UNIVERSITEIT VAN PRETORIA
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YUNIBESITHI YA PRETORIA

DEPARTEMENT BEDRYFS- EN SISTEEMINGENIEURSWESE

DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

FRONT PAGE FOR FINAL PROJECT DOCUMENT (BPJ 420) - 2014

Information with regards to the mini-dissertation

Title	Locating Police Service Points in the Rural Areas of Limpopo, South Africa
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Date	2014/11/24
Keywords	Access norms, ArcGIS, Cohort-component method, Flowmap, GIS, ISRD nodes, Maruleng, SAPS, Sekhukhune, Service location model.
Abstract	Identification of optimal sites for SAPS service points to improve access to SAPS services using a service location model in Flowmap.
Category	Facilities Planning

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LOCATING POLICE SERVICE POINTS IN THE RURAL AREAS OF LIMPOPO, SOUTH AFRICA

by

KIRSTEN WEBBER

A project submitted in partial fulfilment of the requirements for the degree

BACHELORS IN INDUSTRIAL ENGINEERING

at the

FACULTY OF ENGINEERING, BUILT ENVIRONMENT, AND INFORMATION TECHNOLOGY

UNIVERSITY OF PRETORIA

SUPERVISOR: Mrs. G. J. Botha

November 2014

Executive Summary

The population distribution and concentration are continuously changing throughout the rural areas of South Africa as a result of socio-economic factors. These factors include job opportunities, access to water and sanitation, the development of schools, and health care provision.

Many people face great inconvenience is accessing police service points, particularly those living in the rural areas of South Africa. The South African Police Service (SAPS) have the challenging task of locating police service points in such a way that access to these points, in terms of the distance people need to travel, are provided fairly and without bias. The SAPS strive to provide a safe and secure environment, and because their duties play such an influential role in the quality of life for all South Africans, it is important that everyone has access to their services, including the poor and marginalized.

Fifteen Integrated Sustainable Rural Development (ISRD) nodes have been identified throughout South Africa. These nodes are underdeveloped municipalities that experience high poverty levels and are therefore being prioritised by government for development assistance (Rabie, 2011).

In 2009 AfricaScope did a study on the accessibility of fully-fledged police stations in the fifteen ISRD nodes. At that stage the SAPS had not yet developed access norms. As a result, the study was based on the average distance citizens were travelling to access police services and the average capacity of the service points throughout the fifteen ISRD nodes. AfricaScope found that the most notable levels of poor access were in the Maruleng node, a local municipality in Limpopo. In Maruleng, more than half of the north western part required people to travel more than an hour to access the closest SAPS service point. As a result of this finding, Maruleng was selected as the study area, along with Limpopo's other ISRD node, Sekhukhune, thus placing the focus on the ISRD nodes within the Limpopo province.

Since then, the Council for Scientific and Industrial Research (CSIR) have suggested access norms of twenty-four kilometres as the maximum reach for a person to travel to access their nearest police station in rural areas, and a capacity of between sixty thousand and one hundred thousand people per police station.

With these access norms, the current accessibility statistics could be determined and recommendations for future locations have been suggested for the two ISRD nodes, taking into consideration population growth. For this study, population projections have been done using the cohort-component methodology, the same methodology used by both Statistics South Africa (when they determine the mid-year estimates) and the United States Census Bureau to estimate population growth in the future. Because the provision of SAPS services is a long-term project,

population projections help to identify the demand placed on the SAPS in the long run.

In an attempt to improve the accessibility to police service points in the two ISRD nodes, both Flowmap and ArcGIS, two Geographical Information Systems (GIS), have been used. The GIS-based approach to solving locational problems is gaining popularity worldwide and the potential benefits this technology has to offer are made apparent by numerous studies being done using this methodology. Flowmap in particular, has a number of analysis capabilities including service location models, which were particularly attractive for this project. This software has a service location model designed for expansion with the aim of maximum customer coverage, assisting in the determination of optimal locations for new service points.

It was decided that a maximum capacity threshold of 100 000 people would be acceptable for this study. Airline distances were used, in combination with a Crow Flight Conversion Coefficient (CFCC) of 1.2, to determine the distances people living in the study area needed to travel to gain access to an SAPS service point.

The current SAPS facilities are able to serve 88.28 percent of the population, resulting in an unserved population of 150 000 people. The addition of two new fully-fledged police service points can increase the population coverage 97.77 percent, resulting in an unserved population of 28 721 people. These two proposed SAPS service points serve approximately 81 percent of the currently unserved population.

Flowmap was used to identify service points which would result in complete coverage of the study area. However, because the building of SAPS service points is incredibly expensive and the population is sparsely dispersed, some of the suggested points were considered impractical but have also been included in the report.

The proposed locations for new SAPS service points aim to help the SAPS to progress in their fight to combat crime and provide a safe and secure environment for all South Africans. Not only should the SAPS benefit from such a study, but this model can be adapted to suit other locational challenges, such as the provision of health care facilities and schools.

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Glossary

CFCC	-	Crow Flight Conversion Coefficient
CSIR	-	Council for Scientific and Industrial Research
DPSA	-	Department of Public Service and Administration
EA	-	Enumeration Area
GIS	-	Geographic Information System
ISRD nodes	-	Integrated Sustainable Rural Development nodes
SAPS	-	South African Police Service

Chapter 1: Problem Definition

1.1. Introduction & Background

In 2013 the SAPS celebrated a major milestone, the serving and protecting of South African citizens for one hundred years. Now, at the beginning of their second century in service, the SAPS hope to continuously progress in their fight against crime (Saps.gov.za, 2014).

The vision of the SAPS is to "create a safe and secure environment for all the people in South Africa" (Saps.gov.za, 2014). The responsibilities of the SAPS, as documented in chapter eleven of the Constitution of the Republic of South Africa (Saps.gov.za, 2014), are as follows:

- Prevent, combat and investigate crime
- Maintain public order
- Protect and secure the inhabitants of the Republic and their property
- Uphold and enforce the law
- Prevent anything that may threaten the safety or security of any community
- Investigate any crimes that threaten the safety or security of any community
- Ensure criminals are brought to justice, and
- Participation in efforts to address the causes of crime

It is clear from the responsibilities listed above that the SAPS have a significant influence on the quality of life, in terms of safety and security, of all South Africans. Citizens, especially the poor and marginalised living in the rural areas, currently face great inconvenience and have to travel long distances in order to access police facilities (Rabie, 2011). As a result, crimes go unreported and little is done to ensure offenders are brought to justice. Thus, it is a priority for Government to improve access to policing services in these areas if they are to realise their vision of a safe and secure environment for ***all*** South Africans.

This project focuses on addressing the need for better access to police services in the rural areas of Limpopo, South Africa's province with the highest poverty level at 78.9% (Statistics South Africa, 2011). Fifteen Integrated Sustainable Rural Development (ISRD) nodes have been identified throughout South Africa. These nodes are underdeveloped municipalities, either district or local, which experience high levels of poverty. They are therefore being prioritised for development assistance by the government (Rabie, 2011). The two ISRD nodes which fall within the boundaries of the Limpopo province, Maruleng and Sekhukhune, will be addressed in this project.

1.2. Problem Statement

Some people need to travel long distances in order to reach police service points, particularly those living in the rural areas of South Africa. As a result, crimes and other issues impacting on the safety and security of these individuals are often not reported and/or effectively dealt with.

It is incredibly challenging for the SAPS to progress in their fight against crime when they have limited access to the public. It is therefore imperative that this situation be addressed, so as to increase accessibility for all, and ensure a safer, more secure environment.

1.3. Motivation for Solving this Problem

By determining the number of required police facilities and their optimum locations, the access to policing services can be improved. However, there are continuous changes in the distribution and concentration of the population which impacts on the demand for services in different areas. Also, new or proposed developments such as housing and industrial areas can influence key areas. Thus, a dynamic approach to solving this problem is desired so as to assist the SAPS in working towards achieving their vision.

The problem of determining the optimal number and location of facilities is not unique to the SAPS. This model can therefore be adapted to suit a variety of similar problems, including the locating of health care facilities and schools.

1.4. Project Aim

The aim of this project is to improve access to policing services in the poor, underdeveloped rural areas of Limpopo, South Africa.

1.4.1. Project Objectives

- Determine the areas that are well-served and poorly-served with respect to the SAPS access norms.
- Determine the number of police service points required to ensure that access is provided fairly and without bias in the future.
- Determine the optimum locations of the police service points so as to reduce the distance citizens need to travel in order to access police service facilities.
- Consider population growth estimates when determining the number and location of service points.

1.5. Project Scope

A study done by AfricaScope in 2009 found that the most notable levels of poor access to SAPS service points amongst the fifteen ISRD nodes throughout South Africa were in the Maruleng node, a local municipality in Limpopo. In Maruleng, more than half of the north western part required people to travel over an hour to access the closest SAPS service point. As a result of this finding, Maruleng was selected as the study area, along with Limpopo's other ISRD node, Sekhukhune, thus placing the focus on the ISRD nodes within the Limpopo province.

Maruleng is one of five local municipalities making up the Mopani district municipality. Sekhukhune is a district municipality which is made up of five local municipalities: Ephraim Mogale, Elias Motsoaledi, Makhuduthamaga, Fetakgomo and Greater Tubatse. The two ISRD nodes border on one another and thus, they have formed one large study area. A buffer area surrounding the two ISRD nodes will also be included in the study area. This is because people often move across administrative boundaries to access service points (Department of Public Service and Administration, 2011).

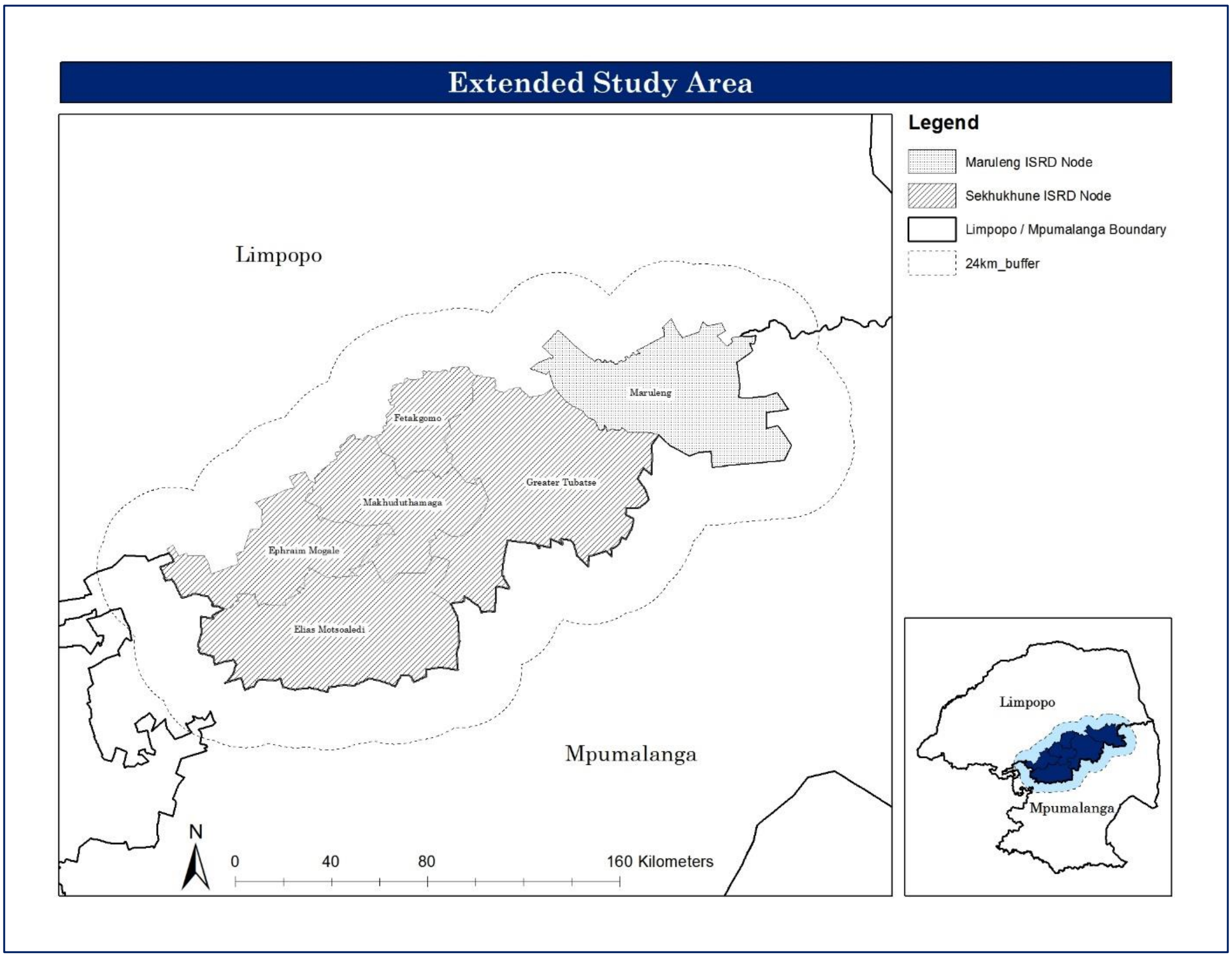

Figure 1. Study area, including buffer

1.6. Project Deliverables

The comprehensive accessibility studies should provide information regarding the following:

1. Well-served and poorly-served geographical areas
2. The required number of additional service points to provide optimum levels of access and service to the public
3. Potential optimum sites for new service points

Chapter 2: Literature Review and Problem Investigation

2.1. South Africa's Integrated Sustainable Rural Development (ISRD) Nodes

South Africa has fifteen ISRD nodes, which are tabulated in Table 1 below. These nodes have been identified as underdeveloped areas which experience high poverty levels and are prioritised by government for development assistance (Rabie, 2011). With the aim of improving access to rural areas in Limpopo, the two ISRD nodes in Limpopo, Maruleng and Sekhukhune, have been selected for this project.

ISRD Node	Province	Type of Municipality	Area [km²]	2011 Population
Alfred Nzo	Eastern Cape	District (DC44)	10 731	801 344
Bushbuckridge	Mpumalanga	Local (MP325)	10 250	541 248
Central Karoo	Western Cape	District (DC5)	38 854	71 011
Chris Hani	Eastern Cape	District (DC13)	36 144	795 461
Kgalagadi (John Taolo Gaetsewe)	Northern Cape	District (DC45)	27 283	224 799
Maluti-A-Phofung	Free State	Local (FS194)	4 338	335 784
Maruleng	Limpopo	Local (LIM335)	3 244	94 857
OR Thambo	Eastern Cape	District (DC15)	12 096	1 364 943
Sekhukhune	Limpopo	District (DC47)	13 528	1 076 840
Ugu	KwaZulu-Natal	District (DC21)	5 047	722 484
Joe Gqabi (Ukhahlamba)	Eastern Cape	District (DC14)	25 663	349 768
uMkhanyakude	KwaZulu-Natal	District (DC27)	13 855	625 846
uMzimkhulu	KwaZulu-Natal	Local (KZN435)	2 435	180 302
uMzinyathi	KwaZulu-Natal	Disctrict (DC24)	8 589	510 838
Zululand	KwaZulu-Natal	District (DC26)	14 799	803 575

Table 1. South Africa's 15 ISRD Nodes

Maruleng Local Municipality is situated within the Mopani District Municipality and is wedged between the Kruger National Park, Timbavati Private Reserve and Blyde River Canyon. Hoedspruit is considered the administrative and economic centre of Maruleng. Agriculture is the major economic driver for this area. During the 2011 census, it was established that this area has an unemployment rate of 39.90% and population growth rate of 0.05% per annum. (Municipalities.co.za, 2014).

The Sekhukhune District Municipality is comprised of five local municipalities, Elias Motsoaledi, Ephraim Mogale, Fetakgomo, Makhuduthamaga and Greater Tubatse. The Olifants River runs through this area, possibly obstructing easy access to SAPS facilities. Community services, mining and trade form the main economic sectors of this area. An unemployment rate of 50.90% and population growth rate of 1.07% were established during the 2011 census (Municipalities.co.za, 2014).

2.2. Long-term Population Forecasting

Statistics South Africa publishes mid-year population estimates on an annual basis. The latest issue (Statistics South Africa, 2013) makes use of the cohort-component methodology to estimate South Africa's mid-year population.

"The cohort-component method is widely used because it provides a flexible and powerful approach to population projection. It can take the form of a purely atheoretical accounting procedure or can incorporate insights from a variety of theoretical models. It can incorporate many application techniques, types of data, and assumptions regarding future population change. It can be used at any level of geography, from nations down to states, counties and subcounty areas." (Smith, Tayman and Swanson, 2002)

The United States Census Bureau began using the cohort-component method for national projections in the 1940s and for state projections in the 1950s and still continues to use a form of this method today. Thus, this longstanding and widely used method seems appropriate for projecting the population of the Maruleng and Sekhukhune nodes over the next decade. These projections will assist in determining the best locations for new police service points that not only meet the current needs of the people living in these areas, but also their future needs.

2.2.1. The Cohort-Component methodology

To project population growth, the cohort-component methodology uses the components of demographic change: births, deaths and migration. The methodology is based on the *demographic balancing equation*, Equation 1, below (Papp.iussp.org, 2014).

$$P_{t+n} = P_t + B_t - D_t + I_t - E_t \qquad (1)$$

Where P_{t+n} is the estimated population after time n

P_t is the actual population at time t (or most accurate estimate thereof)

B_t is the number of births occurring between time t and time t+n

D_t is the number of deaths occurring between time t and time t+n

I_t is the number of immigrants between time t and time t+n

E_t is the number of emigrants between time t and time t+n

At each interval n the base population is advanced by using projected survival rates ($B_t - D_t$) and net migration rates ($I_t - E_t$) as well as a new birth cohort which is added to the population by applying the projected fertility rates to the female population.

This methodology is applied to age group cohorts. It is based on the fact that every year of time that passes, every member of the population becomes a year older. As a result, the 0 to 4 years age group will become the 5 to 9 years age group after five years and so on.

The assumption made by using this method as a projection tool, is that the mortality, fertility and migration rates remain constant throughout the projection period. However, long-term projections can be broken up into smaller intervals to accommodate a change in the demographic change component rates. The results of the first projection will then be used as input for the next projection and so forth.

The step-by-step approach to the cohort-component method can be seen in Figure 2 below. An explanation follows thereafter.

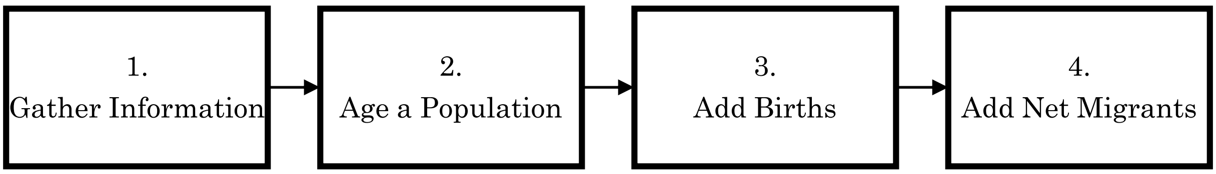

Figure 2. Step-by-step approach to the cohort-component method

1. Gather information

The cohort-component method requires information from both the most recent census and the census prior to that. Information concerning the following needs to be gathered:

- Census information, distributed by age and sex
- The number of births during the last ten years
- Survival rates or an appropriate life table

2. Age the population into the future

Multiply the base census population of a given age group by their appropriate survival rates; this will estimate the population alive after n years.

3. Adding births

Estimate the number of births that take place during the projection period n based on age-specific fertility rates. These rates are multiplied by the number of women in their reproductive years.

4. Add the number of net migrants

This can be a positive or negative flow. Multiply the net migration rate by the 'survived' population to obtain the number of migrants.

2.3. Using a Geographical Information System (GIS) for facility location

"The use of GIS systems to evaluate the access to public facilities and the availability of social services has led to improvements in governance and the targeting of capital investment to areas of greatest need." (Green, Breetzke and Mans, 2009)

A thorough accessibility analysis done with an appropriate GIS allows for the effective provision, management and monitoring of public facilities and services. This approach is objective in nature, with the advantage that the results cannot be influenced for political or other reasons.

This technology also supports the visualisation of results and allows for ongoing reporting on agreed performance indicators in terms of service delivery goals.

Accessibility analyses using a GIS-based method are becoming more and more popular. A study done by Zhang, Johnston and Sutherland (2011) demonstrates the use of a GIS in identifying the optimal location for a biofuel production facility in the Upper Peninsula of Michigan.

In order for this process, whereby forest biomass is converted to biofuel, to be financially successful, this facility needs to be in a location that minimizes transportation, thereby minimizing transportation costs. The location is based on multiple attributes.

Identification of feasible biofuel facility locations was carried out using a GIS. This approach included the use of county boundaries, a county-based pulpwood distribution, a population census, city and village distributions, and railroad and state/federal road transportation networks. (Zhang, Johnson and Sutherland, 2011)

Another example where a GIS-based methodology was used was in the assessment of service provision of libraries in the eThekwini municipality and the development of facility plans for the future. This approach was followed to ensure that the backlog and provision of facilities is based on population distribution and relative shortages.

2.4. Accessibility Study Software

The Department of Public Service and Administration (DPSA) recommends the use of Flowmap in performing accessibility studies for the provision of public and social services (Department of Public Service and Administration, 2011). Their argument is that general GIS software packages lack the ability to consider the combined effects of capacity parameters, distances travelled along a road network and the extent of the target population. Flowmap has the widest range of accessibility models that can simultaneously take into consideration the greatest number of factors when looking at optimizing the location of service points. Its ability to generate accessibility statistics is also a big advantage for this project (Department of Public Service and Administration, 2011).

2.4.1. Flowmap

The Faculty of Geosciences of Utrecht University in the Netherlands developed a software package, Flowmap, specifically for interaction or flow data. This is data connected to two different geographic locations, typically an origin where the flow starts and a destination where the flow ends. The majority of general purpose GIS packages are designed to be used for data relating to a single location in space, and some have limited functionality in terms of analysing and displaying interaction or flow data. Flowmap allows for comprehensive analysis and the display of interaction or flow data. According to Flowmap's website (Flowmap.geo.uu.nl, 2014), the three key functionalities of this software include:

1. The storage, display and analysis of spatial flow patterns such as commuter trips, trade flows and telephone calls.
2. Computing distances, travel times, or transport costs using a transportation network map.
3. Modelling the market areas of existing or planned facilities.

Flowmap has a number of analysis capabilities including service location models, which are particularly attractive for this project. Of these service location models, the expansion model is best suited for the locating of additional police service points. This model assists in determining the number of service points and their different locations required to meet a minimum level of service.

Within this model, there are six alternative approaches to determining the appropriate solution (de Jong and van der Vaart, 2013):

1. Maximise customer coverage
   Additional service points are added where the highest market share will be realized.
2. Minimize overall average distance
   The service points that result in the biggest decrease in average distance travelled are added.
3. Minimize overall worst case distance
   The service points that decrease the worst case distance by the greatest amount are added.
4. Maximise individual market share
   The service points having the biggest impact on the increase in amount of customers covered will be added.
5. Minimize individual customer distance
   Assuming set values for the number of people a service point can serve, this alternative minimizes the distance to a chosen market. An additional service centre is added at the location where the lowest threshold distance can be realised given a set capacity.
6. Maximise individual location profile
   The location where the highest proximity coefficient can be realised, given a set capacity and maximum distance range, will be selected for an additional service centre.

The first approach, to maximise customer coverage, maximises the overall increase in customer coverage by adding the service points that will have the most impact on the increase in the amount of covered customers given a maximum distance range. In the case of the police service points, it will calculate at each step that location which will accommodate the highest number of citizens which can be reached within the maximum distance or less.

This model allows for a partial solution to be used. This would typically be the set of already existing police service points in the study area.

Three possible solution conditions can be set. The first allows Flowmap to find a specified number of best solutions. This is appropriate when the SAPS are prepared to invest in building a set number of police service points. The second allows one to enter the percentage of the population which needs to be covered. The third is to select a threshold value which stops the model when an addition does not reach a certain market share. This is appropriate since the SAPS would not be willing to build a service point where the number of people that would use the service point is very little. Only one of the three can be selected.

An advantage of using Flowmap is that the accessibility statistics are available. Flowmap is able to generate accessibility statistics for both the overall and individual cases. The overall accessibility statistics refer to the statistics for the combined effects of all service locations working together. The individual accessibility statistics refer to the statistics only for the new recommended service locations.

It must be noted that Flowmap is not intended as a general purpose GIS. Apart from its spatial analysis tools, its functionalities are rather basic. However, it has specifically been designed to be used in combination with a Database Management System (DBMS) and a mapping system and/or a general purpose GIS. It is therefore compatible with mainstream GIS packages. The development of accessibility maps will therefore be done using the ArcGIS software where the accessibility statistics generated in Flowmap will be exported to the GIS software.

The educational version of Flowmap is freeware and available for download from the Flowmap website (Flowmap.geo.uu.nl, 2014).

2.4.2. AfricaScope Study using Flowmap

In 2009 AfricaScope conducted multiple physical accessibility studies where physical accessibility was defined as “the proximity of service points to where people reside through the use of existing road networks and transport modes” (AfricaScope, 2009). These studies were done to determine the current levels of access to services provided by eight government departments, including the SAPS, in the fifteen ISRD nodes of South Africa.

AfricaScope developed accessibility models in Flowmap, with the aim of identifying the optimum sites for government services. Three main accessibility analyses were performed on the data:

1. Catchment area analysis was used to calculate the accessibility statistics for the government services in each of the ISRD nodes. This generated information on the average distances travelled and capacity that services have to manage.
2. Accessibility maps were produced to show areas within the ISRD nodes that had poor accessibility. A ‘greenfields’ analysis was done using *Expansion* and *Threshold Distance* models to identify the optimum location of government services.
3. An ‘allocate-reallocate’ analysis was done to see where existing services could be used at optimal sites identified in the ‘greenfields’ analysis.

The results of the catchment area analyses included the average distance that people had to travel to get access to these services as well as the average number of people these services dealt with. The results for Maruleng and Sekhukhune are tabulated in Table 2 below.

Accessibility Statistics	Maruleng	Sekhukhune
Demand [number of people]	95 541	1 074 663
Number of facilities	2	22
Average demand [number of people]	47 771	48 848
Worst case car time [min]	62	56
Average car time [min]	42	15
Average walk time [hh:mm]	12:03	3:26
Percentage of population within 30 min car trip [%]	19.80	96.80
Car trip duration for which 95% of population fall under [min]	59	28
Car trip duration for which 99% of population fall under [min]	62	34

Table 2. Accessibility statistics for Maruleng and Sekhukhune based on car travel time to/from the nearest police station (AfricaScope, 2009)

The accessibility maps relating to these results are depicted in Figures 3 and 4 below.

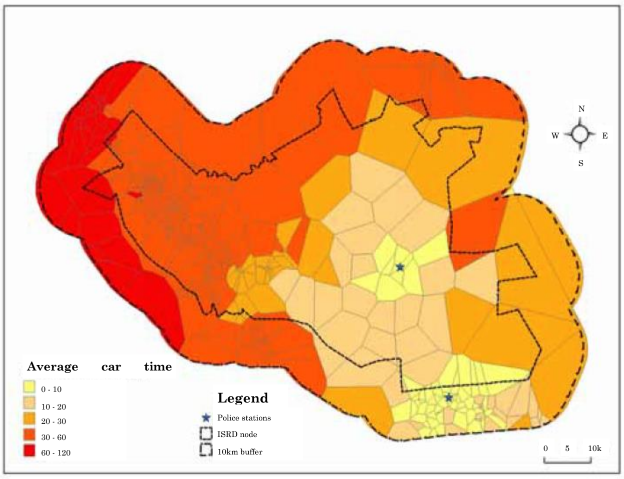

Figure 3. Maruleng accessibility map (AfricaScope, 2009)

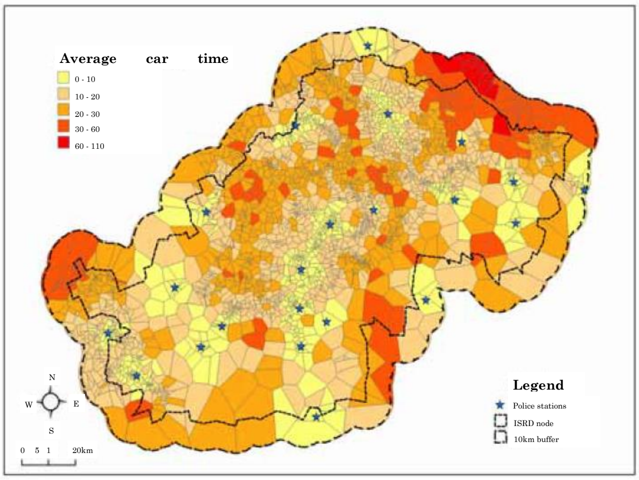

Figure 4. Sekhukhune accessibility map (AfricaScope, 2009)

At the time of this study, more than half of the north western part of Maruleng required people to travel more than an hour to get access to the closest police station. Maruleng is a good example of where police stations have been placed in the towns and not necessarily close to where the largest concentrations of people are. The twenty-two police stations within Sekhukhune were well distributed and as a consequence, most of the area was within a twenty minute drive of a police station.

The accessibility statistics generated from the catchment area analysis were particularly important for evaluating the current access norms and standards of each department. For the departments which did not have access norms and standards, such as the SAPS, these results assisted in developing appropriate norms and standards.

According to the SAPS, the locations and functions of the different service points are determined by a number of factors, including: external environmental determinants, the crime frequency index, social and economic factors, and the needs for different services in different areas. However, at the time of this study, the SAPS did not include access norms and standards for police facilities in their criteria for locating new police stations. This meant that no distance or travelling time was set for the maximum reach between the citizens and the police service point, and no indication was given as to how many people a police facility should be able to manage. As a result, the average travel time and average demand for police stations throughout the fifteen ISRD nodes generated in the accessibility statistics were used. These values are tabulated under the 'primary police station' column in Table 3 below. A drawback of applying the accessibility parameters used in this study is the large variations that exist in terms of travel distances and the number of people that a police station has to service within and between the ISRD nodes.

	Type of Police Facility	
	Primary Police Station	**Secondary Police Station**
Target Population	Total population	Total population
Capacity/Average demand	37 000	10 000
Mode of Transport	Car/Taxi	Car/Taxi
Average car travel time [min]	15	30

Table 3. Norms and standards used in AfricaScope's accessibility modeling of police stations (AfricaScope, 2009)

With an attempt to identify a more differentiated set of access norms, a second round of 'greenfields' analysis was undertaken. These access norms are tabulated in Table 3 in the column 'secondary police stations' above. A study on the combination of primary and secondary police stations was performed.

In the figures below, the large blue cross defines the optimal location of fully-fledged police stations using the primary police station access norms. The smaller blue crosses represent the fully-fledged police stations where the secondary police station access norms were used. These optimal police stations are shown in relation to the existing fully-fledged police stations depicted by the yellow dots.

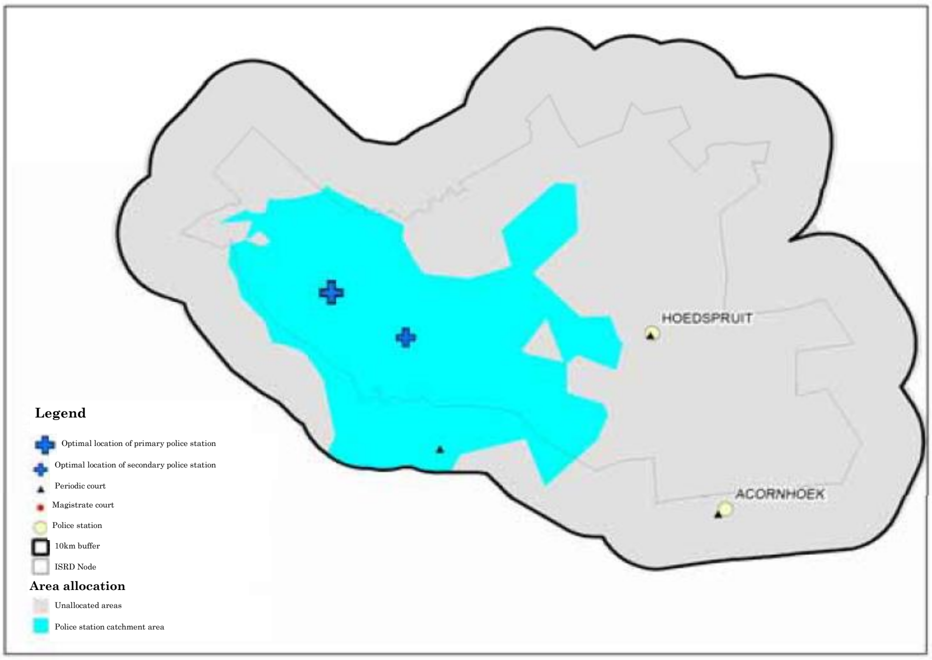

Figure 5. Optimal versus existing police station locations, Maruleng (AfricaScope, 2009)

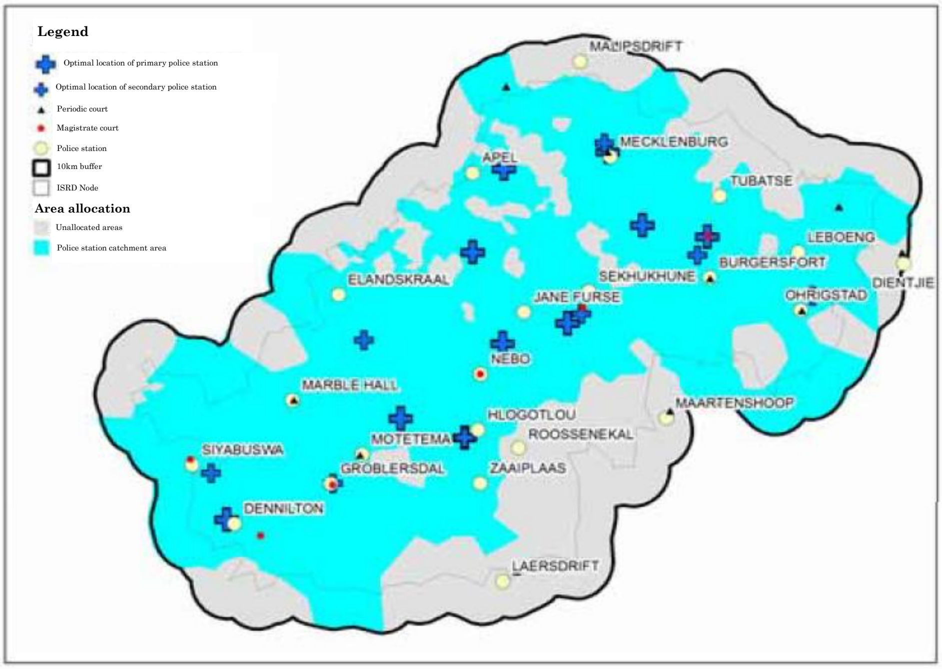

Figure 6. Optimal versus existing police station locations, Sekhukhune (AfricaScope, 2009)

Tabulated below are the results suggested by AfricaScope regarding the number of primary and secondary police stations which could be located to improve accessibility.

ISRD Node		Maruleng	Sekhukhune
Primary Police Station	Number of optimal sites	1	10
	Cumulative share of demand	59.59%	62.58%
Secondary Police Station	Number of optimal sites	1	8
	Cumulative share of demand	85.30%	97.28%
Total number of optimal sites		2	18
Total number of existing police stations		1	17
Under/oversupply of police facilities		Undersupply: 1	Undersupply: 1

Table 4. Optimal police station provision (AfricaScope, 2009)

These results indicated that the SAPS should consider relocating some of their poorly positioned facilities to improve accessibility and/or build new facilities to address the needs of the people.

The accessibility modelling also showed that there was a need for access norms and standards to be incorporated into the criteria used by the SAPS to optimally locate police facilities closer to the people is the ISRD nodes.

A major disadvantage of this study, in terms of the SAPS, is that it was based solely on fully-fledged police stations. The SAPS have three different types of police service points:

1. Fully-fledged police stations
2. Satellite stations – these police service points are smaller and serve as extensions of the fully-fledged police stations, and
3. Mobile contact points – these police service points are situated in areas with high levels of crime

The study did not include the satellite stations and mobile contact points because their spatial coordinates were not made available.

2.5. Access Norms for Police Service Points

Access norms are the standards by which the SAPS can determine whether the geographic access to their service points is adequate. These norms are generally expressed in terms of the maximum distance beneficiaries should travel to service points, and the population threshold for the facilities. Careful consideration should be given to the willingness or ability of the potential user to pay for the trip in terms of time and/or money.

The CSIR have developed guidelines for the provision of social facilities in South African settlements. These guidelines include access norms and thresholds for fully-fledged police stations across various areas of the country.

In terms of a fully-fledged police station which often contains offices, temporary holding cells and interview rooms, a population threshold of between 60 000 and 100 000 people is advised. However, the level of crime should also be taken into account, where high crime areas should have a lower threshold. A police station should be within eight kilometres for urban or metro areas, fifteen kilometres for peri-urban areas and twenty-four kilometres for rural areas. Where areas beyond twenty-four kilometres are being served, a contact point may be established. (Green and Argues, 2012)

A low population density is a typical characteristic of rural areas. This means that multiple small settlements are often spread over very large areas. As a result, the distance one needs to travel is generally the limiting factor for accessibility rather than the maximum number of people a facility can handle. This poses unique challenges to the SAPS in terms of improving accessibility to all.

Chapter 3: Process Design and Methodology

In order to improve access to police service points in the Maruleng and Sekhukhune ISRD nodes, the population not being served (with regards to the suggested accessibility norms) needed to be identified. This could be determined through analysis of the catchment areas for each SAPS service point using the current SAPS service point locations and population projections based on the 2011 Statistics South Africa census data. The results of the catchment area analysis could then be used as inputs for the expansion model of services, which calculates where additional SAPS service points should be placed. Figure 7, below, describes the process used to improve access to SAPS service points in the Maruleng and Sekhukhune ISRD nodes. It is adapted from the work of AfricaScope (2009) and Cullen (2013). Each step in the flow diagram is elaborated on below.

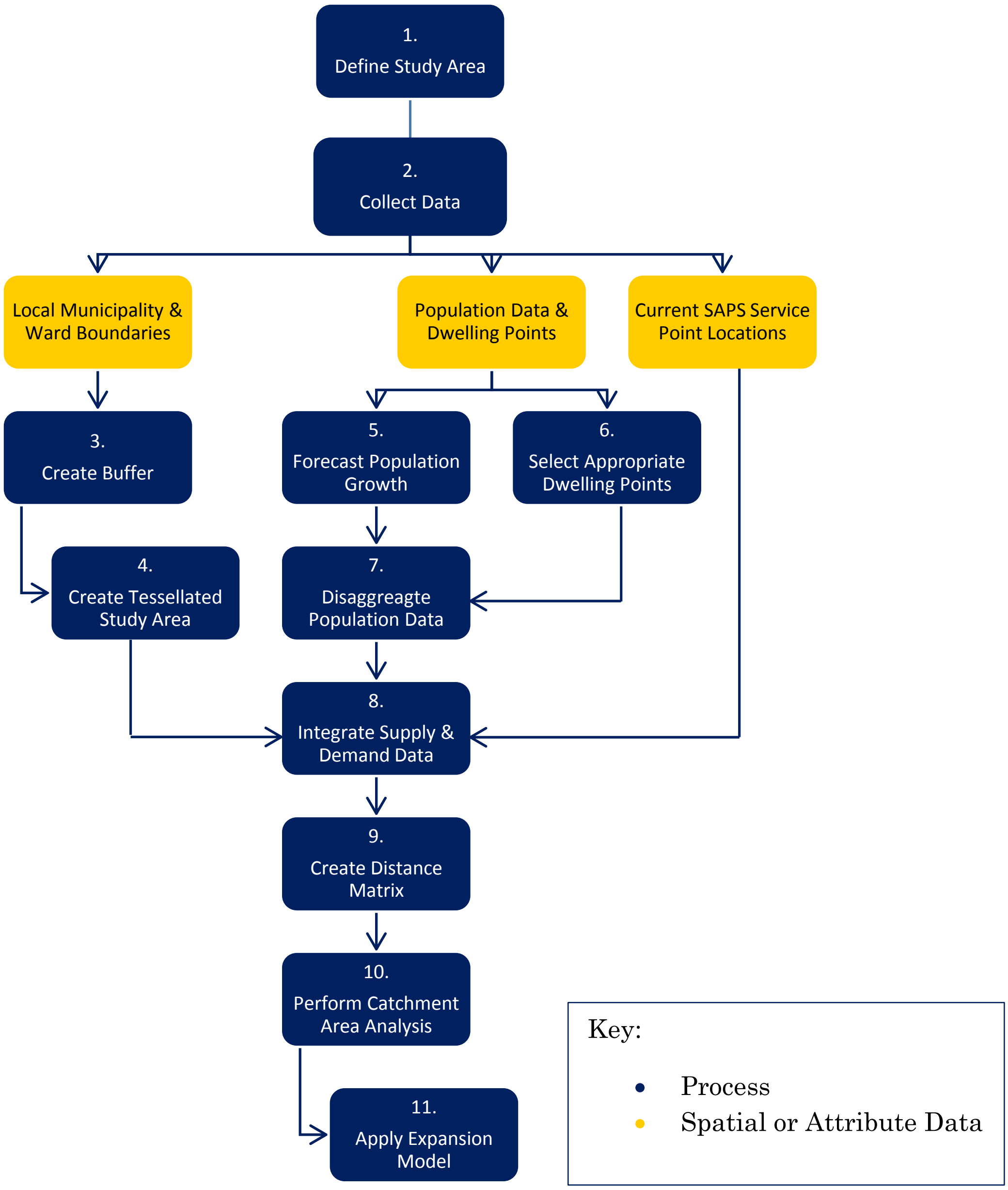

Figure 7. Process flow diagram

3.1. Define Study Area

The local municipality boundaries are somewhat artificial in terms of people accessing police service points. In other words, a person may travel to their nearest service point, a point which is not necessarily in the same municipality as their residential dwelling point. As a result, it was important to consider a buffer area around the two ISRD nodes. This buffer area, together with the six municipalities making up the two ISRD nodes, will be referred to as the extended study area and is depicted in Figure 8 below.

The assumption was made that for rural areas with a highly dispersed population, the accessibility constraint is generally the distance to an SAPS service point rather than the population threshold for a particular service point. Therefore, only supply data (SAPS service point data) was considered for the buffer area. This means that only the people living within the two ISRD nodes were considered but that they were allowed to access closer SAPS service points in the buffer, and that these service points would be readily available to meet their demand.

In lieu of the above discussion, it was decided that a buffer of twenty four kilometres should be added to the core study area. This was to ensure that any SAPS service points which may potentially be closer to the population living within the two ISRD nodes and within the accessibility norms were considered.

The current SAPS service point locations needed to be obtained for the extended study area, whereas the population and dwelling point data needed to be obtained only for the six municipalities.

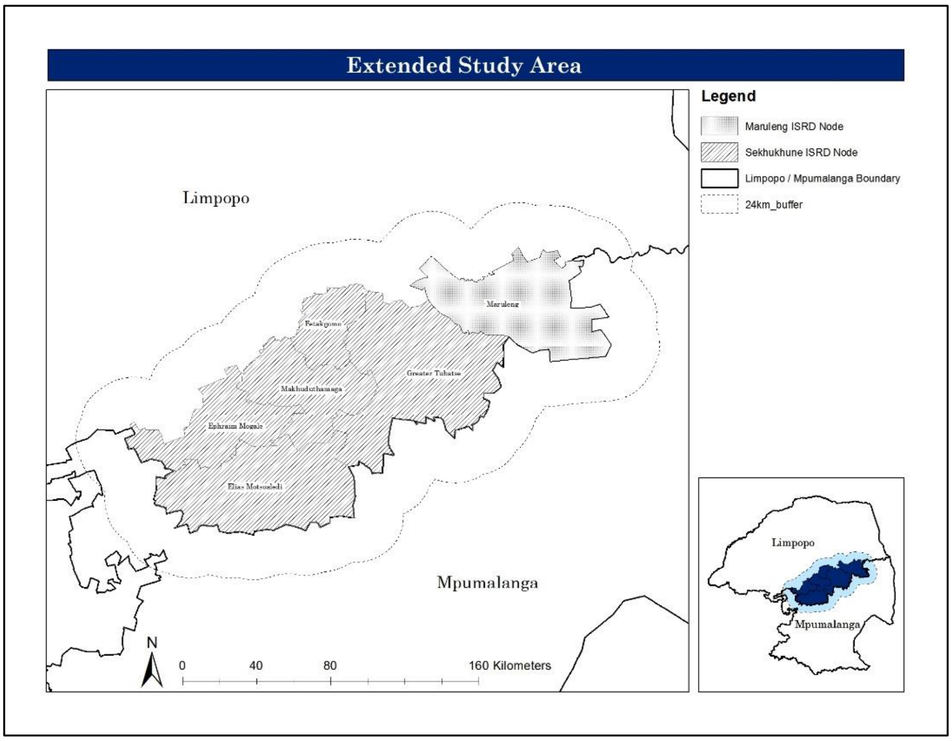

Figure 8. Extended study area

3.2. Collect Data

Before accessibility analyses could be performed, the appropriate data needed to be collected.

3.2.1. Local municipality and ward boundaries

Spatial data of the six local municipality boundaries making up the study area, as well as the ward boundaries within these municipalities, needed to be obtained. This allowed the study area to be defined in ArcGIS and for the buffer area to be created, as depicted in Figure 9 below.

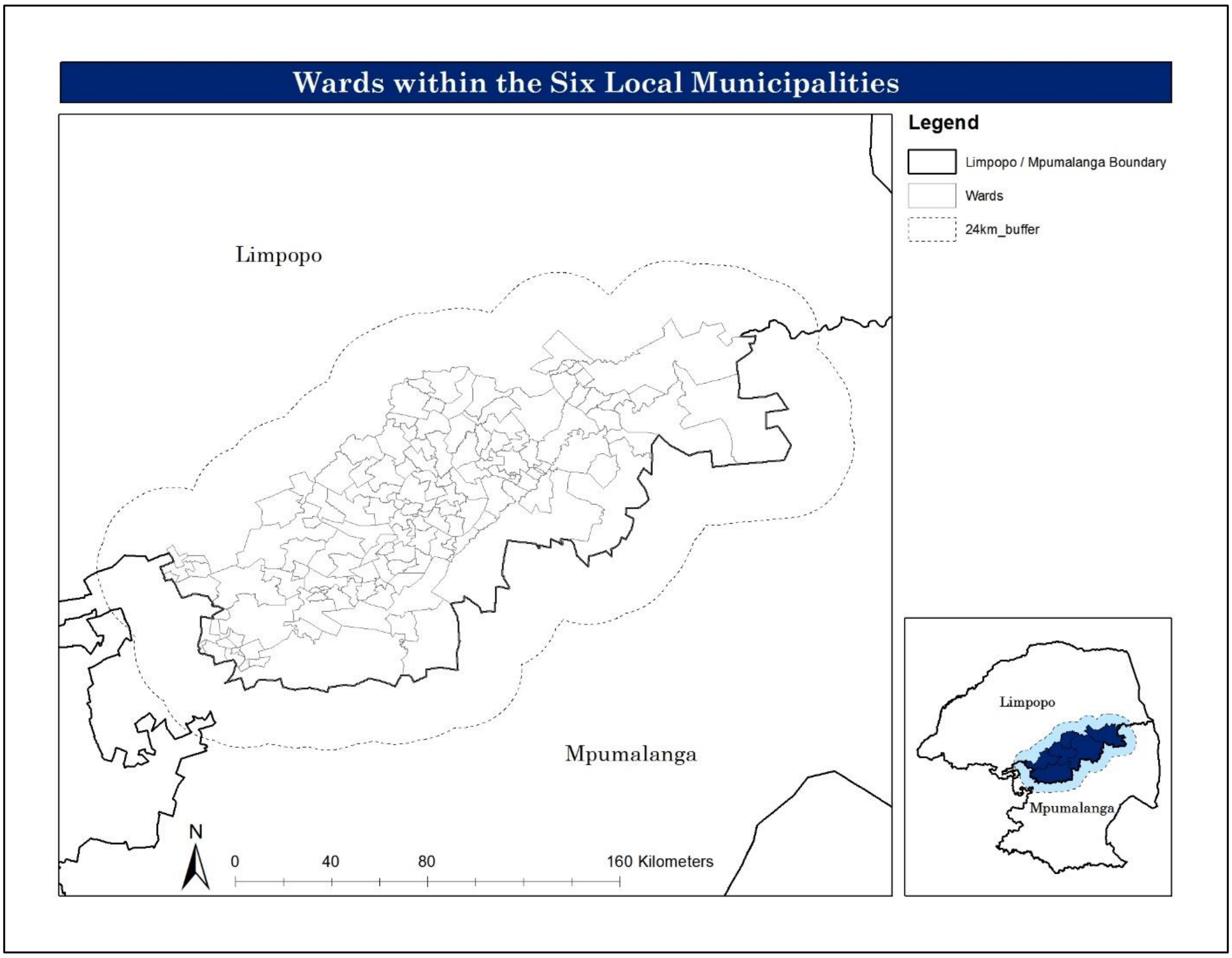

Figure 9. Wards within the six local municipalities

3.2.2. Population data and dwelling points

Demographic information at the smallest area level needed to be obtained for the two ISRD nodes. This assisted in determining the demand which the SAPS should strive to meet.

The most recent South African census was carried out in 2011 by Statistics South Africa. The smallest area level for which this demographic information was obtained was the enumeration area (EA) nodes. However, the demographic information for the rural study area in question was incomplete at the EA node level. The smallest area level with complete data was the ward level and as a result, this level was used.

The dwelling point data shows the physical point locations where people live, businesses are situated or community service facilities are placed. Because the population data is associated with wards of different sizes, these point locations were needed to better distribute the population. This information was obtained through the CSIR from Statistics South Africa.

3.2.3. Current SAPS service point locations

The point locations of the service points already in operation needed to be obtained. This allowed the supply of SAPS services to be determined. This information can be found on the SAPS website and is available to the public. The points are depicted in Figure 10 below.

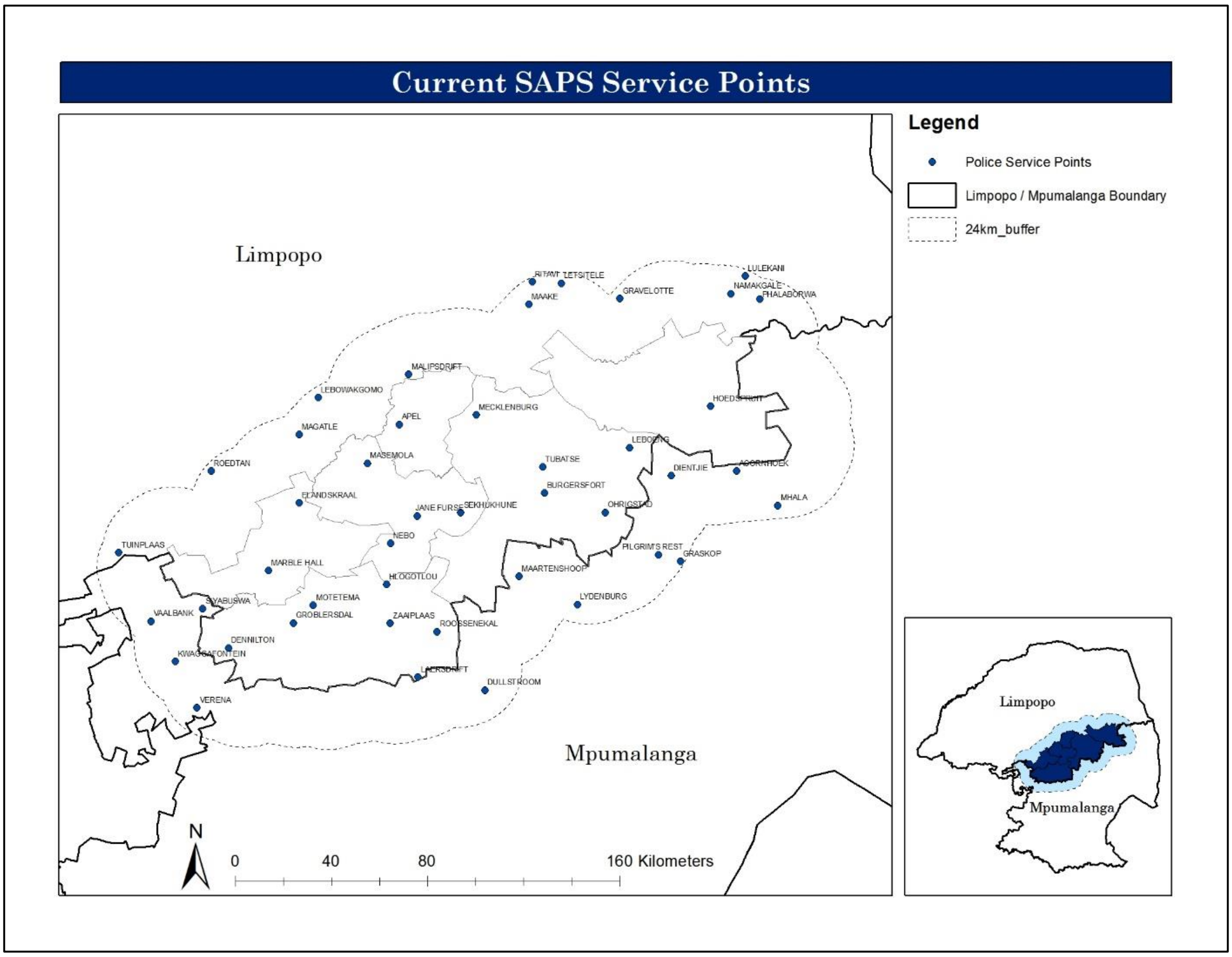

Figure 10. Current police service points

3.3. Create Buffer

The six municipalities were merged, giving the core study area. A buffer of twenty four kilometres was created around this study area in ArcGIS, defining the extended study area.

3.4. Create Tessellated Study Area

Once the buffer had been created, Flowmap was used to divide the extended study area into tessellated polygons, as can be seen in Figure 11. The extended study area was broken up into 4 901 equally sized hexagons, with a side length of 1.7 kilometres (7.5 square kilometre area). Hexagons were included if at least three of their vertices fell within the extended study area.

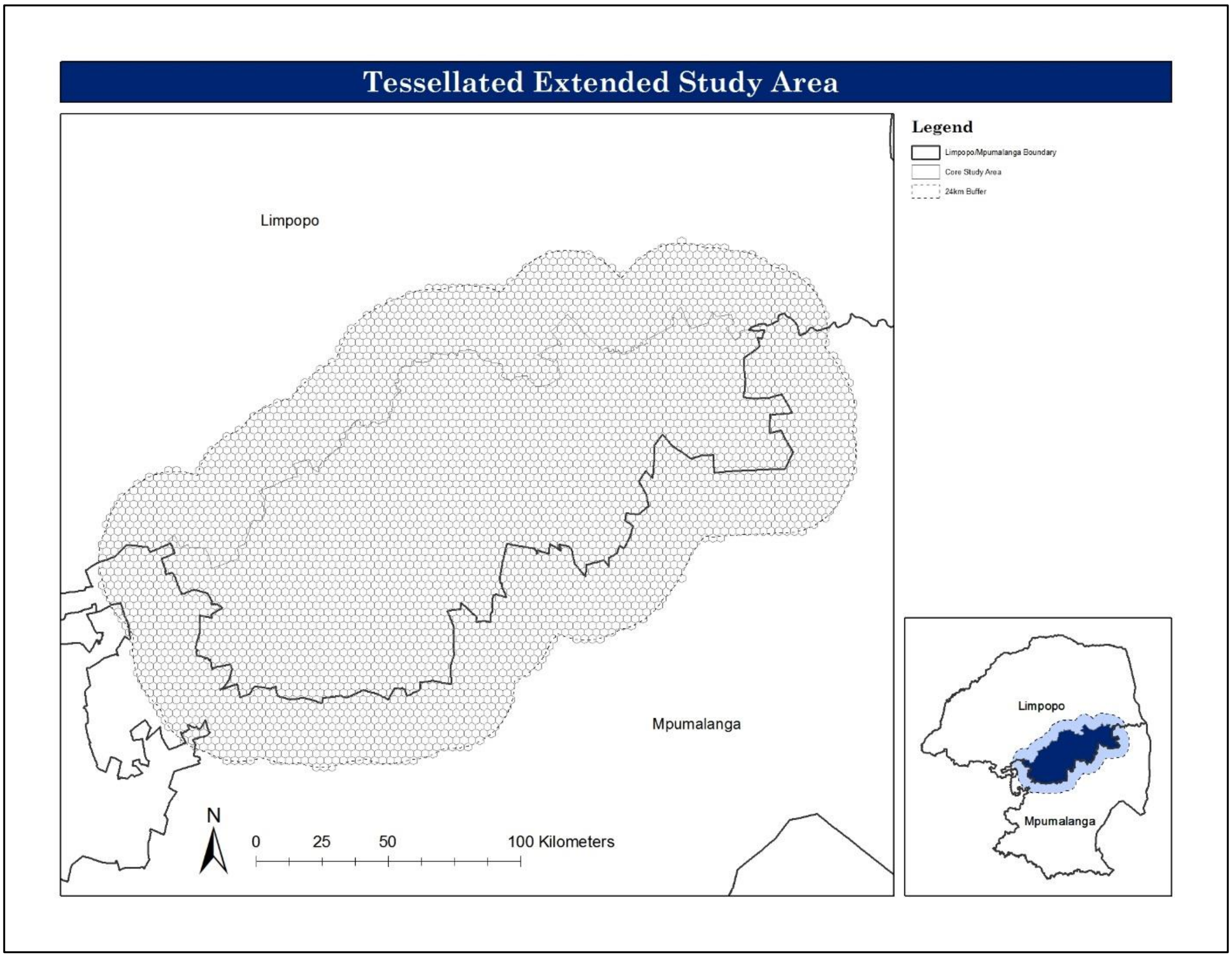

Figure 11. Tessellated extended study area

3.5. Forecast Population Growth

The most recent population data at ward level could be obtained from the 2011 Statistics South Africa census. As a result, the population forecasting was projected from the 2011 statistics. The population forecasting tables have been included in Appendix C for reference.

The 2011 census population figures for each ward were joined to the corresponding spatial data in ArcGIS. This was done by linking the unique ward codes of the spatial data and census data.

Population forecasting was done by means of the cohort-component method described in the literature review. The cohort component method lends itself to forecasting in intervals of similar period to the cohorts. The information available for this study had cohorts of five years; therefore, two population projections were done, one from 2011 to 2016 and another from 2016 to 2021.

The following information is required for this method:

- Gender-specific age group cohort population counts for the study area
- Death probabilities of the age group cohorts
- Proportion of births to female population
- Migration statistics for the study area

The smallest level for which migration statistics in South Africa are available is provincial level. Because of this, the population forecasting was done for the whole of Limpopo and the provincial population growth rate was applied to the population within the study area.

The gender-specific age group cohort population counts were obtained from the mid-year population estimates released by Statistics South Africa (Statistics South Africa, 2011). This gives a breakdown of the population in age group cohorts of five years.

The World Health Organization publishes country-specific probabilities of dying during a particular age group cohort (World Health Organization, 2014). This probability was multiplied by the associated cohort population count to estimate the number of deaths over a five year period. The number of deaths for each age group cohort were summed to give the total deaths for the five year period.

In order to estimate the number of births, a proportion of births to the corresponding female population needed to be calculated. In 2009, StatsSA started including a table in their annual *Recorded live births* publication which tabulates the birth occurrence by province and age of mother (Statistics South Africa, 2010). The mid-year female population estimates for Limpopo as well as these birth figures for 2009, 2010 and 2011 were used to determine an average age group cohort proportion of births to female population. Appendix B shows the tabulated calculations. This annual proportion was multiplied by five and then by the relevant female population to estimate the number of births over a five year period. The number of births for each age group cohort was summed to give the total births for the five year period.

The final component of demographic change to consider was the net migration. Statistics South Africa published the estimated provincial migration streams in their *Mid-year population estimates* report for 2014 for the five-year periods: 2001 to 2006, 2006 to 2011 and 2011 to 2016 (Statistics South Africa, 2014). For the population forecast from 2011 to 2016, the estimated net migration stream of -61 632 people was used. Because no migration stream estimates were available for the period 2016 to 2021, an average of the three published estimates was used. This was because the figures were all fairly similar, but with no particular trend.

With all the demographic change components now estimated, Equation 1 could be applied to estimate the mid-year populations.

The estimated growth rate for the period 2011 to 2016 was 4.52%, with an average annual growth of 0.90% throughout Limpopo province.

In order to perform the second iteration of population forecasting, from 2016 to 2021, the population counts for each cohort needed to be updated. This was done by aging the 2016 mid-year estimates. Each age group cohort was moved to the next age group cohort, less the estimated deaths during the 2011 to 2016 period. The number of births during the 2011 to 2016 period became the zero to four age group cohort. Also, the net migration during the five year period was equally divided amongst the cohorts.

The 2021 mid-year population was then estimated to be 6 106 555, with a growth rate of 5.18% for the 2016 to 2021 period and an average annual growth rate of 1.04%.

The census data that was joined to the spatial data could now be projected, based on the population growth estimates. This could be done by multiplying the associated population count with the growth rate factor for 2016 and again for 2021.

An alternative to this population forecasting approach was to incorporate the growth rates published by Statistics South Africa for the individual local municipalities, as can be seen in Table 5 below. However, only an average annual growth rate over the period 2001 to 2011 was given. Also, the 2001 estimates of this growth rate over the same period differed significantly from the actual growth experienced in these areas, showing that such figures are difficutl to estimates and can be quite inaccurate. The actual annual growth rates were not available to possibly identify trends for forecasting.

Local Municipality	Expected Percentage Annual Growth Rate [2001-2011]	Actual Percentage Annual Growth Rate [2001-2011]
Elias Motsoaledi	0.11	1.18
Ephraim Mogale	4.27	0.19
Fetakgomo	0.97	0.13
Greater Tubatse	3.21	2.19
Makhuduthamaga	0.55	0.46
Maruleng	1.43	0.05

Table 5. Local municipality growth rates

3.6. Select Appropriate Dwelling Points

The dwelling point data is divided into 40 features which are categorized into five different classifications: residential, recreation, business, community services and other. For this project, the decision was taken to disaggregate the population according to the residential dwelling points, making provision for the population to access an SAPS service point within the access norms from their home.

Tabulated below is a breakdown of the residential dwelling point features, showing which features were included for disaggregation.

Residential dwelling points	
Included for disaggregation	**Excluded from disaggregation**
1. Dwelling unit 2. Dwelling under construction 3. Students' residence 4. Home for the aged (excl. frail care centre) 5. Child care institution/orphanage 6. Workers' hostel 7. Boarding school hostel 8. Defence force barracks, camp, ship in harbour 9. Refugee camp, shelter for the homeless	1. Vacant dwelling 2. Demolished structure 3. Unoccupied dwelling

Table 6. Residential dwelling points

3.7. Disaggregate Population Data

The ward shapes all differ in size and population counts. Locating the population count at the centroids of the wards for accessibility analysis could result in significant inaccuracies, particularly with the bigger wards. As a result, an attempt was made to more accurately distribute the population based on the chosen dwelling points. The number of selected dwelling points within each ward was summed and added as an attribute to the ward. The associated population was then divided by the number of dwelling points, giving an average population count per dwelling point in each ward.

3.8. Integrate Supply and Demand Data

The tessellated polygons were created with the aim that the population would be more accurately distributed throughout the study area. This means that instead of using the centroids of the wards, which vary significantly in size, the population would be associated with the centroid of smaller polygons. As a result, all the supply and demand data needed to be added as attributes to the tessellated polygons.

The population counts per polygon were added as an attribute by summing the population counts of each dwelling point which fell inside the polygon. The density of the population per polygon can be seen by the graduated colours in Figure 12 below.

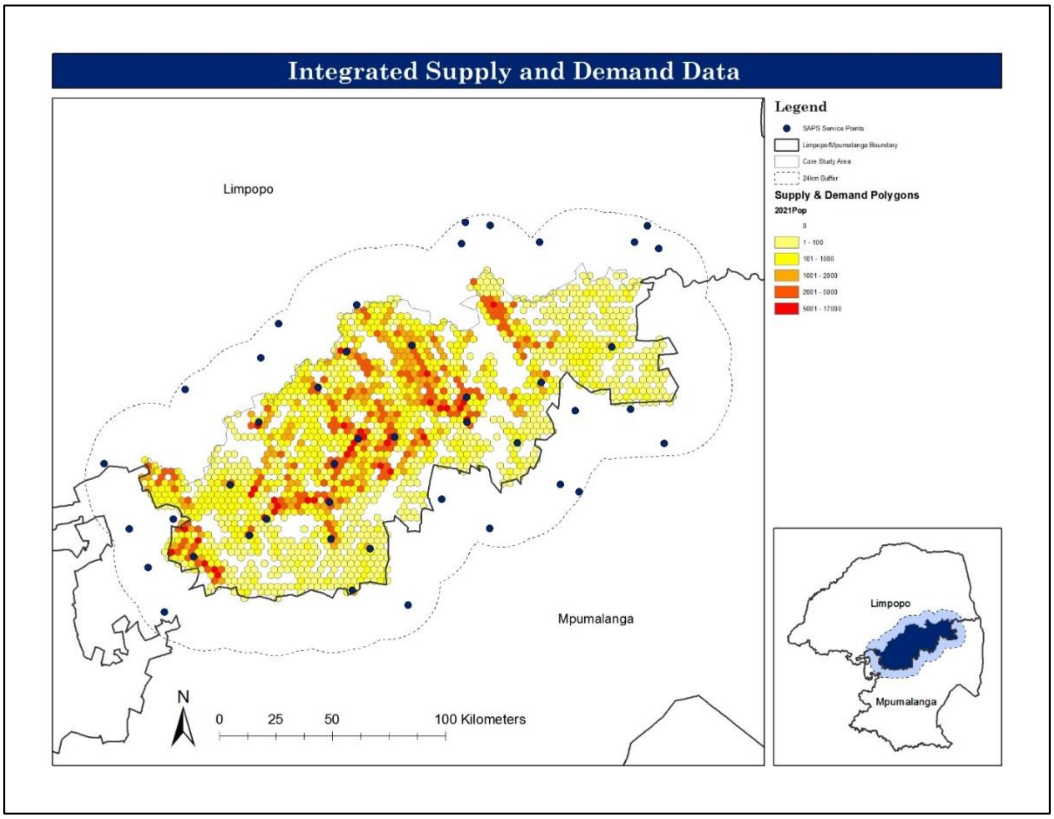

Figure 12. Integrated supply and demand data

Each polygon had to have a number of attributes added to it concerning the supply of SAPS services. These included:

1. An attribute specifying whether or not a polygon contained an SAPS service point.
2. The number of people the polygon could accommodate in terms of SAPS services.

3.9. Create Distance Matrix

Before the unserved population could be determined by means of a catchment area analysis, an origin/destination matrix (ODM) needed to be generated. This was done in Flowmap, using the tessellated polygon file.

In this matrix, the airline distance between each origin and destination was calculated. In theory, all polygons with a significant population count (a population count greater than zero) should serve as the origins, and the polygons containing SAPS service points as the destinations. However, a square matrix was created, with all the tessellated polygons (and associated attributes) serving as both the origins and destinations. This is because, when the expansion model is applied at a later stage, a destination will most likely be allocated to a polygon which does not have an SAPS service point.

An alternative to creating an airline distance matrix would be to create a distance matrix using a road network. This method calculates the distances between the origins and destination along the roads in the study area. It ensures that geographical obstacles such as rivers and mountains are taken into consideration and is a more realistic representation of the distances people are required to travel to gain access to service points. However, if the road network is not connected to a polygon, the polygon is considered inaccessible and cannot be allocated to a service point or be proposed as a new SAPS service point location.

This project is focused on a rural area, where many people travel part, if not most, of the way by footpath. It is unlikely that a road network would capture all possible footpaths available for use in a rural area and thus, the airline distance matrix, incorporating a CFCC (a factor which relates airline distance to actual distance travelled) was deemed to be more suitable.

3.10. Perform Catchment Area Analysis

A catchment area analysis allocates origins (populated polygons) to their nearest destination. Flowmap allows two conditions to be set for catchment area analyses:

1. A maximum capacity for the destination(s)
   In this study, the capacity threshold for the SAPS service points will be used. As suggested by the access norms discussed in the literature review, a capacity threshold of between sixty thousand and one hundred thousand people should be applied to the SAPS service points. The minimum and maximum thresholds were applied to the study, as well as an unconstrained capacity threshold. The unconstrained capacity threshold was applied to determine the actual demand placed on an SAPS service point when people visit their nearest SAPS service point, irrespective of how busy it is.
2. A maximum distance from origin to destination (maximum reach)
   In terms of the distance constraint, a standard twenty kilometre airline distance was used. The access norms suggest that a person living in a rural area should not need to travel more than twenty four kilometres to access an SAPS service point. A Crow Flight Conversion Coefficient (CFCC) of 1.2 was incorporated, meaning that on average, a person travels 1.2 times the airline distance to access an SAPS service point via primary and secondary roads as well as footpaths. A CFCC of 1.2 was deemed appropriate for use in the Netherlands, a relatively flat country without any hairpins bends (Flowmap.geo.uu.nl, 2013). Because of limited information regarding such a factor in South Africa, this factor was considered to be suitable, particularly in the rural areas where many people travel, at least part of the route, via footpaths.

Population growth over a ten year period, from the most recent census data captured in 2011 to 2021, was also considered for the catchment area analyses.

A breakdown of the resulting catchment area analyses have been depicted in Figure 13 below.

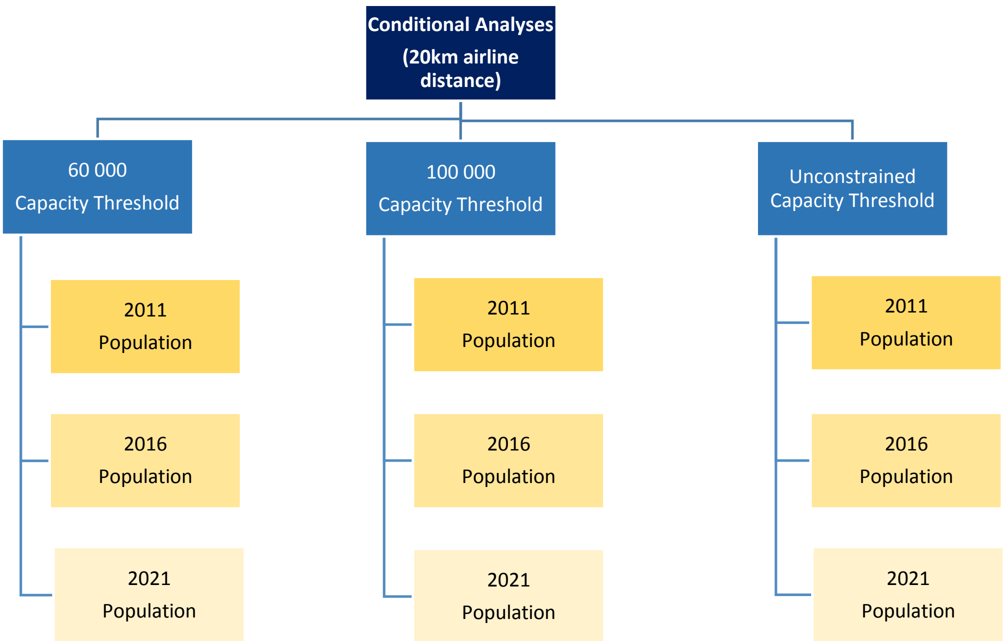

Figure 13. Conditional catchment area analyses

Each analysis produced four outputs:

1. The distance from a tessellated polygon to an allocated tessellated polygon with an SAPS service point, provided it was less than the distance constraint.
2. The demand placed on a tessellated polygon containing an SAPS service point. This is the population counts of the tessellated polygons that have been assigned to the polygon containing the service point under the particular constraints.
3. The identity of the polygon containing an SAPS service point to which the populated polygon has been assigned.
4. The unserved polygons and their associated demand data.

The outputs of the catchment area analysis were saved as additional attributes in the tessellated polygon file.

3.11. Apply Expansion Model

The expansion model entails the question of how many additional locations are required to meet a minimum level of service. The maximum customer coverage model type was used (as explained in paragraph 2.4.1), to ensure that the accessibility to SAPS service points is maximised in terms of the number of people living in the two ISRD nodes. This model maximises the overall increase in customer coverage by adding, step by step, the service point that, at the given step, results in the largest increase in customers covered. Thus, it must be noted that this model is iterative, and that each new service point addition may affect the optimality of earlier additions. However, if new additions are serving different portions of the unserved population more than twice the threshold distance, this optimality is not affected. A limitation of the expansion model is that it cannot incorporate a second objective, such as the minimising of travel distance, which would differentiate equally 'optimal' new service points for the same population being served. This means that a number of points may be considered 'equally optimal' even if they are located away from the unserved population but within the threshold distance.

The model allows for the use of a partial solution. This represents the already existing SAPS service points which satisfy some of the population. Thus, it takes into account the locations of already existing service points and the population they are serving, or failing to serve as a result of the imposed constraints, before determining new service point additions.

When running the expansion model, the user has the option to:

- Find a set number of optimal solutions
- Meet a specified percentage coverage
- Stop when a service point no longer meets a minimum demand

For this analysis, the condition was set to one hundred percent coverage. Although this is the ideal objective, it is understandably impractical to ensure full coverage under the constraints, particularly in a rural area where people are sparsely spread. However, by applying a one hundred percent coverage, the addition of each new service point could be analysed.

As with the catchment area analyses, a number of expansion model runs were carried out, to look at the best locations based on the varying constraints.

Chapter 4: Results

4.1. Catchment Area Analysis

The results generated from the catchment area analysis are tabulated below. This indicates the demand placed on each SAPS service point given the imposed constraints. A summary, giving the total accessibility statistics, is included at the bottom of the table.

Current SAPS Service Point Demand									
SAPS Service Point Capacity Threshold	**60 000**			**100 000**			**Unconstrained**		
Population Projection Year	**2011**	**2016**	**2021**	**2011**	**2016**	**2021**	**2011**	**2016**	**2021**
ACORNHOEK	1 269	1 326	1 395	1 269	1 326	1 395	1 269	1 326	1 395
APEL	51 487	55 764	58 651	48 927	51 141	53 788	48 927	51 141	53 788
BURGERSFORT	60 000	60 000	60 000	57 102	59 685	62 775	57 059	59 640	62 728
DENNILTON	60 000	60 000	60 000	85 204	89 059	93 669	85 204	89 059	93 669
DIENTJIE	1 401	1 464	1 540	1 401	1 464	1 540	1 401	1 464	1 540
DULLSTROOM	50	52	55	50	52	55	50	52	55
ELANDSKRAAL	39 610	41 402	43 545	39 610	41 402	43 545	39 610	41 402	43 545
GRASKOP	0	0	0	0	0	0	0	0	0
GRAVELOTTE	0	0	0	0	0	0	0	0	0
GROBLERSDAL	12 821	13 429	14 134	10 395	10 865	11 427	10 395	10 865	11 427
HLOGOTLOU	60 000	60 000	60 000	77 097	80 585	84 757	77 097	80 585	84 757
HOEDSPRUIT	8 086	8 452	8 889	8 086	8 452	8 889	8 086	8 452	8 889
JANE FURSE	60 000	60 000	60 000	100 000	100 000	100 000	99 543	104 047	109 433
KWAGGAFONTEIN	9 628	10 064	10 585	56	58	61	56	58	61
LAERSDRIFT	3 620	3 784	3 980	3 620	3 784	3 980	3 620	3 784	3 980
LEBOENG	34 676	36 283	38 161	33 448	34 961	36 771	33 448	34 961	36 771
LEBOWAKGOMO	0	0	0	0	0	0	0	0	0
LETSITELE	0	0	0	0	0	0	0	0	0
LULEKANI	0	0	0	0	0	0	0	0	0
LYDENBURG	0	0	0	0	0	0	0	0	0
MAAKE	2 313	2 417	2 542	2 313	2 417	2 542	2 313	2 417	2 542
MAARTENSHOOP	1 523	1 592	1 675	1 133	1 540	1 620	970	1 014	1 067
MAGATLE	0	0	0	0	0	0	0	0	0
MALIPSDRIFT	18 317	19 145	20 137	17 524	18 317	19 265	17 524	18 317	19 265
MARBLE HALL	35 459	37 064	38 983	35 459	37 064	38 983	35 459	37 064	38 983
MASEMOLA	60 000	60 000	60 000	49 362	52 585	55 977	49 362	51 596	54 267
MECKLENBURG	60 000	60 000	60 000	92 298	96 474	100 000	92 298	96 474	101 469
MHALA	0	0	0	0	0	0	0	0	0
MOTETEMA	60 000	60 000	60 000	54 924	57 409	60 381	54 924	57 409	60 381
NAMAKGALE	38	40	42	38	40	42	38	40	42
NEBO	60 000	60 000	60 000	67 513	70 568	75 760	67 513	70 568	74 221

OHRIGSTAD	5 622	5 911	6 327	5 622	5 877	6 181	5 622	5 877	6 181
PHALABORWA	16	17	18	16	17	18	16	17	18
PILGRIM'S REST	0	0	0	0	0	0	0	0	0
RITAVI	0	0	0	0	0	0	0	0	0
ROEDTAN	0	0	0	0	0	0	0	0	0
ROOSSENEKAL	4 936	5 159	5 426	4 858	5 078	5 341	4 858	5 078	5 341
SEKHUKHUNE	60 000	60 000	60 000	100 000	100 000	100 000	115 182	120 394	126 626
SIYABUSWA	45 818	47 908	50 388	41 013	42 869	45 088	41 013	42 869	45 088
TUBATSE	60 000	60 000	60 000	98 252	100 000	100 000	98 252	102 697	108 014
TUINPLAAS	1 635	1 709	1 797	1 635	1 709	1 797	1 635	1 709	1 797
VAALBANK	0	0	0	0	0	0	0	0	0
VERENA	0	0	0	0	0	0	0	0	0
ZAAIPLAAS	19 681	21 706	23 297	19 595	20 482	21 542	19 595	20 482	21 542
Total Demand	**898 007**	**914 690**	**931 567**	**1 057 819**	**1 095 281**	**1 137 191**	**1 072 338**	**1 120 859**	**1 178 883**
Total Served Population	**1 171 695**	**1 224 712**	**1 288 111**	**1 171 695**	**1 224 712**	**1 288 111**	**1 171 695**	**1 224 712**	**1 288 111**
Percentage Served Population [%]	**76.64**	**74.69**	**72.32**	**90.28**	**89.43**	**88.28**	**91.52**	**91.52**	**91.52**
Total Unserved Population	**273 688**	**310 022**	**356 544**	**113 876**	**129 431**	**150 920**	**99 357**	**103 853**	**109 229**
Percentage Unserved Population [%]	**23.36**	**25.31**	**27.68**	**9.72**	**10.57**	**11.72**	**8.48**	**8.48**	**8.48**

* Highlighted SAPS service points (navy) are those which fall in the core study area (not the 24km buffer)
* Highlighted cells (light blue) represent the SAPS service points which have a demand higher than their capacity threshold

* Highlighted cells (yellow) represent the SAPS service points which have a demand that exceeds the maximum recommended service point threshold of 100 000 people

Table 7. Catchment area analyses results

These results are represented graphically in Appendix D, where the unserved population distribution can be seen, as well as the demand on the current SAPS service points.

4.2. Expansion Model

A summary of the expansion model results is tabulated below (a more detailed table can be found in Appendix E). One can see that many additional service points are required to reach full coverage, with the first couple of points significantly increasing the percentage coverage. The increase in coverage starts to become less significant when additional service points are allocated to the sparely populated regions that fall beyond the access norm constraints.

Figure 14 shows the cumulative percentage coverage (for the 2021 population) as a function of the number of additional SAPS service points for the different capacity constraints. The locations of the additional SAPS service points, as proposed by the expansion model, have been depicted in Appendix F.

Expansion Model Output - Percentage Coverage									
Capacity Threshold	**60 000**			**100 000**			**Unconstrained**		
Year	**2011**	**2016**	**2021**	**2011**	**2016**	**2021**	**2011**	**2016**	**2021**
Total population	1 171 696	1 224 711	1 288 109	1 171 696	1 224 711	1 288 109	1 171 696	1 224 711	1 288 109
Number of Additional Service Points									
0	76.64	74.69	72.32	90.28	89.43	88.28	91.52	91.52	91.52
1	84.50	83.35	81.67	96.12	95.32	94.22	97.36	97.36	97.36
2	90.80	89.66	87.98	97.27	97.38	97.27	98.51	98.51	98.51
3	94.88	94.78	94.15	98.51	98.54	98.42	99.07	99.07	99.07
4	96.49	95.93	95.55	99.07	99.07	99.01	99.42	99.42	99.42
5	97.64	97.09	96.83	99.42	99.42	99.36	99.75	99.75	99.75
6	98.53	98.14	97.99	99.75	99.75	99.69	99.89	99.89	99.89
7	99.38	99.06	99.04	99.89	99.89	99.83	99.93	99.93	99.93
8	99.78	99.47	99.44	99.93	99.93	99.90	99.97	99.97	99.98
9	99.85	99.79	99.77	99.97	99.97	99.94	99.99	99.99	99.99
10	99.91	99.86	99.84	99.99	99.99	99.98	100.00	100.00	100.00
11	99.97	99.93	99.91	100.00	100.00	100.00	100.00	100.00	100.00
12	99.98	99.96	99.95	100.00	100.00	100.00	100.00	100.00	100.00
13	99.99	99.98	99.97	100.00	100.00	100.00			
14	99.99	99.99	99.98						
15	100.00	99.99	99.99						
16	100.00	100.00	100.00						
17		100.00	100.00						
18		100.00	100.00						
19			100.00						

Table 8. Summarised expansion model results

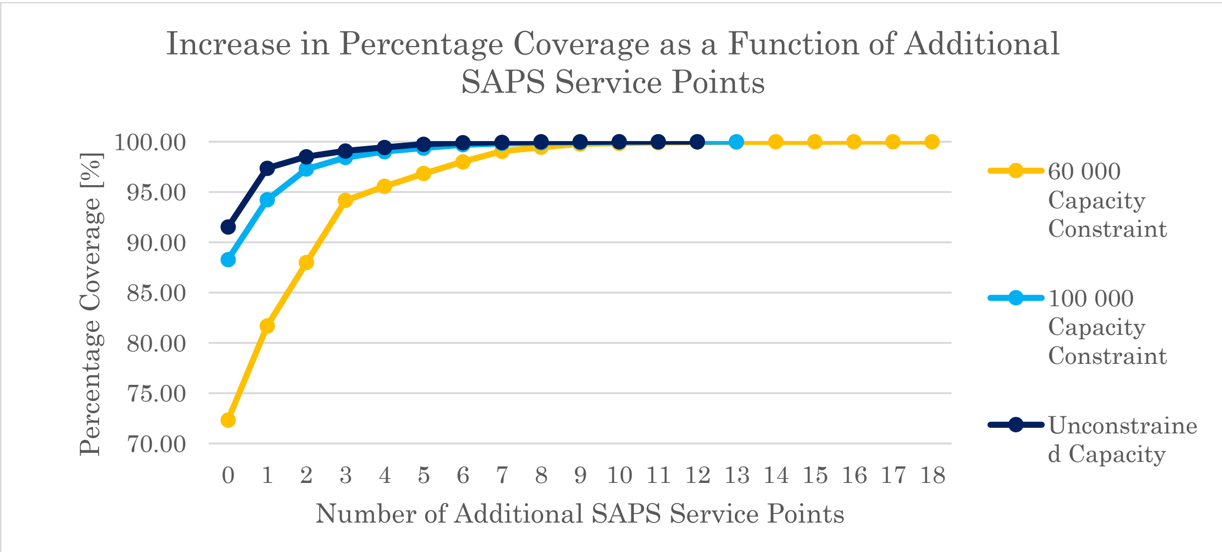

Figure 14. Cumulative percentage coverage as a function of the number of additional SAPS service points

When analysing the figures in Appendix F, it is important to keep in mind that a number of locations can be considered ‘equally optimal’ for the *maximize customer coverage* expansion model (as discussed in paragraph 3.11). The points having multiple options have been identified in Table 9 below. Although these points will result in the same customer coverage, the proposed point may be unrealistic if placed away from the unserved population. Unfortunately, Flowmap does not give any indication of the identity of the ‘equally optimal’ points. However, in developing a strategy, an attempt was made to relocate a couple of the proposed points so as to reduce the distance needed to travel to access these service points.

Equal Candidates										
Capacity Threshold		60 000			100 000			Unconstrained		
Year		2011	2016	2021	2011	2016	2021	2011	2016	2021
Number of Additional SAPS Service Points	0	-	-	-	-	-	-	-	-	-
	1	-	-	-	-	-	-	-	-	-
	2	-	-	-	85	-	-	85	85	85
	3	-	-	-	-	85	85	52	52	52
	4	13	85	5	52	52	40	-	-	-
	5	85	71	5	-	-	-	123	123	123
	6	10	-	85	123	123	123	10	10	10
	7	-	7	3	10	10	10	-	-	-
	8	-	-	-	-	-	5	114	114	114
	9	-	-	-	114	114	-	163	163	163
	10	93	-	4	163	163	114	26	26	26
	11	48	93	-	26	26	163	163	163	163
	12	113	162	162	163	163	163	163	163	163
	13	114	121	121	163	163	163			
	14	148	114	120						
	15	147	162	114						
	16	163	133	133						
	17		163	163						
	18		163	162						
	19			163						

Table 9. Number of equally optimal points

4.3. Validation of Results

Evaluation of the solution sets was done by including the proposed service points in the study and, once again, carrying out a catchment area analysis for each scenario. This would determine whether or not the proposed service location points resulted in the improved accessibility.

One of the limitations of the expansion model is that one cannot put a capacity threshold on newly proposed service points (the output of the expansion model). For example, the first proposed service point for the 2021 population under the 60 000 capacity threshold resulted in an additional 92 086 people being served, with a demand of 101 234 people being allocated to this service point when the catchment area analysis was carried out (see Appendix G). As a result, after performing the catchment area analyses, the total coverage statistics differed from those generated by the expansion model when the threshold distance was applied. This is shown in the table below. The detailed table can be found in Appendix G. One can see that this dilemma affects the 60 000 capacity threshold studies far more than the 100 000 capacity studies.

Results Validation - 2021 Expansion Output					
Capacity Threshold	60 000		100 000		Unconstrained
Constraint	Additional Capacity Restricted	Additional Capacity Unrestricted	Additional Capacity Restricted	Additional Capacity Unrestricted	Additional Capacity Unrestricted
Total Demand	1 249 301	1 288 109	1 288 109	1 288 109	1 288 109
Percetage Coverage	96.99	100.00	100.00	100.00	100.00

Table 10. Results validation of 2021 expansion model output

Chapter 5: Accessibility Improvement Strategy

6.1. Development of Accessibility Improvement Strategy

The improvement of accessibility to SAPS services, by means of new facilities, should have a long term approach. As a result, the strategy that has been developed is based on the 2021 population projections. Although 2021 is just over six years away, this strategy hopes to identify key areas where people are living, and will most likely still be living, beyond the access norm constraints.

Because the expansion of SAPS facilities is a costly project and expansion should be considered for the long term, it is vital that the best options are considered. Increasing the number of fully-fledged service points in order to achieve minimal accessibility improvements may not be worth the additional cost of introducing a new facility.

After analysis of the results, it has been decided that imposing the restrictive 60 000 capacity threshold on a service point is not necessary for the accessibility improvement strategy. Because the access norms suggest a capacity threshold of between 60 000 and 100 000 people, this strategy has allowed for a 100 000 capacity threshold to be acceptable. It is important to note that only four of the current SAPS service points are expected to experience a demand higher than 100 000 in 2021, and this figure is expected to improve with the introduction of new service points.

In order to develop a strategy to improve access to SAPS facilities, the expansion model output locations were studied, specifically the 100 000 and unconstrained capacity threshold results for the 2021 population (see Figure 30 and Figure 31 in Appendix F). It can be noted that there are many similarities in the output generated from these two expansion model runs. Both scenarios were considered, because one has to take into consideration whether it is better to be limited by distance or by capacity threshold.

The following additional points were chosen. The incremental implementation of this strategy is depicted graphically in Appendix I, and the corresponding numerical results can be found in Appendix H.

1. Point 1 from the 2021, unconstrained results
   This point seemed more practical than point 1 from the 2021, 100 000 constrained capacity results because it was located nearer to the higher density population and could still satisfy the surrounding unserved population.
2. Point 4 from the 2021, 100 000 constrained capacity result
   Point 2 was deemed unrealistic, as it was located right next to Sekhukhune service point, typically to serve the unserved population because Sekhukhune has a demand higher than the 100 000 capacity threshold. The approach taken was to rather locate new service points nearer to the community not being served

and reduce travelling distance. As a result, point 4 was selected, to serve part of the surrounding unserved population.

3. Point 3 from the 2021, 100 000 constrained capacity result
   This point is the same as point 2 of the unconstrained result. This point is located in an area where there is an obvious lack of an SAPS service point.
4. Point 5 from the 2021, 100 000 constrained capacity result
   This point would provide access to the sparsely populated region of Maruleng, who do not have access under the access norm constraints. It is fairly central to this population and is deemed suitable to meet the need of the people living in this area. It is also located where there is a clear absence of an SAPS service point.
5. Point 6 (relocated) from the 2021, 100 000 constrained capacity result
   Point 6 was relocated, to provide better access in terms of distance for the unserved population. It was also moved further from the Marble Hall SAPS service points.
6. Point 10 (relocated) from the 2021, 100 000 constrained capacity result
   Because the decision was taken to use point 4 instead of point 2 as the second point for this strategy, a portion of the unserved population which would have been served by point 2 was now left unserved. As a result, point 10 was relocated to this region.
7. Point 7 from the 2021, 100 000 constrained capacity result
   This point serves to provide access to the sparely populated southern region of Sekhukhune. This region is also clearly lacking an SAPS service point.
8. Point 9 from the 2021, 100 000 constrained capacity result
   This point will be able to serve the sparsely populated eastern region of Maruleng, which is just too far in terms of distance to their nearest SAPS service point.

Depicted in Figure 15, below, is the influence of the adding, one at a time, the above mentioned SAPS service points. The first two proposed locations for SAPS service points will result in the coverage of eighty one percent (122 197 people) of the currently unserved population and 97.77 percent coverage of the total population. A third addition will mean that approximately ninety one percent (137 080 people) of the currently unserved population will now have access to SAPS services within the access norm constraints, resulting in a 98.93 percent coverage of the total population.

The first and second proposed service points are easily justifiable, as they improve the accessibility by 75 867 people and 46 330 people respectively. The remaining proposed points only improve the accessibility to SAPS services by a small margin. However, if implemented, these points, particularly the fifth and sixth, will experience high demand as they are a better alternatives, in terms of distance, for people living within their vicinity. They also relieve some of the high demand placed on other service points.

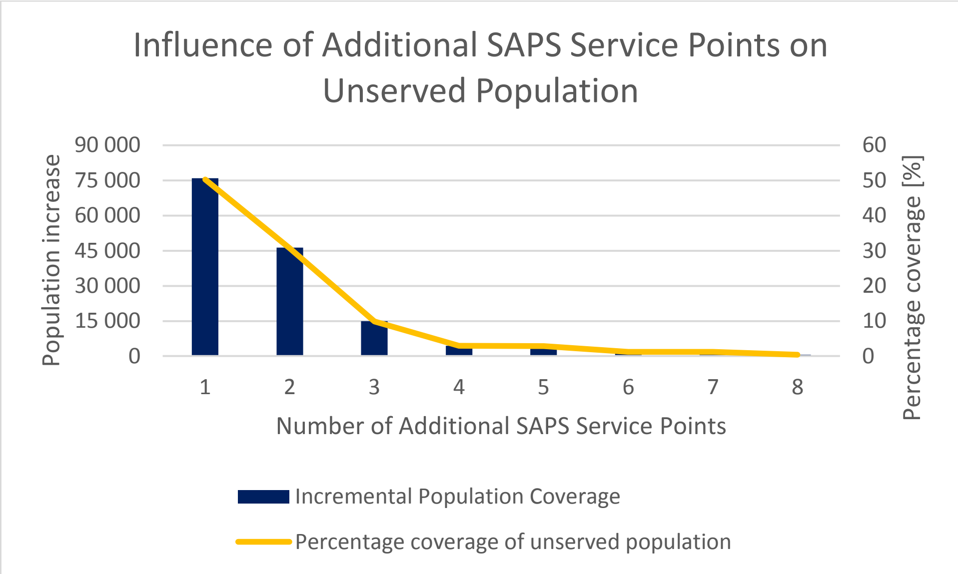

Figure 15. Influence of additional SAPS service points on unserved demand

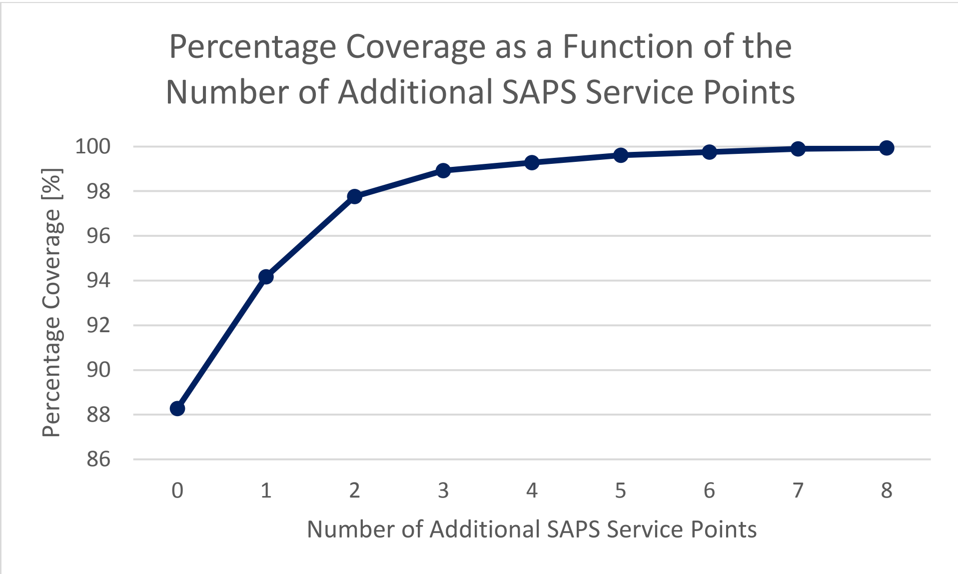

Figure 16. Percentage coverage as a function of additional SAPS service points

6.2. Proposed Strategy

Through analysis of the impact each of the proposed service points has on the improvement of accessibility to SAPS services, it is suggested that point one and point two are prioritised for development of fully-fledged service points. It becomes challenging to justify the construction of a fully-fledged SAPS service point to meet the demand of less than a quarter of the minimum capacity threshold. However, it also becomes challenging to justify why some points are not being considered for development where people are living beyond the access norms, particularly as crime is so prominent in South Africa. In the case that a point has been identified which can further improve the accessibility, smaller facility options should be considered, such as containers or mobile points. This will further help to increase SAPS presence, but in a realistic manner.

6.3. Sensitivity Analysis of CFCC

A sensitivity analysis was conducted to determine how the CFCC affects the coverage statistics of the proposed strategy: two additional fully-fledged SAPS services. The CFCC limits the demand placed on a service point by influencing the maximum reach. What is of particular concern, is how a higher CFCC will reduce the accessibility of the population. As can be seen in Figure 17, the increase of the CFCC from a value of 1.2 to 1.3 only decreases the percentage coverage by 0.45 percent (5 738 people). However, a more noticeable difference is observed when this value is increased to 1.4, resulting in a 4.05 percent decrease in coverage (52 221 people).

Until further information is available concerning the ratio between airline and road network distances for the study area in question, a CFCC value of 1.2 is considered fair, particularly in a rural area with a lot of foot paths and dirt roads providing access. The formal infrastructure may not give a realistic reflection of the accessibility because informal paths provide unlimited opportunities for access in rural areas.

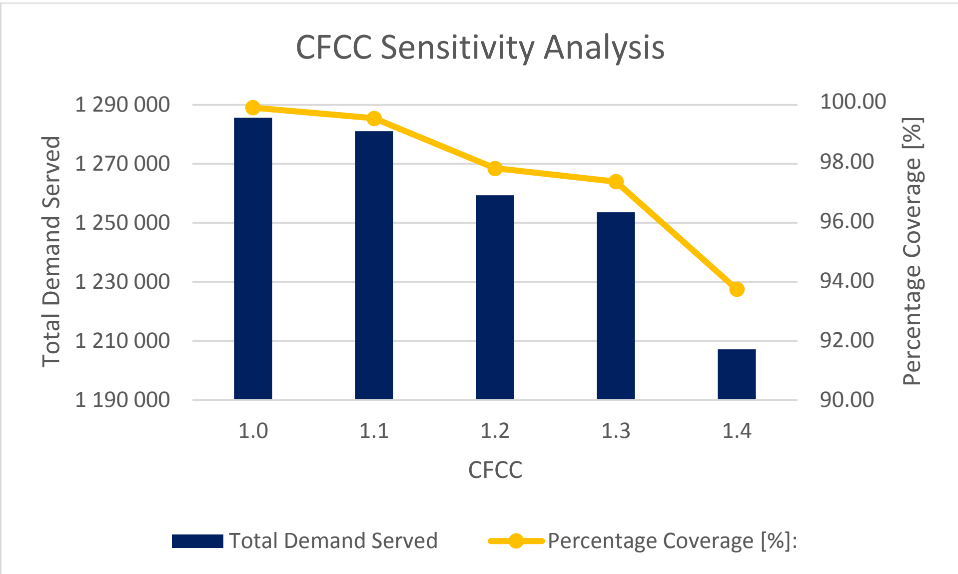

Figure 17. CFCC Sensitivity Analysis

Chapter 6: Conclusion

With the aim to more effectively balance the demand and supply for police service points in Maruleng and Sekhukune, a GIS-based approach has been adopted.

Population projections have been done to ensure that both the current and future needs of the people living within the study area are met. Because of the high costs associated with providing new police facilities and the time lapse to implement such plans, it is worthwhile considering population projections in the long-term. For this project, population growth over ten years was evaluated. However, the census data from which the projections were done is already nearly four years old and thus the projections attempt to give a 6 year perspective of the needs of the community under consideration.

The *maximise customer coverage* service location model in Flowmap assisted in identifying optimal locations for new police stations. These results are based on the new access norms recently developed by the CSIR for access to police service points.

Evaluation of the solution sets, which was based on the demand placed on service points and the proportion and dispersion of the unserved population, was carried out with a realistic and practical expansion strategy in mind. From the accessibility improvement strategy discussed above, it is strongly recommended that point one and point two are considered for fully-fledged SAPS service points, which are able to accommodate a high demand. The other points which formed part of the strategy development, only slightly improved the accessibility statistics. Justification of a fully-fledged SAPS service point would be challenging. However, it is recommended that these locations are not neglected and other alternatives, including smaller facilities or mobile service points, are considered.

The recommendations based on the outcome of this project aim to help the SAPS to progress in their fight to combat crime and provide a safe and secure environment for all South Africans. Not only should the SAPS benefit from such a study, but this model can be adapted to suit other locational challenges, such as the provision of health care facilities and schools.

Chapter 7: Further Opportunities for Expansion

1. The proposed locations for SAPS service points generated by this study are not exact coordinates, but located in one of the tessellated polygons. Further research can be done to determine the best point location for theses service points based on accessibility by road or path, property prices and development opportunities.

2. Scenario planning can be incorporated to better understand the population dynamics and more accurately project the population for long-term planning. This takes into account future development plans such as new mining or industrial areas which are likely to influence migration patterns.

3. Studies can be conducted to more accurately estimate the crow flight conversion coefficient (CFCC) for the study area.

4. The topology of the area, such as rivers and mountains, have not been considered in this study and may influence the accessibility of the SAPS service points. It may be worthwhile comparing this study to one done via road network analysis, which automatically incorporates such factors. Road networks only allow for the crossing of rivers where bridges have been built and roads do not allow for vehicles to travel over cliffs and/or rail way lines.

5. A strategy can be designed, whereby the next steps in the process of improving accessibility, beyond the identification of optimal sites, can be put into place.

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Appendices

Appendix A: Signed Industry Sponsorship Form

Department of Industrial & Systems Engineering
Final Year Projects
Identification and Responsibility of Project Sponsors

All Final Year Projects are published by the University of Pretoria on *UPSpace* and thus freely available on the Internet. These publications portray the quality of education at the University and have the potential of exposing sensitive company information. It is important that both students and company representatives or sponsors are aware of such implications.

Key responsibilities of Project Sponsors:

A project sponsor is the key contact person within the company. This person should thus be able to provide the best guidance to the student on the project. The sponsor is also very likely to gain from the success of the project. The project sponsor has the following important responsibilities:

1. Confirm his/her role as project sponsor, duly authorised by the company. Multiple sponsors can be appointed, but this is not advised. The duly completed form will considered as acceptance of sponsor role.
2. Review and approve the Project Proposal, ensuring that it clearly defines the problem to be investigated by the student and that the project aim, scope, deliverables and approach is acceptable from the company's perspective.
3. Review the Final Project Report (delivered during the second semester), ensuring that information is accurate and that the solution addresses the problems and/or design requirements of the defined project.
4. Acknowledges the intended publication of the Project Report on UP Space.
5. Ensures that any sensitive, confidential information or intellectual property of the company is not disclosed in the Final Project Report.

Project Sponsor Details:

Company:	South African Police Service
Project Description:	Locating Police Service Points in the Rural Areas of Limpopo
Student Name:	Kirsten Webber
Student number:	11071100
Student Signature:	KWebber
Sponsor Name:	Leon Rabie
Designation:	Organisational Design SAPS
E-mail:	rabiel@saps.gov.za
Tel No:	012 393 3016
Cell No:	082 770 4642
Fax No:	–
Sponsor Signature:	[signature]

Appendix B: Proportion of Births to Female Population

Proportion of Births to Female Population										
Mother's Age Cohort	**Births [2011]**	**Female Population [2011]**	**Proportion Births/Female Pop. [2011]**	**Births [2010]**	**Female Population [2010]**	**Proportion Births/Female Pop. [2010]**	**Births [2009]**	**Female Population [2009]**	**Proportion Births/Female Pop. [2009]**	**Average Proportion**
15-19	17 282	343 011	0.050383	14 248	335 700	0.042443	13 724	328 600	0.041765	0.044864
20-24	32 308	301 082	0.107306	31 545	297 400	0.106069	29 977	282 000	0.106301	0.106559
25-29	28 895	264 509	0.109240	27 869	250 900	0.111076	25 668	232 300	0.110495	0.110270
30-34	19 553	207 538	0.094214	18 911	202 700	0.093296	17 650	189 800	0.092993	0.093501
35-39	12 697	181 985	0.069769	11 862	168 100	0.070565	10 550	156 600	0.067369	0.069235
40-44	4 260	132 326	0.032193	4 161	119 400	0.034849	3 835	115 400	0.033232	0.033425
45-49	475	120 474	0.003943	475	109 300	0.004346	487	108 900	0.004472	0.004254
50-54	9	107 372	0.000084	22	97 200	0.000226	17	97 600	0.000174	0.000161
Unspecified *	289	1 318 016	0.000219	35	1 247 200	0.000028	43	1 220 900	0.000035	0.000094

* unspecified or outside the age range of 15-54

Table 11. Proportion of births to female population

Appendix C: Population Forecasting

Population Forecasting [2011-2016]										
Age Group Cohort	Total Pop. [Lim, 2011]	Male Pop. [Lim, 2011]	Female Pop. [Lim, 2011]	Male Death Probability [SA, 2012]	Female Death Probability [SA, 2012]	Male Deaths [5 years]	Female Deaths [5 years]	Annual Proportion Births/Female Pop.	Births [5 years]	Net Migration [2011-2016]
0-4	644 866	324 580	320 286	0.017	0.015	5 518	4 676			
5-9	618 826	310 582	308 244	0.008	0.005	2 485	1 541			
10-14	666 213	331 328	334 885	0.007	0.005	2 319	1 674			
15-19	684 142	341 131	343 011	0.010	0.008	3 411	2 744	0.044864	76 944	
20-24	597 516	296 434	301 082	0.014	0.019	4 150	5 721	0.106559	160 415	
25-29	499 372	234 863	264 509	0.029	0.038	6 811	10 051	0.110270	145 838	
30-34	382 577	175 039	207 538	0.050	0.053	8 752	11 000	0.093501	97 025	
35-39	313 766	131 781	181 985	0.069	0.060	9 093	10 919	0.069235	62 998	
40-44	221 810	89 484	132 326	0.079	0.056	7 069	7 410	0.033425	22 115	
45-49	195 676	75 202	120 474	0.101	0.054	7 595	6 506	0.004254	2 562	
50-54	173 912	66 540	107 372	0.110	0.059	7 319	6 335	0.000161	87	
55-59	150 851	58 400	92 451	0.131	0.072	7 650	6 656			
60-64	125 239	47 829	77 410	0.182	0.097	8 705	7 509			
65-69	91 813	35 140	56 673	0.255	0.139	8 961	7 878			
70-74	76 632	27 291	49 341	0.344	0.200	9 388	9 868			
75-79	56 110	17 288	38 822	0.440	0.282	7 607	10 948			
80+	55 336	15 432	39 904	0.702	0.665	10 836	26 528			
Unspecified			1 318 016					0.000094	621	
Total	**5 554 657**	**2 578 344**	**2 976 313**			**117 670**	**137 964**		**568 604**	**-61 632**
Mid-year Population Estimate [2016] =			**5 805 994**		**% Growth [2011-2016] =**		**4.52**	**Average Annual % Growth =**	**0.90**	

Table 12. Population forecasting, 2011-2016

Population Forecasting [2016-2021]										
Age Group Cohort	Total Pop. [Lim, 2016]	Male Pop. [Lim, 2016]	Female Pop. [Lim, 2016]	Male Death Probability [SA, 2012]	Female Death Probability [SA, 2012]	Male Deaths [5 years]	Female Deaths [5 years]	Annual Proportion Births/Female Pop.	Births [5 years]	Net Migration [2016-2021]
0-4	566 791	275 803	289 175	0.017	0.015	4 689	4 222			
5-9	632 859	317 249	313 797	0.008	0.005	2 538	1 569			
10-14	612 987	306 285	304 890	0.007	0.005	2 144	1 524			
15-19	660 407	327 196	331 398	0.010	0.008	3 272	2 651	0.044864	74 339	
20-24	676 174	335 907	338 454	0.014	0.019	4 703	6 431	0.106559	180 327	
25-29	585 833	290 471	293 549	0.029	0.038	8 424	11 155	0.110270	161 849	
30-34	480 697	226 239	252 645	0.050	0.053	11 312	13 390	0.093501	118 112	
35-39	361 013	164 474	194 726	0.069	0.060	11 349	11 684	0.069235	67 409	
40-44	291 941	120 875	169 253	0.079	0.056	9 549	9 478	0.033425	28 286	
45-49	205 518	80 602	123 103	0.101	0.054	8 141	6 648	0.004254	2 618	
50-54	179 762	65 794	112 156	0.110	0.059	7 237	6 617	0.000161	91	
55-59	158 445	57 408	99 224	0.131	0.072	7 520	7 144			
60-64	134 731	48 937	83 982	0.182	0.097	8 907	8 146			
65-69	107 213	37 311	68 089	0.255	0.139	9 514	9 464			
70-74	73 162	24 367	46 983	0.344	0.200	8 382	9 397			
75-79	55 563	16 090	37 660	0.440	0.282	7 080	10 620			
80+	53 714	12 464	39 437	0.702	0.665	8 752	26 218			
Unspecified			1 283 237					0.000094	604	
Total	**5 805 994**	**2 707 474**	**3 098 521**			**123 512**	**146 358**		**633 635**	**-63 203**
Mid-year Population Estimate [2021] =			**6 106 555**			**% Growth [2016-2021] =**	**5.18**	**Average Annual % Growth =**		**1.04**

Table 13. Population Forecasting, 2016-2021

Appendix D: Graphic Catchment Area Analysis Results

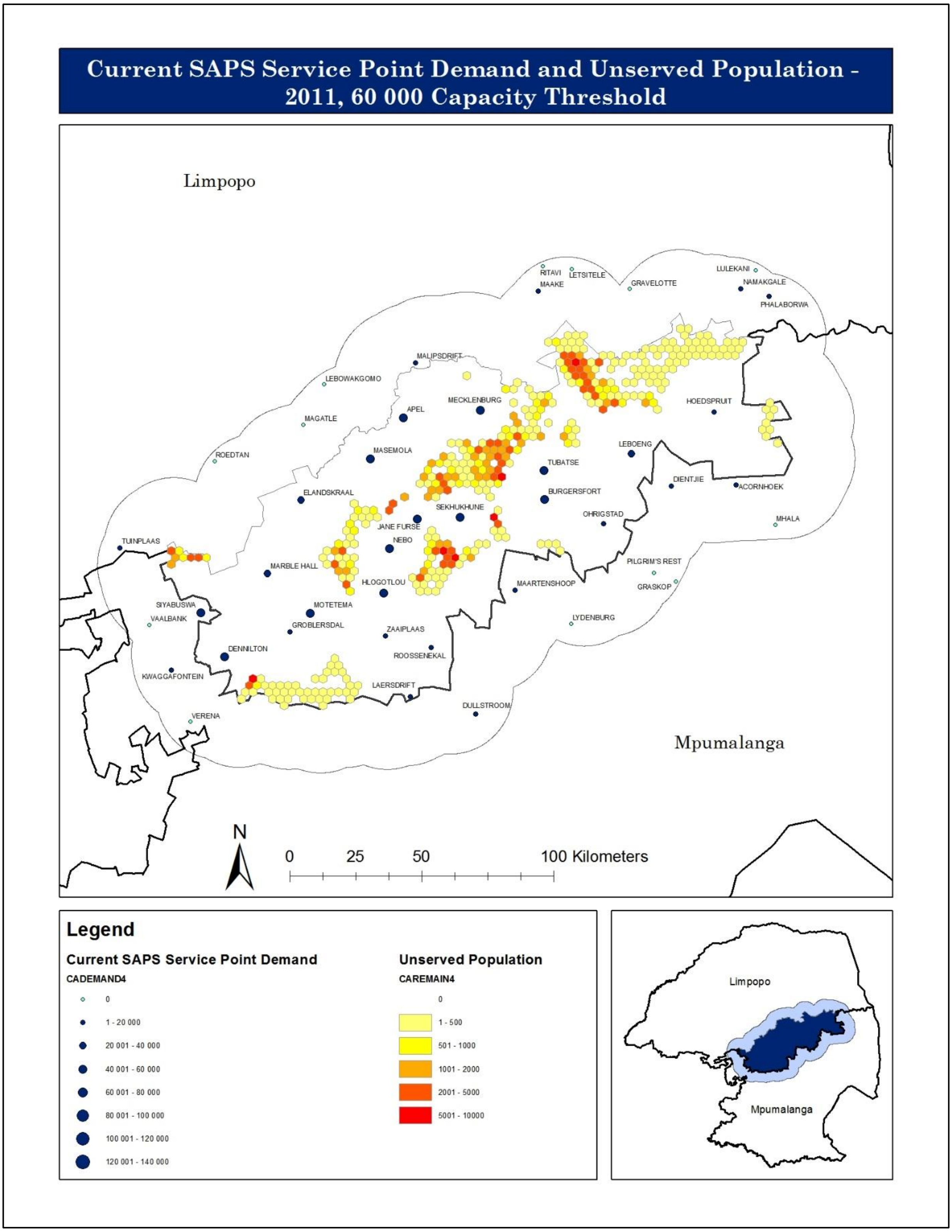

Figure 18. Catchment area analysis results - 2011, 60 000 capacity threshold

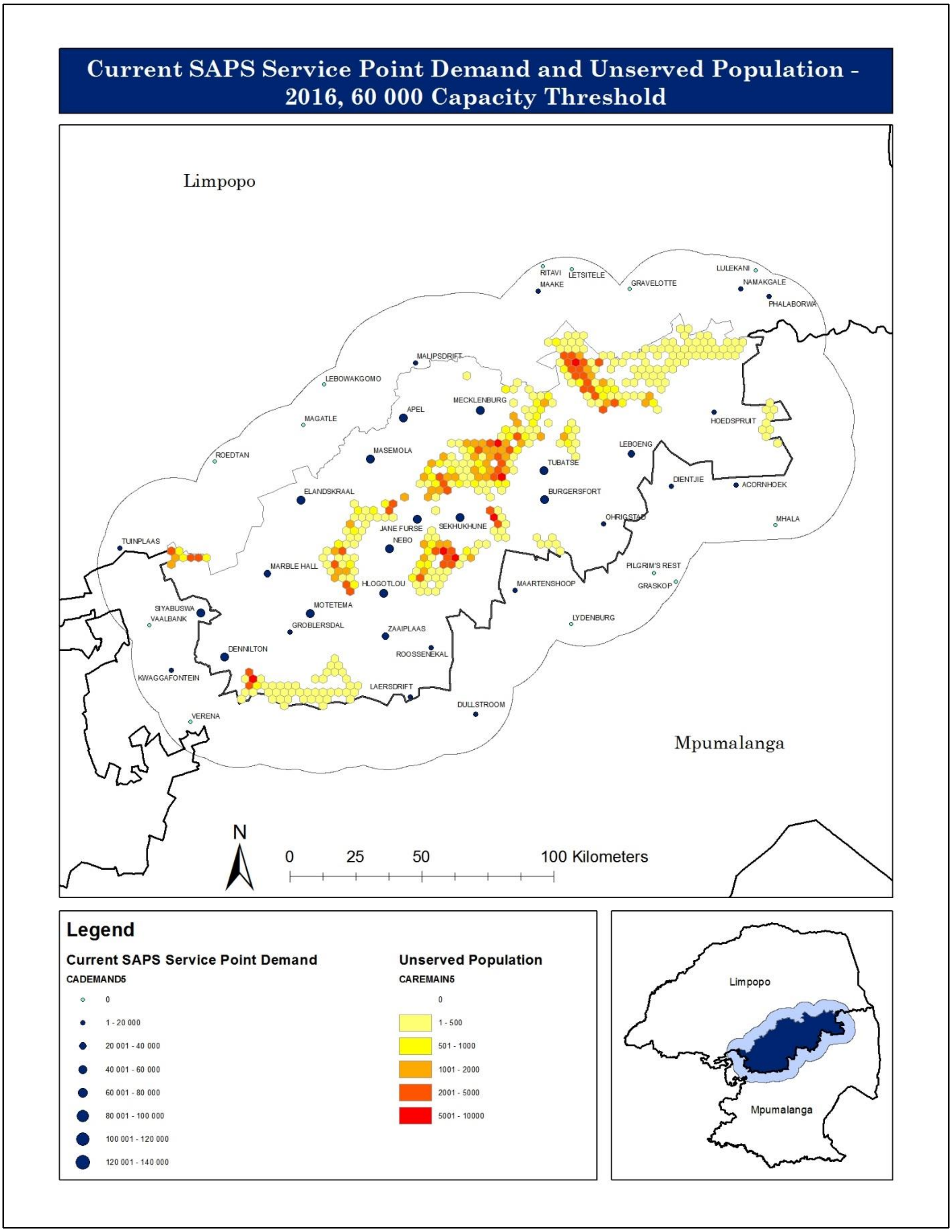

Figure 19. Catchment area analysis results - 2016, 60 000 capacity threshold

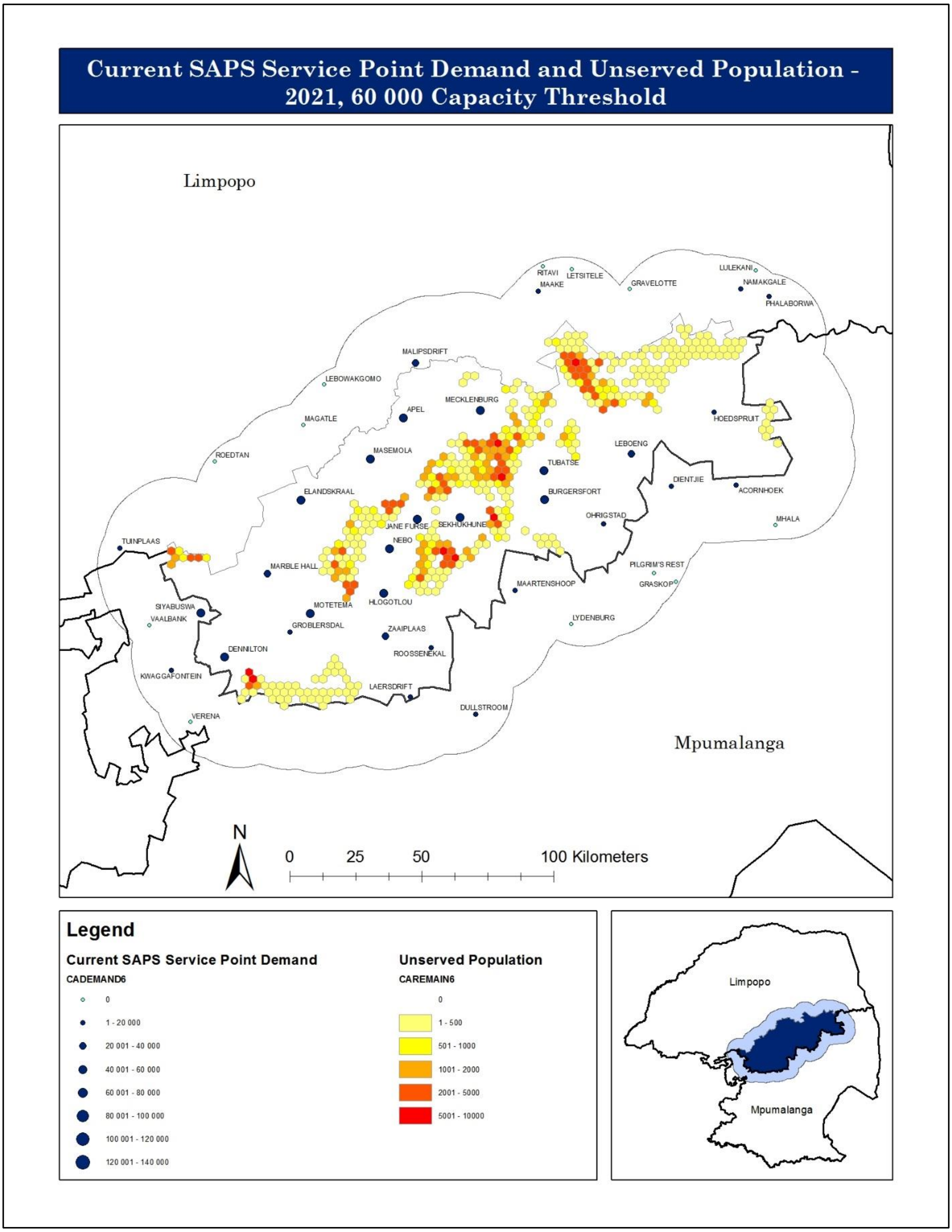

Figure 20. Catchment area analysis results - 2021, 60 000 capacity threshold

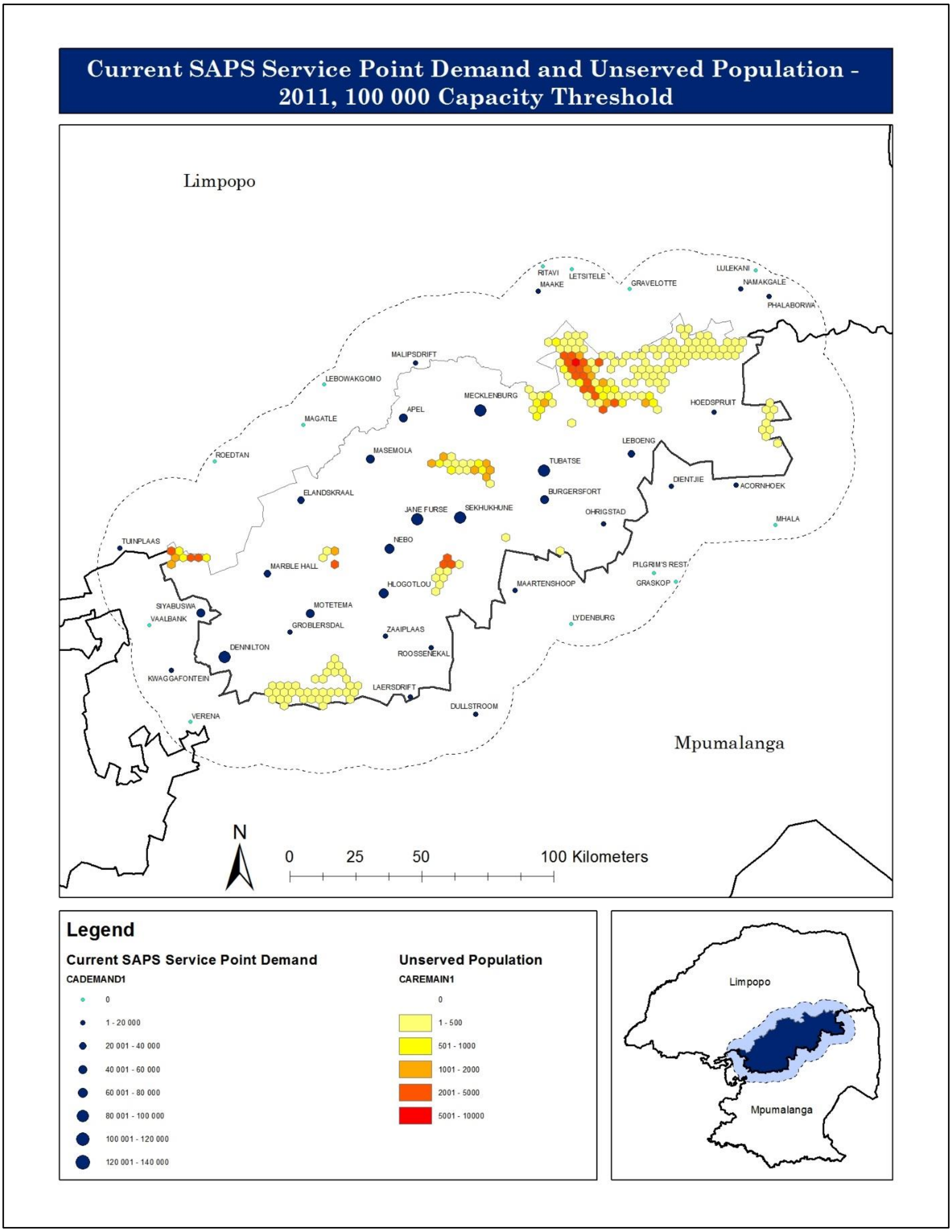

Figure 21. Catchment area analysis results - 2011, 100 000 capacity threshold

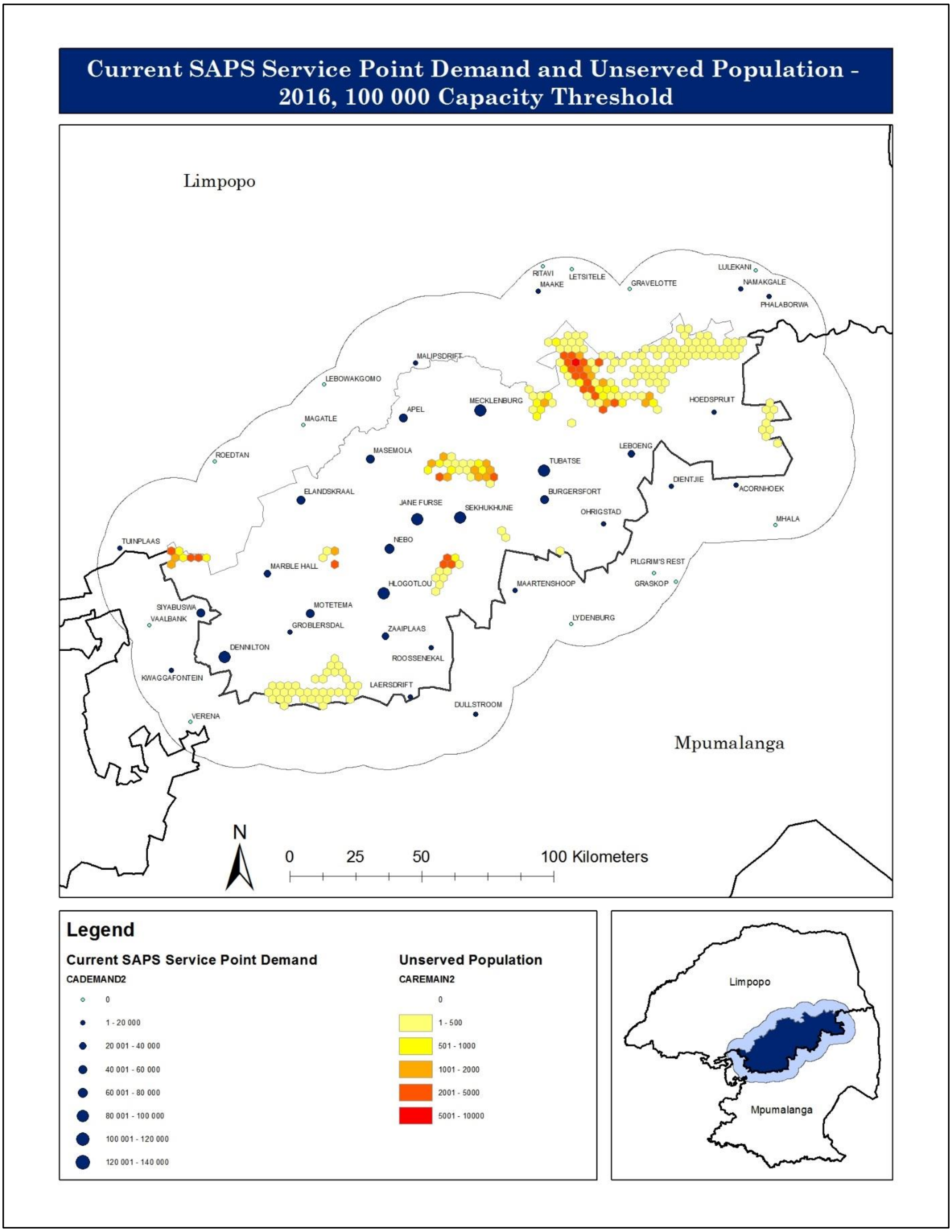

Figure 22. Catchment area analysis results - 2016, 100 000 capacity threshold

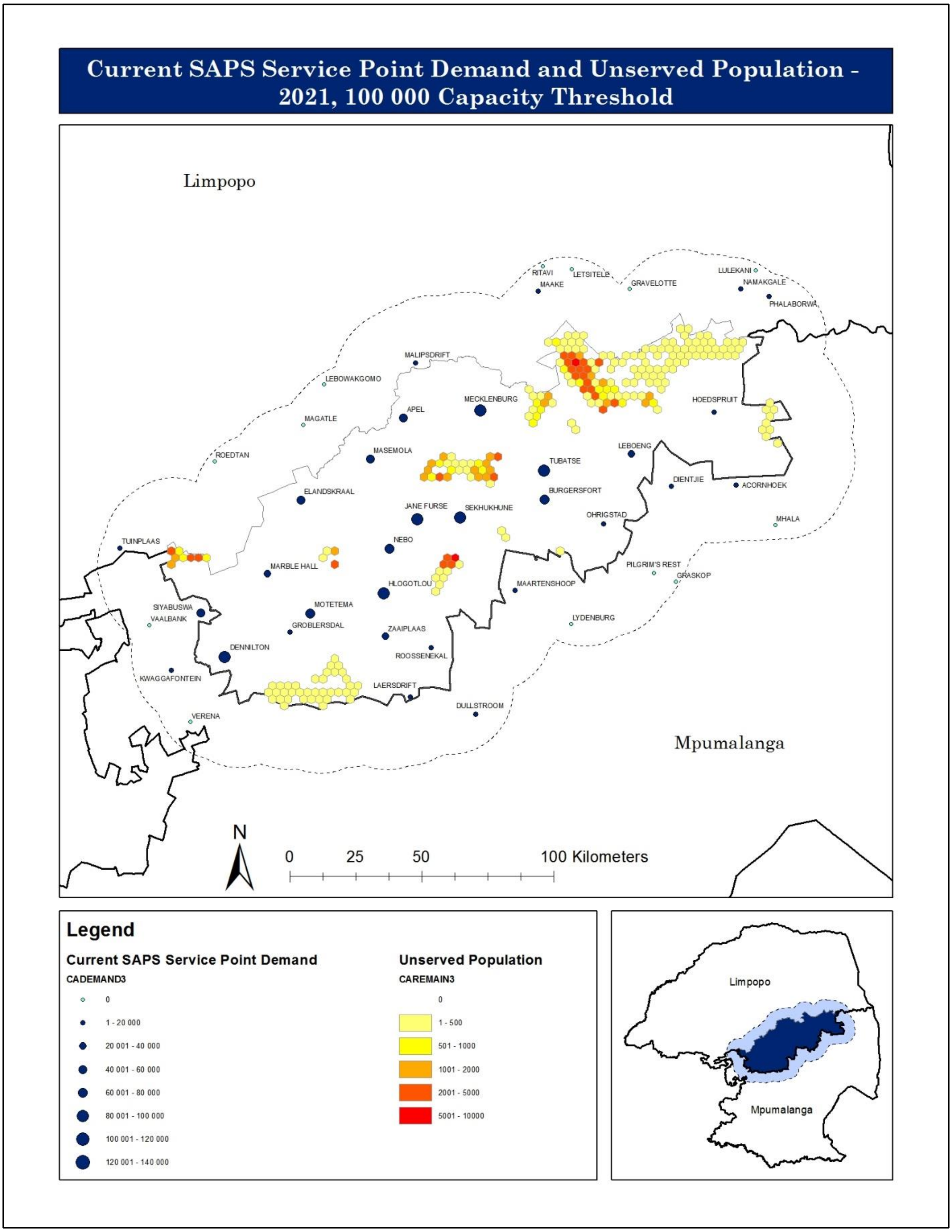

Figure 23. Catchment area analysis results - 2021, 100 000 capacity threshold

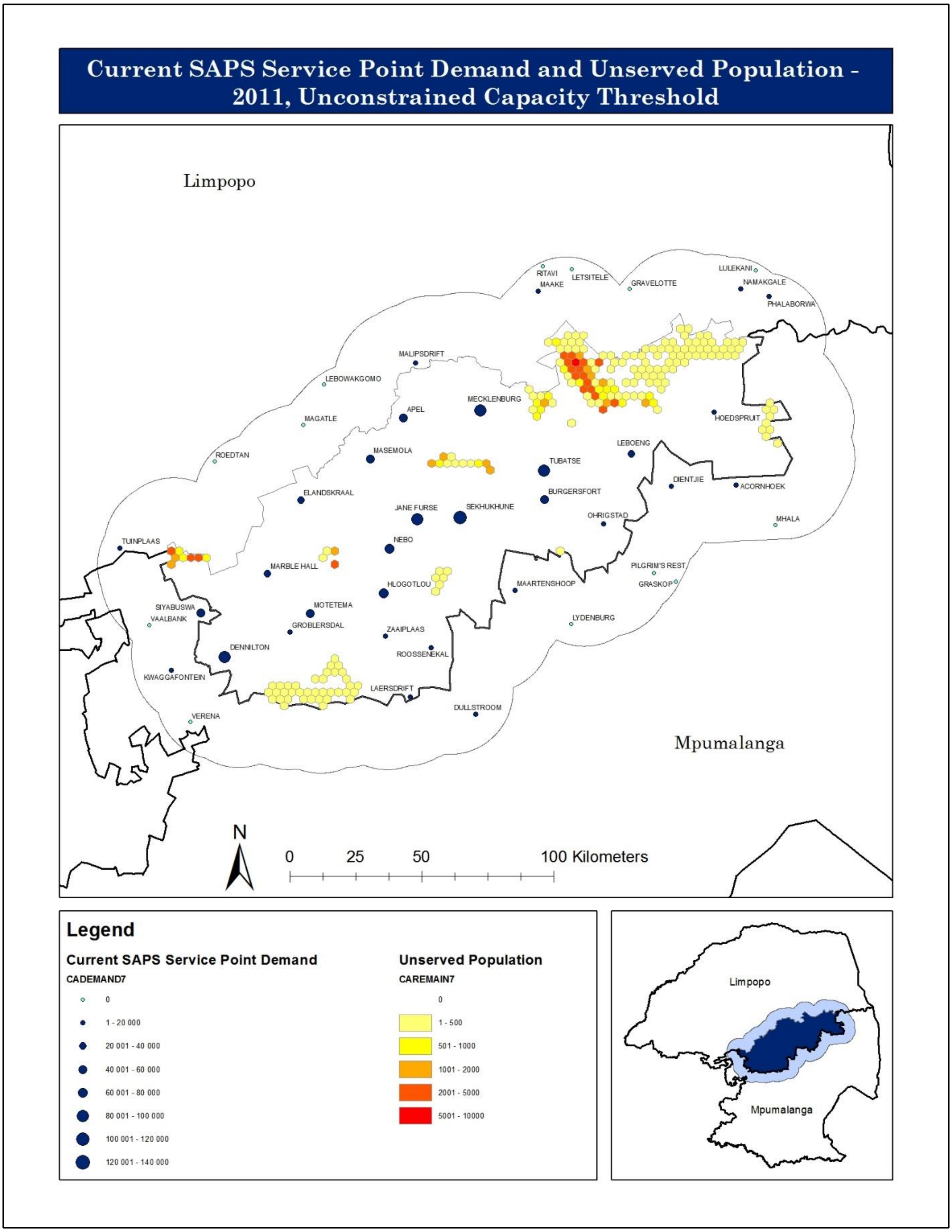

Figure 24. Catchment area analysis results - 2011, unconstraied capacity threshold

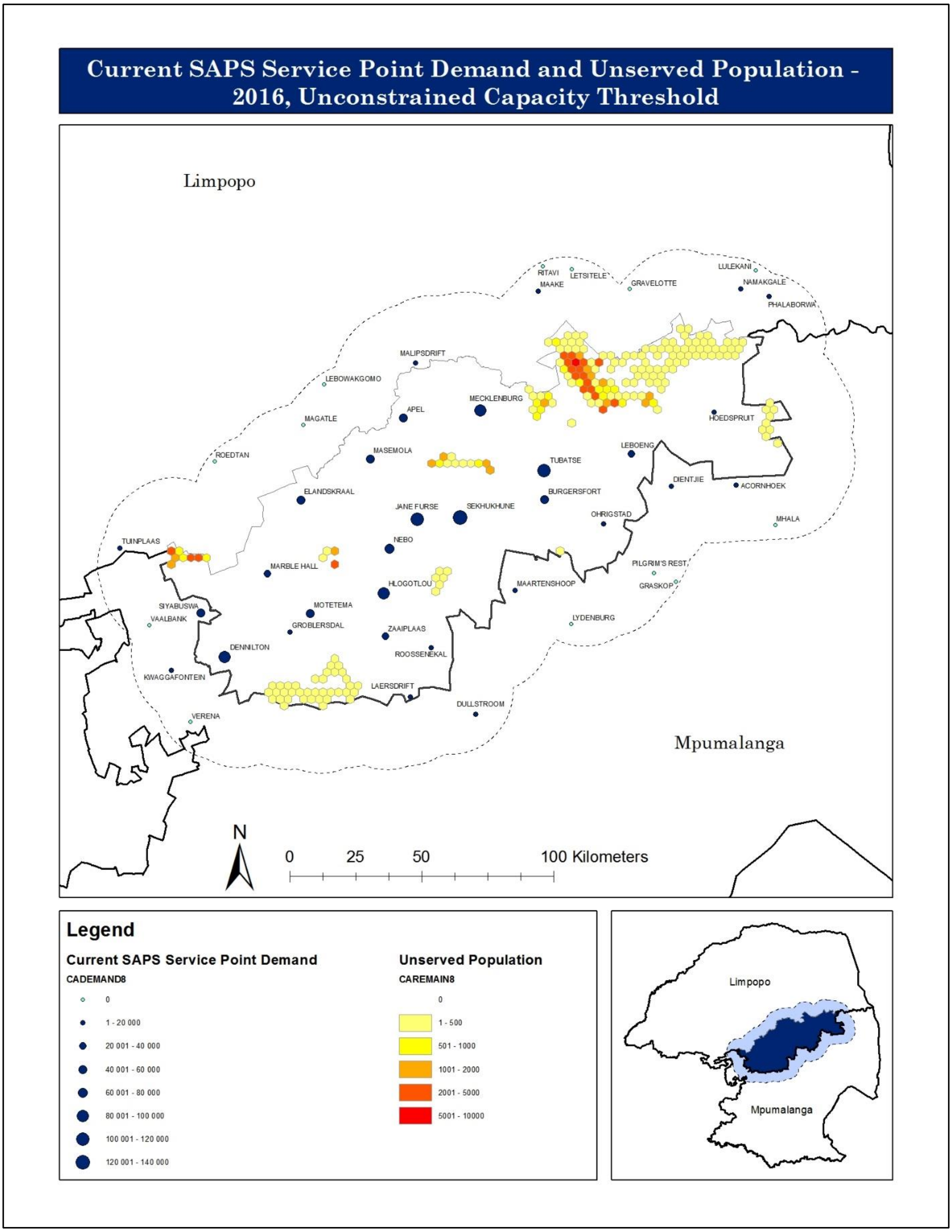

Figure 25. Catchment area analysis results - 2016, unconstrained capacity threshold

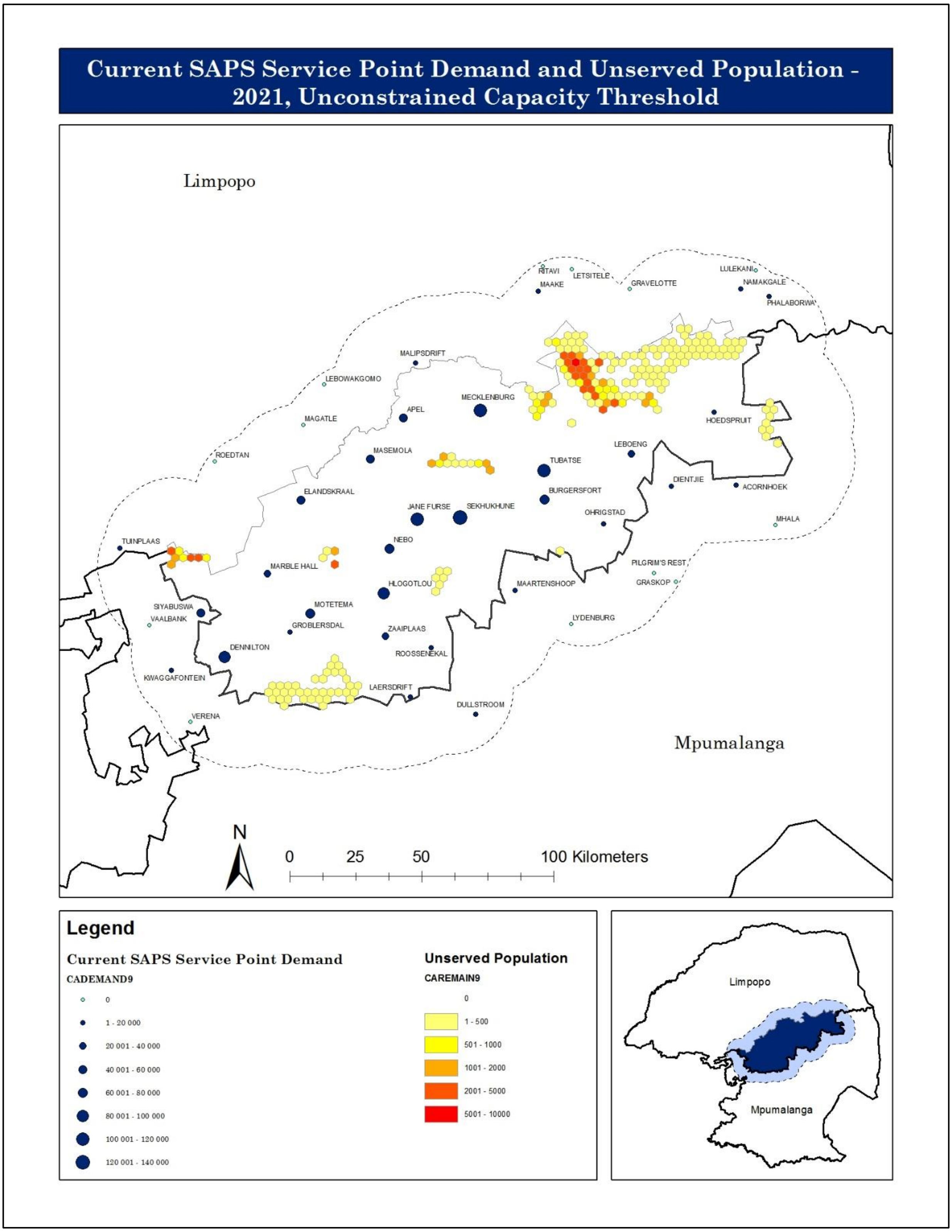

Figure 26. Catchment area analysis results - 2021, unconstrained capacity threshold

Appendix E: Numeric Expansion Model Results

Expansion Model Output										
Capacity Threshold		**60 000**			**100 000**			**Unconstrained**		
Year		**2011**	**2016**	**2021**	**2011**	**2016**	**2021**	**2011**	**2016**	**2021**
Number of polygons		4 901	4 901	4 901	4 901	4 901	4 901	4 901	4 901	4 901
Total population		1 171 696	1 224 711	1 288 109	1 171 696	1 224 711	1 288 109	1 171 696	1 224 711	1 288 109
0	No. of served polygons	4 526	4 496	4 466	4 679	4 673	4 666	4 690	4 690	4 690
	Total population served	898 007	914 690	931 567	1 057 819	1 095 281	1 137 191	1 072 338	1 120 859	1 178 883
	Percentage coverage [%]	76.64	74.69	72.32	90.28	89.43	88.28	91.52	91.52	91.52
1	New service point ID	12 517	12 517	12 517	13 326	13 326	13 325	13 326	13 326	13 326
	No. of served polygons	4 596	4 578	4 555	4 743	4 735	4 732	4 755	4 755	4 755
	Total population served	990 093	1 020 805	1 051 979	1 126 205	1 167 414	1 213 681	1 140 724	1 192 340	1 254 063
	Incremental pop. coverage	92 086	106 115	120 412	68 386	72 133	76 490	68 386	71 481	75 180
	Percentage coverage [%]	84.50	83.35	81.67	96.12	95.32	94.22	97.36	97.36	97.36
2	New service point ID	13 267	13 267	13 267	10 164	12 512	12 376	10 164	10 164	10 164
	No. of served polygons	4 666	4 649	4 626	4 751	4 755	4 752	4 763	4 763	4 763
	Total population served	1 063 921	1 098 045	1 133 218	1 139 743	1 192 621	1 252 895	1 154 262	1 206 490	1 268 946
	Incremental pop. coverage	73 828	77 240	81 239	13 538	25 207	39 214	13 538	14 150	14 883
	Percentage coverage [%]	90.80	89.66	87.98	97.27	97.38	97.27	98.51	98.51	98.51
3	New service point ID	12 166	11 956	11 956	12 375	10 164	10 164	12 242	12 242	12 242
	No. of served polygons	4 709	4 717	4 704	4 763	4 763	4 760	4 774	4 774	4 774
	Total population served	1 111 723	1 160 760	1 212 742	1 154 262	1 206 771	1 267 779	1 160 793	1 213 317	1 276 126
	Incremental pop. coverage	47 802	62 715	79 524	14 519	14 150	14 884	6 531	6 827	7 180
	Percentage coverage [%]	94.88	94.78	94.15	98.51	98.54	98.42	99.07	99.07	99.07
4	New service point ID	11 353	10 164	11 293	12 242	12 175	12 313	14 035	14 035	14 035
	No. of served polygons	4 735	4 725	4 718	4 774	4 774	4 766	4 832	4 832	4 832
	Total population served	1 130 539	1 174 911	1 230 732	1 160 793	1 213 316	1 275 351	1 164 876	1 217 585	1 280 615
	Incremental pop. coverage	18 816	14 151	17 990	6 531	6 545	7 572	4 083	4 268	4 489
	Percentage coverage [%]	96.49	95.93	95.55	99.07	99.07	99.01	99.42	99.42	99.42
5	New service point ID	10 164	11 052	11 039	14 035	14 035	14 035	10 947	10 947	10 947
	No. of served polygons	4 743	4 736	4 759	4 832	4 832	4 824	4 836	4 836	4 836
	Total population served	1 144 077	1 189 062	1 247 323	1 164 876	1 217 585	1 279 840	1 168 806	1 221 692	1 284 936
	Incremental pop. coverage	13 538	14 151	16 591	4 083	4 269	4 489	3 930	4 107	4 321
	Percentage coverage [%]	97.64	97.09	96.83	99.42	99.42	99.36	99.75	99.75	99.75
6	New service point ID	12 594	11 039	10 164	10 947	10 947	10 947	11 093	11 093	11 093
	No. of served polygons	4 756	4 777	4 767	4 836	4 836	4 828	4 873	4 873	4 873
	Total population served	1 154 479	1 201 883	1 262 207	1 168 806	1 221 692	1 284 160	1 170 427	1 223 387	1 286 718
	Incremental pop. coverage	10 402	12 821	14 884	3 930	4 107	4 320	1 621	1 695	1 782
	Percentage coverage [%]	98.53	98.14	97.99	99.75	99.75	99.69	99.89	99.89	99.89
7	New service point ID	11 037	12 661	13 030	11 093	11 093	11 093	14 430	14 430	14 430
	No. of served polygons	4 797	4 791	4 788	4 873	4 873	4 865	4 887	4 887	4 887
	Total population served	1 164 403	1 213 255	1 275 696	1 170 427	1 223 387	1 285 942	1 170 924	1 223 906	1 287 264

	Incremental pop. coverage	9 924	11 372	13 489	1 621	1 695	1 782	497	519	546
	Percentage coverage [%]	99.38	99.06	99.04	99.89	99.89	99.83	99.93	99.93	99.93
8	New service point ID	13 880	13 880	13 880	14 430	14 430	13 385	11 813	11 813	11 813
	No. of served polygons	4 855	4 849	4 846	4 887	4 887	4 878	4 893	4 893	4 893
	Total population served	1 169 100	1 218 164	1 280 859	1 170 924	1 223 906	1 286 820	1 171 400	1 224 404	1 287 787
	Incremental pop. coverage	4 697	4 909	5 163	497	519	878	476	498	523
	Percentage coverage [%]	99.78	99.47	99.44	99.93	99.93	99.90	99.97	99.97	99.98
9	New service point ID	14 390	12 832	12 832	11 813	11 813	14 430	12 831	12 831	12 831
	No. of served polygons	4 874	4 859	4 857	4 893	4 893	4 892	4 894	4 894	4 894
	Total population served	1 169 918	1 222 160	1 285 154	1 171 400	1 224 404	1 287 366	1 171 582	1 224 594	1 287 988
	Incremental pop. coverage	818	3 996	4 295	476	498	546	182	190	201
	Percentage coverage [%]	99.85	99.79	99.77	99.97	99.97	99.94	99.99	99.99	99.99
10	New service point ID	13 042	14 390	12 802	12 831	12 831	11 813	13 328	13 328	13 328
	No. of served polygons	4 882	4 878	4 861	4 894	4 894	4 898	4 899	4 899	4 899
	Total population served	1 170 665	1 223 016	1 286 091	1 171 582	1 224 594	1 287 890	1 171 676	1 224 692	1 288 090
	Incremental pop. coverage	747	856	937	182	190	524	94	98	102
	Percentage coverage [%]	99.91	99.86	99.84	99.99	99.99	99.98	100.00	100.00	100.00
11	New service point ID	12 831	13 042	14 390	13 328	13 328	12 831	14 336	14 336	14 336
	No. of served polygons	4 885	4 886	4 880	4 899	4 899	4 899	4 900	4 900	4 900
	Total population served	1 171 305	1 223 796	1 286 991	1 171 675	1 224 691	1 288 090	1 171 692	1 224 708	1 288 108
	Incremental pop. coverage	640	780	900	93	97	200	16	16	18
	Percentage coverage [%]	99.97	99.93	99.91	100.00	100.00	100.00	100.00	100.00	100.00
12	New service point ID	11 742	11 621	11 621	14 336	14 336	14 336	13 382	13 382	13 382
	No. of served polygons	4 891	4 887	4 881	4 900	4 900	4 900	4 901	4 901	4 901
	Total population served	1 171 496	1 224 191	1 287 406	1 171 691	1 224 708	1 288 108	1 171 695	1 224 712	1 288 111
	Incremental pop. coverage	191	395	415	16	17	18	3	4	3
	Percentage coverage [%]	99.98	99.96	99.95	100.00	100.00	100.00	100.00	100.00	100.00
13	New service point ID	14 336	10 343	10 343	13 382	13 382	13 382			
	No. of served polygons	4 896	4 890	4 884	4 901	4 901	4 901			
	Total population served	1 171 583	1 224 444	1 287 672	1 171 695	1 224 712	1 288 112			
	Incremental pop. coverage	87	253	266	4	4	4			
	Percentage coverage [%]	99.99	99.98	99.97	100.00	100.00	100.00			
14	New service point ID	11 093	14 336	13 042						
	No. of served polygons	4 898	4 895	4 890						
	Total population served	1 171 636	1 224 535	1 287 894						
	Incremental pop. coverage	53	91	222						
	Percentage coverage [%]	99.99	99.99	99.98						
15	New service point ID	10 341	12 906	14 336						
	No. of served polygons	4 900	4 896	4 895						
	Total population served	1 171 679	1 224 612	1 287 991						
	Incremental pop. coverage	43	77	97						
	Percentage coverage [%]	100.00	99.99	99.99						
16	New service point ID	13 882	11 093	11 093						
	No. of served polygons	4 901	4 899	4 898						
	Total population served	1 171 695	1 224 682	1 288 064						

	Incremental pop. coverage	16	70	73						
	Percentage coverage [%]	100.00	100.00	100.00						
17	New service point ID		13 882	13 882						
	No. of served polygons		4 900	4 899						
	Total population served		1 224 698	1 288 082						
	Incremental pop. coverage		16	18						
	Percentage coverage [%]		100.00	100.00						
18	New service point ID		11 740	11 979						
	No. of served polygons		4 901	4 900						
	Total population served		1 224 712	1 288 097						
	Incremental pop. coverage		14	15						
	Percentage coverage [%]		100.00	100.00						
19	New service point ID			11 740						
	No. of served polygons			4 901						
	Total population served			1 288 111						
	Incremental pop. coverage			14						
	Percentage coverage [%]			100.00						

* The number on the left hand side represents the number of additional SAPS service points

Table 14. Numeric expansion model results

Appendix F: Graphic Expansion Model Results

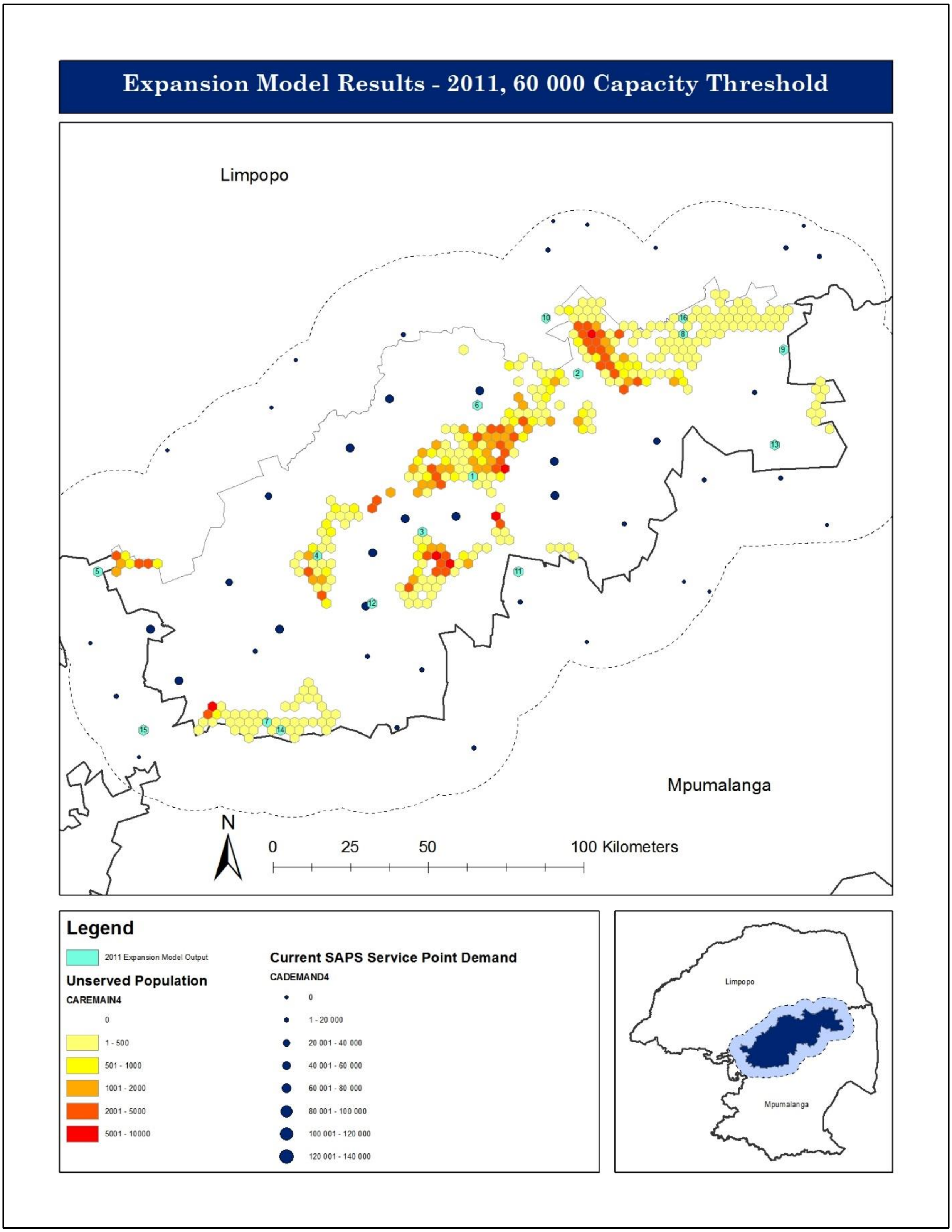

Figure 27. Expansion model results – 2011, 60 000 capacity threshold

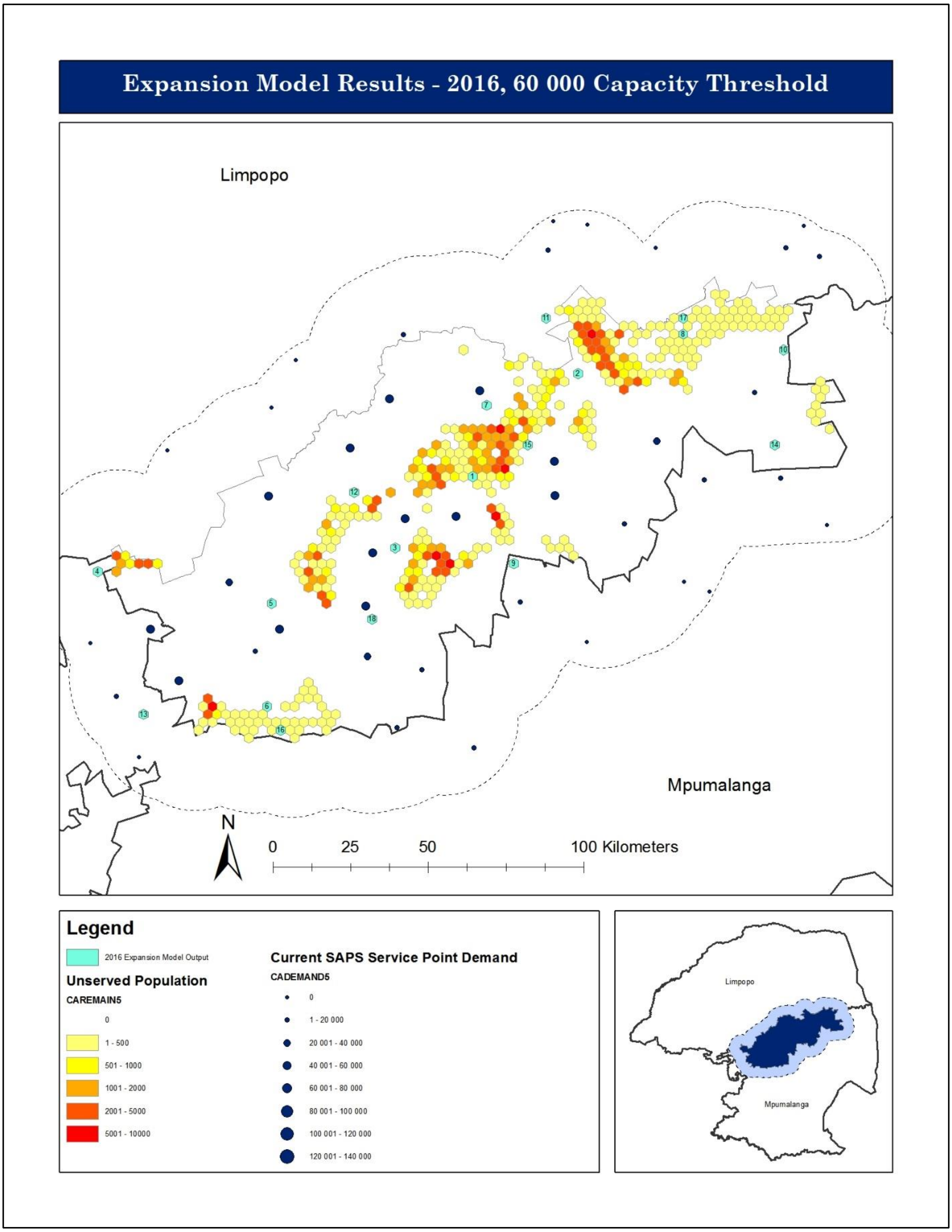

Figure 28. Expansion model results – 2016, 60 000 capacity threshold

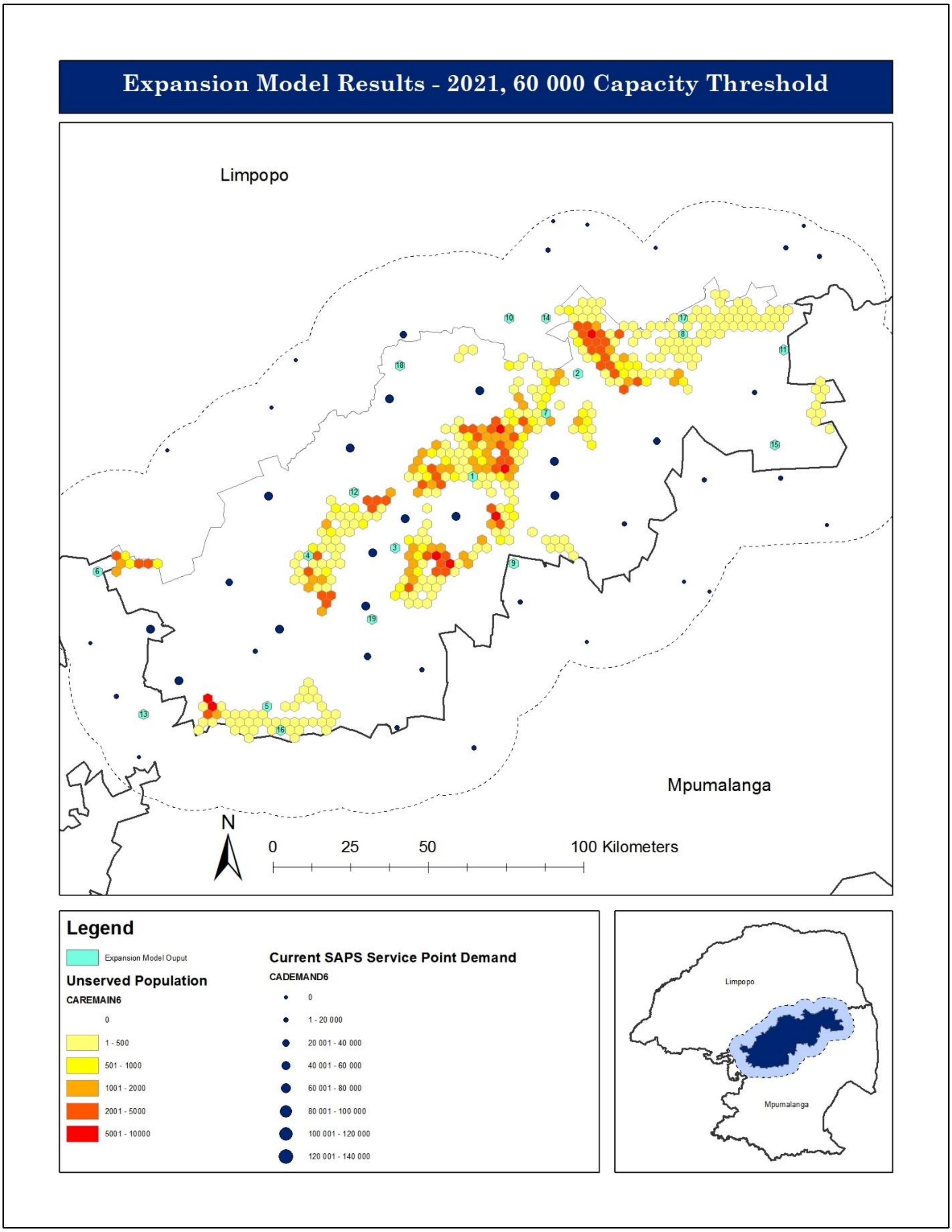

Figure 29. Expansion model results – 2021, 60 000 capacity threshold

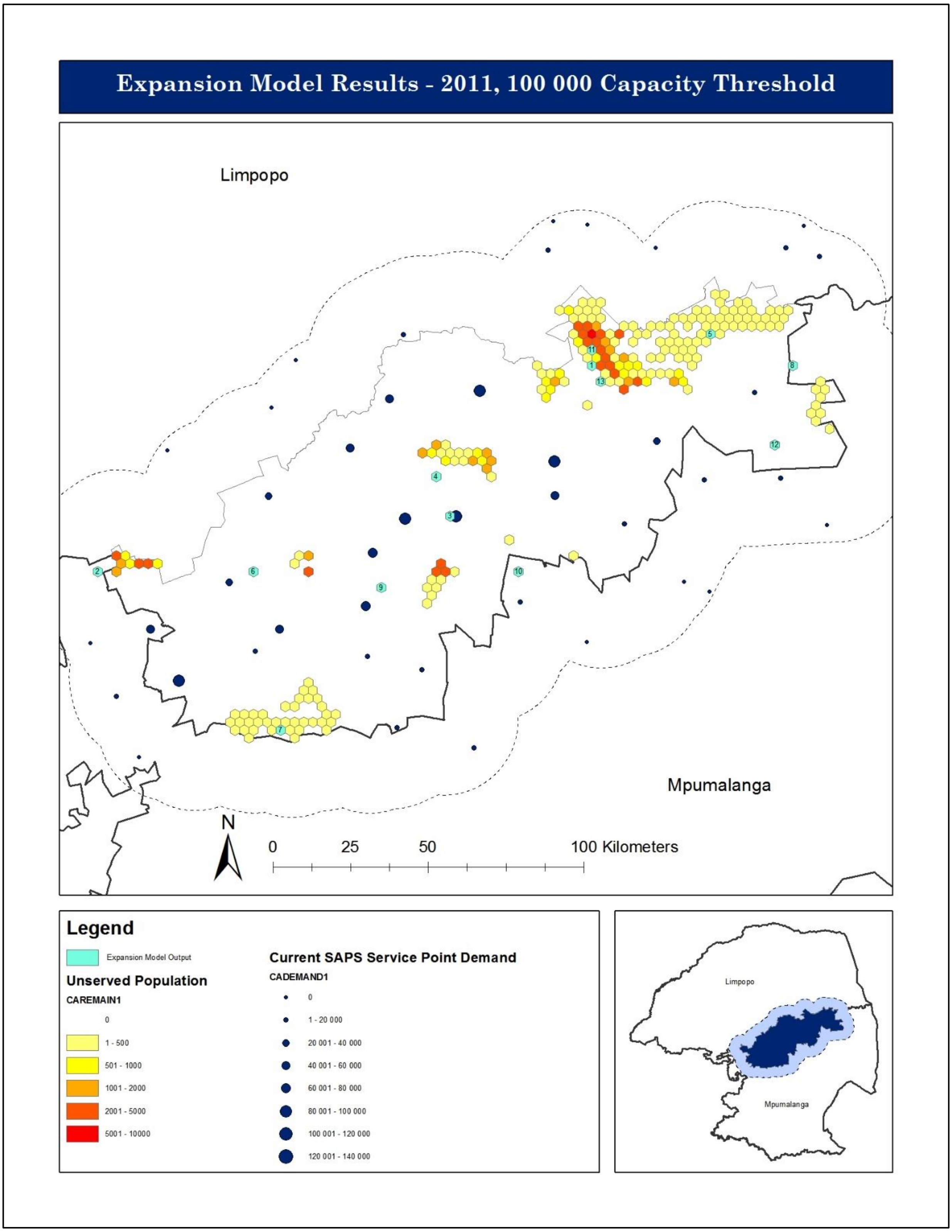

Figure 30. Expansion model results – 2011, 100 000 capacity threshold

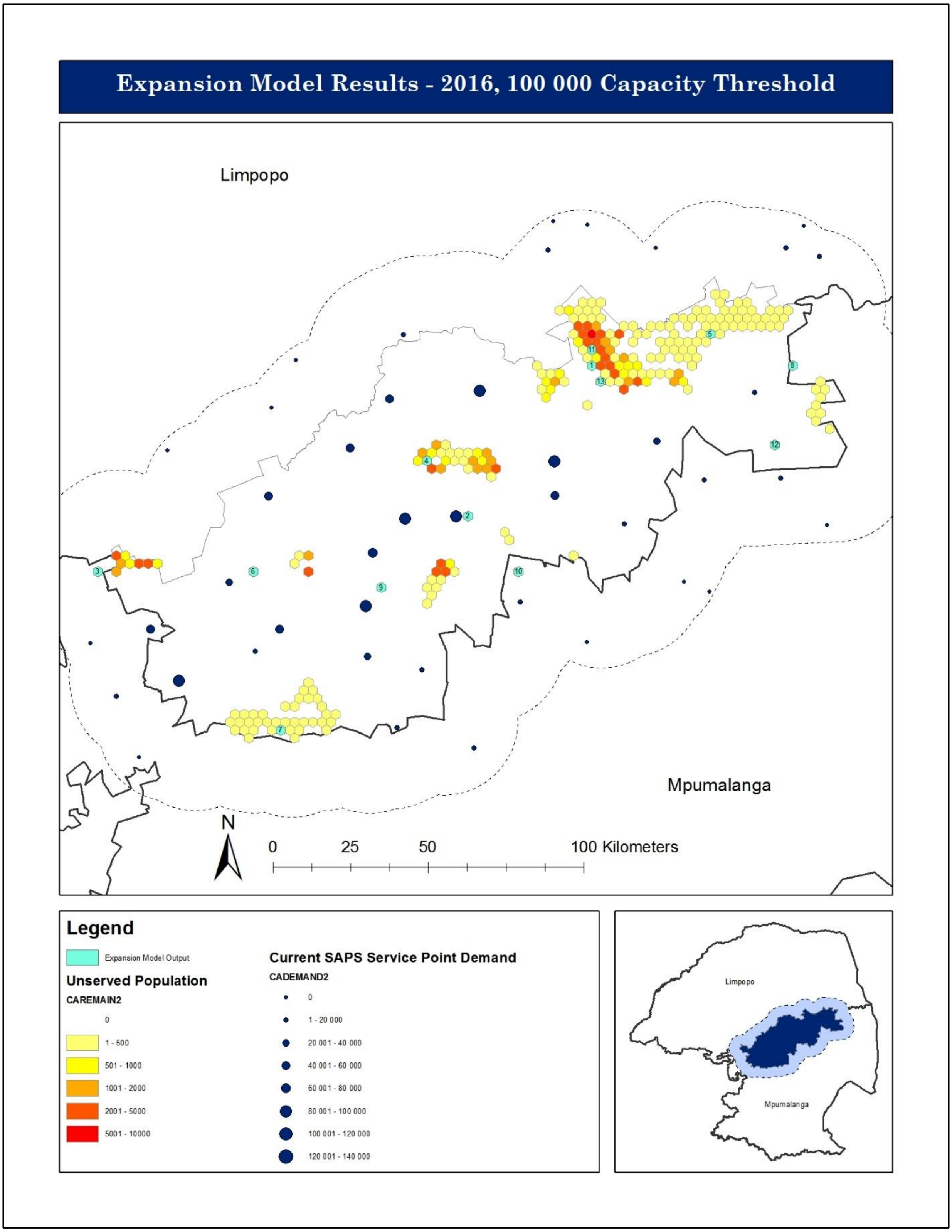

Figure 31. Expansion model results – 2016, 100 000 capacity threshold

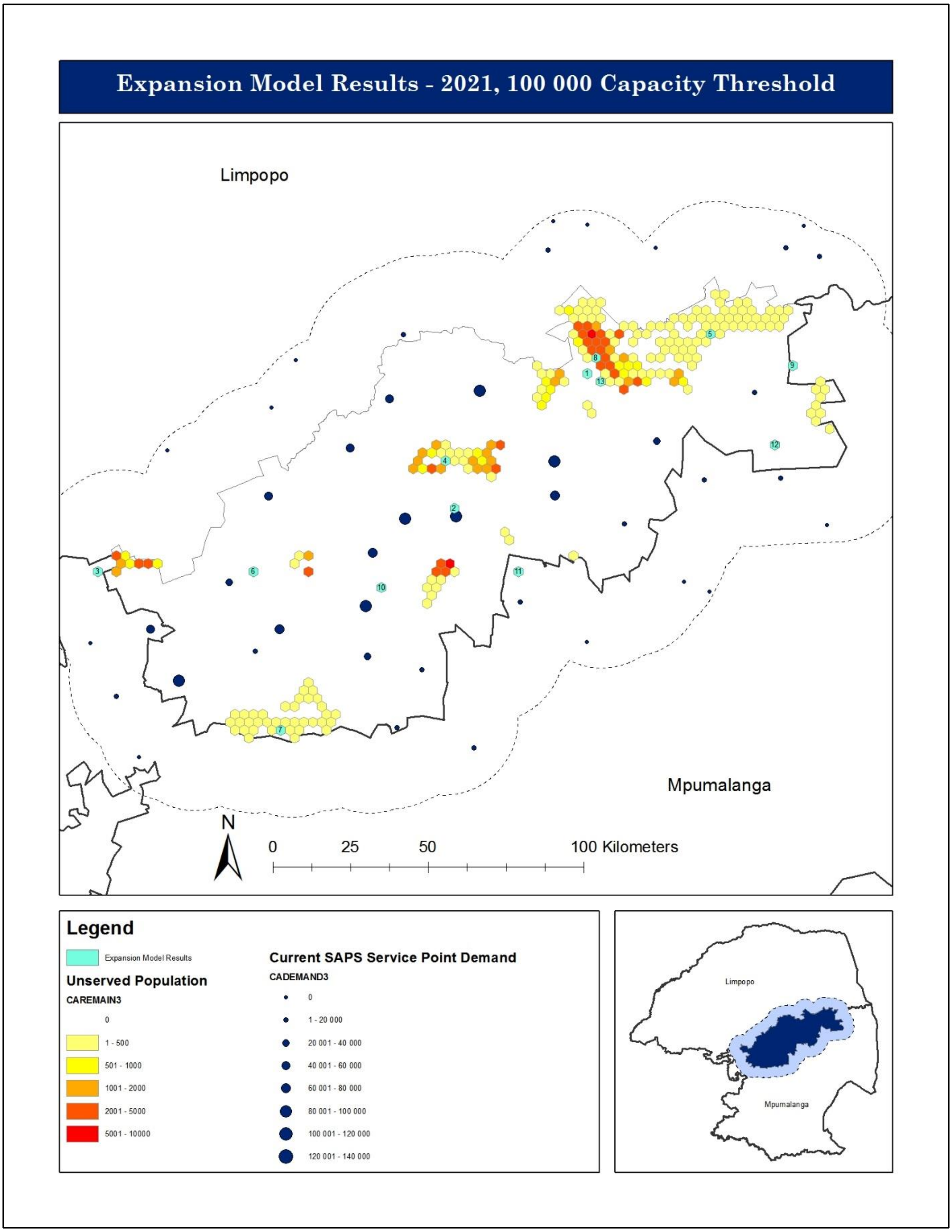

Figure 32. Expansion model results – 2021, 100 000 capacity threshold

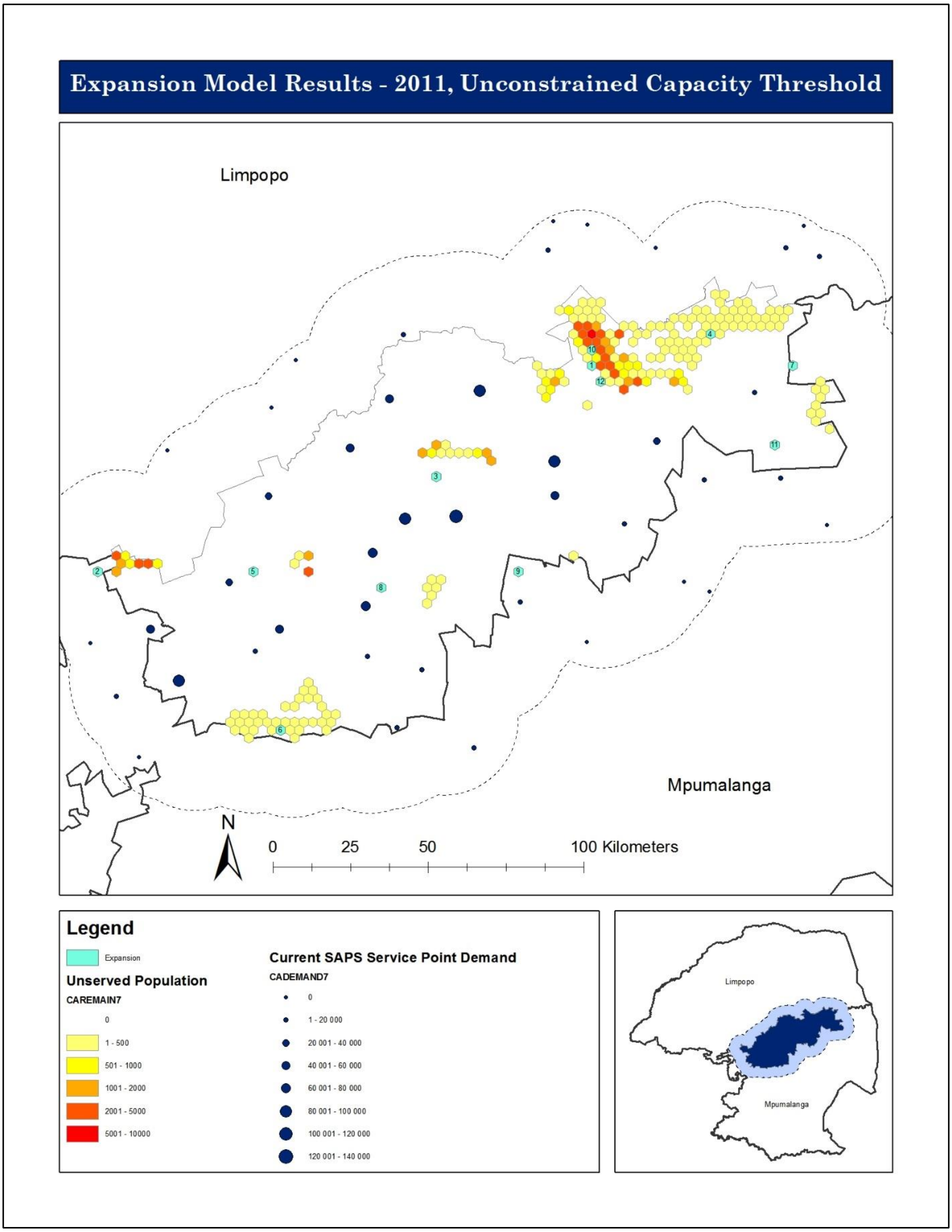

Figure 33. Expansion model results – 2011, unconstrained capacity threshold

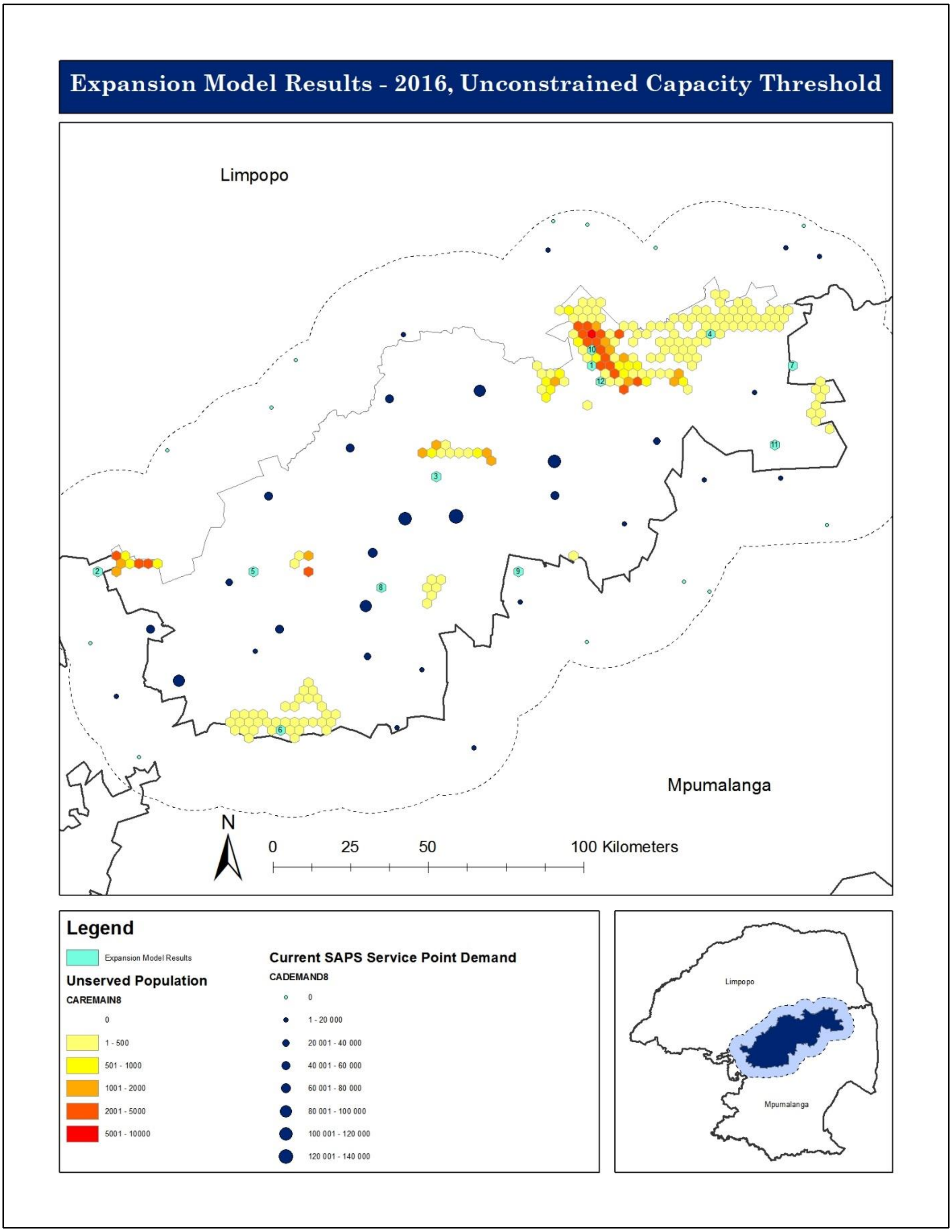

Figure 34. Expansion model results – 2016, unconstrained capacity threshold

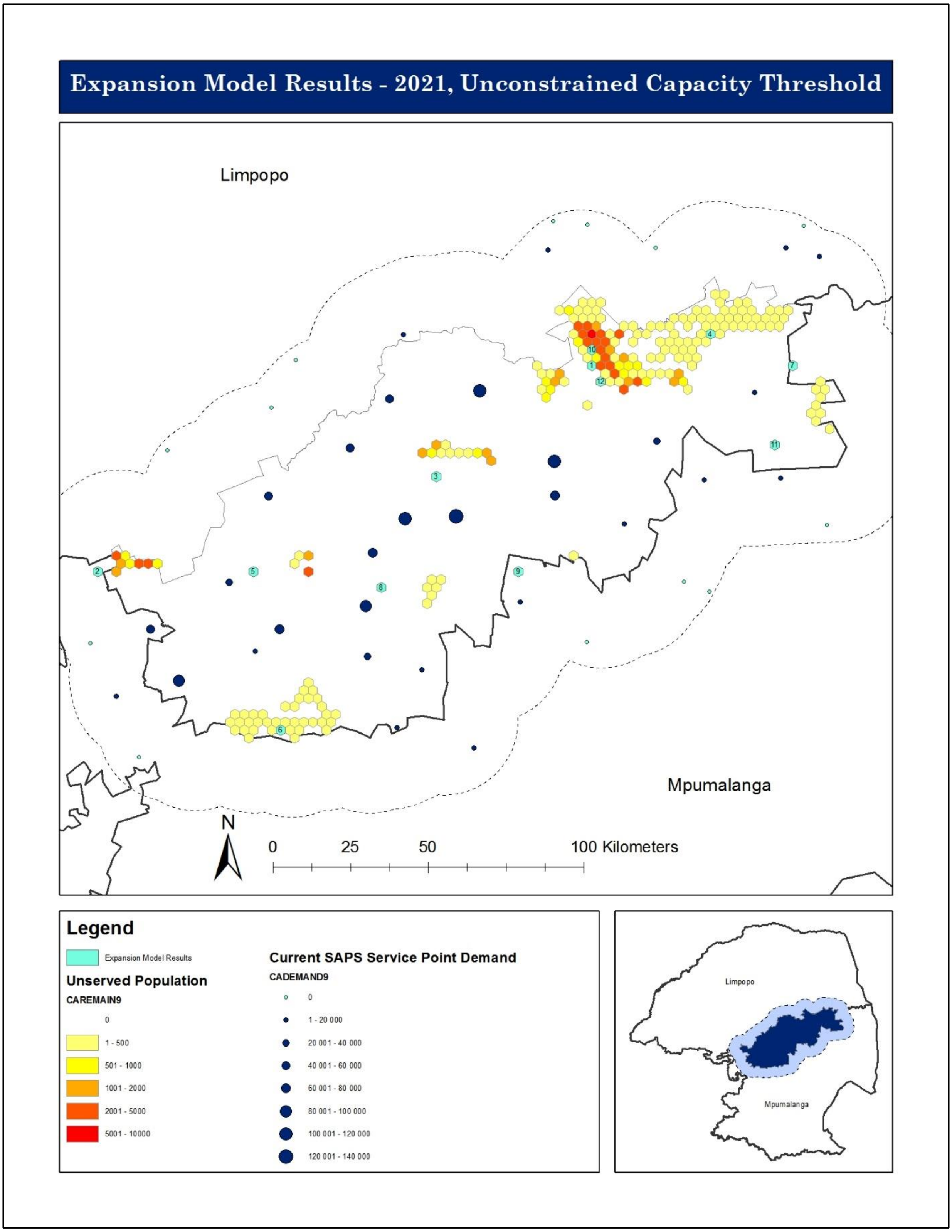

Figure 35. Expansion model results – 2021, unconstrained capacity threshold

Appendix G: Expansion Model Validation Results

Results Validation - 2021 Expansion Output										
Capacity Threshold	60 000				100 000				Unconstrained	
Constraint	Additional Capacity Restricted		Additional Capacity Unrestricted		Additional Capacity Restricted		Additional Capacity Unrestricted		Additional Capacity Unrestricted	
SAPS Service Point	Capacity	Demand	Capacity	Demand	Capacity	Demand	Capacity	Demand	Capacity	Demand
ACORNHOEK	60 000	394	60 000	394	100 000	394	100 000	394	Uncon.	394
APEL	60 000	47 970	60 000	46 884	100 000	47 163	100 000	47 163	Uncon.	48 533
BURGERSFORT	60 000	60 000	60 000	58 022	100 000	60 975	100 000	60 975	Uncon.	61 898
DENNILTON	60 000	60 000	60 000	60 000	100 000	93 669	100 000	93 669	Uncon.	93 669
DIENTJIE	60 000	1 198	60 000	1 198	100 000	1 198	100 000	1 198	Uncon.	1 198
DULLSTROOM	60 000	55	60 000	55	100 000	55	100 000	55	Uncon.	55
ELANDSKRAAL	60 000	29 294	60 000	29 294	100 000	42 026	100 000	42 026	Uncon.	42 026
GRASKOP	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
GRAVELOTTE	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
GROBLERSDAL	60 000	11 306	60 000	11 306	100 000	11 133	100 000	11 133	Uncon.	11 133
HLOGOTLOU	60 000	60 000	60 000	60 000	100 000	68 646	100 000	68 646	Uncon.	68 646
HOEDSPRUIT	60 000	7 599	60 000	7 599	100 000	7 343	100 000	7 343	Uncon.	7 343
JANE FURSE	60 000	60 000	60 000	60 000	100 000	96 408	100 000	96 408	Uncon.	94 806
KWAGGAFONTEIN	60 000	10 585	60 000	10 585	100 000	61	100 000	61	Uncon.	61
LAERSDRIFT	60 000	3 980	60 000	3 980	100 000	3 980	100 000	3 980	Uncon.	3 980
LEBOENG	60 000	32 302	60 000	32 077	100 000	26 818	100 000	26 818	Uncon.	26 818
LEBOWAKGOMO	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
LETSITELE	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
LULEKANI	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
LYDENBURG	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
MAAKE	60 000	0	60 000	0	100 000	2 542	100 000	2 542	Uncon.	25
MAARTENSHOOP	60 000	433	60 000	433	100 000	510	100 000	510	Uncon.	510
MAGATLE	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
MALIPSDRIFT	60 000	7 202	60 000	7 202	100 000	19 265	100 000	19 265	Uncon.	19 265
MARBLE HALL	60 000	32 919	60 000	32 919	100 000	12 073	100 000	12 073	Uncon.	12 073
MASEMOLA	60 000	41 273	60 000	41 273	100 000	49 765	100 000	49 765	Uncon.	49 759
MECKLENBURG	60 000	60 000	60 000	60 000	100 000	90 080	100 000	90 080	Uncon.	99 871
MHALA	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
MOTETEMA	60 000	60 000	60 000	60 000	100 000	57 038	100 000	57 038	Uncon.	57 038
NAMAKGALE	60 000	35	60 000	35	100 000	42	100 000	42	Uncon.	42
NEBO	60 000	37 347	60 000	37 347	100 000	59 605	100 000	59 605	Uncon.	59 605
OHRIGSTAD	60 000	6 217	60 000	6 181	100 000	6 181	100 000	6 181	Uncon.	6 181
PHALABORWA	60 000	0	60 000	0	100 000	18	100 000	18	Uncon.	18
PILGRIM'S REST	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
RITAVI	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
ROEDTAN	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
ROOSSENEKAL	60 000	5 275	60 000	5 275	100 000	5 341	100 000	5 341	Uncon.	5 341

SEKHUKHUNE	60 000	60 000	60 000	60 000	100 000	76 123	100 000	76 123	Uncon.	95 743
SIYABUSWA	60 000	38 582	60 000	38 582	100 000	33 282	100 000	33 282	Uncon.	33 282
TUBATSE	60 000	60 000	60 000	60 000	100 000	100 000	100 000	100 000	Uncon.	106 822
TUINPLAAS	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
VAALBANK	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
VERENA	60 000	0	60 000	0	100 000	0	100 000	0	Uncon.	0
ZAAIPLAAS	60 000	17 222	60 000	17 222	100 000	21 516	100 000	21 516	Uncon.	21 516
1st	60 000	60 000	Uncon.	101 234	100 000	6 318	Uncon.	6 318	Uncon.	10 796
2nd	60 000	60 000	Uncon.	60 267	100 000	26 540	Uncon.	26 540	Uncon.	28 487
3rd	60 000	60 000	Uncon.	76 790	100 000	28 487	Uncon.	28 487	Uncon.	59 364
4th	60 000	40 716	Uncon.	40 716	100 000	68 850	Uncon.	68 850	Uncon.	5 658
5th	60 000	18 615	Uncon.	18 615	100 000	5 658	Uncon.	5 658	Uncon.	36 092
6th	60 000	28 487	Uncon.	28 487	100 000	36 092	Uncon.	36 092	Uncon.	2 103
7th	60 000	49 522	Uncon.	39 892	100 000	2 103	Uncon.	2 103	Uncon.	824
8th	60 000	10 492	Uncon.	10 492	100 000	55 586	Uncon.	55 586	Uncon.	34 266
9th	60 000	15 847	Uncon.	9 323	100 000	824	Uncon.	824	Uncon.	3 258
10th	60 000	1 651	Uncon.	1 651	100 000	34 266	Uncon.	34 266	Uncon.	46 798
11th	60 000	1 461	Uncon.	1 461	100 000	3 258	Uncon.	3 258	Uncon.	1 460
12th	60 000	37 519	Uncon.	37 519	100 000	1 460	Uncon.	1 460	Uncon.	31 356
13th	60 000	266	Uncon.	266	100 000	25 420	Uncon.	25 420		
14th	60 000	14 593	Uncon.	14 593						
15th	60 000	1 539	Uncon.	1 539						
16th	60 000	941	Uncon.	941						
17th	60 000	439	Uncon.	439						
18th	60 000	21 567	Uncon.	21 567						
19th	60 000	14 458	Uncon.	14 458						
Total Demand		**1 249 301**		**1 288 111**		**1 288 111**		**1 288 111**		**1 288 111**
Percetage Coverage		**96.99**		**100.00**		**100.00**		**100.00**		**100.00**

Table 15. Expansion model validation results

Appendix H: Numeric Accessibility Improvement Strategy Results

Accessibility Improvement Strategy									
SAPS Service Point	Number of additional service points added								
	0	1	2	3	4	5	6	7	8
ACORNHOEK	1 395	1 395	1 395	1 395	1 395	1 395	1 395	1 395	1 284
APEL	53 788	53 788	47 163	47 163	47 163	47 163	47 163	47 163	47 163
BURGERSFORT	62 775	62 775	62 728	62 728	62 728	62 728	62 728	62 728	62 728
DENNILTON	93 669	93 669	93 669	93 669	93 669	93 669	93 669	93 669	93 669
DIENTJIE	1 540	1 540	1 540	1 540	1 540	1 540	1 540	1 540	1 540
DULLSTROOM	55	55	55	55	55	55	55	55	55
ELANDSKRAAL	43 545	43 545	43 545	43 545	43 545	37 686	37 686	37 686	37 686
GRASKOP	0	0	0	0	0	0	0	0	0
GRAVELOTTE	0	0	0	0	0	0	0	0	0
GROBLERSDAL	11 427	11 427	11 427	11 427	11 427	11 427	11 427	11 133	11 133
HLOGOTLOU	84 757	84 757	84 757	84 757	84 757	75 001	71 826	71 826	71 826
HOEDSPRUIT	8 889	8 889	8 889	8 889	7 629	7 629	7 629	7 629	7 372
JANE FURSE	100 000	100 000	96 733	96 733	96 733	96 733	92 287	92 287	92 287
KWAGGAFONTEIN	61	61	61	61	61	61	61	61	61
LAERSDRIFT	3 980	3 980	3 980	3 980	3 980	3 980	3 980	3 980	3 980
LEBOENG	36 771	32 069	32 069	32 069	32 069	32 069	32 069	32 069	32 069
LEBOWAKGOMO	0	0	0	0	0	0	0	0	0
LETSITELE	0	0	0	0	0	0	0	0	0
LULEKANI	0	0	0	0	0	0	0	0	0
LYDENBURG	0	0	0	0	0	0	0	0	0
MAAKE	2 542	2 542	2 542	2 542	2 542	2 542	2 542	2 542	2 542
MAARTENSHOOP	1 620	1 620	1 067	1 067	1 067	1 067	684	684	684
MAGATLE	0	0	0	0	0	0	0	0	0
MALIPSDRIFT	19 265	19 265	19 265	19 265	19 265	19 265	19 265	19 265	19 265
MARBLE HALL	38 983	38 983	38 983	38 983	38 983	32 919	32 919	32 919	32 919
MASEMOLA	55 977	55 977	49 765	49 765	49 765	49 765	49 765	49 765	49 765
MECKLENBURG	100 000	100 000	90 430	90 430	90 430	90 430	90 430	90 430	90 430
MHALA	0	0	0	0	0	0	0	0	0
MOTETEMA	60 381	60 381	60 381	60 381	60 381	49 840	49 840	49 840	49 840
NAMAKGALE	42	42	42	42	42	42	42	42	42
NEBO	75 760	75 760	74 221	74 221	74 221	68 055	62 168	62 168	62 168
OHRIGSTAD	6 181	6 181	6 181	6 181	6 181	6 181	6 181	6 181	6 181
PHALABORWA	18	18	18	18	18	18	18	18	18
PILGRIM'S REST	0	0	0	0	0	0	0	0	0
RITAVI	0	0	0	0	0	0	0	0	0
ROEDTAN	0	0	0	0	0	0	0	0	0
ROOSSENEKAL	5 341	5 341	5 341	5 341	5 341	5 341	5 341	5 341	5 341
SEKHUKHUNE	100 000	100 000	100 000	100 000	100 000	100 000	68 300	68 300	68 300

SIYABUSWA	45 088	45 088	45 088	33 282	33 282	33 282	33 282	33 282	33 282
TUBATSE	100 000	100 000	100 000	100 000	100 000	100 000	100 000	100 000	100 000
TUINPLAAS	1 797	1 797	1 797	0	0	0	0	0	0
VAALBANK	0	0	0	0	0	0	0	0	0
VERENA	0	0	0	0	0	0	0	0	0
ZAAIPLAAS	21 542	21 542	21 542	21 542	21 542	21 542	21 542	21 516	21 516
1st additional		80 570	80 570	80 570	80 570	80 570	80 570	80 570	80 570
2nd additional			74 144	74 144	74 144	74 144	74 144	74 144	74 144
3rd additional				28 487	28 487	28 487	28 487	28 487	28 487
4th additional					5 750	5 750	5 750	5 750	5 658
5th additional						42 706	42 706	42 706	42 706
6th additional							47 427	47 427	47 427
7th additional								2 103	2 103
8th additional									1 005
Total Served Demand	**1 137 191**	**1 213 058**	**1 259 388**	**1 274 271**	**1 278 760**	**1 283 081**	**1 284 916**	**1 286 699**	**1 287 245**
Percentage Coverage [%]	**88.28**	**94.17**	**97.77**	**98.93**	**99.27**	**99.61**	**99.75**	**99.89**	**99.93**
Incremental population coverage		**75 867**	**46 330**	**14 883**	**4 489**	**4 320**	**1 836**	**1 782**	**546**

* Cell highlighted in yellow have reached their maximum capacity threshold

Table 16. Accessibility improvement strategy results

Appendix I: Accessibility Improvement Strategy Figures

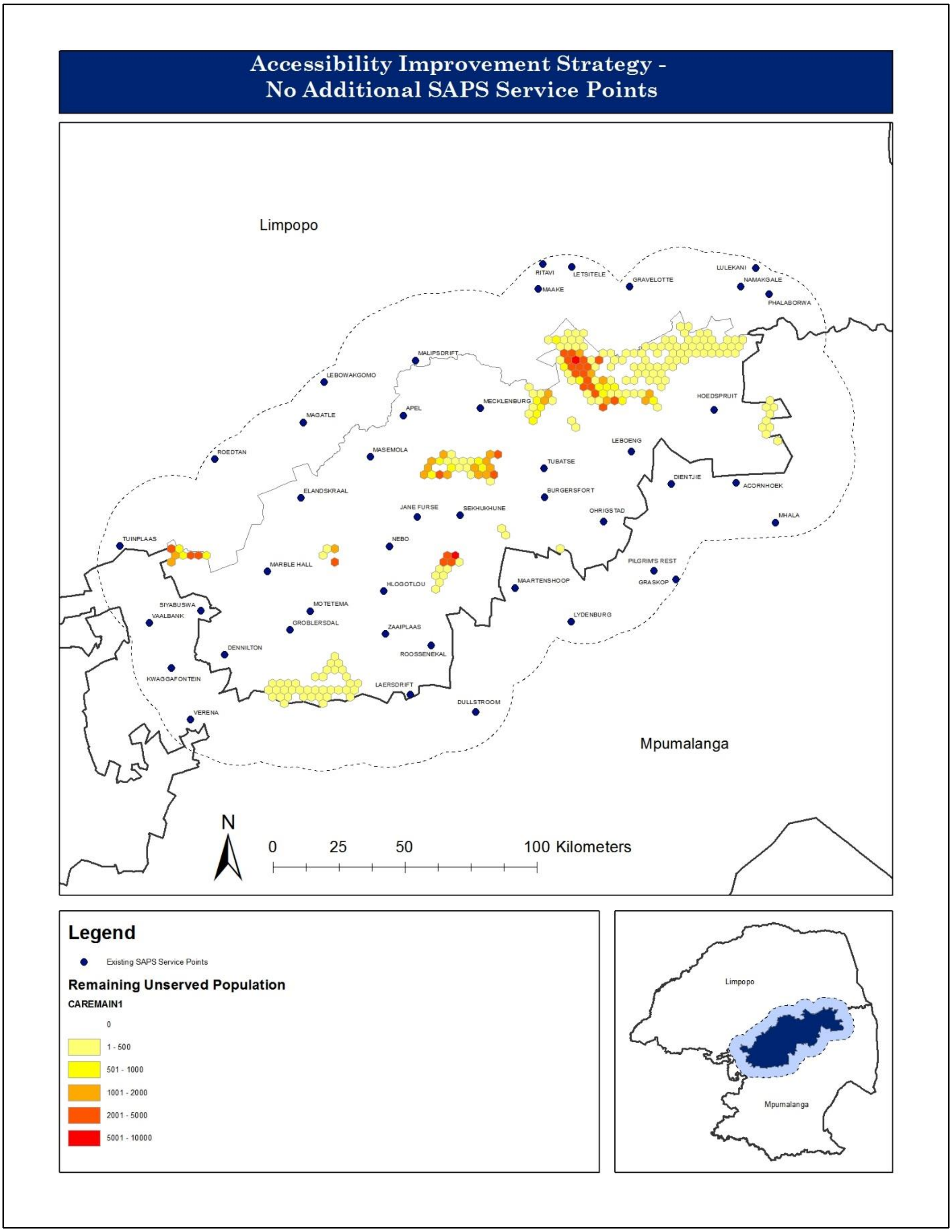

Figure 36. Accessibility improvement strategy – No additional SAPS service points

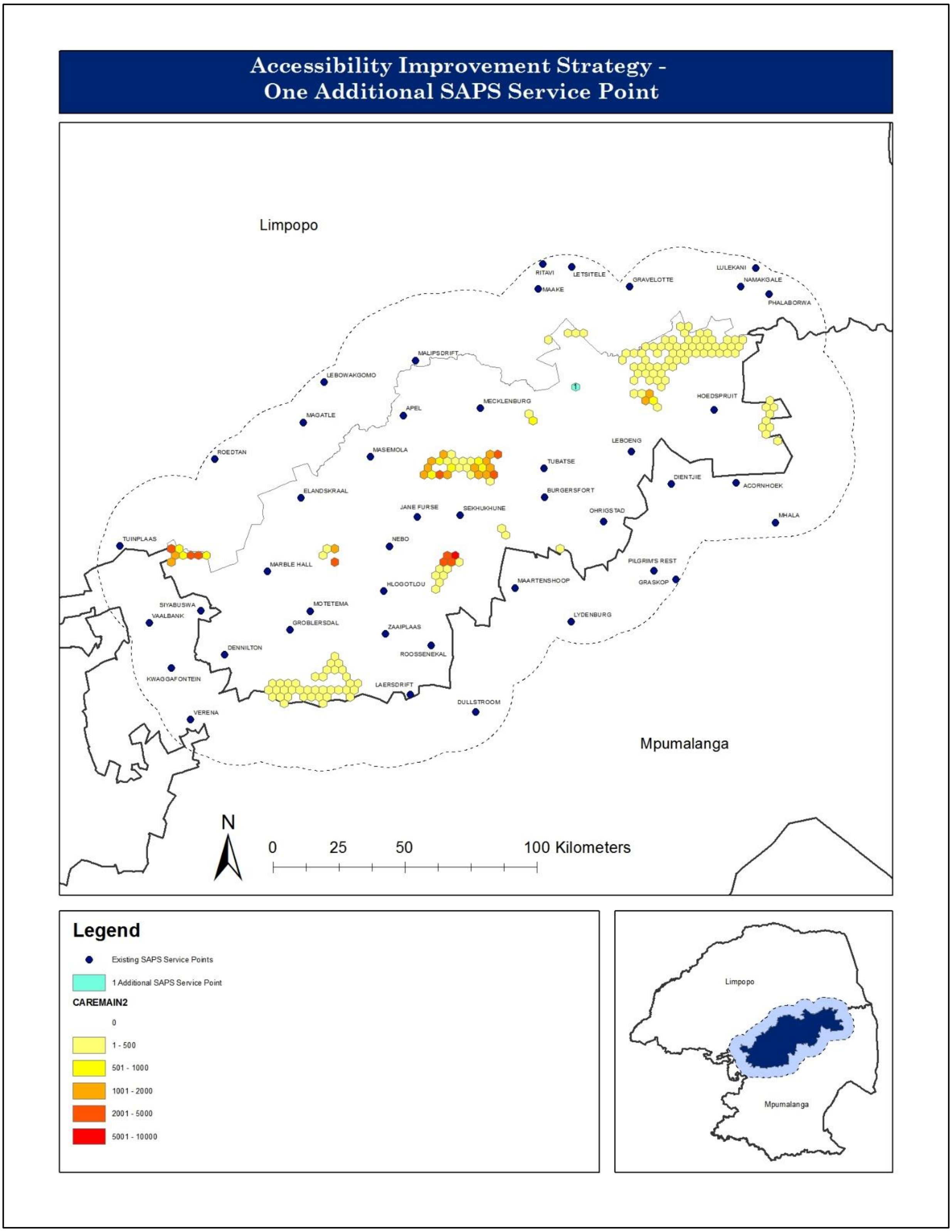

Figure 37. Accessibility improvement strategy – One additional SAPS service points

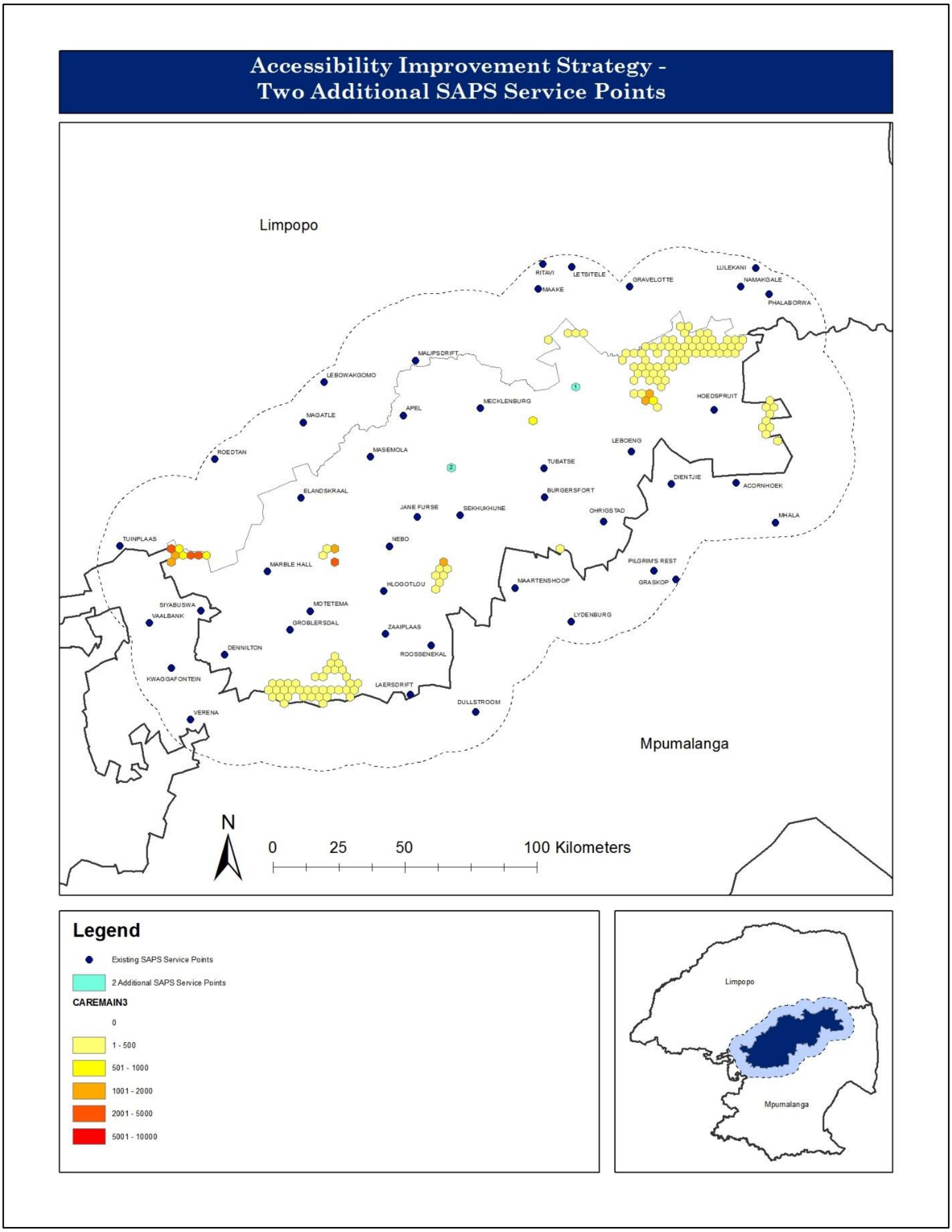

Figure 38. Accessibility improvement strategy – Two additional SAPS service points

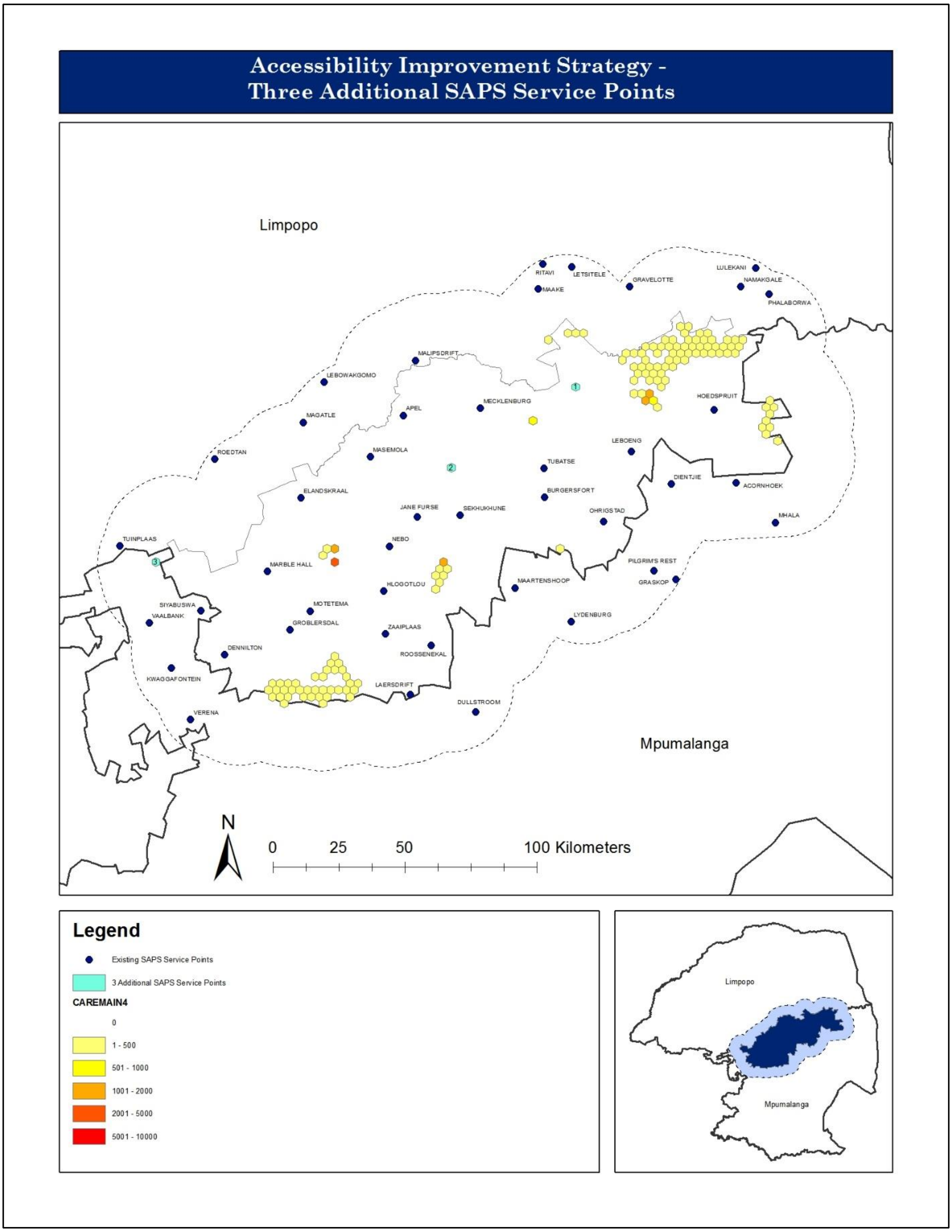

Figure 39. Accessibility improvement strategy – Three additional SAPS service points

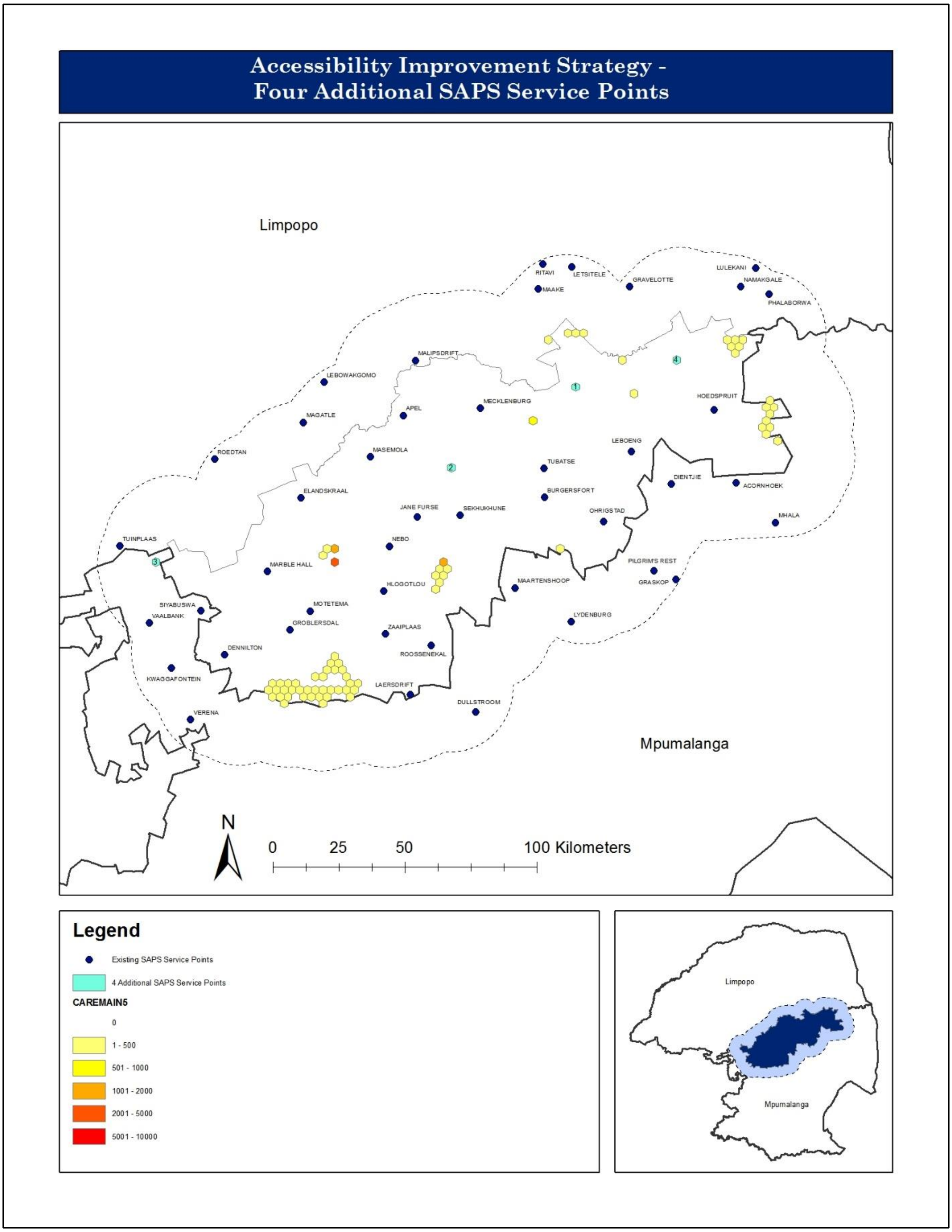

Figure 40. Accessibility improvement strategy – Four additional SAPS service points

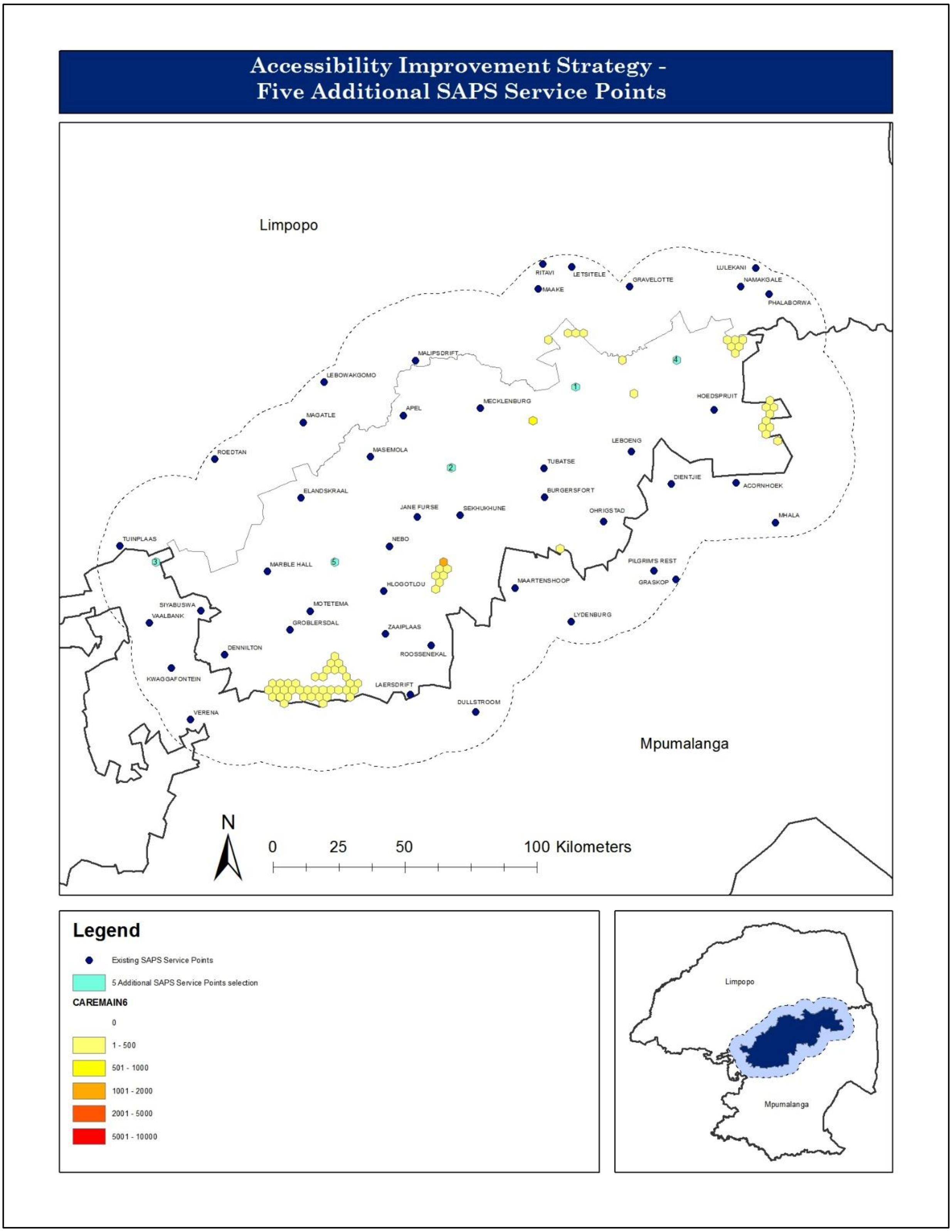

Figure 41. Accessibility improvement strategy – Five additional SAPS service points

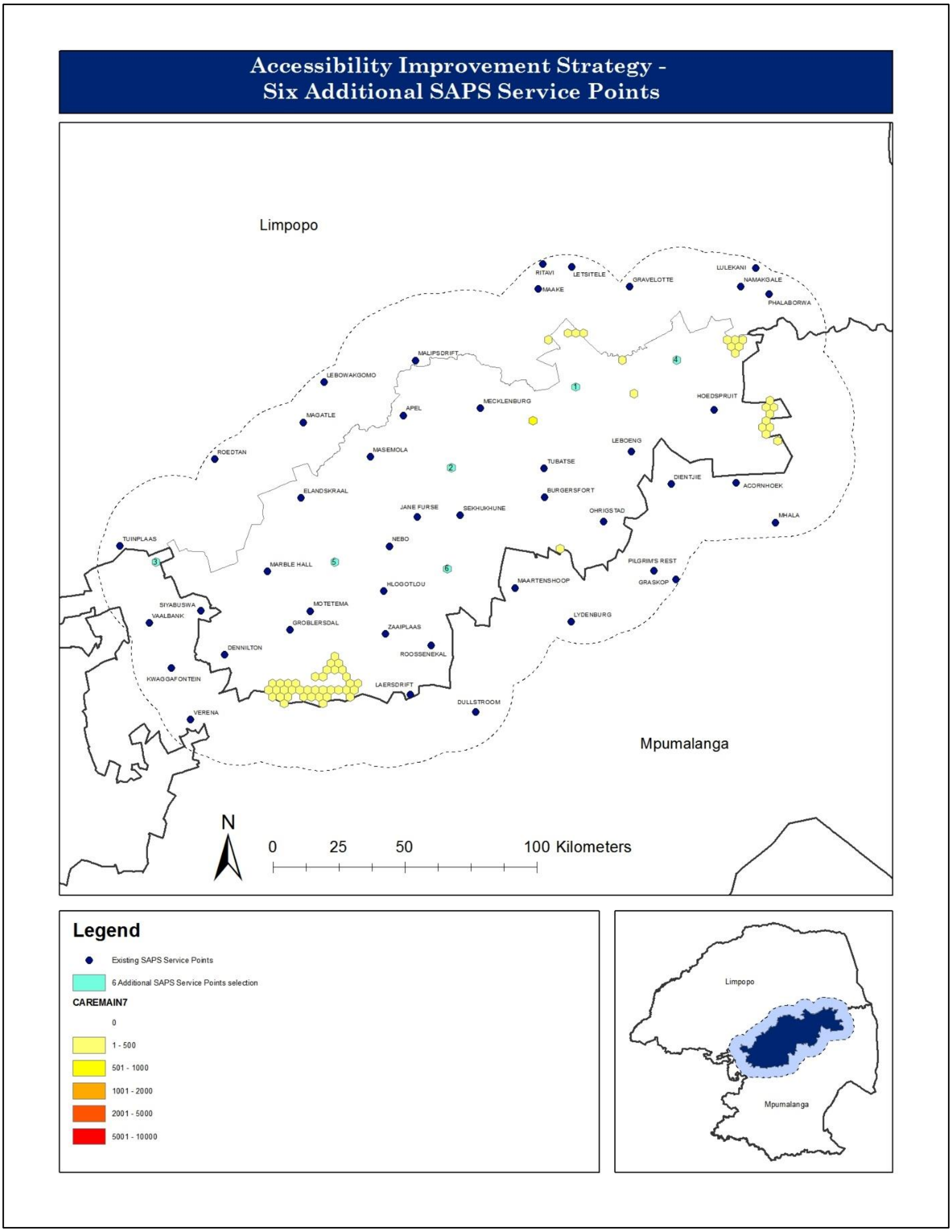

Figure 42. Accessibility improvement strategy – Six additional SAPS service points

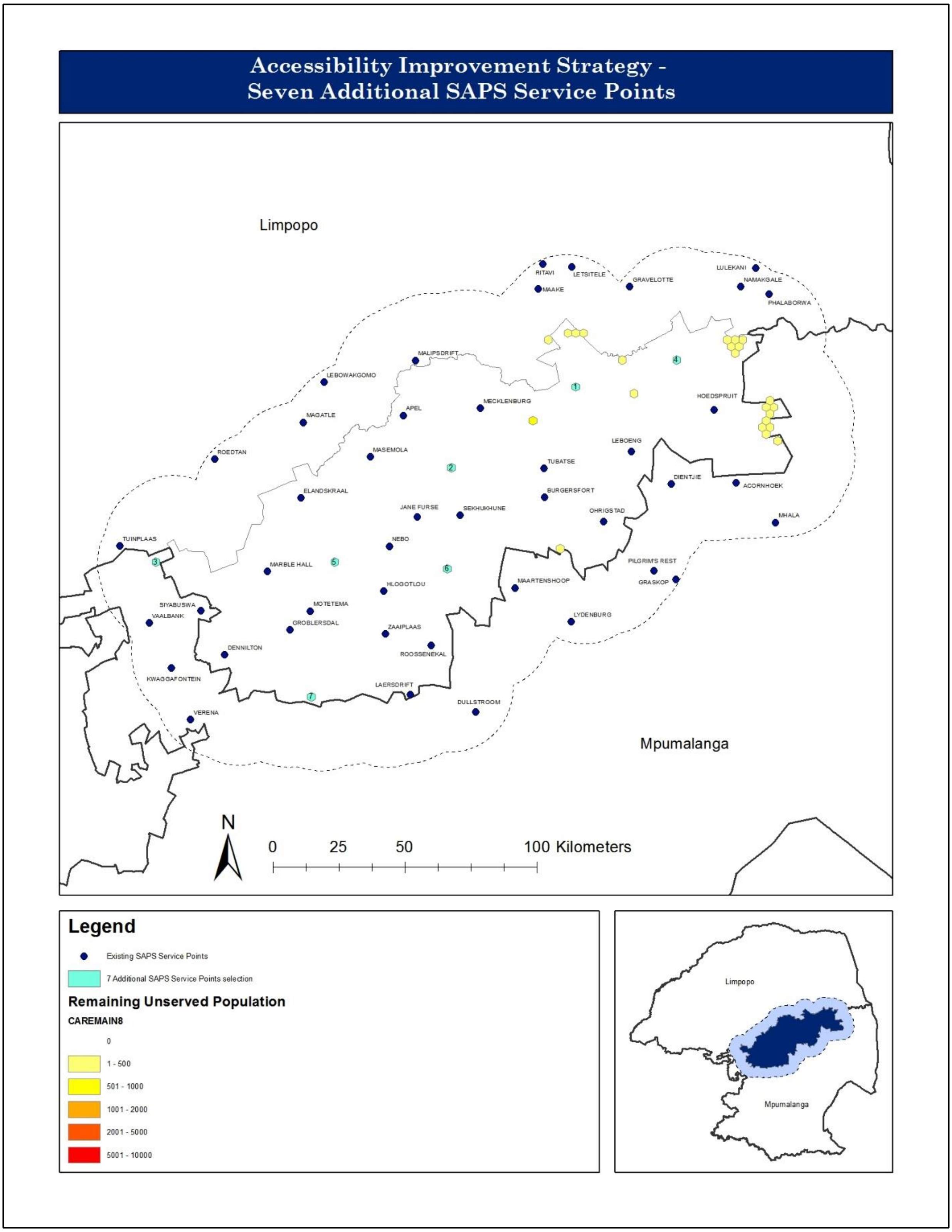

Figure 43. Accessibility improvement strategy – Seven additional SAPS service points

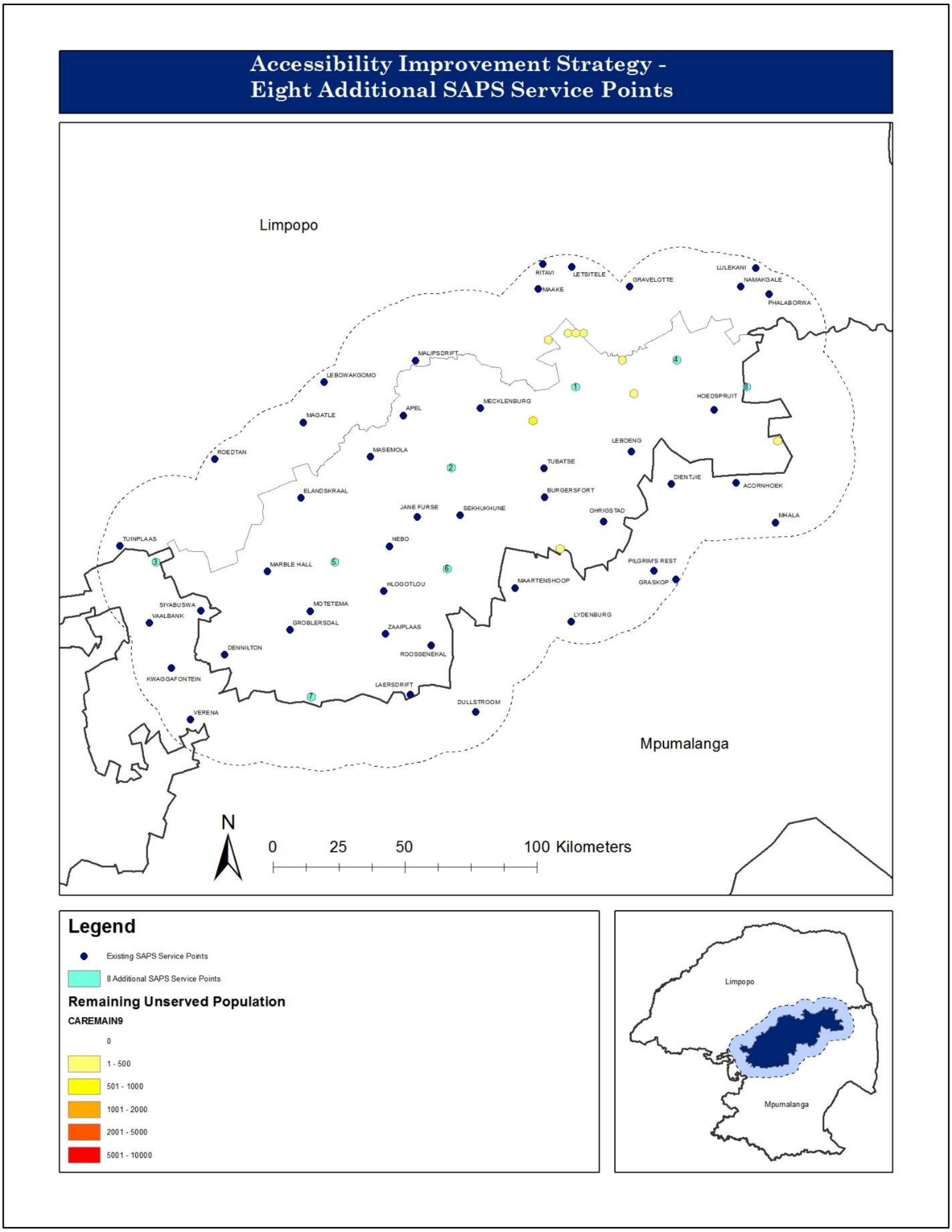

Figure 44. Accessibility improvement strategy – Eight additional SAPS service points

Appendix J: Sensitivity Analysis Results

Crow Flight Conversion Coefficient Sensitivity Analysis					
CFCC	**1.0**	**1.1**	**1.2**	**1.3**	**1.4**
ACORNHOEK	81 215	81 190	80 570	79 965	76 760
APEL	74 144	74 144	74 144	74 144	71 137
BURGERSFORT	1 459	1 459	1 395	1 220	1 176
DENNILTON	47 163	47 163	47 163	47 163	47 163
DIENTJIE	62 728	62 728	62 728	62 728	61 266
DULLSTROOM	93 727	93 701	93 669	93 669	93 659
ELANDSKRAAL	1 540	1 540	1 540	1 540	1 540
GRASKOP	55	55	55	55	55
GRAVELOTTE	43 551	43 551	43 545	43 462	43 247
GROBLERSDAL	0	0	0	0	0
HLOGOTLOU	0	0	0	0	0
HOEDSPRUIT	11 816	11 711	11 427	11 417	11 238
JANE FURSE	87 306	87 287	84 757	84 757	82 948
KWAGGAFONTEIN	10 638	9 407	8 889	8 442	7 584
LAERSDRIFT	98 045	98 045	96 733	96 733	96 733
LEBOENG	61	61	61	61	61
LEBOWAKGOMO	4 049	3 980	3 980	3 964	3 959
LETSITELE	33 394	33 384	32 069	32 010	25 082
LULEKANI	0	0	0	0	0
LYDENBURG	0	0	0	0	0
MAAKE	0	0	0	0	0
MAARTENSHOOP	0	0	0	0	0
MAGATLE	2 567	2 567	2 542	2 488	15
MALIPSDRIFT	1 067	1 067	1 067	1 008	513
MARBLE HALL	0	0	0	0	0
MASEMOLA	19 265	19 265	19 265	19 249	19 239
MECKLENBURG	38 983	38 983	38 983	38 983	37 714
MHALA	49 765	49 765	49 765	49 753	48 786
MOTETEMA	90 430	90 430	90 430	90 080	87 623
NAMAKGALE	0	0	0	0	0
NEBO	60 777	60 777	60 381	60 350	60 303
OHRIGSTAD	278	116	42	42	25
PHALABORWA	76 115	75 635	74 221	72 558	67 748
PILGRIM'S REST	6 381	6 381	6 181	6 171	6 153
RITAVI	18	18	18	18	0
ROEDTAN	0	0	0	0	0
ROOSSENEKAL	0	0	0	0	0
SEKHUKHUNE	0	0	0	0	0
SIYABUSWA	5 341	5 341	5 341	5 341	5 341
TUBATSE	100 000	100 000	100 000	98 297	94 846
TUINPLAAS	53 879	53 879	45 088	45 067	38 297

VAALBANK	100 000	100 000	100 000	100 000	95 678
VERENA	7 889	5 786	1 797	1 383	0
ZAAIPLAAS	0	0	0	0	0
VERENA	0	0	0	0	0
ZAAIPLAAS	21 984	21 621	21 542	21 532	21 279
Total Demand Served	**1 285 627**	**1 281 036**	**1 259 388**	**1 253 650**	**1 207 167**
Percentage Coverage [%]:	**99.81**	**99.45**	**97.77**	**97.32**	**93.72**

Table 17. Sensitivity Analysis Results