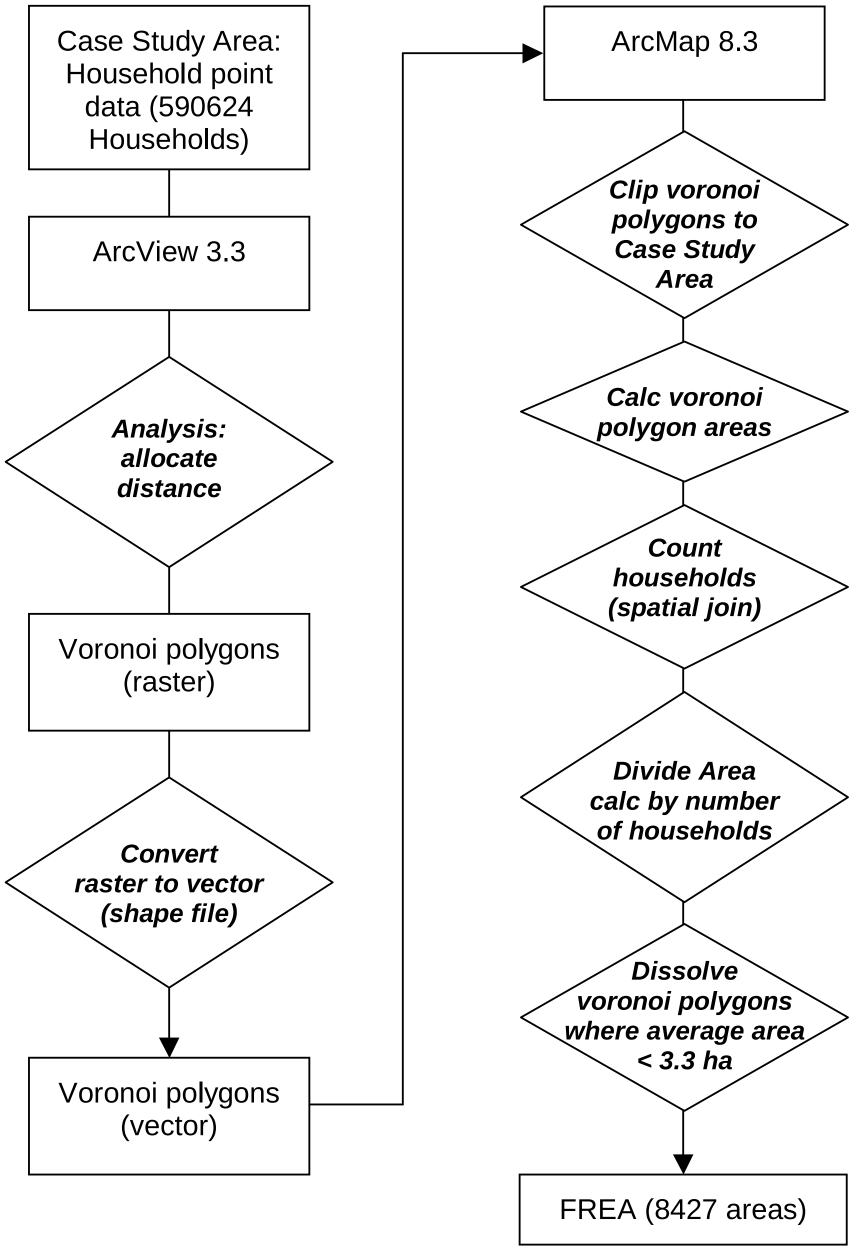
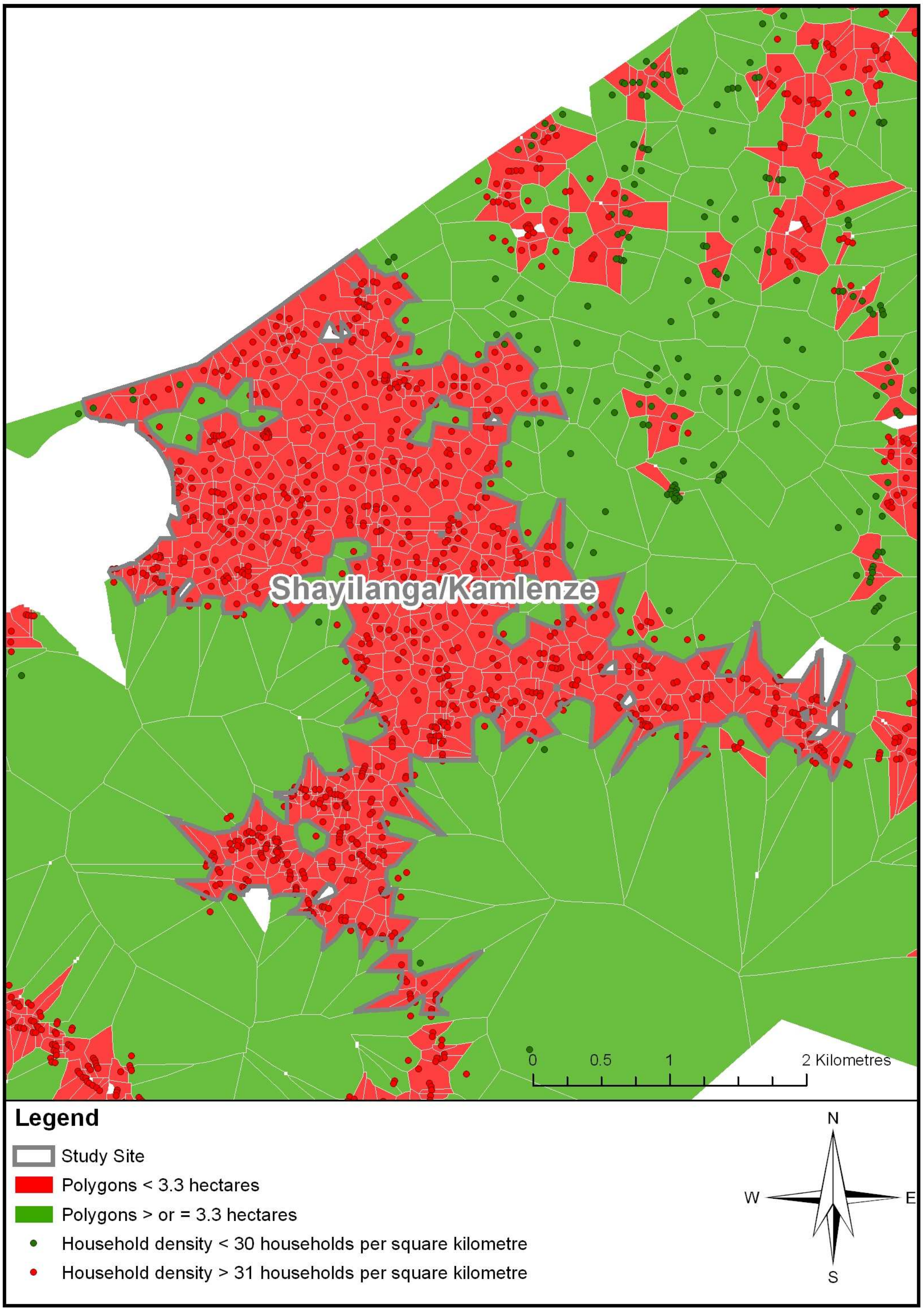


Figure 3.3: Identification of FREA



Map 3.2: Example of voronoi polygons: Extract of Shayilanga / Kamlenze electrification area

3.4.4 Prioritization of FREA according to demand

Once the FREA had been identified, they needed to be prioritized and this was done by applying a points and weighting system. The points scoring model used for villages is based on the Namibian points allocation process formulated during the Namibia Electrification Master Planning exercise and was further developed by Dr Douglas Banks of RAPS Consulting for the user interface of the Electrification Planning Model tool developed between 2000 and 2003. In the model villages are scored according to the possible income that they can generate, based on village size, density and income levels. Villages containing police stations, schools and hospitals/clinics may get priority due to the points included for those facilities. Weighting is applied to the total points for quality of road access, housing type and the presence of other infrastructure. This serves to modify the total points allocated per village and helps to identify those areas with a relatively higher level of development where electrification is outstanding.

- Fields were added to the schools and medical facilities datasets in order to calculate points using the RAPS tables (see table 3.2).
- Additional weighting for housing types, telephone services, water supply and sanitation was determined and used to modify the scores in the schools dataset (see table 3.3 and 3.4).
- A count was done of the number of schools, medical facilities and households in each area by spatially joining each dataset in turn to the FREA.
- The household count was added to the schools and medical facility scores to obtain the final total points for all FREA.

Table 3.2: RAPS Base scores used

Dataset			Points	Source
Households			1	HELP
Health		Clinics	15	Health Department (2005)
		Health Care Centers	30	
		Hospitals	60	
Schools	Primary		8	Education Department (2001)
	Primary per student		0.06	
	Secondary		12	
	Secondary per student		0.1	

Table 3.3: RAPS Weighting factors used

Attribute data		Weighting
Quality of road access	Good Tar / Gravel Broken Tar / Unknown Poor gravel / Footpath	1.05 1.00 0.95

Table 3.4: Further weighting factors used on schools dataset (based on RAPS principles)

Attribute data		Weighting
Housing types	Brick / Cement Prefab / Zinc / Other / Unknown Mud	1.05 1.00 0.95
Telephone Services	Yes Unknown No	1.05 1.00 0.95
Water supply	Yes Unknown No	1.05 1.00 0.95
Sanitation	Yes Unknown No	1.05 1.00 0.95

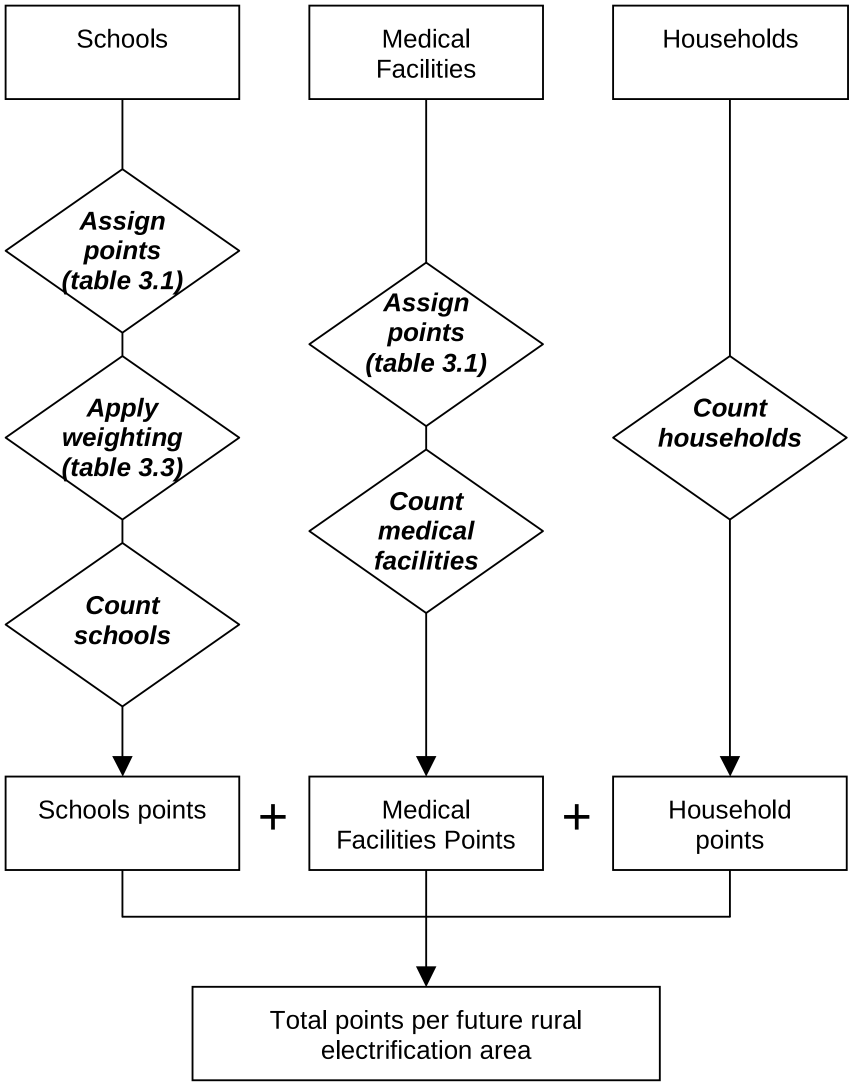


Figure 3.4: Prioritization of FREA according to demand

3.4.5 Constraints to the electrification of FREA from a supply perspective

Constraints to electrifying the list of FREA were then considered. Factors such as average household density should be considered in order to satisfy the criterion of not less than 30 households per km², areas containing schools or medical facilities should still be considered a priority, and for engineering purposes, the electrification area must be within 30 kilometres of a 22.00 kV substation (Eskom Distribution, 2000, Carter-Brown, 2005).

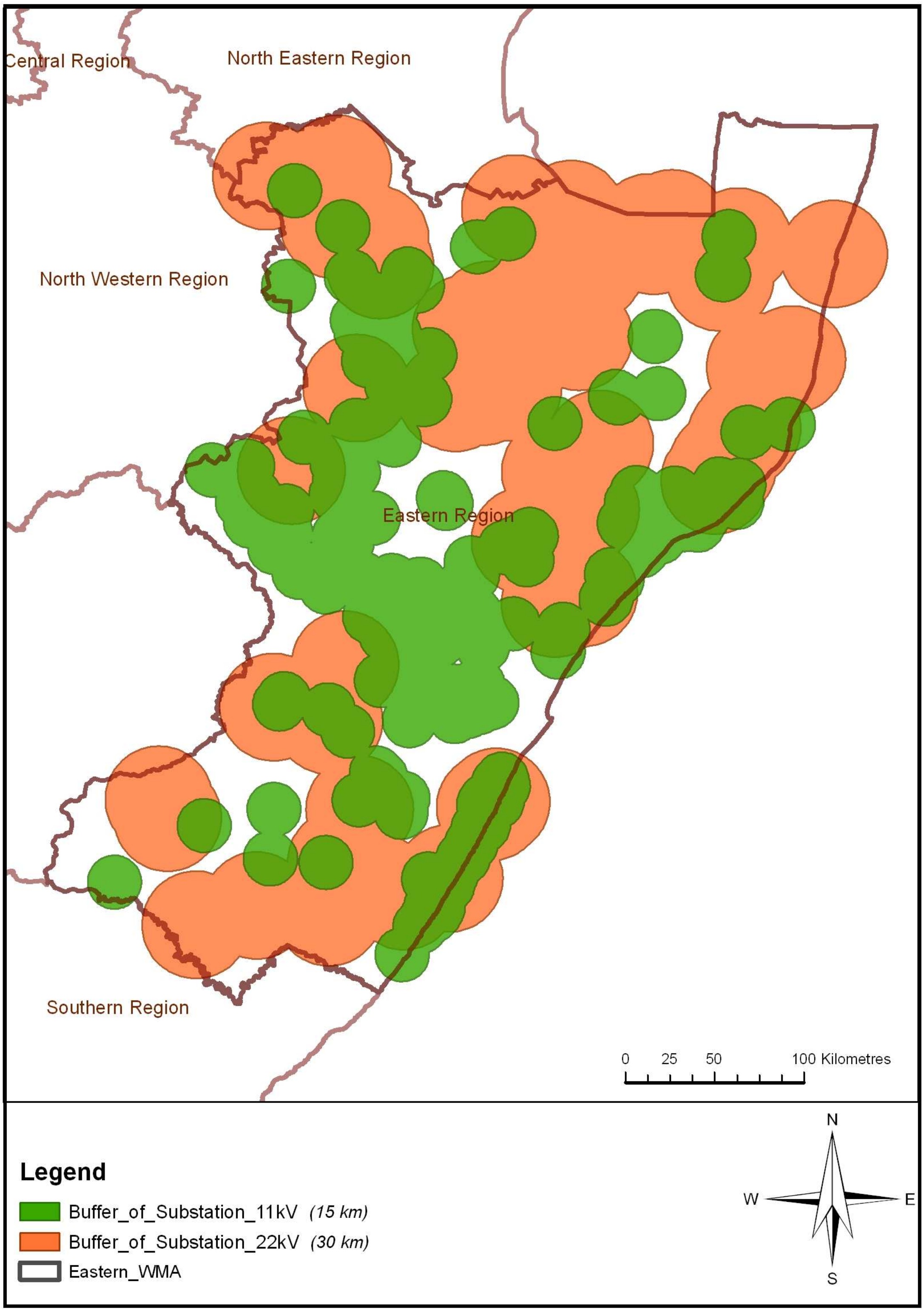
Furthermore, distance from the existing grid must be a factor in the supply of electricity to a FREA. It would be impractical to electrify an area with a high score that is far from the grid before an area with a low score that is much closer to the grid and those closest should be considered a priority. Once a shortlist has been established, a date should be assigned to each FREA on that shortlist and the constraints reconsidered repeatedly at increasing distances from the existing grid until all FREA have been assigned a date for electrification and plans made to resolve all constraints.

3.4.5.1 Average Household Density

Households clustered with a density of more than 30 households per km² are currently considered to be suitable for on-grid electrification. Therefore the average household density for each electrification area polygon had to be determined and all polygons with an average density of less than 30 were excluded.

3.4.5.2 Substations

Substations with an outgoing voltage of 22.00 kV had to be identified and this was done by selecting all MV cable / conductors where the voltage was equal to 22.00 kV and then selecting all substations that were within 100 metres and feeding those MV cable / conductors. The result was buffered by 30 kilometres (see Map 3.3) and only FREA that had their centre within this buffer were selected.



Map 3.3: Network capacity in terms of distance from substation (substation buffers)

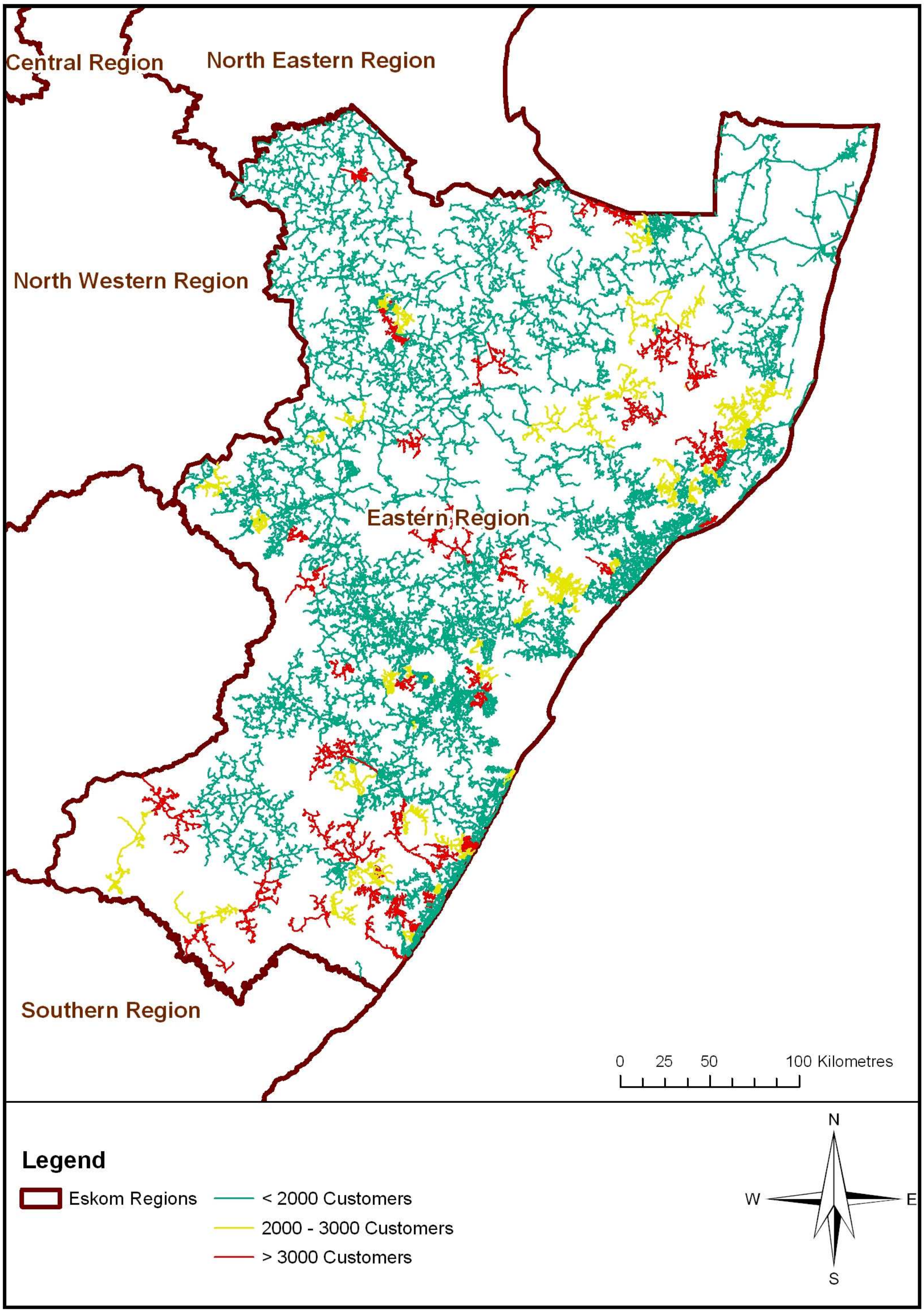
3.4.5.3 Network capacity

In line with current practice, networks with more than 3000 customers were excluded and areas more than 30 kilometres from the substations were excluded from consideration:

- The MV cable / conductors were dissolved on the standard label field in order to create networks.
- The customer data was extracted from Oracle, converted to DBF files and joined through the transformer name to the MV stations.
- The MV networks were then joined spatially to the MV stations summing the customers per transformer to determine the total customers per network. Where networks already had over 3000 customers, they were rejected for extension.
- Networks were classified according to the number of customers which is a measure of capacity and the results are shown in Map 3.4.
- FREA within 2 kilometres of networks with less than 2000 customers were selected.

3.4.5.4 Schools and Medical Facilities

The selection was then further refined by selecting FREA containing schools and / or medical facilities in line with government policy of the past few years of promoting access to energy for schools (DME, 1998). The process followed to identify FREA that could be electrified immediately is shown in Figure 3.5.



Map 3.4: Network capacity in terms of total customers on each network

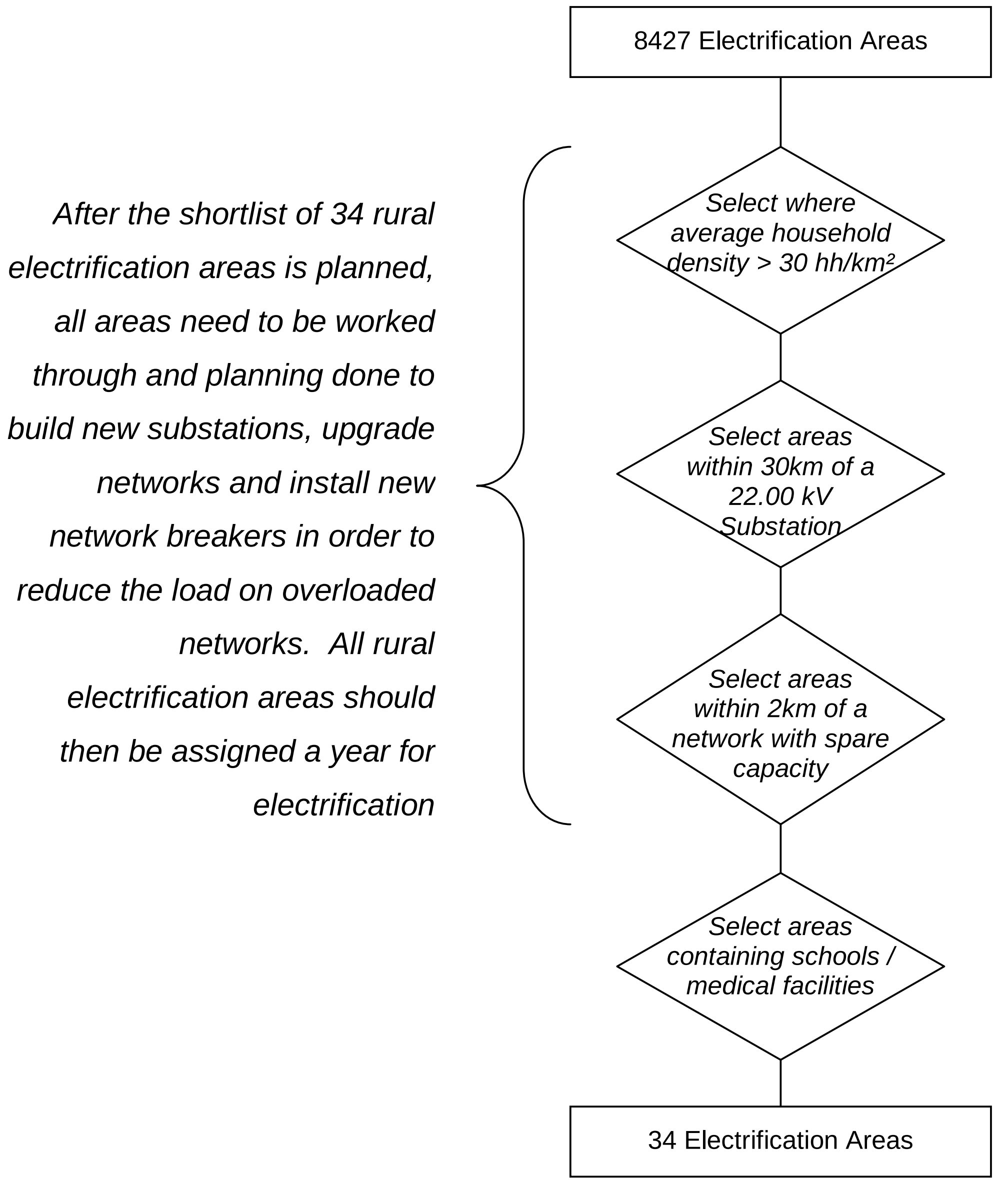


Figure 3.5: Constraints to the electrification of FREA from a supply perspective

3.4.5.5 Summary

The initial shortlist of 34 FREA were the result of applying a points and weighting system, household count and density, number of schools and medical facilities and constraints of distance from the nearest 22.00 kV substation and number of customers already supplied on the nearest network. As these can be electrified immediately, the year (2006) should be added next to them in the initial list of 8427 FREA. The rest of the FREA then need to be prioritised by changing criteria and rerunning the analysis. Network Planning can investigate the possibility of adding another network breaker to a substation to split the load where a network supplies more than 3000 customers. Where a FREA is more than 30 km from a 22.00 kV substation, the feasibility of building a new substation needs to be considered. The year that these constraints are envisioned to be resolved must be added to the original list.

Out of the initial list of FREA, the three highest scoring case study sites were selected to demonstrate the use of spatial analysis techniques in applying constraints in terms of roads, land cover, households, and slope; in order to determine a shortest path to a central point in a FREA such as a school or medical facility. It is often assumed that the shortest distance between two points is a straight line, but this is usually not the case when planning a route for electricity supply. Criteria such as avoidance of steep slopes and environmentally important areas such as forests and wetlands, consideration of roads and household positions should be considered when planning a route and it will be shown how GIS can be used to do this effectively (Eskom Distribution, 2000).

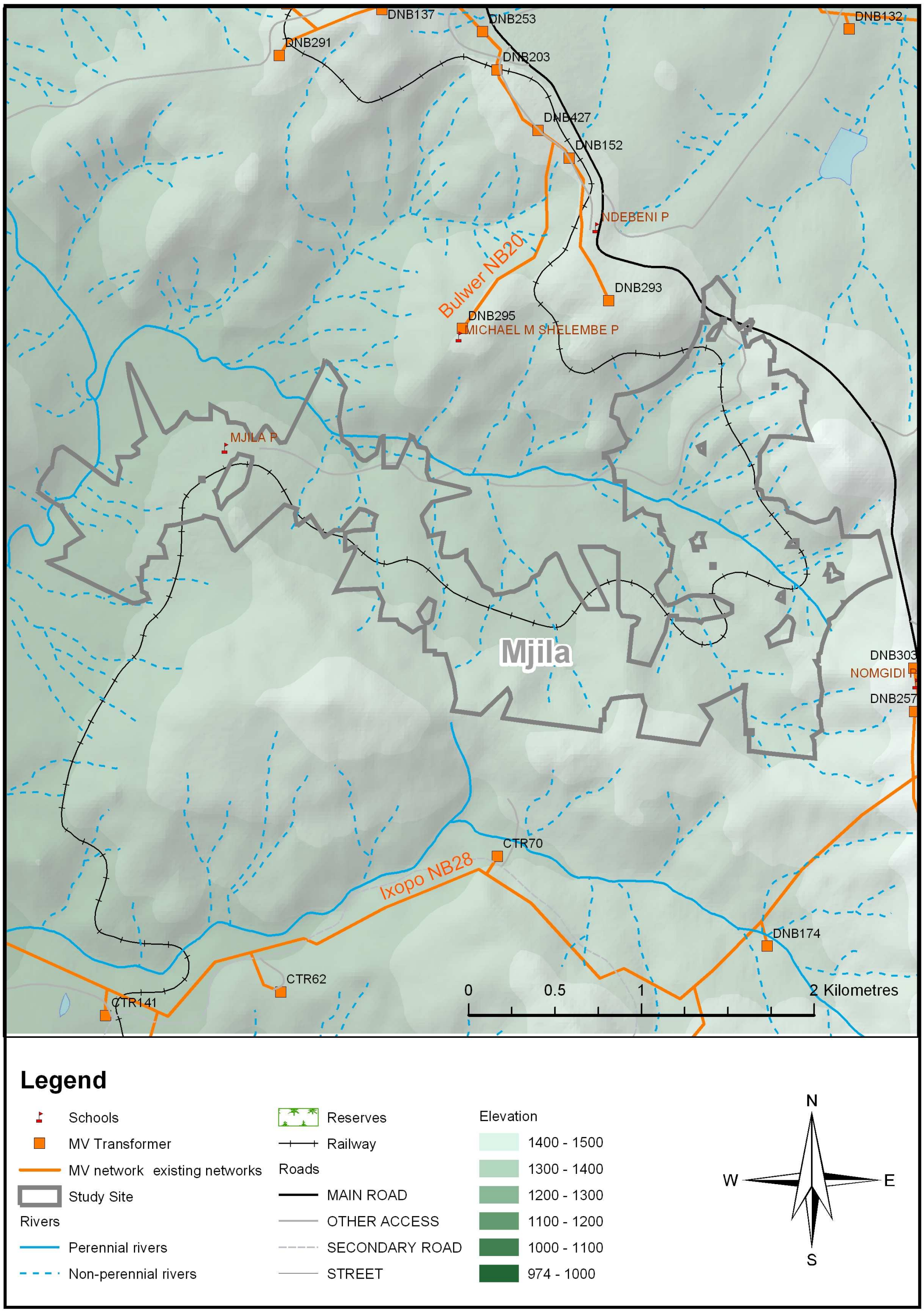
For economic reasons and in accordance with electrical engineering principles, the transformers should be placed in the densest areas serving approximately 80 households off a 16.00 kV transformer. For the purposes of this study however, the design will extend the network to supply the schools in each area in accordance with government principles (DME, 1998, KZN, 2005). The case study sites chosen fall within the boundaries of the municipal subplaces known as Mjila, Mqatsheni and Shayilanga / Kamlenze.

3.4.6 Mjila

Mjila is situated north of the town of Creighton between the Bulwer NB20 and Ixopo NB28 Eskom MV networks (see Maps 3.1 and 3.5). There are currently very few services to Mjila and the IDP (Integrated Development Plan) for Ingwe Municipality (Ingwe, 2006) contains several projects scheduled for Mjila (see table 3.5). It is evident that the need for development in the sub place area of Mjila has already been identified as important.

Table 3.5: Summary of statistics for the sub place of Mjila

Census 2001	
District Municipality	Sisonke
Local Municipality	Ingwe
Main Place	Memela
Sub Place	Mjila
Ingwe IDP for Mjila	
2005/2006	Poultry houses
2006/2007	Electricity, hall and crèche
2006/2007/2008	Housing
2008/2009	School upgrade, bulk services, water
No date given	Establishment of a farming co-op to support poverty alleviation
Mjila	
Households	519 Households
Average Density of Households	87.80 Households per square kilometre
Total Points	544.82 Points
Schools	Mjila Primary School, Grade R–7, 322 pupils
Land cover	Predominantly divided between unimproved grassland and temporary cultivated subsistence farming



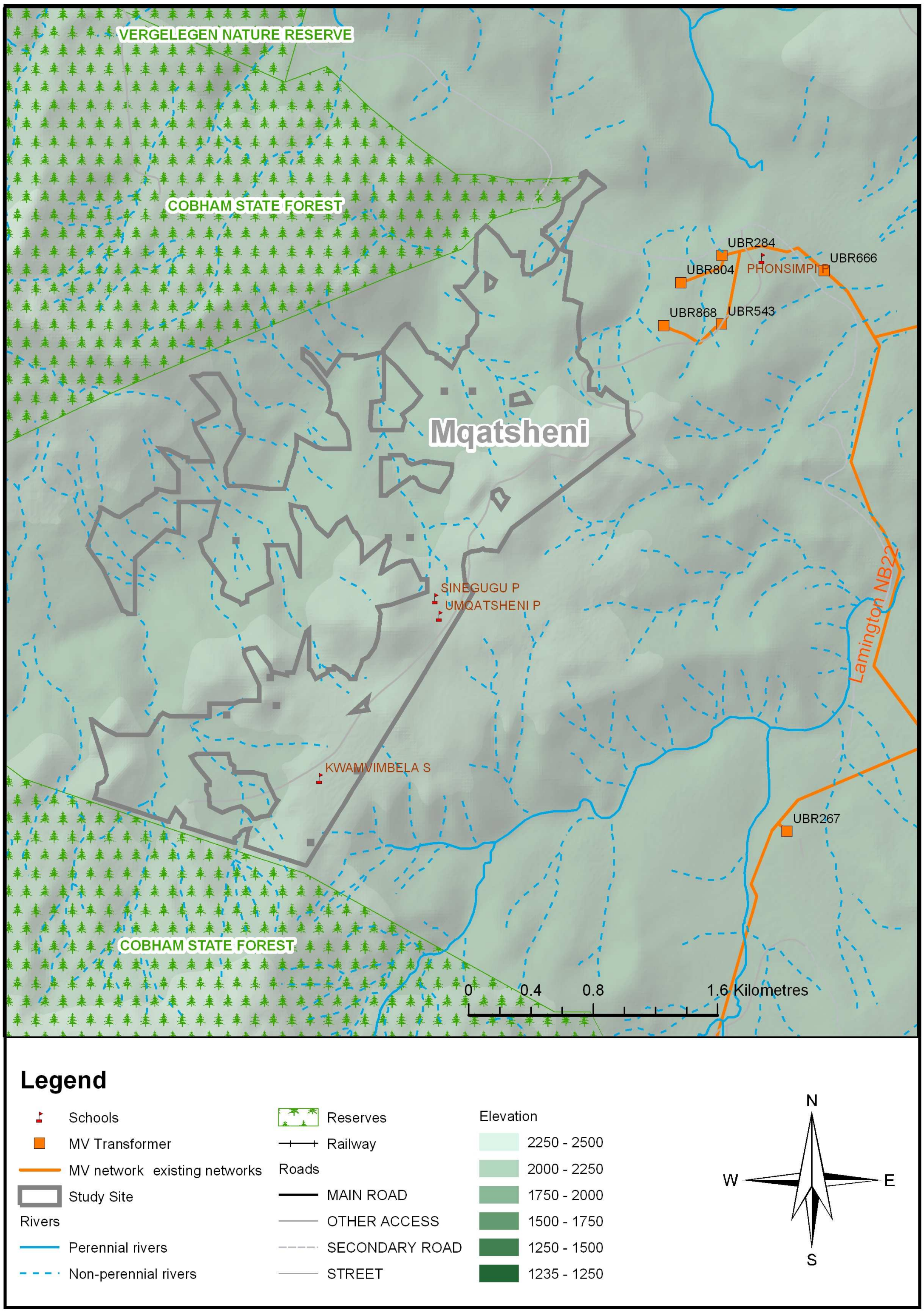
Map 3.5: Case study site of Mjila showing relief, school, roads, rivers, railway line and current Eskom MV networks and transformers

3.4.7 Mqatsheni

Mqatsheni is situated approximately 20 kilometres from the Lesotho border to the east of the Cobham State Forest near to the Lamington NB22 Eskom MV network (see Maps 3.1 and 3.6). According to the KwaSani IDP, Mqatsheni is scheduled for a number of projects which are categorized as priority 1 to 5 (KwaSani, 2006) (see table 3.6). The community themselves have requested these projects and also a multi-purpose centre and AIDS initiative project for the area.

Table 3.6: Summary of statistics for the sub place of Mqatsheni

Census 2001	
District Municipality	Sisonke
Local Municipality	KwaSani
Main Place	Batlokoa
Sub Place	Mqatsheni
KwaSani IDP for Mqatsheni	
Priority 1	New water supply, sports facility, pension point, taxi shelters and a social worker
Priority 2	Electricity provision and school
Priority 3	Sanitation, sewerage and housing
Priority 4	Road upgrade and maintenance
Priority 5	Crèche
Mqatsheni	
Households	476 Households
Average Density of Households	75.77 Households per square kilometre
Total Points	557.51 Points
Closest Town:	Himeville
Schools	Sinegugu Primary – Grade 1-4, 121 pupils Umqatsheni Primary – Grade 1-7, 346 pupils Kwamvimbela School – Grade 8-12, 293 pupils
Land cover:	Unimproved grassland with pockets of forest plantations



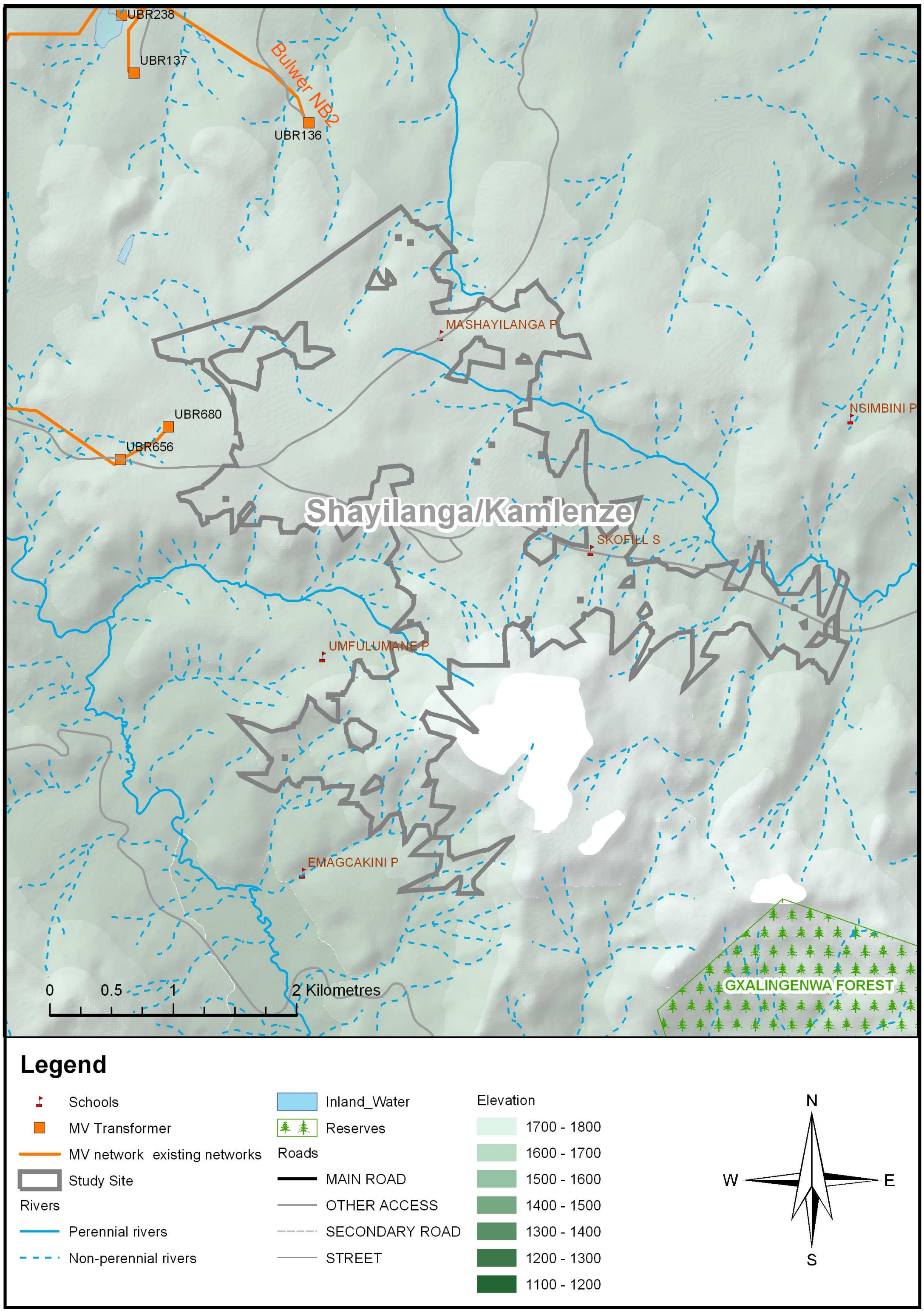
Map 3.6: Case study site of Mqatsheni showing Cobham State Forest, elevation, schools, roads, rivers, and current Eskom MV networks and transformers

3.4.8 Shayilanga / Kamlenze

The area including Shayilanga and Kamlenze is situated north of Gxalingenwa Forest (see Maps 3.1 and 3.7). The area scored the highest number of points of the 34 short-listed electrification areas due to the number and density of households, and the number of pupils at the two schools in the area (see table 3.7). There are very few projects currently planned for the area as per the IDP for Ingwe Local Municipality (Ingwe, 2006).

Table 3.7: Summary of statistics for the sub places including Shayilanga and Kamlenze

Census 2001	
District Municipality	Sisonke
Local Municipality	Ingwe
Main Place	Bhidla
Sub Places	Shayilanga and Kamlenze
Ingwe IDP for Shayilanga / Kamlenze	
2006/2007	Access road
2007/2008	School refurbishment
No date given	Fencing project
Shayilanga /Kamlenze	
Households	792 Households
Average Density of Households	68.25 Households per square kilometre
Total Points	904.35 Points
Closest Town:	Underberg
Schools	Mashaliyanga Primary – Grade R–7, 889 pupils Skofill School – Grade 8-12, 342 pupils
Land cover:	Predominantly divided between unimproved grassland and temporary cultivated subsistence farming



Map 3.7: Case study site of Shayilanga/Kamlenze showing Gxalingenwa forest, elevation, schools, roads, rivers, and current Eskom MV networks and transformers

3.4.9 Determination of shortest paths from networks to central points inside FREA

Planning of a route using GIS takes into account any number of factors simultaneously to determine the shortest path (Berry, 2005). For this study, four of the most important factors will be used and these are roads, land cover, household positions, and slope (Eskom Distribution, 2000). Other considerations could include rivers (where no access across is possible), environmentally sensitive areas, historical monuments, visibility (planning a route so that it is not visible from a resort for instance), temperature and weather patterns to mention a few.

For each factor the vector data must be converted to raster and then reclassified with suitability ratings according to the desired outcome. So if it is essential that a slope of more than 40 degrees be avoided, then where slopes are 40 degrees or steeper should be allocated a very high rating. If a route should follow the edge of a road, then that area should carry a zero rating. Ratings should be carefully decided on after some discussion between engineers and planners as to existing practices, and then can easily be changed if needed (Bailey *et al*, 2005). Each factor can then also be weighted according to its importance, so if, for example, slope is twice as important as any other factor then the rating for slope can be doubled (Berry, 2005). Weightings were not applied in this study.

The suitability ratings allocated in this study were estimated and each factor has been allocated a rating between 0 (best) and 100 (worst). The reclassified raster layers for each study site were added together to create a combined raster and the most suitable path for a new route was determined using shortest path algorithm. Figure 3.6 summarizes the process followed after examples of this process are worked through for the selected study sites – Mjila, Mqatsheni and Shayilanga / Kamlenze. Each factor is applied to all three sites and discussed in more detail below.

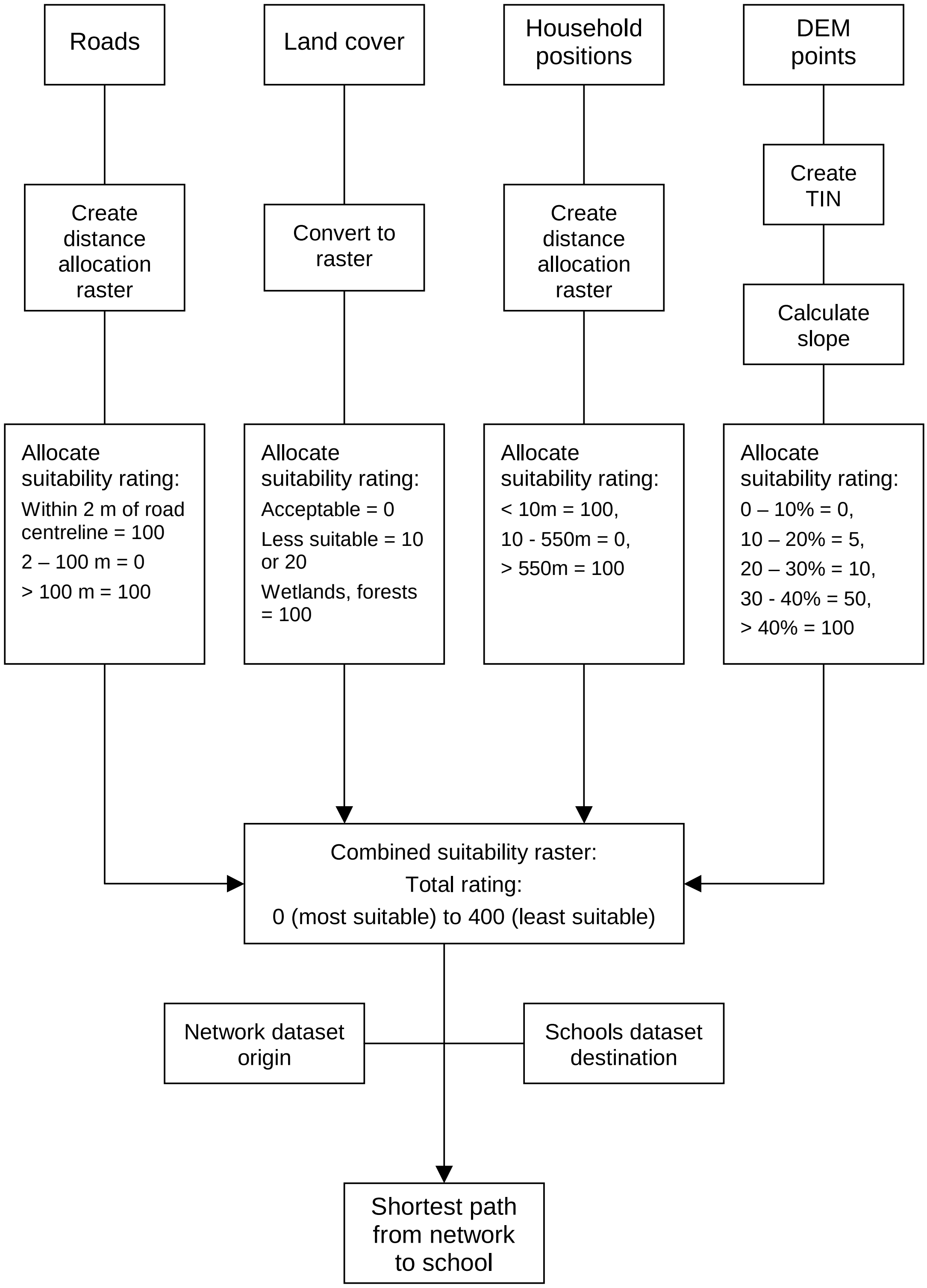


Figure 3.6: Study sites: Determining shortest path from network to school

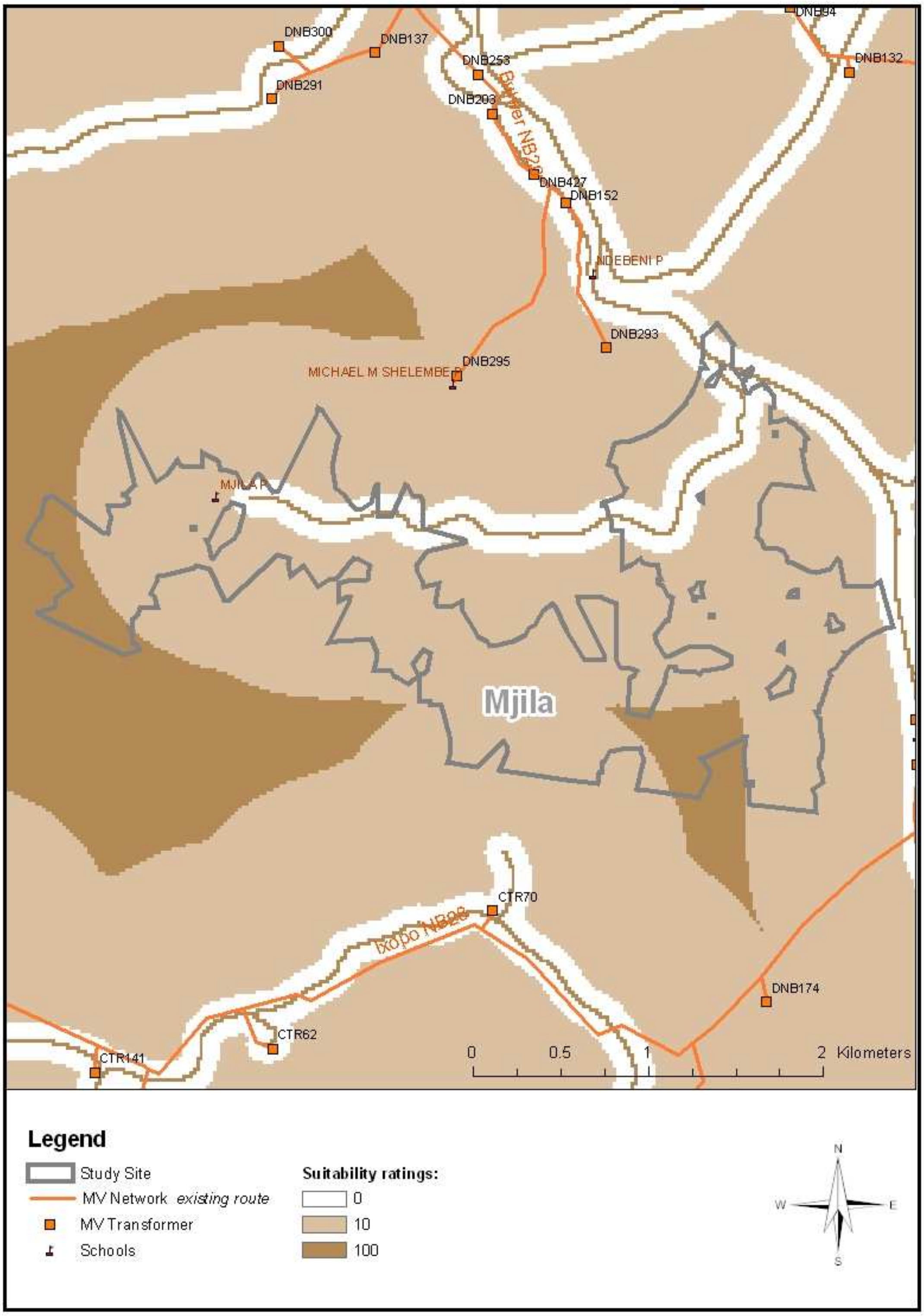
3.4.9.1 Roads

Roads are ideal routes along which to plan electricity networks as they are usually already leveled, at a reasonable gradient, cleared of vegetation and networks next to roads are convenient for line patrols, planned maintenance and emergency work. A straight line distance raster was created of the roads data which was then reclassified according to the following table:

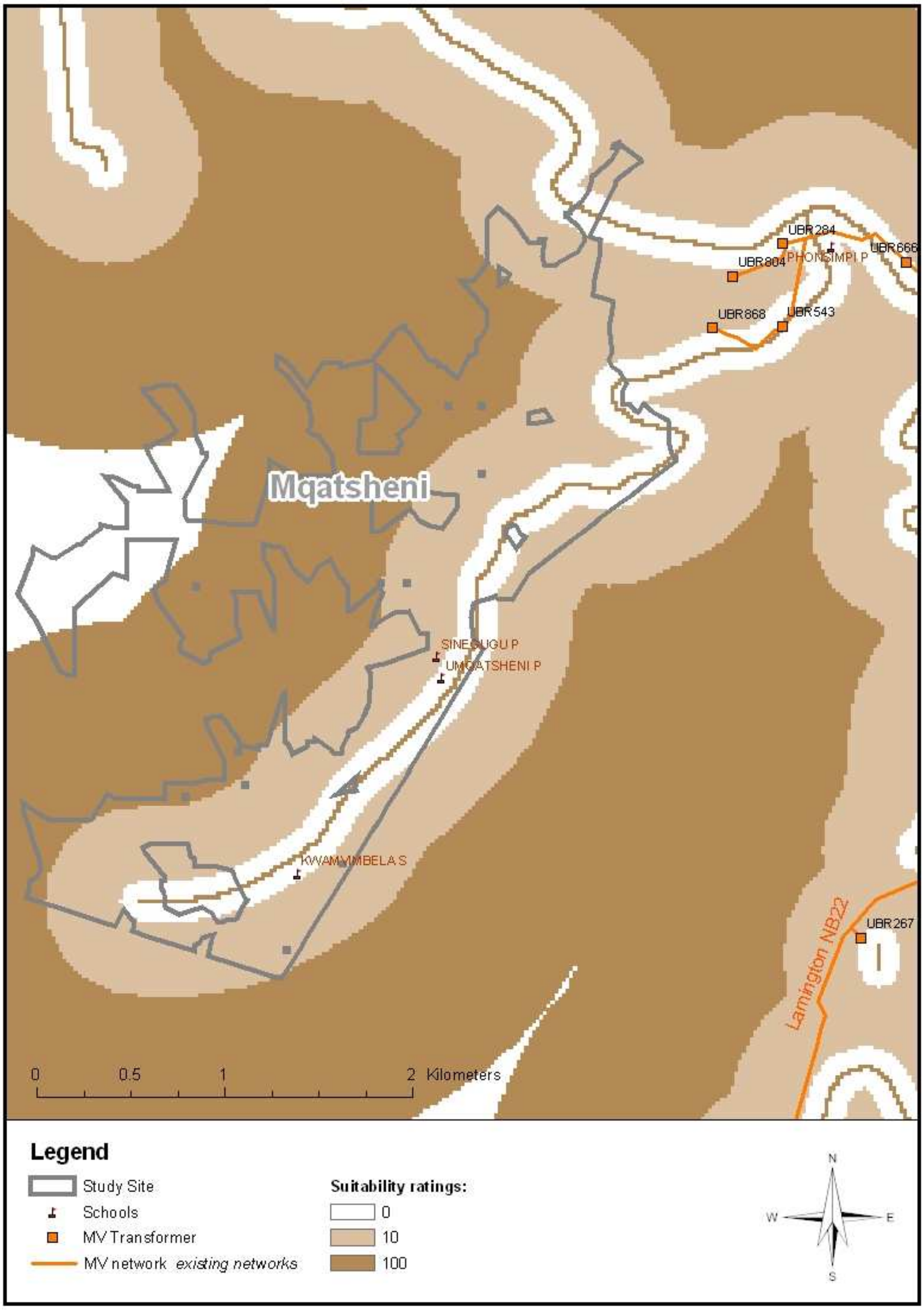
Table 3.8: Points allocated for reclassification of the straight line distance rasters created from roads data

Road Centreline	**Suitability rating (Scale: 0 – 100)**
Within 2 metres of the road centreline	100
2 – 100 metres	0
100 – 500 metres	10
> 500 metres	100

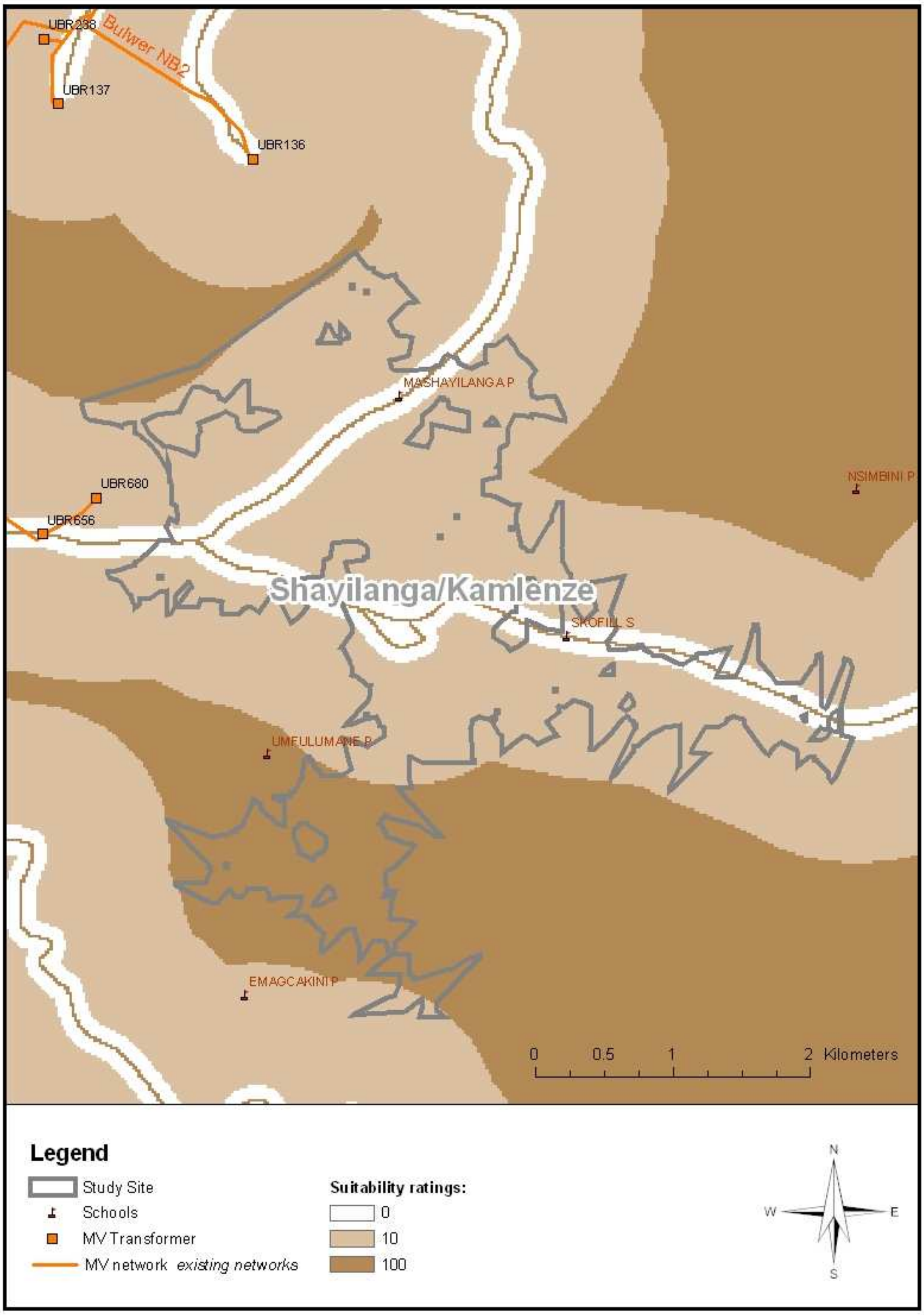
Table 3.8 summarizes the scores allocated in terms of suitability ratings. The road centerline and 2 metres on either side were given the maximum rating so as to avoid the planned route running on the road itself. From the estimated road edge to 100 metres from the road was allocated a zero rating as this would be the optimal place in which to build the network by making it accessible for faults, maintenance, line clearing and inspections. Between 100 and 500 metres was given a suitability rating of 10 as it is still a viable option to build in this area, and lastly over 500 metres from the road centreline was again given the maximum rating. Maps 3.8, 3.9, and 3.10 record the allocation of suitability ratings with respect to roads for each of the case study sites.



Map 3.8: Study site: Mjila: Reclassification of straight line distance raster created from roads



Map 3.9: Study site: Mqatsheni: Reclassification of straight line distance raster created from roads



Map 3.10: Study site: Shayilanga / Kamlenze: Reclassification of straight line distance raster created from roads

3.4.9.2 Land cover

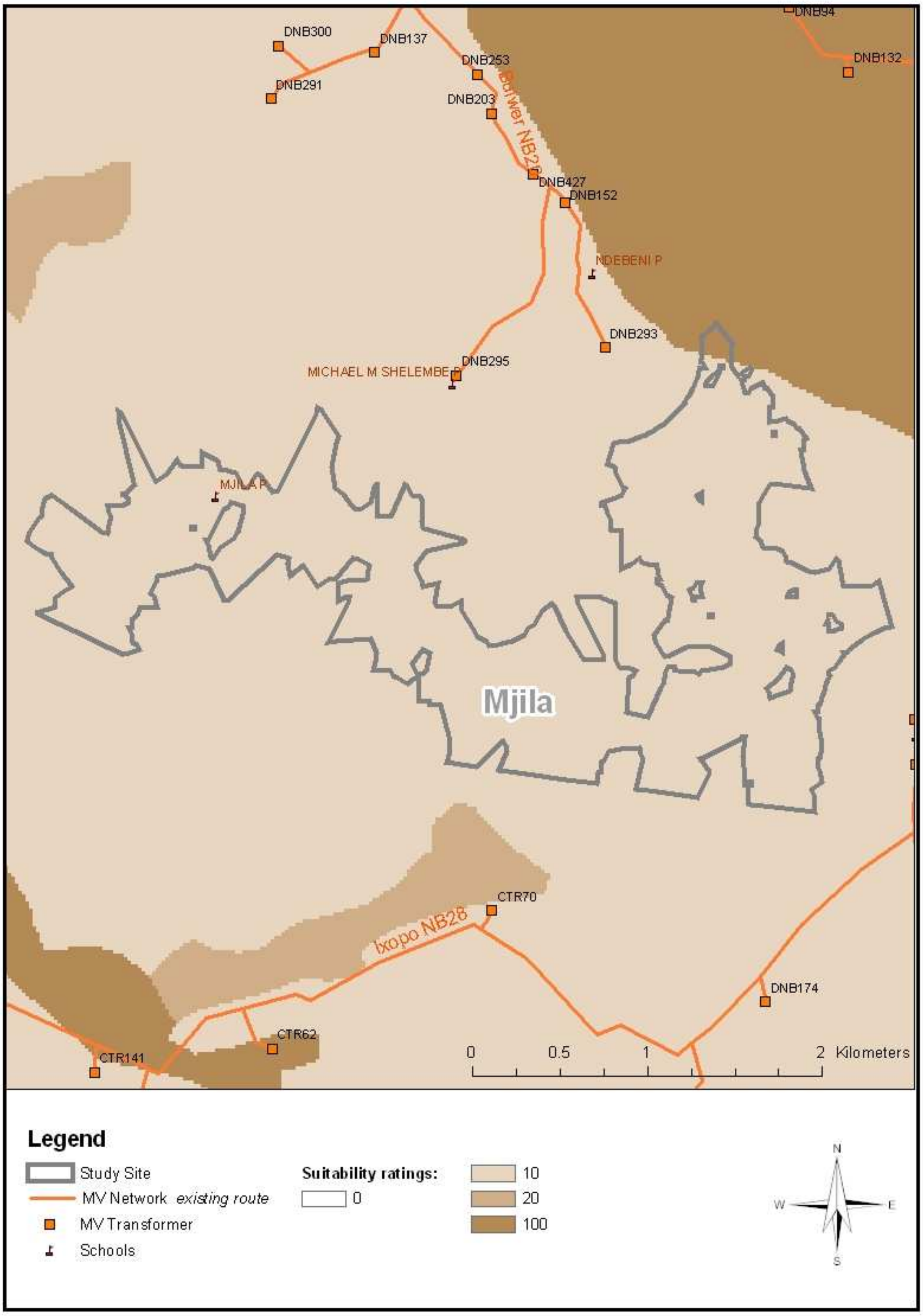
The land cover data contains areas demarcated as different types of cultivated land, degraded land, grasslands, mines, scrubland, forests, wetlands and others. This data was converted to raster and reclassified as listed in table 3.9:

Table 3.9: Points allocated for reclassification of the rasters created from land cover data

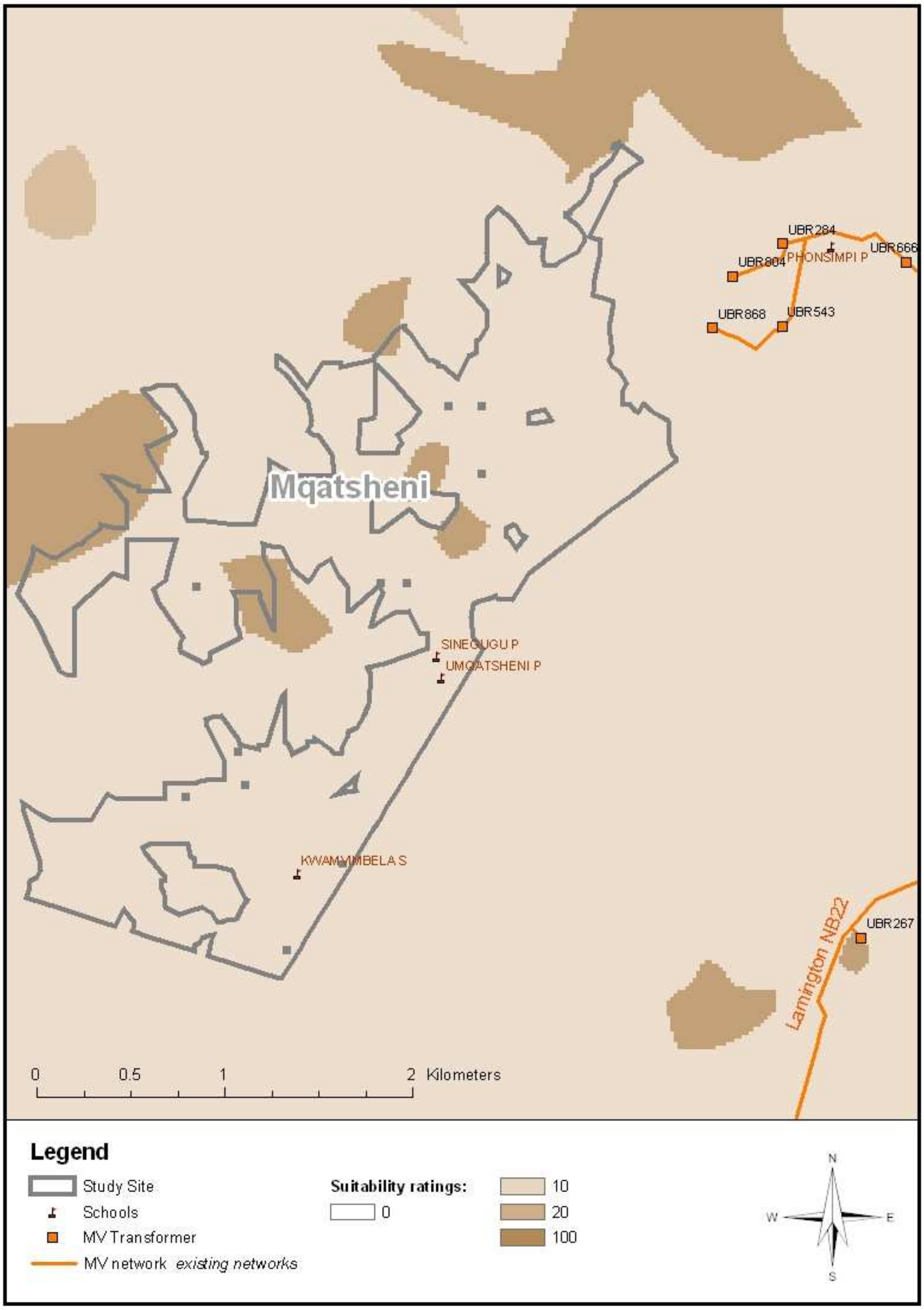
Land Cover	**Suitability rating (Scale: 0 – 100)**
Improved Grassland	0
Unimproved Grassland / Degraded / Cultivated / Urban	10
Thicket / Shrubland / Barren Rock / Dongas	20
Forests / Wetlands / Water Bodies	100

Environmentally sensitive areas such as forests, wetlands and other water bodies must be avoided and therefore were allocated a suitability rating of 100. Improved grassland was allocated nil points as being optimal area in which to site networks. Unimproved grassland, degraded, cultivated and urban areas were allocated 10 points. Thicket, shrubland, barren rock and dongas were allocated 20 points due to construction and clearing costs.

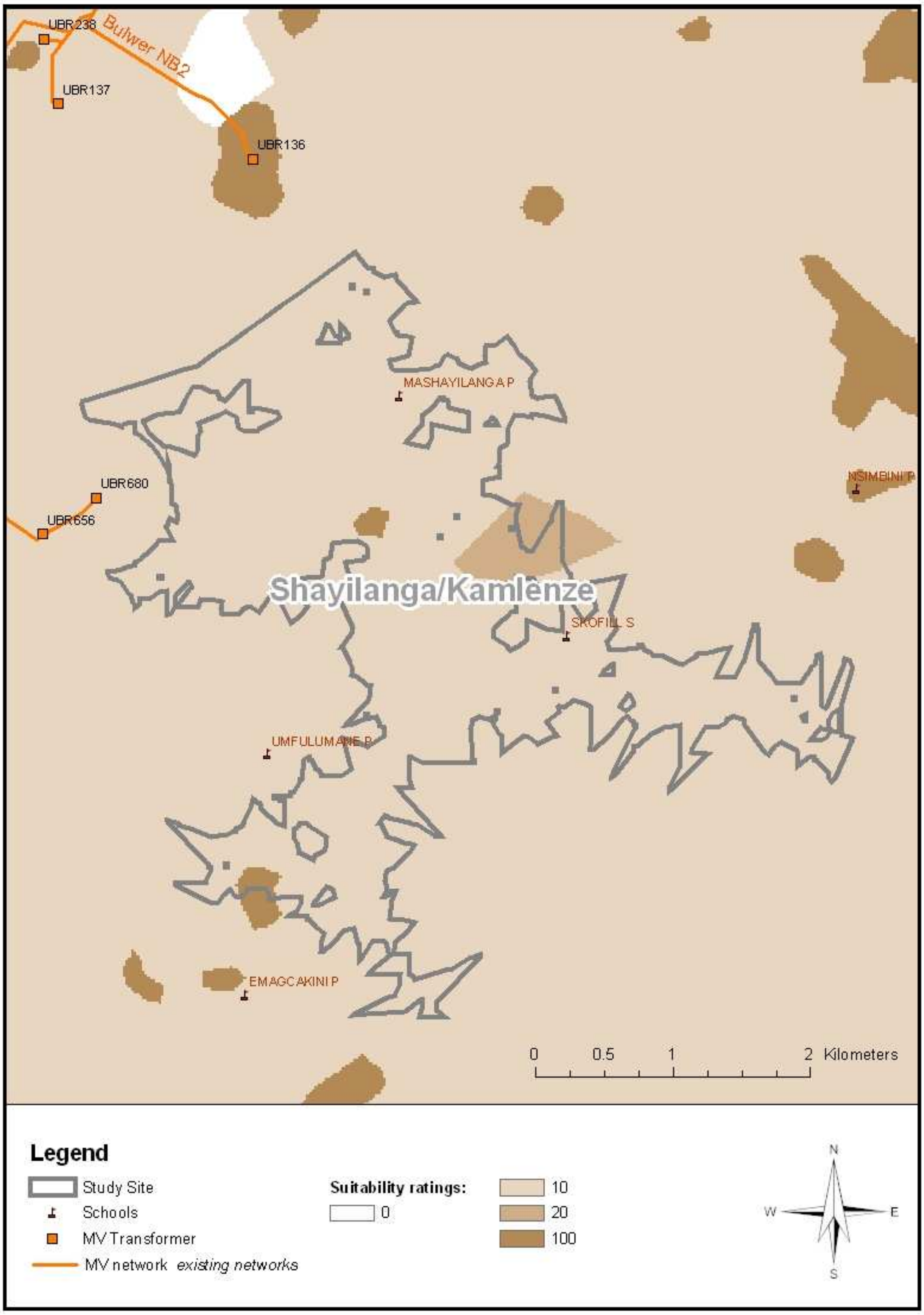
Maps 3.11, 3.12 and 3.13 show the reclassification of land cover in each of the study sites.



Map 3.11: Study site: Mjila: Reclassification of raster created from land cover



Map 3.12: Study site: Mqatsheni: Reclassification of raster created from land cover



Map 3.13: Study site: Shayilanga / Kamlenze: Reclassification of raster created from land cover

3.4.9.3 Households

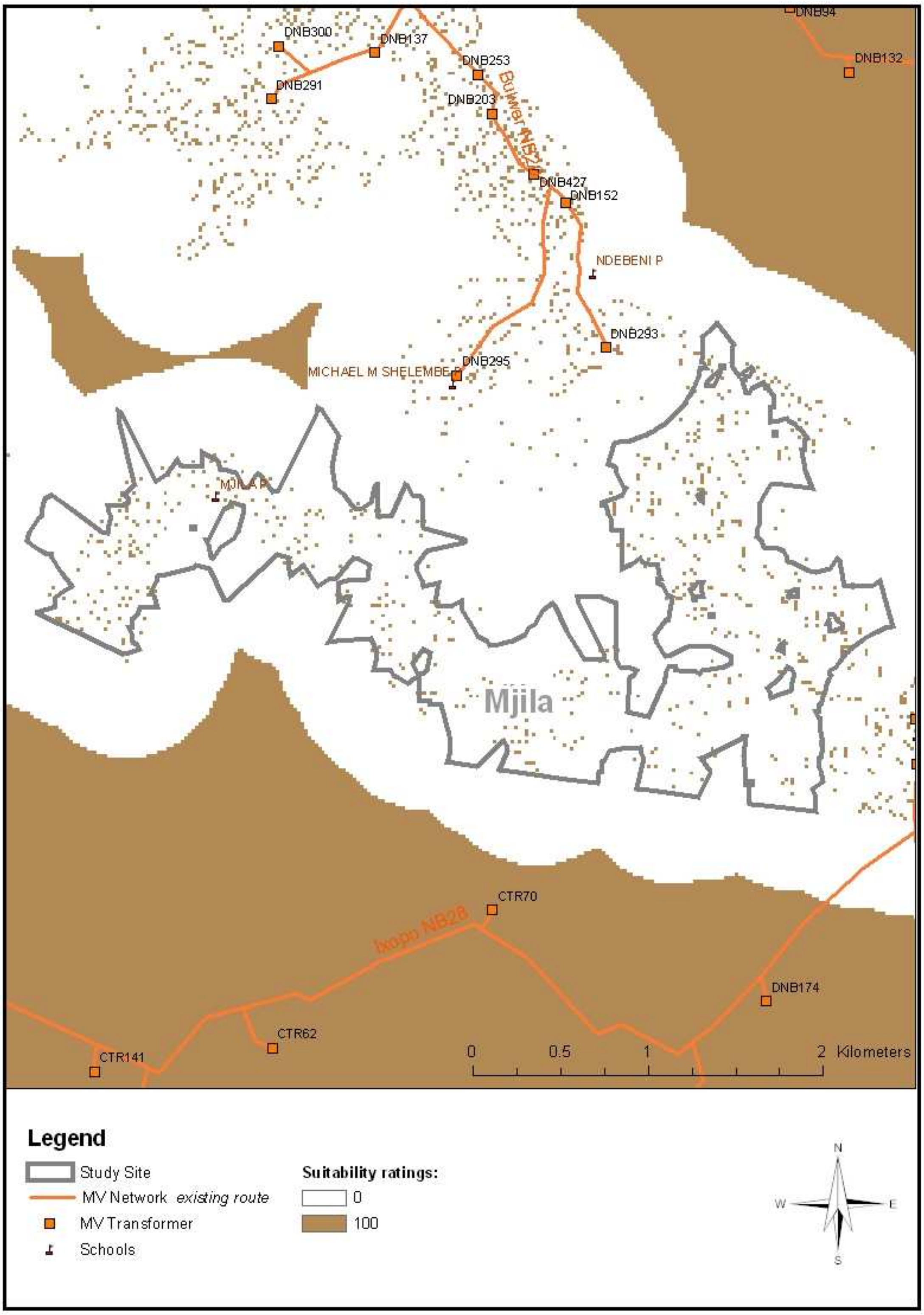
A distance allocation raster was created from the household point data which was then reclassified according to the following table:

Table 3.10: Points allocated for reclassification of the straight line distance rasters created from household data

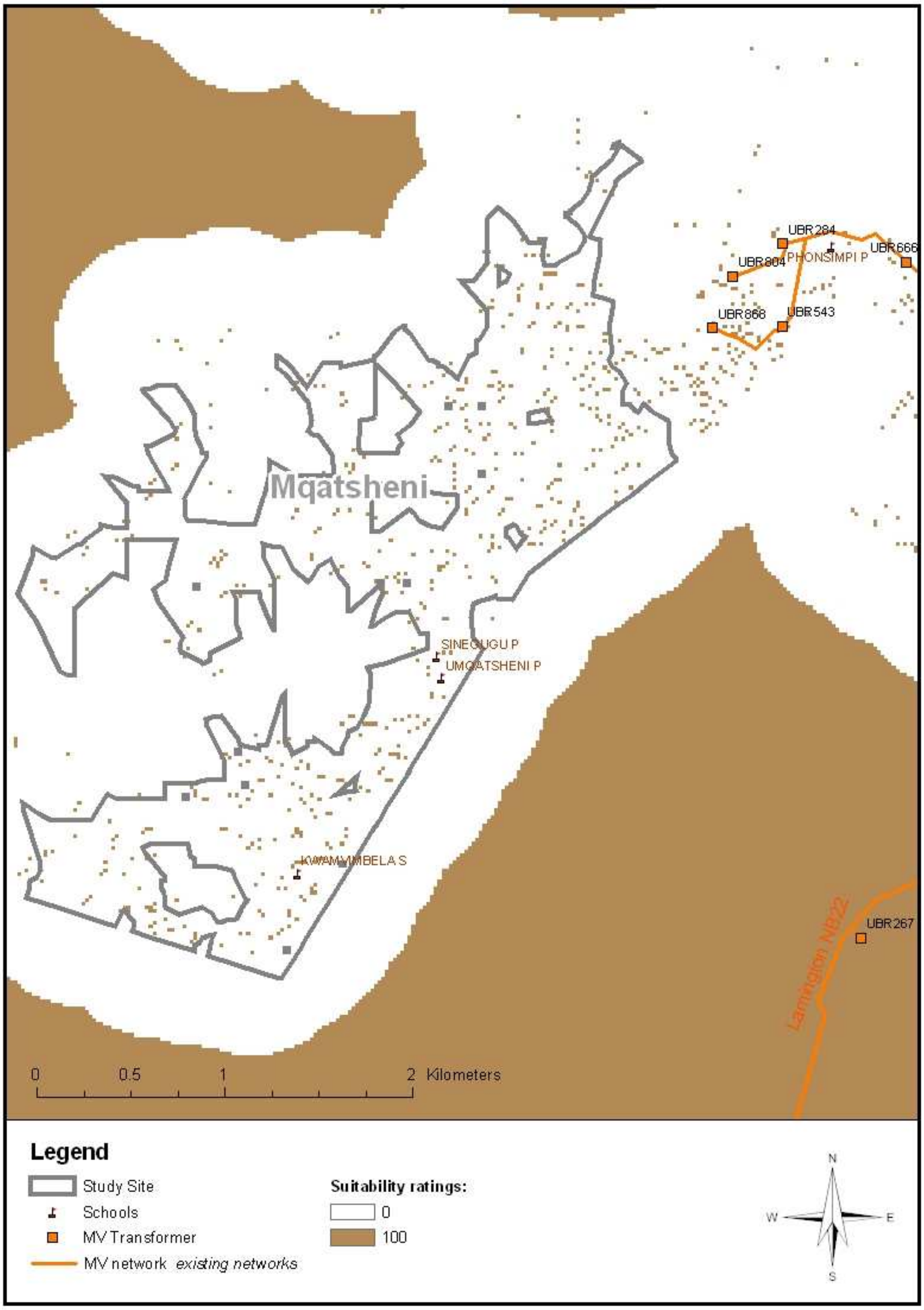
Households	**Suitability rating (Scale: 0 – 100)**
Within 10 metres of a household	100
10 – 550 metres	0
> 550 metres	100

Each household (or grouping of houses that would require 1 connection point) has been defined by a point; and a radius of 10 metres was used to simulate the outer boundary of those households. The inner area was allocated the maximum points of 100 so as to avoid running the network through households. 90% of all customers are within 550 metres of a transformer (Eskom Distribution, 2000) and so the area between 10 and 550 metres was therefore allocated a suitability rating of zero.

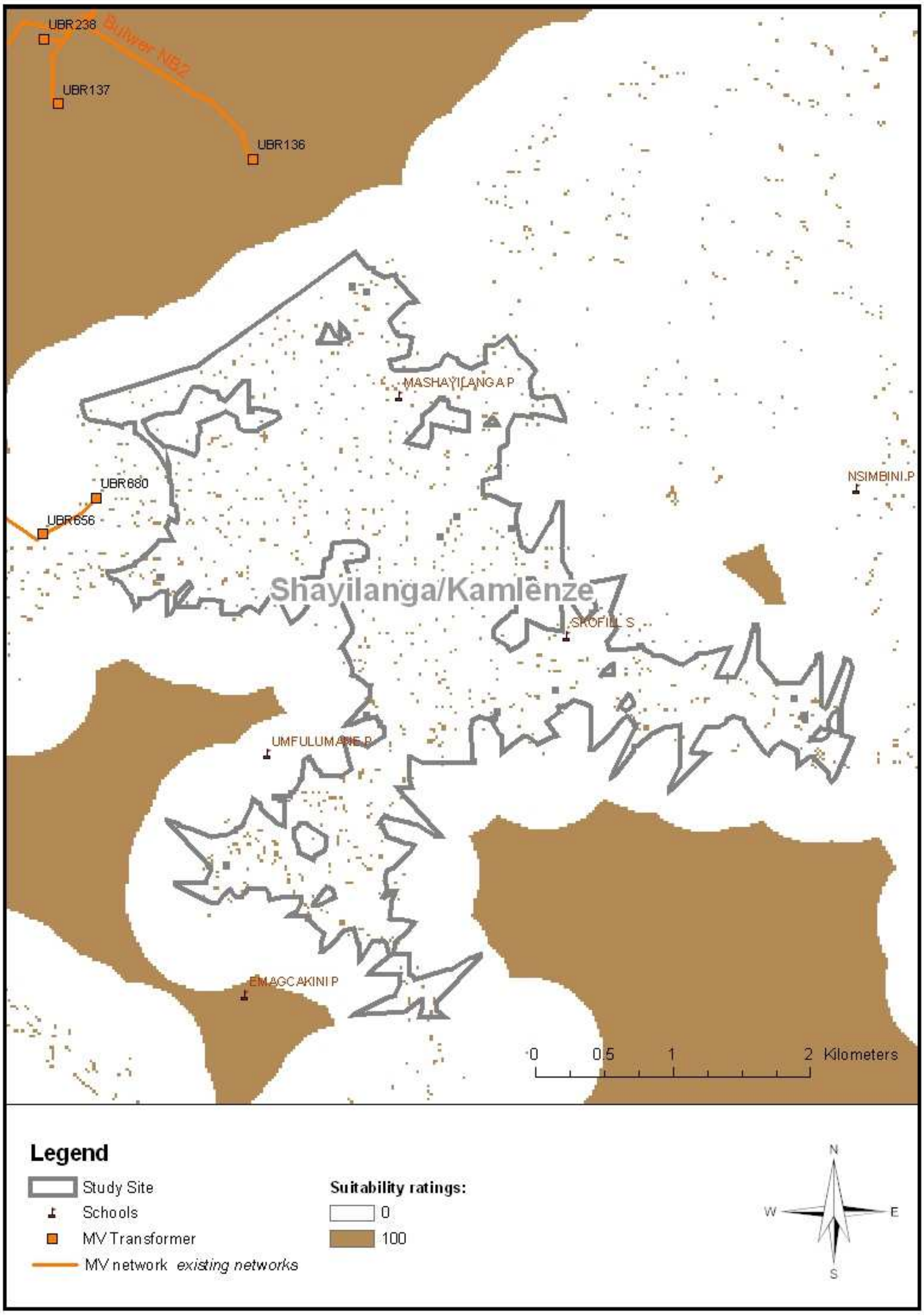
Using 550 metres created groupings of households as evidenced in Maps 3.14, 3.15, and 3.16 although in practice a lesser distance might be more sensible. Allocating maximum points to areas more than 550 metres from households ensures that a planned network will avoid these areas and run closer to the households reducing costs of connection.



Map 3.14: Study site: Mjila: Reclassification of straight line distance raster created from households



Map 3.15: Study site: Mqatsheni: Reclassification of straight line distance raster created from households



Map 3.16: Study site: Shayilanga / Kamlenze: Reclassification of straight line distance raster created from households

3.4.9.4 Slope

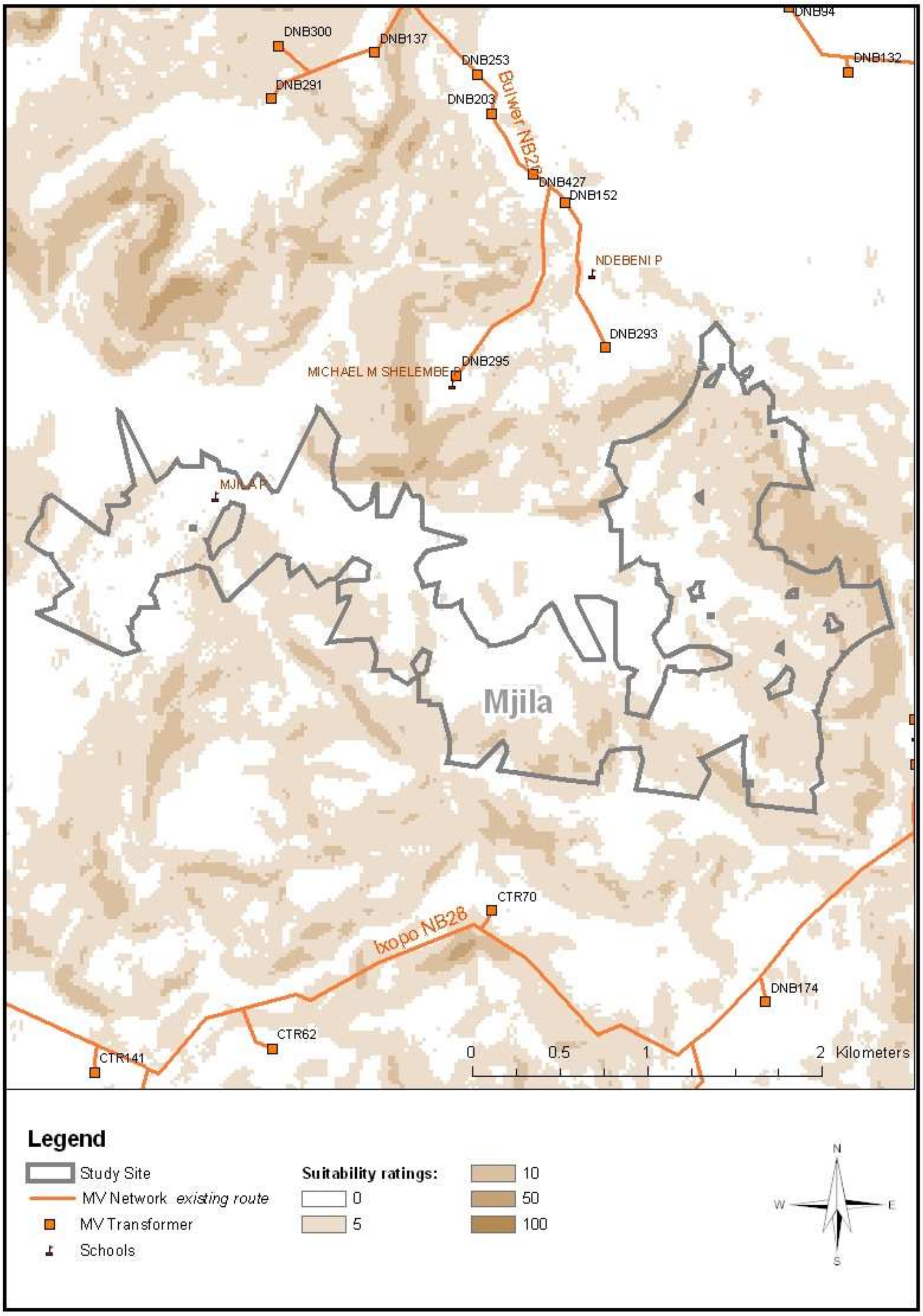
DEM (Data Elevation Model) 20 metre point data was used to create a TIN (Triangular Irregular Network) for each study site using ArcView 3.3 (ESRI, 2006b). A TIN interpolates DEM height data to create a generalized model which emulates the actual physiology of the ground. The TIN was then used to create a slope dataset. The slope dataset was reclassified as per the following table:

Table 3.11: Points allocated for reclassification of the rasters created from slope data

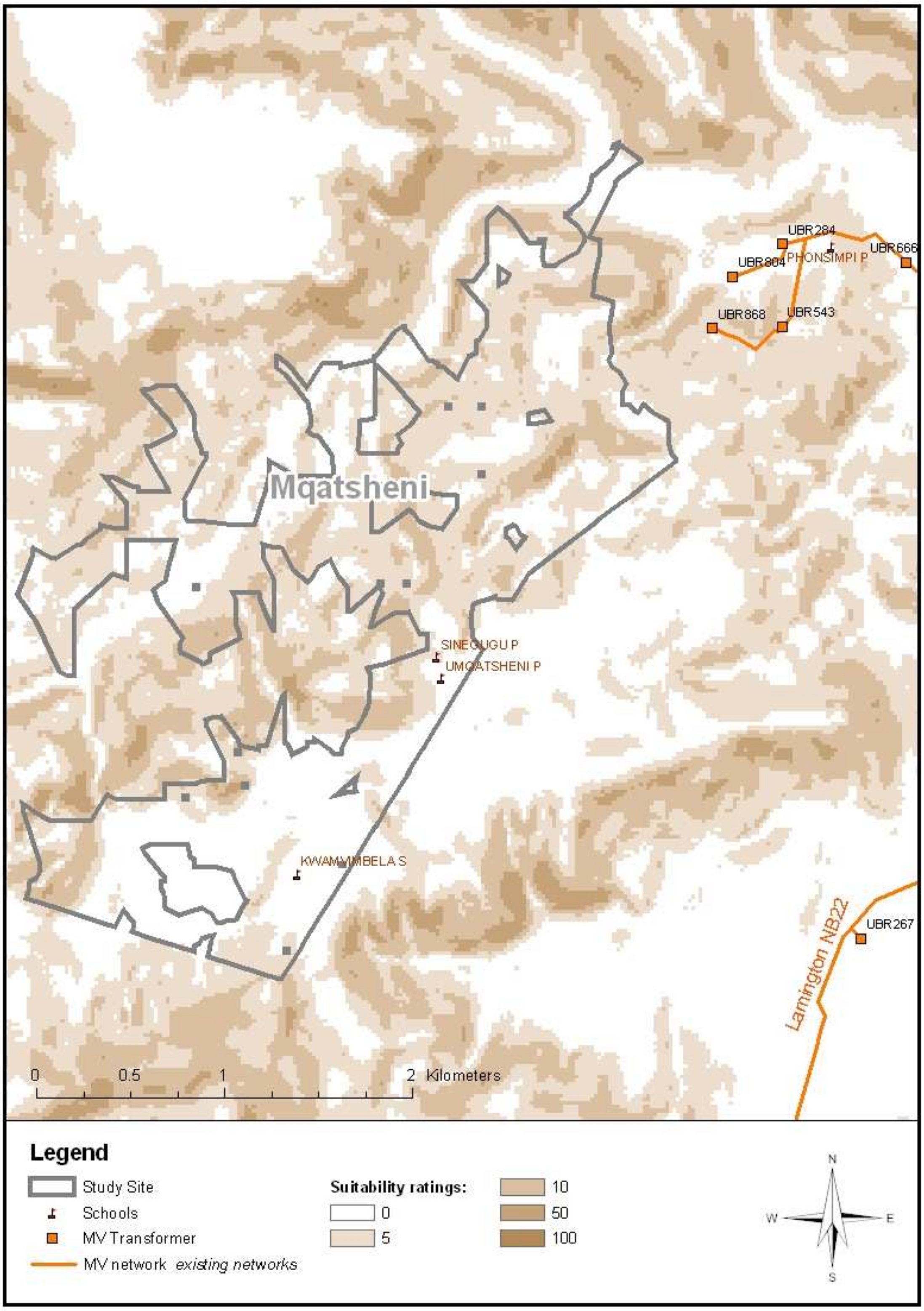
Slope	**Suitability rating (Scale: 0 – 100)**
0 – 10 Degrees	0
10 – 20 Degrees	5
20 – 30 Degrees	10
30 – 40 Degrees	50
40 – 90 Degrees	100

Costs of building a network increase according to slope as more structures and conductor is needed as the slope increases (Eskom Distribution, 2000). These figures were sourced from network planners within Eskom Distribution and are in line with those used in other studies.

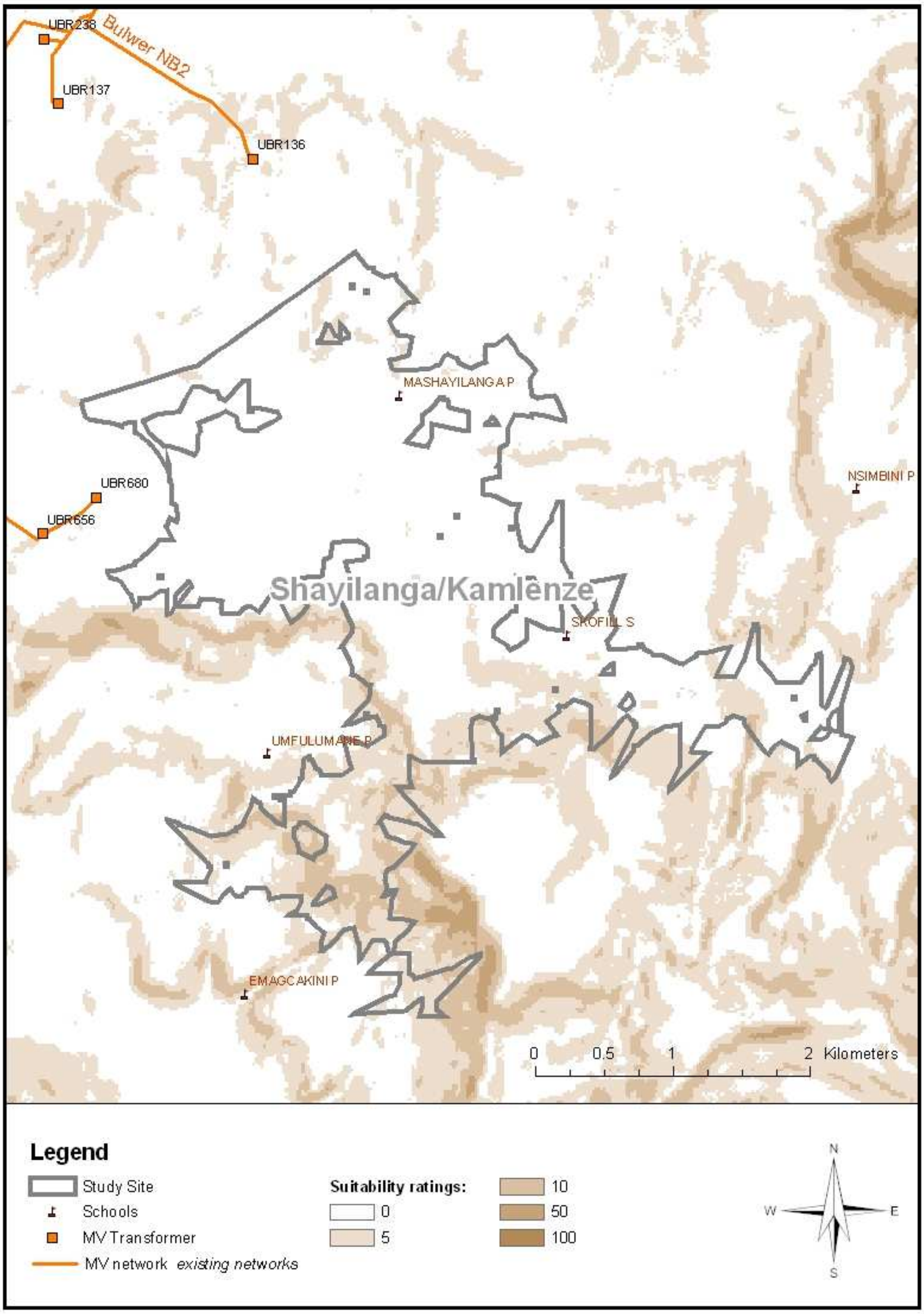
The reclassification of the rasters created from slope data for each study site can be seen in Maps 3.17, 3.18, and 3.19.



Map 3.17: Study site: Mjila: Reclassification of raster created from slope



Map 3.18: Study site: Mqatsheni: Reclassification of raster created from slope



Map 3.19: Study site: Shayilanga / Kamlenze: Reclassification of raster created from slope

3.4.9.5 Creation of Combined Suitability Raster

The raster calculator was used to add together all four raster layers (roads, land cover, households and slope) to create a combined suitability raster layer which could be used to determine the shortest path from a network to a central point such as a school or medical facility inside the FREA. The rasters were added together without weighting resulting in suitability ratings for each raster cell ranging from 0 (most suitable) to 400 (least suitable). The combined suitability rasters for each study site can be seen in Maps 3.20, 3.21, and 3.22.

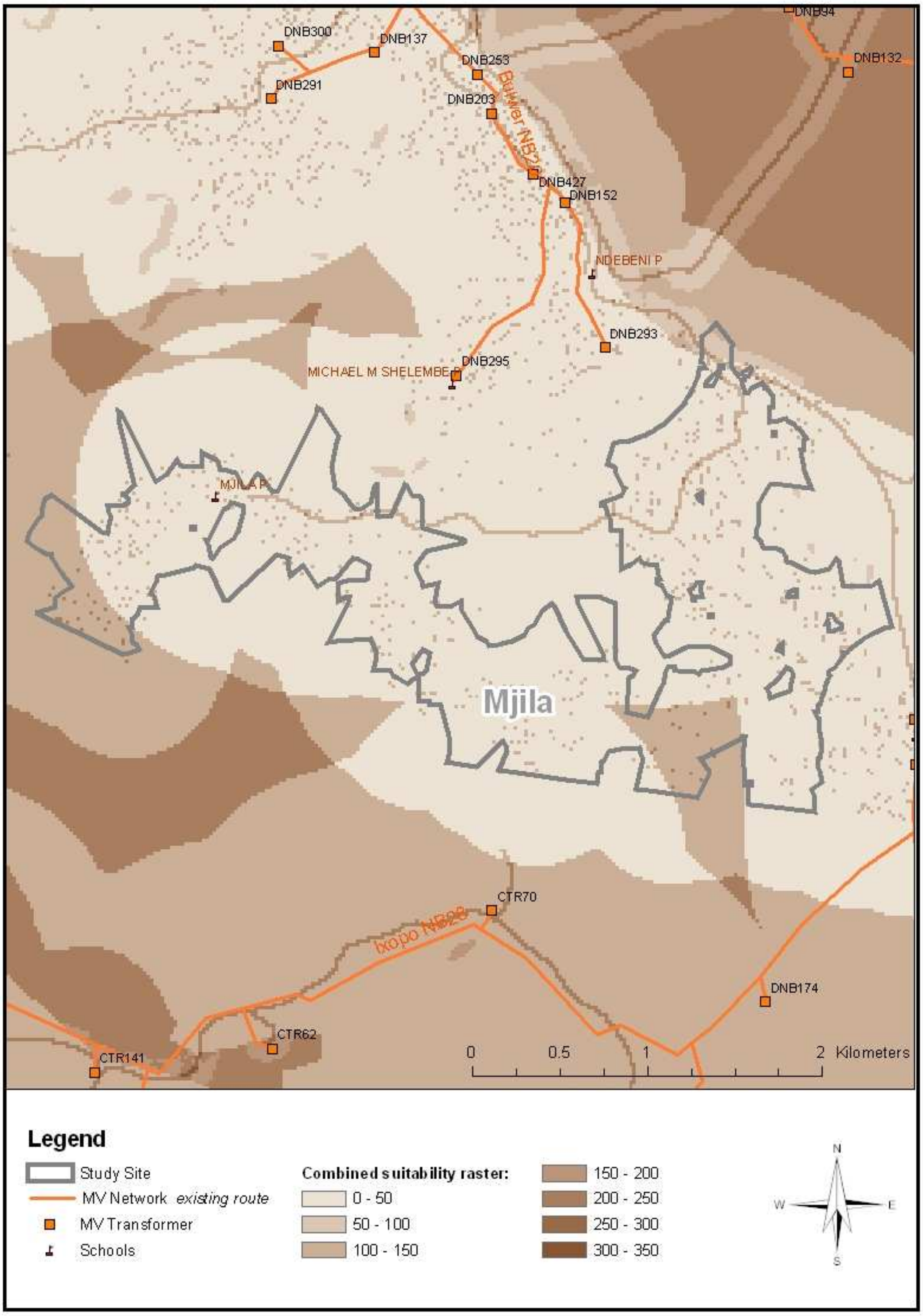
Each reclassified layer was given equal weighting as at this stage no criterion is given more importance than another in practice – all are considered while doing network planning. It is however possible to weight each one differently if required.

3.4.9.6 Cost Weighted Distance

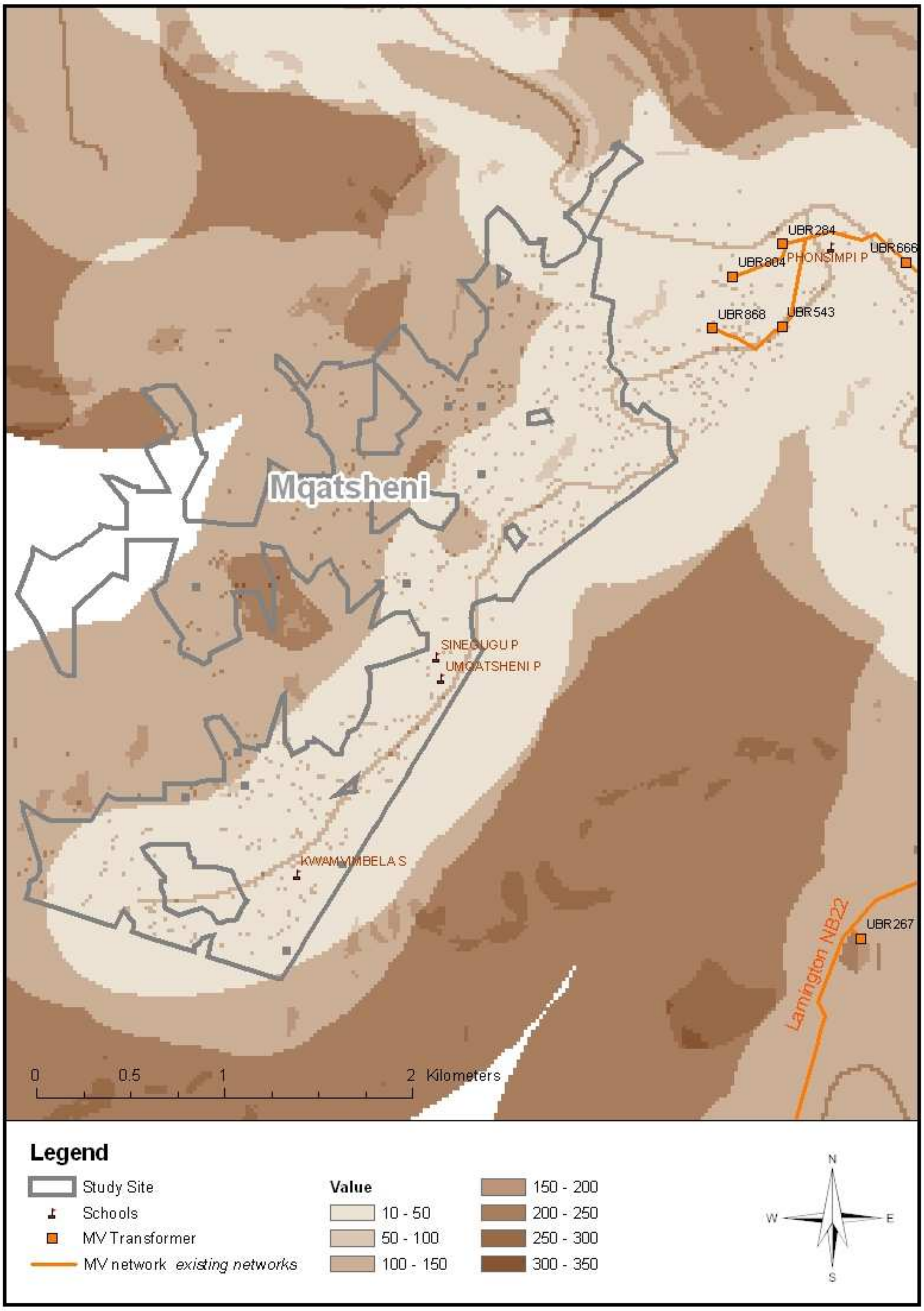
A cost weighted distance raster determines a value for each cell that relates to the smallest accumulated cost of moving from each cell with reference to a source point (ESRI, 2004), for instance, the nearest point on a network. In most cases the nearest transformer on an existing network was used, but a point on the network between transformers could be used if more viable. The combined suitability raster was used to create a cost weighted distance raster radiating out from the nearest source point on a network.

3.4.9.7 Shortest Path

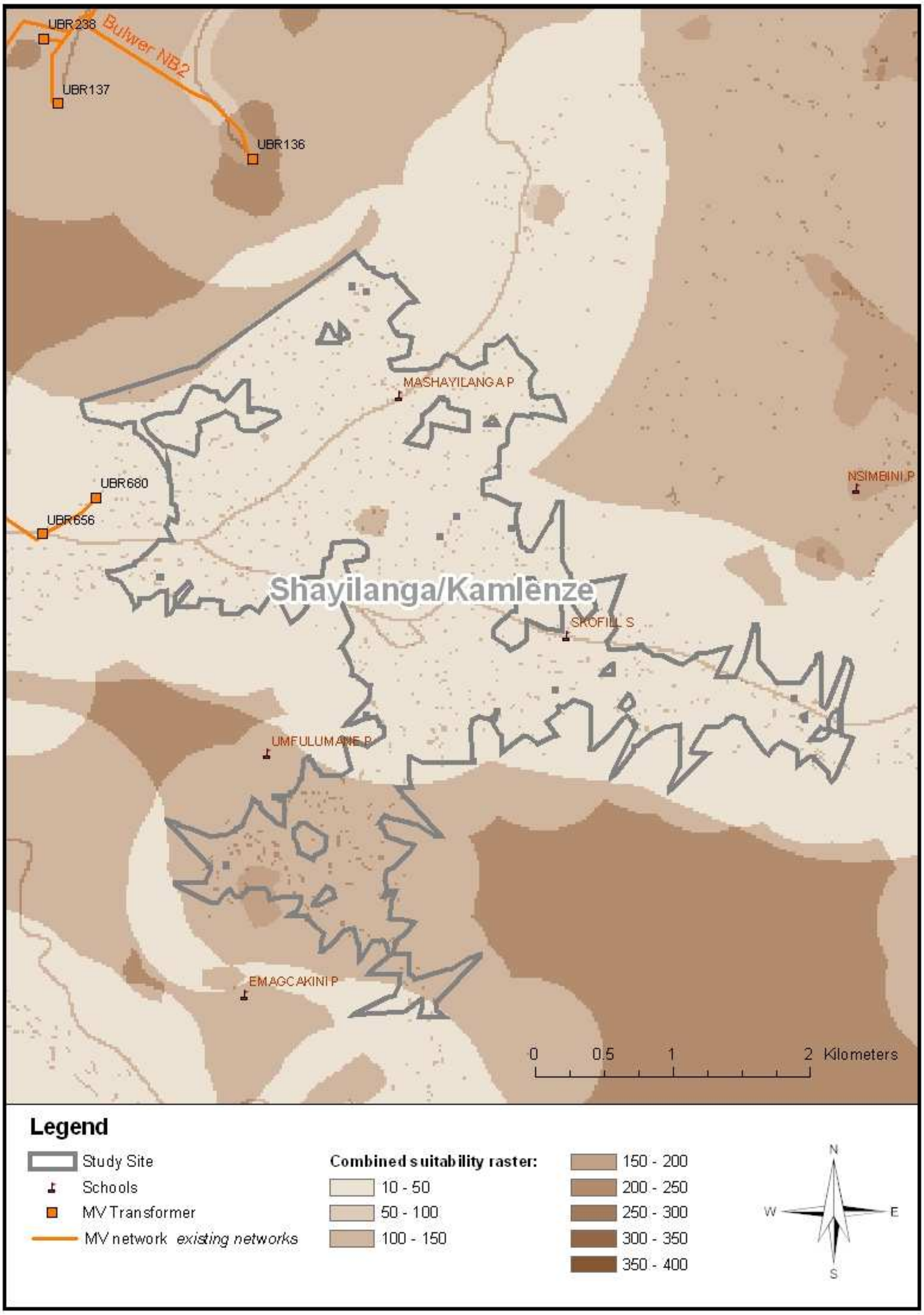
The path from a source point to a destination can be determined using the shortest path algorithm (ESRI, 2004). The cost weighted distance raster was used to determine the shortest path from the source point to a school or schools within each study site.



Map 3.20: Study site: Mjila: Combined suitability raster



Map 3.21: Study site: Mqatsheni: Combined suitability raster



Map 3.22: Study site: Shayalinga / Kamlenze: Combined suitability raster

3.5 Summary

This chapter has endeavored to show how a framework could be developed using GIS – firstly to identify and prioritise areas that need electrification, and secondly, to plan the shortest path from existing networks with spare capacity to central points within such areas taking various factors into account.

Eskom records do not define current customer areas, so areas that still need electrification had to be deduced theoretically. Most outstanding electrification areas are informal rural and that total fragmented area was defined for KwaZulu-Natal as per the 1996 election data. From that dataset, Ethekwini Metropolitan Municipality was excluded as were current electrification project areas, transformer zones (assumed to be part of the current customer base) and reserves as protected areas. The balance of the study area was polygonised as per the household positions to identify dense areas which could be assumed to be settlements of people.

Network planning has historically involved consideration of a number of criteria and these include slope, density of households, schools, quality of roads, and many more. However, the network planner currently works predominantly off aerial photographs and maps, using scale rulers and making visual comparisons of the data. The results show that it is vital that all network planners begin to use GIS as demonstrated in this study, as not only will it speed up this part of their process, additional functionality will enable them to see further patterns through analysis and therefore make better business decisions.

The results of this study and discussions of those results follow in Chapter 4.

Chapter 4: Results and Discussions

4.1 Introduction

There is a need for proper planning of electrification projects and through this study a list of 34 focus areas was determined through a weighting and elimination process that successfully identified areas that could be considered for electrification almost immediately. These areas could now be assigned dates for connection and municipalities informed when areas are to be electrified. This would in turn assist local municipalities in structuring their internal planning for other service delivery.

Municipalities who have received funds for electrification or have other service delivery planned for an area can approach Eskom for consideration to move individual communities up the list for earlier connection in accordance with their IDP. The methods used here could be applied to form the logical foundation for developing a more stable system for electrification planning from a supply perspective that at the same time is flexible enough to add or remove external criteria on the demand side to test different options. For instance, if other projects such as roads, water provision or sanitation are planned for an area, they should have a positive effect on the prioritization of electrifying that area.

In the sites chosen for further studying in order to perform network planning, the results confirm that it is unlikely the shortest path between two points will be a straight line. In order to avoid steep slopes, ecologically sensitive areas, and other criteria, it may be more cost-effective and practical for a network to meander.

Currently network planning in Eastern Region is predominantly done manually using maps, aerial photography and site visits and is prioritised mainly on demand from municipalities, distance from the grid and capacity of the nearest network to feed extra customers. This process could be significantly shortened and the approach standardized by using GIS.

Setting up such a system should be done jointly by all relevant professionals, as each would recognize certain requirements as being important from their particular aspect. A company's professional engineers, environmentalists, and planning specialists, amongst others, should therefore discuss each criterion, and its weighting and point allocation so that decisions made using the tool will be accepted by all as being the best decision possible. It is also important that the tool be applied, as it is only through that use that it can be continually modified to cover all aspects needed. Only then will a tool be developed that will be of the most benefit to the company.

4.2 FREA - Identification and Prioritization

Dissolving the boundaries of the 1996 informal rural enumerator areas of KwaZulu-Natal resulted in fragmented polygons from which Ethekwini Metropolitan Municipality, current electrification areas, reserves, and transformer zones were excluded to successfully determine rural areas requiring electrification. For electrification, clusters of households then needed to be identified in order to place transformers and plan networks.

There are a number of ways to determine areas of density; and using voronoi polygons did succeed in identifying areas within the case study area that need electrification and through this process, 8427 FREA were determined. A points rating system was applied to schools and medical facilities in each FREA and household counts added making it possible to sort the list into priority order. The maximum points scored were 2995.64 for an area west of Pietermaritzburg and north of Edendale, which contains 2529 households, one medical facility, and 8 schools with a total of 4724 students. The lowest point scored was 1 which was by isolated households spread across the province.

In practice, the lowest number in a grouping of households that would usually be electrified is 10, electrifying less than this number would possibly mean that one or more households is related to farming, business or a medical facility or school. Out of the list of 8427 FREA, only 1583 contain more than 10 households, which means that less than 19 percent of rural areas needing electricity will normally be considered. However, using GIS to run a simple query ascertained that of the 6844 FREA containing 10 households or less, more than 50 percent were within one kilometre of a network, which would reduce the cost of connection and therefore these areas could be considered.

Although each FREA was prioritised according to a points and weighting system, a number of constraints to the original list of 8427 FREA, that could affect their immediate electrification, still needed to be considered. An important criterion was that the average density of an area must be greater than 30 households per square kilometre (Carter-Brown, 2004). The average density as calculated for the households was averaged for each FREA, and 1780 (21%) were found to have an average density greater than 30 households per square kilometre. A constraint was that the FREA should be within 30 kilometres of a substation with an outgoing voltage of at least 22.00 kV and applying this constraint resulted in 1110 (13% of the original total) FREA being suitable for immediate electrification.

Actual network performance is based on daily running and includes a number of conditions including fault levels, feeder voltage, thermal rating limits and load flows. These factors from various sources are currently combined into a power system simulation study. All studies are currently filed for future reference and extensively reused as a basis for network extension. A database needs to be designed that is continually updated and easily accessed as in reality planners struggle to obtain accurate load related information in a usable format (Eskom Distribution, 2003). The 'rule-of-thumb' method used was to exclude networks that already serve in excess of 3000 customers as to connect more customers would result in those networks being overloaded. Out of 696 networks, 39 (5.6 %) were found to supply more than 3000 customers, the maximum being 10013 customers which is already a serious overload. All FREA that were near to these 39 networks could not be considered for connection until either a new substation or network is built in order to split the load. 556 FREA (6.6%) had to be excluded to comply with this constraint leaving a total of 554 FREA which could be electrified immediately.

Lastly, all FREA that contained one or more schools were selected and shortlisted as being priority areas for connection, which resulted in 34 FREA containing a total of 6247 households for urgent consideration (see table 4.1). Once these areas are planned, the other 522 FREA can be considered; and depending on the work needed to remove the constraints on the rest of the 8427 FREA identified, dates must be assigned for their electrification at a later stage.

Table 4.1: Final list of rural electrification areas in descending order of total points

Average Density	Households	Medical Facilities	Schools	Schools Points	Total Points	Municipal Sub Place Name(s)
68.25	792	0	2	112.35	904.35	Shayilanga / Kamlenze
75.77	474	0	3	83.51	557.51	Mqatsheni
74.81	502	0	1	51.06	553.06	Ngwangwane / Mfulumane
87.81	519	0	1	25.82	544.82	Mjila
74.26	480	0	1	41.08	521.08	Mgetane
57.79	398	0	1	78.08	476.08	Qulashe
90.01	370	0	2	54.88	424.88	Sizanenjane
102.73	366	0	1	17.14	383.14	Mhlungwana
106.28	304	0	1	43.88	347.88	Emadrisini
90.61	285	0	1	31.89	316.89	Mqundelkweni
109.00	267	0	1	37.99	304.99	Mkobeni / Kamensia / Chibini / Mhlatini
145.50	239	0	1	16.26	255.26	Bethlehem
40.50	32	0	2	202.57	234.57	NONE
37.09	32	0	3	152.99	184.99	Sonkonbo / Esigodi / Abejuti
94.81	119	0	2	44.21	163.21	Mqulela
72.27	114	0	1	47.69	161.69	Ndindindi
48.91	117	0	1	20.10	137.10	Kwa-Nokweja
43.07	91	0	1	45.33	136.33	Fakude
52.66	113	0	1	19.08	132.08	Makhambane
47.23	77	0	1	31.74	108.74	Mbudle
35.49	96	0	1	11.02	107.02	Ntontonto
47.92	36	0	1	66.05	102.05	Maduladula
41.34	56	0	1	44.43	100.43	Mbambankunzi
38.05	22	0	1	77.14	99.14	Cobe

Table 4.1 Continued:

Average Density	Households	Medical Facilities	Schools	Schools Points	Total Points	Municipal Sub Place Name(s)
53.76	67	0	1	31.89	98.89	Isigcalaba
45.02	64	0	1	15.63	79.63	Nkothweni
79.52	50	0	1	20.33	70.33	Emnywaneni
30.50	32	0	1	31.20	63.20	Nomcondo
30.53	34	0	1	27.10	61.10	Rhebokfontein
30.44	16	0	1	41.52	57.52	Shudu
30.39	23	0	1	25.48	48.48	Ogedhleni
33.70	20	0	1	28.10	48.10	Amahlungulu
38.51	35	0	1	12.28	47.28	Sonkonbo / Esigodi / Shudu
36.40	5	0	1	14.74	19.74	Nkothweni

4.3 Shortest path from an existing network to a central point in a FREA

For routing a new network, four criteria were considered, these being household positions, land cover, slope, and proximity to roads. Weighting and overlaying these four layers in a combined raster enabled the calculation of a cost weighted route from the network to schools in the study sites. Initial estimations for electrification of an area must be within 65% of the final cost (Eskom Distribution, 2000) and GIS can help to make this far more accurate. As evidenced in Shayilanga / Kamlenze, the second route between the schools is shorter than running the connection along the road, an option not always obvious without using GIS.

4.3.1 Mjila

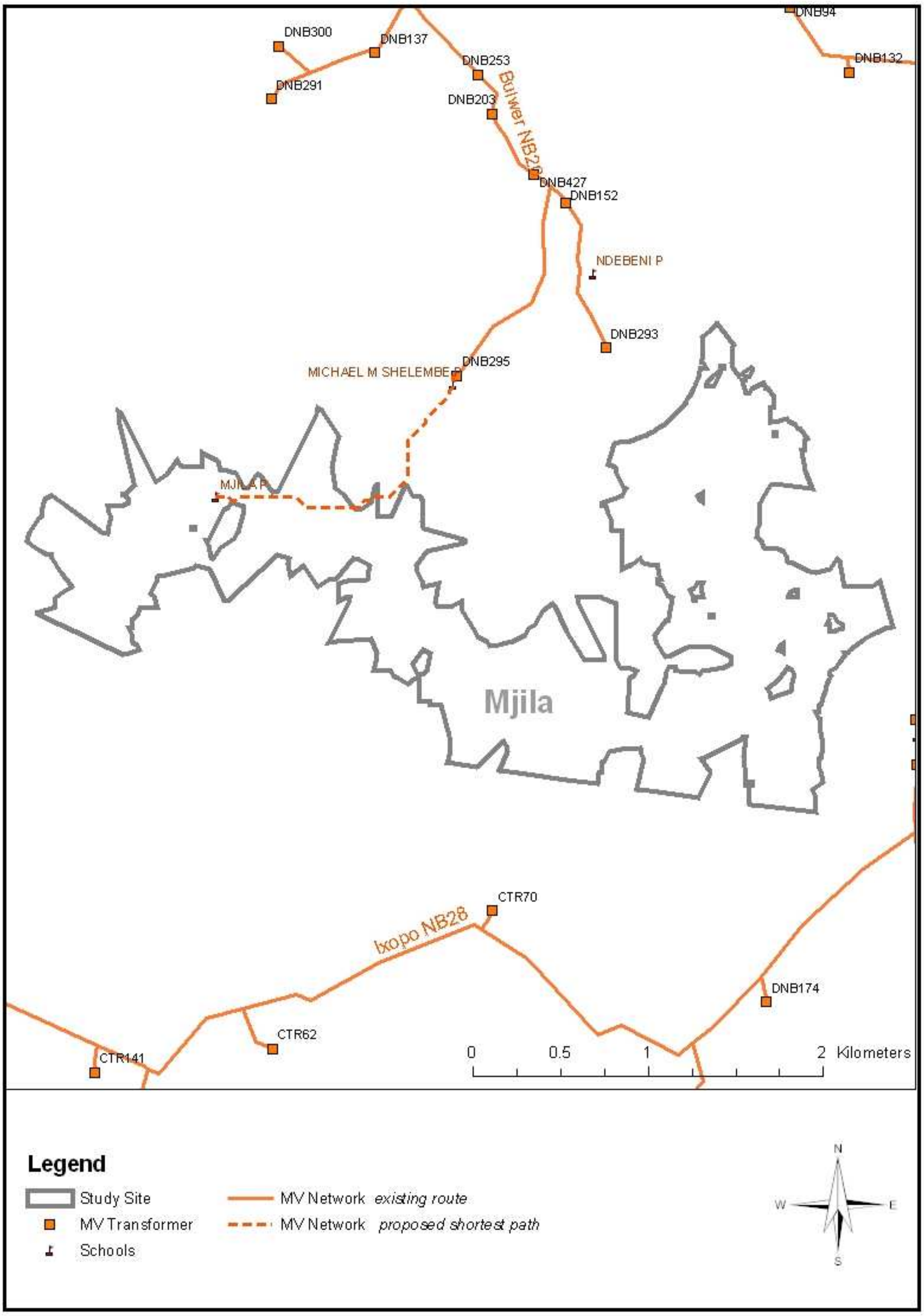
In Mjila, the electricity networks that run closest to Mjila Primary are Bulwer NB20 and Ixopo NB28. Bulwer NB20 was chosen to supply Mjila as the network was found to have capacity to support around 1200 more customers – suitable for extension, whereas Ixopo NB28 already has over 4700 customers - far in excess of the approximate allowable limit of 3000, which meant that it was not considered. The final route is shown in Map 4.1. If Ixopo NB28 had had surplus capacity, analysis would have been done for both options as the result from Ixopo NB28 to Mjila Primary may have produced a shorter path than the one from Bulwer NB20 to Mjila Primary, despite the fact that the nearest point on Bulwer NB20 - DNB295 - appears closer in terms of straight-line distance.

Initially, the network extension needs to navigate a hill with slopes of up to 40 degrees. Weighting the slope ensured that steeper slopes were successfully avoided and only a small section ran through a slope of between 20 and 30 degrees where it was unavoidable. The Electrical Power Research Institute (EPRI) and Georgia Transmission Corp. (GTC) study identifies slopes of between 0 and 15% as being desirable, 15 and 30% as less desirable, and over 30% as undesirable (Glasgow *et al*, 2004). Using this weighting would give a similar result.

The weighting of the road ensured that as soon as the proposed network came near to the road it largely followed it along the edge – a desired result due to easy access for maintenance, more desirable gradient, and less legal issues with networks cutting through properties. Land cover in Mjila is predominantly divided between unimproved grassland and temporary cultivated subsistence farming. As both were allocated 10 points in the reclassification of the land cover raster, land cover had no effect on the derived position of the network extension.

Scattered households between DNB295 and Mjila Primary School were taken into consideration in that points allocated ensured that the network extension was not planned through a house, but ran near to houses so that they could easily be connected.

The combined raster added the reclassified rasters of roads, land cover, households and slope together to create a raster where each pixel was allocated a sum of the points. The final step was to run a process that determines the shortest path while traveling through the pixels with the lowest value and this created the path as shown in Map 4.1.



Map 4.1: Study site: Mjila: Shortest path from Bulwer NB20 to Mjila Primary School

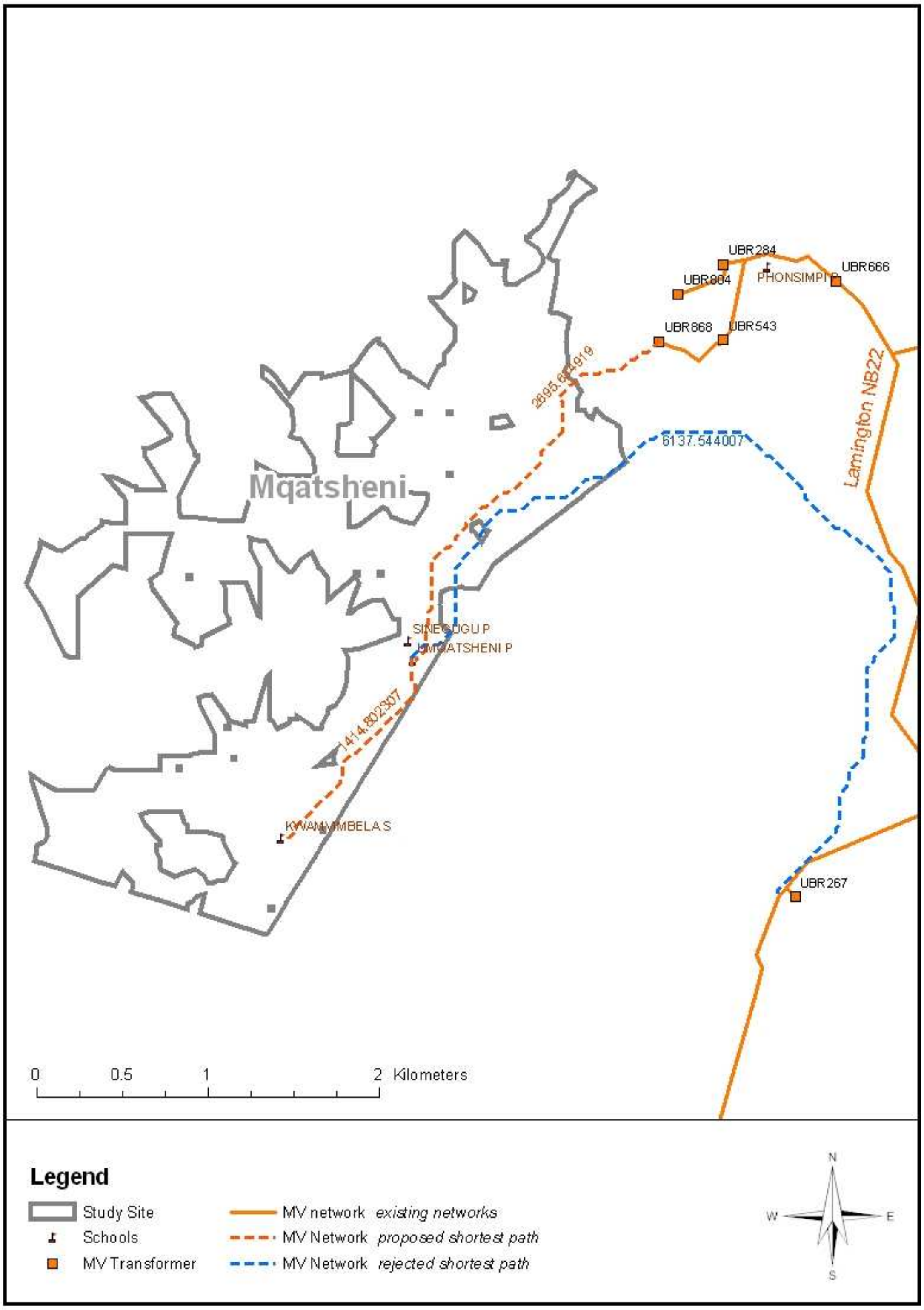
4.3.2 Mqatsheni

Mqatsheni is near to only one network – Lamington NB22, and two points on the network could at first glance be seen to be equidistant from Mqatsheni Primary School. However determining the cost weighted route from UBR868 resulted in a line of 2695.63 metres while the line from the nearest point between UBR267 and UBR666 resulted in a line of 6137.54 metres as the network would have to go around a slope of 30 to 40% and the latter was therefore rejected. Map 4.2 shows the comparison.

A road runs close to UBR668 and continues past all three schools and as expected the final route ran close to that road. Land cover in Mqatsheni is predominantly unimproved grassland with pockets of forest plantations. The first part of the network extension between UBR668 and Sinegugu and Umqatsheni Primary Schools avoided the forest plantations, which was the desired result. Between the transformer UBR668 and the schools are areas of relatively high density - on average 100 households per square kilometre. The network found a path through the households that runs near to them but not through them.

Along the proposed route there is only one area where the slope is over 30 degrees which was avoided by the result. The extension did go through an area where the slope is between 20 and 30% - deviating from the road and it may be better to follow the road where the slope is mainly between 10 and 20%. It may be that the divisions and allocation of points to those divisions for slope need to be discussed and applied to a number of different scenarios before a standard can be found for this criteria.

Routes calculated from UBR668 to Sinegugu and Umqatsheni Primary Schools had a similar result – so either could be used. The two schools are only approximately 117 metres apart – so could possibly be served by the same transformer. From there, the route to Kwamvimbela School is predominantly at a slope of less than 10%, with no forest plantations and the result therefore followed the road in most places except where it needed to avoid going through households.



Map 4.2: Study site: Mqatsheni: Shortest path from Lamington NB22 to schools in Mqatsheni

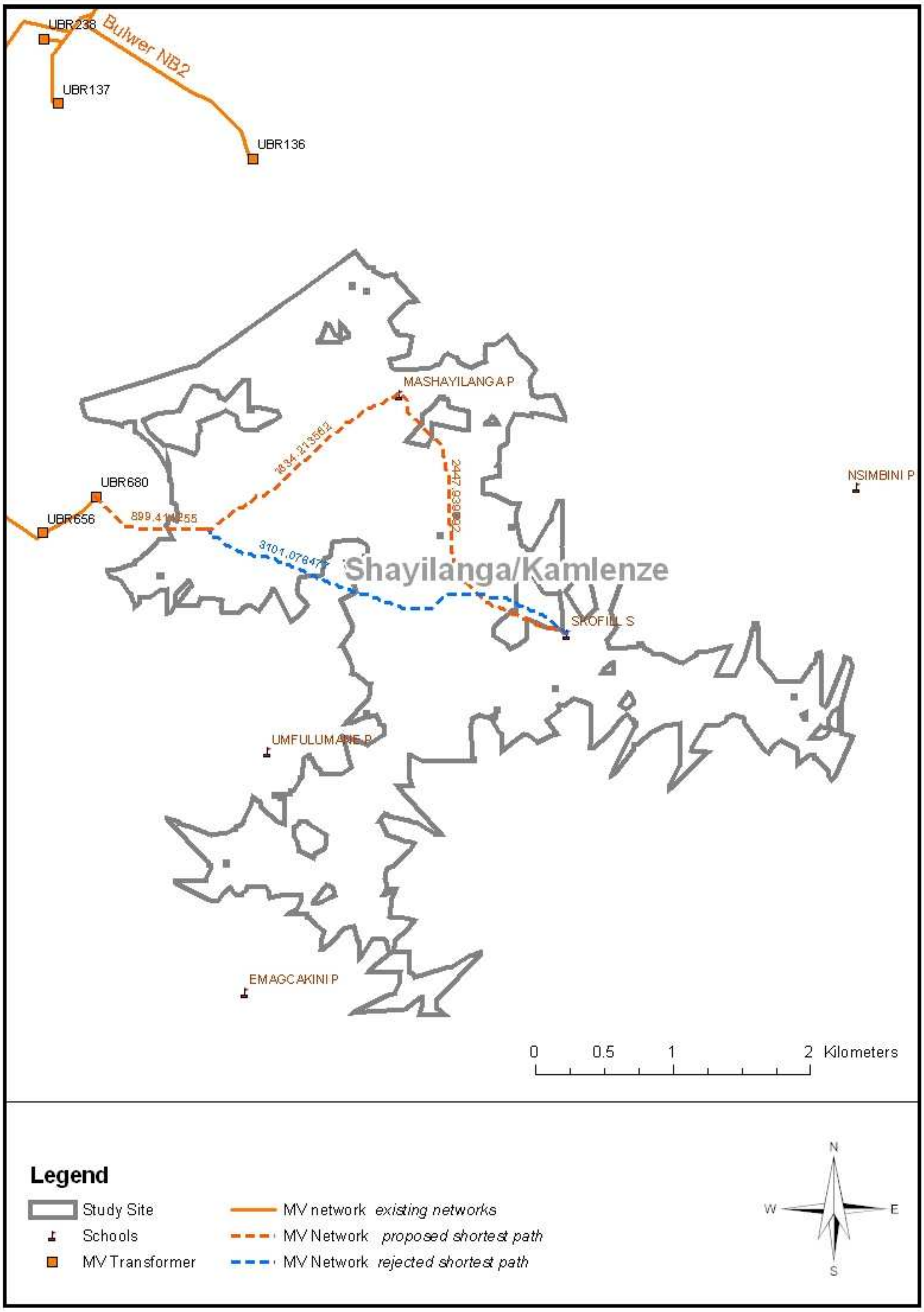
4.3.3 Shayilanga / Kamlenze

Shayilanga / Kamlenze area is closest to UBR680 on Bulwer NB2 so the most logical start point was to extend the network from that transformer. This area has two schools with a large number of pupils – namely Mashaliyanga Primary School (889 pupils) and Skofill School (342 pupils). Over 52% of the people living in the ward this area falls in are under 15 years old.

The two schools and transformer fall roughly in a triangle so different routes could be considered. Initially two paths were derived; from the transformer to the two schools and then a third, which ran between the two schools. Comparing the results found that the shortest path would start at the transformer, run via Mashaliyanga Primary School and end at Skofill School. Apart from the fact that this area scored the highest number of points, it was chosen as a study site due to the arrangement of the nearest point on the network and the two schools needing to be electrified.

As with Mjila, land cover in this area is predominantly divided between unimproved grassland and temporary cultivated subsistence farming which were allocated the same number of points so land cover will not have an effect on the outcome. Most of the slope is between 0 and 10% so slope will not be a factor in determining the optimal route.

Household density along the extensions is relatively high (in places around 80 houses per square kilometre) – and the network extensions had to avoid going through those households. Map 4.3 shows the results for Shayilanga / Kamlenze.



Map 4.3: Study site: Shayilanga / Kamlenze: Shortest path from Bulwer NB2 to schools in Shayalinga / Kamlenze.

Chapter 5: Conclusions and Recommendations

5.1 Summary

The provision of services including electrification can reduce the migration of people from rural to urban areas (DME, 1998, Tshering, 2005) where they would stand a greater chance of employment. The availability of electricity in a village can foster the growth of existing small business and agriculture (Clark, 2002), greatly ease the burden of collecting fuel especially on women in rural areas and some of the health issues (especially respiratory) arising from the use of that fuel (Sepp, 2005). One of the key needs for the improvement of economic activity in poverty stricken rural areas is electrification (DME, 1998, Gehl, 2005) and public funds are now being allocated to Eskom and the Municipalities for the electrification of rural areas and to subsidise basic electricity, which relieves the financial burden on Eskom, who financed much of the electrification up until 2001 (Basson, 2003). In the past Eskom Distribution has predominantly electrified areas of densities greater than 70 households per square kilometre, large municipalities, agricultural and industrial businesses, and villages with a relatively high income – where they were virtually guaranteed a return on their investment. This calls for a turn around in thinking as Eskom now needs to consider electrification in areas where there is extreme poverty, to assist in building infrastructure and realizing future economic growth (Gaunt, 2005).

The promise of universal access for all to electricity by 2012 and ensuing subsidies by the government for basic electricity means that all communities near the current MV grid must now be considered for electrification. And although the Department of Education and Culture Master Strategic Plan 2003 – 2006 (DEC, 2003) cites limited financial resources as being a factor affecting service delivery and that 60% of schools have no power supply, as of October 2005, only R 37 million out of R 129 million allocated for electrification had been transferred to municipalities as some were still working on 2004/2005 and even 2003/4 projects

(AMEU, 2005). Eskom, on the other hand, have spent their full budget of R277 million for 2005 and need to consider assisting those municipalities with planning.

5.2 Conclusions

Electrification planners have in the past managed to identify FREA, largely through requests from external users such as local and district municipalities. However, it has become increasingly evident that planning those new electricity connections primarily from demand is not always sustainable, as some projects are partly planned and then have to be abandoned due to a lack of capacity in nearby networks (Bunge, 2005). In addition, very little comparison is done between the common needs of these projects and often more contact and complaints from municipal managers and communities results in certain projects being prioritised, sometimes unfairly.

In an attempt to devise of a fairer system, this study used GIS to identify the main focus areas for electrification within rural KwaZulu-Natal, and then broke them down using average density into smaller areas which could then be grouped and prioritised according to a points and weighting system. This identified possible FREA from a demand side using a far more practical and impartial method.

The next logical step was to further analyze and prioritise FREA from a supply perspective and GIS was used to prioritise each FREA according to household density, the presence of schools and medical facilities, nearest network capacity and distance from the nearest 22.00 kV substation. This analysis resulted in a list of FREA that can be electrified immediately and needs to be repeated using varying values to further prioritise the rest of the FREA in terms of the resolution of the aforementioned constraints to the supply of electricity. For instance, if a FREA is near to a network that has no spare capacity, studies need to be done to determine a resolution to the problem and a date assigned as to when that constraint can be removed and the area electrified.

There are a number of ways in which to prioritise electrification planning projects using GIS and the best approach would be to involve engineers and other professionals in determining which criteria are important and deciding on weightings. Many other criteria such as small businesses or farming enterprises in an area or imminent public works projects can be added in using the points system to refine the prioritization of electrification. A key requirement for the successful use of a GIS for planning is also the accuracy of data (Thompson *et al*, 2001); and common standards and collection of such data for use between departments in an organization, and external business and other service providers are vital.

Three areas from the final shortlist of FREA were selected and analysis techniques applied to show how the shortest path in terms of roads, land cover, household positions and slope could easily be determined to a central point within those areas by using GIS. In each case a school (or schools) was used as a central point, but in practice, any logical central point could be used or a centroid determined from groupings of households. Existing practice involves working with a number of paper maps, aerial photography and a scale ruler; and standards applied vary according to available data. The process used in this study defined the optimal path in terms of the same constraints considered in each case and would be a far more accurate and quicker method to consider using.

Currently, plans already far advanced have to be put aside from time to time, due to various reasons such as a lack of capacity, and when those constraints are resolved, the entire project has to be researched and replanned due to changes on the ground. However, if a FREA plan created using the principles in this study has to be put aside for any reason, it would be relatively simple to rerun the analysis with new data. In essence, electrification plans could be created now for every area determined and prioritised in this study, and the planners could keep those plans up to date by rerunning analysis as new developments are planned or growth in areas takes place.

Using GIS for electrification and network planning would completely revise current methods used and result in viable planning for network extensions where there is still currently spare capacity. Where no spare capacity exists, GIS can be used for identification of overloaded networks and ideal placing of new substations.

5.3 Limitations of the Study

Some of the results arising out of this study could be questioned in terms of the extent of the study area, age (especially household data), and quality (land use data) of some of the data used, and the exclusion of transformer zones. In addition, demographic data was not used as a criterion due to the high level of statistics only being available to a ward level at the time that this study was done. Statistics South Africa has since released a Small Area dataset that has demographic details for much smaller areas, and it is vital that dataset be considered in order to determine poverty levels and needs for each FREA.

Data on household positions was not previously collected in more formal rural areas. However, there are possible FREA in formal rural areas where communities have grown around farm workers, schools and clinics have been built, and therefore the whole of the region should now be considered.

In February, 2006 the recapture of household point data for the municipality of Umhlabuyalingana was financed and completed as a test pilot to check the household count. In the 1996 dataset there are 17598 households and in the 2006 dataset this number has increased by 70% to over 30000 households. This result led to the recapture of the household for the whole of Eastern Region and an increase of approximately 100% overall confirms that to be at all useful, the household data needs to be maintained more regularly. In fact, this recapture was digitized off aerial photography up to 4 years old, meaning that the new household dataset, while now offering full coverage, is already out of date. Investigations are currently underway into entering into partnership with a group of government departments headed by the CSIR to purchase satellite imagery and to use remote sensing methods to determine household positions.

The generally accepted assumptions on transformer zones (Eskom Distribution, 2000) also need to be reconsidered. Recent analysis has shown that in some cases, transformers have been placed to electrify only one household (possibly a school or clinic) and surrounding households within 550 metres have not been electrified. A comparison check on counts of customers connected to transformers with the count on households within the 550 metre transformer areas in the recaptured area of Umhlabuyalingana municipality found that only a third of those customers are connected. A first comparison run overall on the new household data comparing it with the customer data shows that a quarter of outstanding connections are within 550 metres of a transformer. This may be due in part to customer data accuracy but this exercise needs to be repeated in more detail to determine where customer data needs to be verified and where there is possibility of infill projects.

However, it is felt that the methods used in this study are sufficiently sound enough to be used to initiate spatial analysis in electrification and network planning and should be rerun on the whole of Eastern Region as soon as more recent and better quality data is available.

5.4 Recommendations

Using GIS to identify and prioritise areas for connection to the existing electrical grid must take into account all relevant standards and requirements in order to be effective. The resultant areas for future development can then be built up into an explicit long term plan. Once identified, those areas can then be planned using GIS - in order to define cost effective routes easily in terms of all the constraints currently considered when designing building electricity networks to customers.

5.4.1 Database structure

It is vital that a business data model and structure be independent of all software run on the system. It has been experienced by several companies that one GIS package often does not have all the capabilities required and therefore, for certain business operations or one off projects, they purchase a number of licenses for alternate software. It is important that spatial modeling and information management are both considered equally important when designing an effective GIS.

A comprehensive needs study and analysis of the entire business is therefore essential to successfully create a robust data model totally independent of software and this can be done using open source (Ahmed, 2006). A number of GIS projects introduced into business fail or continually need to be redesigned because all user problems, workflows, needs and requirements were not properly identified or considered at the outset (European Commission, Undated).

5.4.2 Data Quality

Internationally there has been a trend towards the privatisation of utilities and, in order to remain competitive, utilities are starting to realize the urgency of looking at all facets of managing business data; including where it sits, quality, data structures and accessibility; and to begin connecting that data spatially to use GIS as a strategic resource aligned to overall corporate strategy. There is increasing pressure on utilities to manage assets within operational, safety, environmental and performance standards and a well structured GIS can do this effectively.

If data structures are sound and existing data has been verified to ensure quality of the data used, sound business decisions can be made based on the output of an information system. Currently when a new application is added to Eskom's system, either a new object or attributes are added that have to be captured, or changes are made to objects requiring amendments to the data structures (usually automated but sometimes manual) and these changes are considered and made one at a time. In some cases there is duplication between different systems and every time changes are made to one system, extensive work has to be done to reconcile the data in others.

The basis of a well constructed information system is the data itself and results are to a high degree also dependant on the awareness of the user regarding the quality of that data (Thompson *et al*, 2001). At Eskom, engineering data has already been verified by the linking of electrical to survey data for importing into the GIS, and anomalies at the time of import were resolved by field checks. However, no definite process has yet been put into place for the maintenance of that data and more needs to be done to ensure that standards are adhered to and that maintenance of the data is done as quickly as possible. Customer data was linked to the transformer data and displayed spatially for the first time as part of this study and one of the findings was that approximately 15% of transformers did not link to a record in the customer database. An exercise in validating every customer against each transformer number needs to be done and such a project could be done using metre readers (Newhouse *et al*, 2004) or through a stand-alone project.

5.4.3 Electrification Planning

Creating a long-term rural electrification plan is difficult when relying on requests from prospective customers. Using a GIS can effectively identify and then prioritise such customers both from a supply and demand aspect. Methods used to identify and prioritise electrification areas need to be dynamic and flexible enough to be rerun in response to changes in relevant data.

Potential benefits such as revenue from sales, other planned service projects, health, socio-economic and environmental improvements and savings on installation costs of renewable energy were not considered and research is needed into the need to include such information (Thom, 2000). Most current IDP drawn up by the district municipalities clearly list all projects by area for the next 5 years, and it is vital that this information be recorded and made available spatially so that it can be considered when prioritising areas for all types of service provision.

While prioritising FREA from a supply perspective, it became evident that many areas are near networks already reaching full capacity or too far from a substation to be connected without causing performance problems on that network. GIS should be used to determine optimal placing of new substations or networks from existing substations relative to potential customers. Projects to plan, build and commission those facilities can then be prioritised using FREA priorities and data from Transmission networks (availability of extra energy supply) and completion dates calculated. Those dates can be used to allocate dates for electrification of FREA.

All FREA with dates calculated to be beyond 2012 will need to be assigned as soon as possible to companies that can investigate and install a combination of alternative renewable energy for electrification. These areas need to be monitored by Eskom (Bamenjo, 2002) and defined in the system so that planners can ignore them at the present time. Renewable energy for rural electrification in South Africa is considered to be feasible for solar power, and to a lesser extent, biomass and hydro power in selected regions (Banks *et al*, 2004b), and GIS can also be used to determine the best renewable energy or combination of energies to use until those areas can be connected to the grid at a later stage (Amador *et al*, 2005). There is a concern that solar electricity does not supply the same level of power as the grid and therefore people would reject this form of electricity, but in a survey done in January, 2003; of the houses surveyed 90% were satisfied with solar power and 89% found life easier since its installation (Gothard, 2004) which is encouraging for an interim solution.

However, the original statement made by the South African government was that off-grid electrification must be done in areas where the grid will not reach for a number of years, but the intention has always been that eventually every household will have the choice of being connected to the grid (GVEP, 2004).

5.4.4 Network Planning

Planning the shortest path for an extension to a network is a complex exercise when working manually with a combination of a number of maps, statistics, and constraints. Instead, all standards and current planning procedures could be used to build a network planning tool based on GIS that would standardize analysis and allow the planner to easily compare all constraints in order to accurately determine the shortest path from a selected network to a predefined point or points in a community.

Any number of further optional criteria could be built into the network planning tool to assist in determining the shortest path for connecting new customers to existing networks and in so doing assist in improving network performance and reducing short and long-term costs. These could include conditions such as environmental impact studies which have to be assessed as part of each new network or extension (Eskom Distribution, 2003), and areas with extreme weather conditions which can prove costly in terms of future maintenance. For instance, avoiding areas with extremely damp conditions can extend the life of wood poles and save on costs of early replacement. Care also needs to be taken when incorporating rivers in network planning as only perennial rivers with no bridge near the proposed network position need to be avoided. This could be verified as part of the standard site visit and then added into the network planning tool if necessary.

5.4.5 Partnership programs

The position of every proposed and existing small business and agricultural initiative, together with community centres, orphanages, churches and centres of worship, and dates and the areas for the supply of services from different departments and municipalities needs to be captured and policies on sharing of that data between service suppliers should be drawn up. Then if a road is being upgraded and water and sanitation are being planned for an area, planning the electrification of that area should take these factors into consideration. The provision of services is currently not synchronized and an integrated approach to service delivery at least in terms of electricity, education, health, agriculture, water supply, and transport would provide for more comprehensive and personalised solutions for rural areas (ERC (Energy Resource Centre), 2004).

Rural electrification programs have also benefited from partnerships between communities and service providers and the need for energy centres has already been identified, although to date very few have actually been set up (Clark et al, 2002). Public participation through the use of interactive internet GIS software could be set up to inform and improve communication by recording each others needs, and this could also be installed at energy centres.

5.4.6 Web-Based GIS / Information Management System

The DIMS™ system which is set up to be accessible by staff and contractors over the Internet through passwords defining level of access is an ideal example of a full Information Management System (Intermap, 2005). Also of great benefit would be an interactive map as part of the IMS whereby users could zoom to an area and see projects against networks and other relevant background data. Setting up an internet GIS gives staff easy visual access to company data and a well set up system will also include basic queries and reports for all levels of management.

Many companies have thus far published drawings on their intranet for easy access by staff, but very few have gone further to set up interactive mapping systems over the web, where users can document errors and even redline updates over the intranet (Schutzberg, 2005). Investigation needs to be done into developing a system that can read files live from the database; and a further step would be to publish the results of queries in the form of interactive maps, spreadsheets and graphs over the intranet for easy access by management. A complete User Needs Analysis of the process should be done to define requirements and set up standards for the datasets and queries needed.

5.4.7 Implementing GIS in Business

GIS is now offered as part of most tertiary diplomas and degrees and is being taught from Grade 10 in schools as from 2006. An effective GIS uses understanding, creativity and perspective to sustain decision making (Berry, 2005). Developments in GIS software are ongoing and its capabilities are restricted only by the limits of its designers. The existing specialists within a company, such as engineers, surveyors and environmentalists, need to learn how to apply GIS in their respective fields. A well designed GIS model will satisfy the requirements of all aspects of a company including financial, maintenance, planning, fault management and could even cover staff management. Using GIS professionals only to design a system, will result in a system which will need to be reworked repeatedly to be successfully applied across the business sector.

Utility companies worldwide are starting to appreciate the benefits of using GIS for purposes other than that of facilities management and automated mapping and their experience could benefit Eskom Distribution in restructuring their data model to realize the benefits of spatial analysis. GIS is increasingly being used for managing rural electrification, ranging from basic planning models to full Information Management Systems. Ground breaking practices in using GIS and sharing information with other service providers and local communities are gaining momentum. It is strongly recommended that Eskom Distribution research some of these projects, especially in areas with similar demographics such as in other countries in Africa, with a view to deciding what type of system would be best to use.

It is also Eskom's duty as the largest electricity provider in South Africa to assist in determining where the greatest needs are, and to manage prioritising those needs, designing network extensions and sustaining those enterprises contracted to electrify communities through a strict support and training regimen in order to assist the South African government in building a better life for all.

References

Abdullah, K., 2005, ***Renewable energy conversion and utilization in ASEAN countries,*** Energy Volume 30, Issues 2-4 , February-March 2005, Pages 119-128

AgileWorks (Pty) Ltd, South Africa, 2005, ***Electrification modelling tool***, Available from: http://www.agileworks.net/AgileWorks/services/gis/projects/electrification-modelling-tool, *Accessed: 14 November 2005*

Ahmed, F., 2005 and 2006, ***Pers. Comm.,*** University of KwaZulu-Natal, South Africa

Amador, J., Dominguez, J, 2005, ***Application of geographical information systems to rural electrification with renewable energy sources,*** Renewable Energy for Development, v30, n12, pp1897-1912

AMEU Bulletin, 2005, ***Electrification funding,*** Government Gazette, Available from: http://www.ameu.co.za/library/ebulletin/Bulletin%20October%202005.pdf, *Accessed: 14 November 2005*

Appleyard, D., 2005, ***One step at a time: Electrifying Nepal,*** International Water Power and Dam Construction [online], v57, n1, pp14-17

Bailey, K., Grossardt, T., Jewell, W., 2005, ***Participatory Routing of Electric Power Transmission Lines using the EP-AMIS GIS / Multicriteria Evaluation Methodology,*** (ed) CORP2005: Proceedings of the 10th International GeoMultimedia Symposium 10: 137-142. Vienna, Austria.

Bamenjo, J.N., 2002, ***Energy Sector Privatisation in Africa: What Perspectives for Rural Electrification,*** Presentation to the Second International Conference: Energy for Sustainable Societies, Bogota, Columbia, 25-27 July 2002, Available from: http://www.tni.org/energy-docs/jaff.pdf, *Accessed: 25 October 2005*

Banks, D., 2000, ***Electrification Modelling for South Africa - discussion of the methodology employed - Version 4,*** Rural Area Power Solutions Pty Ltd

Banks, D. I., Aitken, R., 2004, ***KwaZulu-Natal Mini-grid Feasibility Study - Chapter 1: Site Identification and Assessment,*** Rural Area Power Solutions Pty Ltd, Available from: http://www.rapsconsulting.co.za/Downloads/NuRa_Mini-grid_Report_Chapter1.pdf, *Accessed: 23 September 2005*

Banks, D. I., Mocke F., Jonck E. C., Labuschagne E., Eberhard R., 2000, ***Electrification planning decision support tool,*** Rural Area Power Solutions (RAPS), Mockes Business Consultants, Megasub Software Development, Cape Associates.

Banks, D. I., Willemse, J., Willemse, M., 2004, ***Energy services to rural areas - an integrated approach,*** Rural Area Power Solutions Pty Ltd, Available from: http://www.rapsconsulting.co.za/Downloads/Energy-Services-To-Rural-Areas.pdf, *Accessed: 17 May 2006*

Basson, J., 2003, ***Towards a Just South Africa - The Political Economy of Natural Resource Wealth - Chapter 2: Energy Policies and Practices,*** WWF

Macroeconomics Program Office and CSIR-Environmentek, Available from: http://assets.panda.org/downloads/rsabookenergy.pdf, *Accessed: 14 November 2005*

Baumann, J., 2003, ***GIS -- A Light in the Darkness in the Sahel,*** Directions Magazine, Available from: http://www.directionsmag.com/article.php?article_id=340&trv=1, *Accessed: 14 October 2005*

Berry J. K., 2004, ***Beyond mapping – computers quickly characterise spatial coincidence***, Available from: http://www.innovativegis.com/basis, *Accessed: 21 May 2005*

Berry, J. K., 2005, ***Map Analysis - Procedures and Applications in GIS Modelling,*** Available from: http://63.78.10.20/basis/MapAnalysis/Default.htm, *Accessed: 22 September 2005*

Bettes, L., Undated, ***Successfully Integrate Environmental and Transportation Planning ,*** Quantm™, Available from: http://www.geoplace.com/uploads/OnlineExclusives/quantm.asp, *Accessed: 17 August 2005*

Bradbury, D., 2005, ***Computer-savvy retailers plot your habits - geographical information systems replace catchment maps and pins,*** Financial Post, Available from: http://www.dmtispatial.com/pdfs/Computer-savvy%20retailer%20plot%20your%20habits.pdf, *Accessed: 17 June 2005*

Bunge, E., 2005, ***Pers. Comm.,*** Network Planning Manager, Eskom Distribution, Eastern Region

Burt D., 2005, ***Pers. Comm.,*** Information Management, Eskom Distribution, Eastern Region

Bush, R., 1999, ***Five Utilities lead the way to the 21st Century,*** Transmission & Distribution World Overland Park: Jan, 1999, v51, issue 1, pp 14-23

Carter-Brown, C., 2004, ***Eastern Region electrification backlog connection and bulk strengthening Costs,*** Network Planning, Eskom Distribution, Eastern Region (internal document)

Cassim, R., Akinboade O.A., Niedermeier E.W., Sibanda F., Jackson, W., 2004, ***Sustainable Development: The Case of Energy in South Africa ,*** Trade Knowledge Network, Available from: http://www.tradeknowledgenetwork.net/pdf/tkn_energy_south_africa.pdf, *Accessed: 25 October 2005*

Christensen J., Denton F., Garg A., Kamel S., Pacudan R., Usher E., 2006, ***Changing Climates - the role of renewable energy in a carbon-constrained world,*** Renewable Energy Policy Network for the 21st Century (REN21), the United Nations Environment Programme (UNEP), Available from: http://www.ren21.net/climatechange/REN21CC%20rapport.pdf, *Accessed: 02 May 2006*

Clark, A., Drimie, S., 2002, ***Energy Sustainability for South Africa's Poor - Weighing up the Alternatives,*** Human Sciences Research Council (HSRC), South Africa / Nexus, 2002.

Corbley, K., 2000, ***Information is Power: Duke Energy plans to empower its employees to meet the ongoing challenges of industry deregulation by putting as much information as possible at their fingertips,*** GeoWorld, Available from: http://www.geoplace.com/gw/2000/0009/0900ug.asp, *Accessed: 19 April 2005*

Creamer, 2006, ***65 000 MW needed by 2024, says Eskom,*** Creamer media, publisher of Engineering News, Mining Weekly, and Polity, Available from: http://www.engineeringnews.co.za/components/print.asp?id=83386, *Accessed: 31 March 2006*

CSIR (Council for Scientific and Industrial Research), 2004, ***Proposal for linking data to Homer/RE GIS,*** Available from: http://www.dme.gov.za/newscentre/presentations/energy/DME_Homer.pdf, *Accessed: 14 October 2005*

DBSA (Development Bank of Southern Africa), 2005, ***Footprints of Development 2001-2005 - The DBSA's Contribution - "KwaZulu-Natal Municipal Capacity Building Programme",*** Available from: http://www.dbsa.org/document/pAnnualReport2005/FINAL%20-%20Footprints%20report.pdf, *Accessed: 14 November 2005*

De Laborde, G., 2005, ***Pers. Comm.,*** Intermap (Pty) LTD, South Africa

DEC (Department of Education and Culture), KwaZulu-Natal, 2003, ***Master Strategic Plan 2003 - 2006,*** Available from: http://www.kzntreasury.gov.za/documents/strat_plans/Vote05-Education&Culture.pdf, *Accessed: 14 November 2005*

Demarcation Board, 2005, ***SA Explorer,*** Available from: http://www.saexplorer.org.za/about.asp , *Accessed: 21 November 2005*

DME (Department of Minerals and Energy), South Africa, 1998, ***White Paper on the Energy Policy of the Republic of South Africa 1998,*** Available from: http://www.dme.gov.za/publications/wp_ene/whitepaper1998.htm, *Accessed: 20 April 2005*

DME (Department of Minerals and Energy), South Africa, 2004, ***White Paper on the Renewable Energy Policy of the Republic of South Africa,*** Available from: http://www.info.gov.za/gazette/whitepaper/2004/26169.pdf, *Accessed: 25 April 2005*

DME (Department of Minerals and Energy), South Africa, 2006, ***DME Workshop held in the Freestate as part of the Commission on Sustainable Development (CSD)***

DSM (Demand Side Management), 2006, ***Eskom Corporate Communications: series of internal Eskom employee updates on DSM in the Western Cape*** (internal e-mails)

Duke Energy, 2002, ***Duke Power awards mobile GIS project to Mapframe,*** Transmission & Distribution World Overland Park: Mar 2002, v54, issue 3, p 12,

ERC (Energy Resource Centre), 2004, ***Energy for sustainable development: South African profile,*** University of Cape Town, South Africa, Available from: http://www.erc.uct.ac.za/publications/Energy%20for%20sustainable%20development%20%20-%20SA%20profile%202003%20final.pdf, *Accessed: 25 November 2005*

EPRI (Electrical Power Research Institute (USA)): GIS/GPS Workshop, 1999, ***Applications and developments for electric utilities,*** Available from: http://www.epri.com/OrderableitemDesc.asp?product_id=TR%2D113513%2DCD&targetnid=270696&value=05T035.0&marketnid=270628&oitype=1&searchdate=7/21/1999, *Accessed: 27 May 2005*

Eskom Distribution, 2000, ***Distribution standard: Part 1: Planning and Design Section 12: Electrification Design - Rural,*** Revised January 2003 (internal document)

Eskom Distribution, 2003, ***Distribution Planning Training Guide*** (internal document)

Eskom Distribution, 2005, ***Maxi 2 Employee Briefing Pack: Glossary of 70 Frequently Used Terms*** (internal document)

Eskom Distribution, 2006, ***Regional Legend Bulletin, April 2006*** (internal document),

ESRI, 2003, ***Redline Map Editing goes Digital.,*** Energy Currents, Available from: http://www.esri.com/library/reprints/pdfs/enercur-burbank.pdf, *Accessed: 07 March 2005*

ESRI, 2004, ***ArcGIS 9.1 - using ArcGIS Spatial Analyst,*** Chapter 7: Performing spatial analysis

ESRI Energy Currents, 2004, ***Vegetation Management Solutions for High-Voltage Transmission Lines,*** Energy Currents, Available from: http://www.esri.com/library/reprints/pdfs/enercur-nypa.pdf, *Accessed: 18 November 2004*

ESRI, 2006 a, ***ArcNews Online: Electric Utilities turn to ESRI for GIS Solutions,*** Available from: http://www.esri.com/news/arcnews/spring06articles/electric-utilities.html, *Accessed: 15 June, 2006*

ESRI, 2006 b, ***380 New York Street, Redlands, CA 92373-8100,*** http://www.esri.com/

European Commission, Undated, ***Guidelines for Best Practice in User Interface for GIS - Section 4: "Analysis of GIS users, tasks and workflows",*** European Commission ESPRIT/ESSI project no. 21580, Kingston University, England: accompaniment to UniGIS notes "Chapter 9: GIS and Organisations"

Gaunt, C.T., 2005, ***Meeting electrification's social objectives in South Africa, and implications for developing countries,*** Energy Policy, v33, n10, pp1309-1317

Gehl, S. M., 2005, ***Targets and technologies for African electrification,*** 2005 IEEE Power Engineering Society General Meeting, v2, p 1828

GE (General Electric Energy), 2006, ***4200 Wildwood Parkway, Atlanta, GA 30339,*** http://www.gepower.com/

Glasgow, J.; French, S.; Zwick, P.; Kramer, L.; Richardson, S., Berry, J.K., 2004, ***A consensus method finds preferred routing,*** GeoWorld, Available from: http://www.geoplace.com/gw/2004/0404/0404pwr.asp, *Accessed: 15 July 2004*

Gothard, E., 2004, ***NuRA Household Survey Report,*** Elize Gothard - rural development, communication, training, marketing, Available from: http://www.rapsconsulting.co.za/Downloads/NuRa-Household-Survey-Report.pdf, *Accessed: 23 September 2005*

Grimshaw, D., 1994, ***Bringing Geographical Information Systems into Business,*** Longman, Harlow. Extract from: Kingston University, England: UniGIS notes "Chapter 1: Introduction to GIS"

Gullberg, M., Ilskog, E., Katyega, M., Kjellstrom, B., 2005, ***Village electrification technologies - An evaluation of photovoltaic cells and compact fluorescent lamps and their applicability in rural villages based on a Tanzanian case study,*** Energy Policy, v33, n10, pp1287-1298

GVEP (Global Village Energy Partnership), 2004, ***United Nations Development Programme - South African Government Department of Minerals and Energy,*** Available from: http://www.gvep.org/files/11403_Signed_UNDP_Prodoc.pdf, *Accessed: 02 May 2006*

Harder, C., 1999, ***Enterprise GIS for Energy Companies,*** ESRI, Inc. Redlands, CA, U.S.A., CD: ArcFM™ - GIS for Utilities

Holland, R., Perera, L., Sanchez T., Wilkinson R., Undated, ***Decentralised rural electrification: the critical success factors (experience of ITDG),*** ITDG, Available from: http://www.itdg.org/docs/energy/Rural%20Electrification.PDF, *Accessed: 22 November 2005*

Igbokwe, J.I., Emengini, E.J., 2005, ***GIS in Management of Electricity Distribution Network: A case study of Onitsha-North L.G.A., Anambra state, Nigeria,*** Available from: http://www.gisdevelopment.net/application/utility/power/utilityp0022pf.htm, *Accessed: 15 June 2006*

Ilskog, E., Kjellstrom, B., Gullberg, M., Katyega, M., Chambala, W., 2005, ***Electrification co-operatives bring new light to rural Tanzania,*** Energy Policy, v33, n10, pp1299-1307

Ingwe Municipality: 2005/2006, ***Integrated Development Plan,*** KwaZulu-Natal Department of Local Government and Traditional Affairs: Development Planning, Available from: http://devplan.kzntl.gov.za/idp_reviewed_2005_6/ipddisplay.aspx?MDBNAME=KZ5a1&STATUS=Adopted&municname=Ingwe%20Municipality, *Accessed: 02 May 2006*

Intermap (Pty) LTD, 2005, ***DIMS™,*** Available from: http://www.intermap.co.za/Products/dims.aspx, *Accessed: 25 September 2005*

Johnson, E., 2005, ***South Africa Country Analysis Brief,*** Energy Information Administration (EIA), USA, Available from: http://www.eia.doe.gov/emeu/cabs/safrica.html, *Accessed: 25 October 2005*

Juhl, G., 1998, ***Utilities Race for a Competitive Edge,*** GeoWorld, Available from: http://www.geoplace.com/gw/current/598util.asp, *Accessed: 14 January 2005*

Kaijuka, E., 2006, ***GIS and Rural Electricity Planning: a case study Uganda,*** African Technology Development Forum (ATDF) Journal Vol. 2, Iss. 1, pp 23 - 28

Kumar V., Chandra, A., 2004, ***Role of Geographical Information Systems in distribution management,*** Available from: http://www.gisdevelopment.net/application/utility/power/utilityp0013pf.htm, *Accessed: 19 March 2004*

KwaSani Municipality: 2005/6, ***Integrated Development Plan,*** KwaZulu-Natal Department of Local Government and Traditional Affairs: Development Planning, Available from: http://devplan.kzntl.gov.za/idp_reviewed_2005_6/ipddisplay.aspx?MDBNAME=KZ5a2&STATUS=Adopted&municname=KwaSani%20Municipality, *Accessed: 02 May 2006*

KwaZulu-Natal, 2005, ***State of the Province Address by the Honourable Sibusiso Ndebele, Premier of KwaZulu-Natal, Pietermaritzburg***

Lynch, R., 2002, ***An energy overview of the Republic of South Africa,*** Department of Energy, USA - Fossil Energy International, Available from: http://www.fossil.energy.gov/international/safrover.html, *Accessed: 25 October 2005*

Marmar, S., Undated, ***Implementing a GIS in an electrical utility: The growth pains,*** http://www.gisdevelopment.net/application/utility/power/utilityp0001pf.htm, *Accessed: 31 July 2006*

Mason, G., 2003, ***Growth and Development Summit Agreement: Broad-Based Black Economic Empowerment (BEE),*** South African Regional Poverty Network, Available from: http://www.workinfo.com/BEE/Agreement.doc, *Accessed: 12 October 2005*

Meehan, W.J. (Director: Utility Solutions: ESRI), 2005, ***Enterprise GIS: If you build it, it will fund,*** ESRI, Inc. Redlands, CA, U.S.A., Available from: http://www.geoplace.com/uploads/featurearticle/0503gi.asp, *Accessed: 19 April 2005*

NDA (National Development Agency Act), 1998, ***Act 108 of 1998,*** Government Gazette, Available from: http://www.info.gov.za/gazette/acts/1998/a108-98.pdf, *Accessed: 03 March 2005*

National Environmental Management: Protected Areas Act, 2003, ***Act 57 of 2003,*** Government Gazette, Available from: http://www.info.gov.za/gazette/acts/2003/a57-03.pdf, *Accessed: 03 March 2005*

NER, 2005, ***National Electricity Regulator Strategy,*** Available from: http://www.ner.org.za, *Accessed: 05 August 2005*

Newhouse, G.M. and Revers, M.M., 2004, ***Enterprise Intergration: Do You Really Know Where Your Customers Are?*** GeoWorld, Available from: http://www.geoplace.com/gw/2004/0403/0403ent.asp, *Accessed: 19 April 2005*

Office of the Premier, KZN, 2006, ***An Update on the progress of the Office of the Premier's GIS Nerve Centre initiative,*** Presentation given by Michael Breare at a meeting of the KZN Provincial GIS forum meeting, 14 June 2006

President Thabo Mbeki, 2004, ***State of the Nation address, 21 May, 2004; to the first joint sitting of the third democratic Parliament, Cape Town,*** Available from: http://www.info.gov.za/speeches/2004/04052111151001.htm, *Accessed: 2 May 2006*

Rajopadhyay, N., Arora, M., Madhusudhan, P., 2002, ***Role of GIS in preventing power pilferage,*** GIS Development, Available from: http://www.gisdevelopment.net/application/utility/power/utilityp0015pf.htm , *Accessed: 12 April 2005*

REDEO, 2004, ***Rural Electrification Decentralised Energy Options Newsletter n°2***

REN21, 2005, ***South African Renewable Resource Database and Electrification Planning Tool,*** Available from: http://www.ren21.net/iap/commitment2.asp?id=187, *Accessed:*

South African Government, 2004, ***Government's Programme of Action,*** Updated 8 February, 2005, Available from: http://www.polity.org.za/pdf/Programme%20of%20action.pdf, *Accessed: 25 November 2005*

SARPN, 2005, ***South African Regional Poverty Network: Section 2: More jobs, better jobs, decent work for all,*** Available from: http://www.sarpn.org.za/documents/d0000370/page2.php, *Accessed: 08 December 2005*

Schutzberg, A., 2005, ***Location Technology and Business Intelligence 2005: Nine Ideas Worthy of Note,*** Directions Magazine, Available from: http://www.directionsmag.com/article.php?article_id=859, *Accessed: 17 August 2005*

Sepp, C., 2002, ***Briefing paper: Household energy & forestry: an introduction,*** Sparknet, Available from: http://sparknet.info/uploads/file/HHEforestryIntro.pdf, *Accessed: 25 October 2005*

Speit, R.J., Cornell C.D., Kaplan, U.T., 2000, ***Renewable energy conversion and utilization in ASEAN countries,*** International Journal of Science and Technology, Vol. 23, No. 2, 2000, pp. 125-134

Thom, C., 2000, ***Evaluation of the electrification modelling tool 'benefit point' scoring methodology - draft for discussion,*** Energy and Development Research Centre, University of Cape Town, South Africa

Thompson, M.W., Vink, E.R., Fairbanks, D.H.K., Ballance, A., Shackleton, C.M., 2001, ***Comparison of extent and transformation of South Africa's woodland biome from***

two national databases, South African Journal of Science 97, May/June 2001, pp 179-181

Tshering, K., 2005, ***Energy Development, Rural Electrification Policy and Project Identification in Bhutan,*** Rural Electrification Workshop, Bangkok; February 23 - 25, 2005, Available from: http://www.e7.org/pages/A-Projects/RuralElectrification/Index.htm, *Accessed: 14 October 2005*

UNEP Risoe Centre, 2000, ***The National Electrification Programme - A brief overview,*** Available from: http://www.uneprisoe.org/RETSouthAfrica/NationalElectrificationProgram.pdf, *Accessed: 21 November 2005*

UNEP, 2005, ***Using GIS as convening factor in rural electrification programmes,*** Energy, Climate and Sustainable Development (A Newsletter of UNEP Risoe Centre (URC) and UNEP) September, Available from: http://www.uneprisoe.org/E+/September05.htm, *Accessed: 14 October 2005*

USAID SARI / Energy Program, 2004, ***Improving Participatory Rural Energy Services in Karnataka: A Policy and Program Framework for the PRESK Cell,*** Available from: http://www.sari-energy.org/ProjectReports/PreskFinalPolicypaper.pdf, *Accessed: 14 November 2004*

Van Der Post, C.H.M, 2004, ***Human Sprawl and the African Wilderness of the Okavango,*** South African Geographical Journal, v86, issue 2, pp 122-130

WBCSD (World Business Council for Sustainable Development), 2005, ***Case Study - Access to Electricity program eases poverty,*** Available from: http://www.wbcsd.org/DocRoot/Cm9iGJcvAPP4YKkbg6Rk/abb_electricity_access_full_case_final_web.pdf, *Accessed: 12 May 2006*

WBCSD (World Business Council for Sustainable Development), 2006, ***Case Study - Eskom - Electrifying South Africa,*** Available from: http://www.wbcsd.org/web/publications/case/electrification_full_case_web.pdf, *Accessed: 12 May 2006*

Williams, B.R., Mansfield, C., Bown, R.E., Kazemzadeh, H., 2003, ***Engineering Tools Move into Cyberspace,*** Available from: http://tdworld.com/mag/power_engineering_tools_move/index.html, *Accessed: 18 April 2006*

Wilson, J., 1998, ***Enterprise Resource Planning Creates New Opportunities for GIS in Utilities,*** Available from: http://www.geoplace.com/gw/1998/0598/598ent.asp, *Accessed: 15 July 2004*