SITE SELECTION FOR THE SMALL-SCALE AQUACULTURE FARMING SYSTEMS IN THE WESTERN CAPE: A GIS APPLICATION

Lorn Adam Steer

Thesis presented in partial fulfilment of the requirements for the degree of Master of Arts at the University of Stellenbosch.

Supervisor: Dr PH de Necker

April 2006

DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature: -------------------------------

Date: -------------------------------

SUMMARY

The Rural Aquaculture Development Programme (RADP) of the Division of Aquaculture at Stellenbosch University (DASU) has the objective of socio-economic development of farm workers and rural communities from previously disadvantaged communities through the provision of opportunities for sustainable economic development by establishing small-scale fish-farming systems on irrigation dams.

The Small-Scale Aquaculture Farming Systems (SSAFS) is an initiative of RADP. DASU intends implementing 20 new projects by the end of 2005, 100 by 2010 and at least 200 by 2020. Thus far, sites which can accommodate 25 projects have been identified. The owners of the land on which these 25 possible projects are located are being contacted to gain permission to use the sites for the SSAFS. It is possible that some of the owners of the sites will not allow them to be used so that not all 25 projects will necessarily be implemented.

At present the predominant search method employed by DASU to find new sites involves two steps. Initially knowledge is acquired through word of mouth about dams that may be suitable. Personnel then drive to these dams for further inspection, to see if they are indeed suitable. This method of search is clearly both expensive and time-consuming. Geographical information systems (GIS) have as yet not been considered as an alternative and/or supplementary site selection method for the SSAFS. GIS tools and principles can reduce both expenses and time in locating sites by reducing the number of dams to be visited to only those that are optimal (i.e. they present the least risk of the SSAFS projects failing).

A new site selection methodology using GIS was developed which is faster and less expensive than existing site selection methods. The GIS site selection methodology revolves around the isolation and selection of dams in the Berg and Breede River water management areas, based on their ability to fulfil certain parameters of critical variables comprising dam dimensions, environmental issues, distance measures and site security, according to a priority hierarchy, that determine a successful site for trout farming according to methods employed by the SSAFS. Once this methodology was produced, it was presented to five people who are directly involved with the SSAFS as well as four others who are not involved with the SSAFS but who might find the methodology useful, to determine whether they hold that the methodology is indeed better than existing search methodologies. Those who were presented the GIS site selection methodology felt that it is very

useful and that it could be employed in future to make more informed choices when locating new sites for the SSAFS as well as other aquacultural enterprises.

KEYWORDS & PHRASES

aquaculture, Berg and Breede River water management areas, Division of Aquaculture at Stellenbosch University (DASU), farm irrigation dams, geographical information systems (GIS), Rural Aquaculture Development Programme (RADP), site selection method, Small-Scale Aquaculture Farming Systems (SSAFS), trout farming, Western Cape

OPSOMMING

Die Landelike Akwakultuurontwikkelingsprogram (RADP) van die Afdeling Akwakultuur by die Universiteit van Stellenbosch (DASU) het as oogmerk die sosio-ekonomiese ontwikkeling van plaasarbeiders en landelike gemeenskappe van voorheen benadeelde bevolkingsgroepe deur die voorsiening van geleenthede vir volhoubare ekonomiese ontwikkeling deur die daarstelling van moontlikhede vir kleinskaalse visboerdery in besproeiingsdamme.

Die Kleinskaalse Akwakultuur Boerdery-sisteme (SSAFS) is ’n inisiatief van die RADP. DASU beoog die implementering van 20 nuwe projekte teen die einde van 2005, 100 teen die jaar 2010 en ten minste 200 teen 2020. Tot dusver is alreeds terreine geïdentifiseer wat 25 projekte kan akkommodeer. Die eienaars van die grond waarop hierdie 25 projekte ontwikkel kan word, word tans versoek om verlof te gee dat die terreine gebruik kan word vir SSAFS. Dit is moontlik dat sommige van die eienaars van hierdie terreine nie hul toestemming sal gee dat dit gebruik mag word nie, met die gevolg dat nie al die 25 projekte noodwendig geïmplementeer sal word nie.

Die vernaamste ondersoekmetode wat die DASU tans gebruik om nuwe terreine te vind, behels twee stappe: Aanvanklik word inligting ingewin deur onderlinge gesprekvoering met plaaslike inwoners oor moontlike geskikte damme. Personeel ry dan na hierdie damme vir verdere inspeksie en om te bepaal of hulle werklik geskik is. Hierdie metode is ooglopend duur sowel as tydrowend. Geografiese inligtingstelsels (GIS) is tot dusver nog nie oorweeg as ’n alternatiewe en/of aanvullende seleksiemetode vir die SSAFS nie. GIS se tegnologie kan ’n besparing teweegbring in sowel die tyd as die uitgawes verbonde aan die bepaling van geskikte terreine deur die uitwys van slegs daardie damme wat optimaal geskik is (d.w.s. dié wat die kleinste risiko inhou vir die SSAFS-projek om moontlik te kan misluk).

’n Nuwe metodologie vir die seleksie van terreine deur van GIS gebruik te maak wat beide vinniger en goedkoper as bestaande metodes is, is ontwikkel. Die GIS-metodologie vir terreinselektering behels die opspoor en seleksie van damme in die Berg- en Breederivier waterbestuursareas, gebaseer op hul moontlikhede om te voldoen aan sekere parameters van kritieke veranderlikes. Hierdie veranderlikes wat o.a. die dimensies van die damme, omgewingsimpakkwessies, afstandsbeperkings, en terrein-sekuriteit insluit, was volgens ’n hiërargiese prioritisering wat determinerend is vir ’n suksesvolle terrein vir forelboerdery volgens die metodes aangewend deur die SSAFS. Nadat hierdie bepaalde metodologie ontwikkel is, is dit voorgelê aan vyf persone wat direk betrokke is by die SSAFS sowel as aan vier ander persone, wat nie betrokke is by die SSAFS

nie, maar wat die metodologie bruikbaar kan vind, om vas te stel of hulle van oordeel is dat die metodologie werklik beter is as die bestaande metodologië. Almal wat bekend gestel is aan die GIS metode van terreinseleksie was van mening dat dit baie bruikbaar is en dat dit in die toekoms gebruik kan word om beter ingeligte keuses te maak in die bepaling van nuwe terreine vir die SSAFS sowel as ander akwakultuurprojekte.

TREFWOORDE & FRASES

Afdeling Akwakultuur by die Universiteit van Stellenbosch (DASU), akwakultuur, Berg- en Breërivier waterbestuursgebiede, forelboerdery, Geografiese inligtingstelsels (GIS), Kleinskaalse Akwakultuur Boerdery-sisteme (SSAFS), Landelike Akwakultuurontwikkelingsprogram (RADP), metodologie vir die seleksie van terreine, plaasbesproeiingsdamme, Wes-Kaap

ACKNOWLEDGEMENTS

A special thanks to Dr PH de Necker, my supervisor, for standing by me, helping me and encouraging me throughout the research process.

A special thanks to Mr K Salie, Project Manager and mentor of the Small-Scale Aquaculture Development Programme, Division of Aquaculture, Department of Agriculture at Stellenbosch University, for his advice, expertise and use of equipment. Without his input this research would not have been possible.

Thanks to my redactor, Prof EP Hees, for correcting my language.

Thanks to Mr D Impson, Mr G Stubbs and Mr E Hinrichsen, who gave considerable advice throughout the research.

Thanks to Stellenbosch University, Cape Nature and Ninham Shand for supplying data gratis. Also a special thanks to Mr T Morgan at Map-it for determining the point locations of the processors, hatcheries and feed suppliers and then supplying these points in a shape file, free of charge.

Thanks to all the interviewees and respondents to the questionnaires for listening to the presentations and providing insightful answers and comments.

Thanks to Mr FC Basson, a friend and fellow student and to Mr M Silberbauer, a friend, for their technical assistance.

Thanks to Mr J de Villiers for translating the summary into Afrikaans.

Lastly thanks to my family for standing by me and supporting me throughout this lengthy research process.

CONTENTS

TABLES

FIGURES

ACRONYMS

AFMA - African Feed Millers' Association

AASA – Aquaculture Association of Southern Africa

CPU - Conservation Planning Unit

DASU - Division of Aquaculture, Stellenbosch University

DMS – Degrees, minutes, seconds

DWAF - Department of Water Affairs and Forestry

ESRI - Environment Systems Research Institute

GIS - Geographic information systems

GPS - Global positioning system

HOFFC - Hands-On Fish Farmers' Co-operative

RADP - Rural Aquaculture Development Programme

SSADP - Small-Scale Aquaculture Development Programme

SSAFS - Small-Scale Aquaculture Farming Systems

SU - Stellenbosch University

1 GEOGRAPHICAL INFORMATION SYSTEMS (GIS) AND TROUT FARMING

1.1 THE ROLE OF GIS IN AQUACULTURE

Simply stated, aquaculture can be defined as the farming of aquatic organisms (Middleton 1996). Aquaculture is an ancient practice that was developed by the Chinese thousands of years ago (Blakely & Hrusa 1989). Aquaculture's importance to the human population is undisputed, as it has been a source of food for millions of people over the centuries.

The world's population is escalating at an alarming rate and as a result there is a shortfall in the provision of food to vast numbers of people. Because of this shortfall, there is ever-increasing pressure on the world's natural resources. "Fish is an important component in the human diet, but its production is not likely to keep up with demand" (Kent 1997: 393). It has been contended by Aguilar-Manjarrez & Ross (1993: 49) that increased aquaculture can alleviate these problems: "The rapidly rising world population is creating great pressure on the land and water space and there is a continuing need to increase food output. One realistic way of supplying more food protein is to increase fish production through the extension of aquaculture and inland fisheries…. This is especially so because of the projected decline in the world capture fisheries over the next few decades." In the field of agriculture, the Green Revolution has resulted in a release of the pressure placed on the world's natural resources by increasing agricultural production.

The Green Revolution has been defined as the intensification of crop farming in agriculture (Middleton 1996) through the introduction of a "complex package that includes improved seeds and a wide range of management practices" (Huke 1985: 248). If the Green Revolution resulted in an increase in production in agriculture, could a Blue Revolution not aid in the increase in aquacultural production? Middleton (1996) maintains that, if the equivalent were to occur in the field of aquaculture and it replaces capture fisheries as the main source of aquatic food production, it could be referred to as a Blue Revolution. How would such a blue revolution occur?

Geographic information systems (GIS) could be an importantant ingredient of the answer. A simple definition of a GIS is that they: "…are tools that allow for the processing of spatial data into information, generally information tied explicitly to, and used to make decisions about, some portion of the earth" (DeMers 2000: 7). Using GIS would fulfil the prophecy that technology and research will be further refined in the aquaculture industry in the future (cf. Nash 1995). "One of the advantages of a GIS is that it can be used to predict the attributes of a specified site and/or to locate all sites with specified attributes" (Aguilar-Manjarrez & Ross 1993: 49). GIS is thus both an exciting and promising tool in the field of aquaculture. It could be especially valuable for its ability to assess sites, especially in South Africa, as the country is perceived as dry with little opportunity for aquaculture (Brink 2001). "Selecting the right site for an aquatic farming operation is vital, as it can greatly influence economic viability" (Aguilar-Manjarrez & Ross 1995: 53).

GIS was developed at the same time cartography started, as any map is a simple GIS; however, it only matured as a technology in the 1980s and 1990s (Clarke 1999). Today it is widely used in the fields of engineering, mining, forestry, nature conservation and agriculture, to mention but a few. Having said this, it is surprising to note that an extensive literature search has shown that GIS has not been given much attention in aquaculture (Steer 2003).

This is not to say that there have been no GIS applications to aquaculture, but that there is only a small body of literature on the use of GIS in the field of aquaculture when compared to other fields. Nevertheless, these works are important as they are evidence of GIS being applied to aquaculture in general, and in some cases to specific types of aquatic animals, for example trout farming. They also provide useful information on what can be done with GIS in aquaculture and how to apply it successfully. Some of the more important examples are discussed in the following paragraphs.

Two studies in particular have influenced this research profoundly. The one case study of primary importance to this research is by Meaden (1987). The purpose of Meaden's study was to find suitable sites for trout farming in Britain by using GIS. This research has the same goal, namely finding sites for trout farming using GIS, but in the Western Cape. Another important aspect of Meaden's study is his methodology which is relatively simple and logical. For these reasons Meaden (1987) will be used as the primary guide in the quest to locate sites suitable for trout farms in the Western Cape. His methodology will be followed, but adapted where necessary. The major drawbacks of Meaden's research are that it is somewhat dated and GIS technology has changed dramatically since 1987. The latter will be accounted for in this research in the Western Cape.

The other study that has influenced the research is an earlier work by the researcher (Steer 2002). The main consideration is that the methodology of the 2002 study to rate dams according to their potential as sites for a certain type of aquaculture (carp farming) can be developed further. For example, the dams could not only be rated but also eliminated if not optimal. Steer (2002) provides useful guidelines and contains informative references on aquaculture, GIS and GIS applications in aquaculture. Steer (2002) also contained a useful contact in the aquaculture field in the Western

Cape, who was consulted extensively on the GIS site selection methodology research, namely Salie (2005, pers. com.).

Other studies that deal with the use of GIS to locate sites for various types of aquaculture are Kapetsky, Hill & Worthy (1988) on catfish farming development; Ali, Ross & Beveridge (1990) on microcomputer spreadsheets for carp farming in Pakistan; Kapetsky, Wijkstrom, MacPherson, Vincke, Ataman & Caponera (1990) on fish farming in Ghana; and the application of GIS to shrimp farming in Sinola, Mexico described by Aguilar-Manjarrez & Ross (1995). These sources provide further evidence of GIS being used in aquaculture, thus reinforcing the notion that GIS might be beneficial to trout farming in the Western Cape.

If GIS is to be beneficial to trout farming in the Western Cape, what role will it play in making it beneficial? This is discussed in the following section.

1.2 THE ROLE OF GIS IN RAINBOW TROUT FARMING

In aquaculture numerous and diverse different species are cultivated. This is especially evident in the contents of aquaculture textbooks such as those of Nash & Novotny (1995) and Pillay (1993). Nash & Novotny (1995) cover no less than twenty major aquatic species in detail while Pillay (1993) looks at a wide range of species from seaweed to carps, both salt water as well as fresh water species.

The type of GIS application in aquaculture depends on the type of species being cultivated, because the different species of aquatic organisms require different farming practices. It is impractical within the time limits and financial constraints of this study to apply GIS to aquaculture in general, as each species has to be treated individually. Therefore it is advisable to research the application of GIS to the farming of one or maybe two species. Hopefully the results can be used as a model that can be applied to other species.

The focus of this research is on commercial rainbow trout (*Oncorhynchus mykiss*) (see Figure 1.1) farming as done by the Small-Scale Aquaculture Farming Systems (see section 1.3.1) and the application of GIS to this type of farming in the Western Cape. The reason for this is that the Division of Aquaculture of Stellenbosch University (DASU) intends finding additional sites for more of these farming systems. GIS can play an important role in this process by helping to find optimal locations for these systems. It can also be used as a site location model for all trout farming, not only the SSAFS and as such play an important role in the whole trout farming industry. There are, however, other reasons why rainbow trout was chosen as the species to focus on.

(Source: Adam Steer)

Figure 1.1: Researcher displaying a rainbow trout (*Oncorhynchus mykiss*)

First, trout is one of the older, more established species under cultivation worldwide (Nash & Novotny 1995). As a result there is a large body of literature and research on the subject of trout farming which results in the information being accessible and easily attainable. For example, there are books dedicated to trout farming alone. Sedgwick (1995) is a good example as it provides extensive information on trout farming practices. Second, one of the prime species cultivated in South Africa is rainbow trout (Salie 2005, pers. com.). In 2003 rainbow trout had, by far, the highest production value (R44 million) amongst the fresh water species, while the next highest was R11.8 million generated by shrimp (*Penaes indicus*) (Brink 2003).

The focus of this research however is not important. What is important is that it, in the end, provides a model or methodology which will pave the way for further GIS applications in aquaculture. It was stated earlier that GIS can play an important role in helping with the process of finding optimal sites for the SSAFS. What will this role of GIS be? In other words, how will GIS help in finding optimal sites for the SSAFS? This will be answered in the following section.

1.3 THE USE OF GIS IN THE DEVELOPMENT OF SMALL-SCALE AQUACULTURE FARMING SYSTEMS (SSAFS)

This section provides a background to the SSAFS and what they are. It also highlights why GIS can aid in the development of the SSAFS as well how it will be used to aid this development.

1.3.1 The Rural Aquaculture Development Programme (RADP) and the SSAFS

The RADP was launched in 1995 by the DASU in the Faculty of Agricultural and Forestry Sciences. The objective of the RADP is the socio-economic development of farm workers and rural communities from previously disadvantaged communities through the provision of opportunities for sustainable economic development by establishing small-scale fish farming systems on irrigation dams (University of Stellenbosch 2002). The major role-players of the RADP are the DASU, land owners and the small-scale farmers. DASU is responsible for the following: site selection and selection of the small-scale farmers; the development of production systems suitable for application by small-scale farmers; development and transfer of production technology; the supply of feeds, fingerlings and equipment; the provision of training courses and material for the small-scale farmers; and the co-ordination of marketing amongst small-scale farmers. The land-owners or farm management contribute to the contractual availability of resources (dams and farm infrastructure), assistance to the small-scale farmers with construction and maintenance of farming systems, and managerial assistance to the small-scale farmers. The small-scale farmers are responsible for loan applications and contractual responsibilities, the completion of the training, production management, administration and reporting and preparation, processing and marketing of produce (University of Stellenbosch 2002).

The SSAFS is an initiative of RADP. Currently these SSAFS are organized under the Hands-On Fish Farmers' Co-operative (HOFFC). The SSAFS are made up of small-scale farming units. The units consist of a floating platform with two polyethylene cage nets each 10m x 10m x 5m in size which are placed in dams (see Figure 1.2). Fingerlings are bought at the beginning of each season and grown out in these cages. In the warmer summer months the crop consists of Mozambique tilapia (*Oreochromis mossambicus*) and common carp (*Cyprinus carpio*), which are sold as an affordable food source to local communities. In the colder winter months the crop consists of rainbow trout (*Oncorhynchus mykiss*), which are sold under contract to existing processing companies for the manufacture of high-value products.

(Source: Kalied Salie)

Figure 1.2: Small-Scale Aquaculture Farming System at Worcester (Note the floating cages).

1.3.2 Envisaged SSAFS development

The SSAFS have as a whole been successful and as a result DASU wants to implement 20 new projects by the end of 2005, 100 by 2010 and at least 200 by 2020 (*Kampusnuus* 2004). Thus far, a number of dams have been identified that may be chosen as sites to accommodate 25 projects (Stander 2005, pers. com.). The owners of the land on which these 25 projects are envisaged are being contacted for permission to use the sites for the SSAFS. It is possible that some of the owners of the sites will not allow them to be used so that not all 25 projects will necessarily be implemented.

1.3.3 The use of GIS for more efficient site selection for the SSAFS

The SSAFS are used to grow out rainbow trout in the winter months and common carp and Mozambique tilapia in the summer months. Site selection of dams is based on acceptable parameters of variables that best suit the growth of trout, as trout are more sensitive than tilapia or carp to their environment. Consequently, sites that are suitable for trout are by virtue suited for carp and tilapia. Thus the development of a GIS methodology in this research to search for optimal sites/dams, will be based on the fact that suitability for trout farming, according to the methods used in the SSAFS, is suitable for the SSAFS as a whole.

At present the predominant search method employed by DASU to find new sites involves two steps. They first acquire knowledge about dams that may be suitable by word of mouth. They then drive out to these dams for further inspection to see if they are indeed suitable (Stander 2005 pers. com.). This method of search is both expensive and time-consuming. GIS has, to date, not been considered as an alternative and/or supplementary site-selection method for the SSAFS. GIS has the potential to reduce both expenses and time in the location of sites by reducing the number of dams to be visited, through the application of various GIS tools and principles, to only those that are optimal (i.e. that carry the least risk of the SSAFS projects failing). The contention is that a GIS application can aid in the development and improvement of the SSAFS by finding optimal sites and as such be useful to other forms of aquaculture in the country.

This chapter has highlighted the problem that current search methods for SSAFS sites are slow and expensive, hence the challenge to resolve this problem, namely by the cheaper and faster application of GIS to find optimal sites for the SSAFS. In the next chapter the problem statement and aim are set out in more detail. In addition, the objectives in achieving this aim are formulated and the research methodology is described.

2 DEVELOPMENT OF THE GIS SITE SELECTION METHODOLOGY

The purpose of this study is to apply GIS to find sites for the SSAFS. To do this a GIS site selection methodology will be created. A further purpose of the study is to ensure that the methodology can be replicated, adapted and improved so that it can be used as a model for other types of aquaculture. For this to be possible the procedures employed in the creation of the GIS site selection methodology need to be documented. This chapter outlines the problem statement, aim and objectives, study area, data requirements and research methodology, while the procedures are described in chapter 3.

2.1 PROBLEM STATEMENT: SITE SELECTION FOR THE SSAFS – A SLOW AND COSTLY EXERCISE

According to Brink (2003) in 2003 South Africa produced rainbow trout to the value of R44 million, while the next highest, amongst the fresh water species, was R11.8 million generated by shrimp (*Penaes indicus*). This high production value came from only 1 750 metric tons of fish produced, compared with 51 300 metric tons produced through capture fisheries by South Africa in 1998 (Brink 2001). This, however, falls far short of the country's potential fresh water aquacultural output: "Net in Wes-Kaapland is daar bykans 2000 geskikte damme wat tot 8000 ton vis per jaar kan lewer - genoeg vir twee en 'n half miljoen mense elke jaar!" (*Kampusnuus* 2004: 4). The aim of the SSAFS is to increase the output by utilizing some of these dams, but the implementation of these SSAFS is slow. A reason for this is that the current predominant search method employed to find sites is expensive and time-consuming: "The most difficult obstacle in the way of the aspiring rainbow trout farmer is finding and acquiring a satisfactory site for a fish farm" (Sedgwick 1995: 9).

By applying GIS tools and principles to lessen costs and hasten site selection procedures for the SSAFS, output could be considerably increased by allowing more time and funds to be allocated to production. This will in turn reduce time and development costs by reducing unnecessary research and the wasteful development of unsuitable sites.

2.2 AIM AND OBJECTIVES

The purpose of this study is to create a methodology that is fast and inexpensive using GIS for the location of new sites for the SSAFS, and which can be adapted and improved in the future for other uses. Five objectives will be pursued, namely:

Objective 1: Identify the important factors (variables) that influence site selection for the SSAFS.

Objective 2: Determine a hierarchy of the variables to systematically and logically isolate dams that are potentially optimal sites for the SSAFS.

Objective 3: Determine the parameters of the variables that influence site selection for the SSAFS so that the dams may be selected and displayed accordingly.

Objective 4: Produce outputs (maps, diagrams, tables) showing the dams that are optimal for the SSAFS.

Objective 5: Establish the acceptability and effectiveness of the GIS methodology.

Objectives 1, 2, 3 and 4 combined form a GIS site selection methodology which can be replicated and/or improved and adapted, while objective 5 determines whether the research aim has been achieved. These objectives will be pursued by following a research methodology that is described in section 2.5.

2.3 DATA REQUIREMENTS

This section deals with the data and information that is needed in the GIS site selection methodology.

2.3.1 Shape files

The variables referred to in objective 1 constitute the data needed in the GIS methodology. The GIS software that is used in the methodology is ArcView 3.2 therefore the data are in the form of shape files. "Shapefiles are a simple, non-topological format for storing the geometric location and attribute information of geographic features" (ArcView 1999). Specifically, the shape files obtained or created are:

- The dataset of dams from which the optimal sites for the SSAFS could be selected (nda_wcsa_ge.shp);
- Areas where trout farming may or may not be prohibited, namely conservancies (ca_conservancies.shp); local authority nature reserves (ca_loc.shp); South African national parks (sa_national_parks_gw.shp); national heritage sites (ca_nhs2.shp); private nature reserves (private_nature_reserves.shp); protected natural environment areas (ca_pne.shp);

provincial nature reserves (ca_cnc.shp); sensitive wetlands (sensitive_wetlands.shp); the West Coast Biosphere Reserve (wc_biosphere_zones_ge.shp); and the Kogelberg Biosphere Reserve (kobio_zones_final.shp);

- Areas where sensitive lower vertebrates occur (sens_lower_vert.shp);
- Areas identified by an environmental expert as suitable for rainbow trout farming with regards to successful permit application (accept_tr_til.shp);
- Roads (sa_roads.shp);
- Fish processors, hatcheries and feed suppliers (fish.shp); and
- Census 2001 data (wards.shp).

2.3.2 Information

Information that was required is the parameters of the variables, i.e. objective 2. This comprises dimensions of the dams, which areas will prohibit trout farming, what sensitive lower vertebrates will be negatively affected by trout farming, location of the areas where permit applications for trout farming will be successful, the maximum distance dams must be located from roads that can support an 8-ton truck, the distances from the dams to major processors, major hatcheries and major feed suppliers, the definition of security risk areas, location of areas deemed security risks and the minimum distance dams must be located from security risk areas.

2.3.3 Data and information collection

The shape file of the dams in the Berg and Breede River water management areas was obtained from Beuster (2003, pers. com). The shape files of the protected areas and sensitive lower vertebrate areas were obtained from Conservation Planning Unit (2002). The areas identified by an environmental expert as being suitable for trout farming were obtained from Impson (2005, pers. com) and digitized to create a shape file. The addresses of the major feed suppliers, major hatcheries and major processors were obtained from the respective businesses themselves. The addresses were converted to point locations in a shape file by Morgan (2004, pers. com). The 2001 census shape files were obtained from *SA Explorer Version 1.0* (Municipal Demarcation Board 2002) and the roads shape file was obtained from the Department of Geography and Environmental Studies at Stellenbosch University. Information on the parameters including dam dimensions, the maximum distance dams must be located from roads, the distances from the dams to processors, hatcheries and feed suppliers was obtained from Salie (2005, pers. com.) through interviews, telephone and e-mail. Information regarding which areas will prohibit trout farming was obtained from Hinrichsen (2004, pers. com.) via e-mail. Information regarding those sensitive lower vertebrates that will be negatively affected by trout farming and the location of the areas where permit applications will be successful was obtained from Impson (2005 pers. com.). Definition of security risk areas and the delineation of security risk areas as well as the minimum distance dams should be located from these areas were determined by the researcher following advice from Salie (2005, pers. com.).

2.4 STUDY AREA

The dataset used to select dams for SSAFS sites, using the GIS site selection methodology, was a dataset of dams contained in a shape file named nda_wcsa_ge.shp. The reason this dataset was used is that it is the only dataset of dams that includes dam dimensions. The dams in this shape file are situated in the Berg River and Breede River water management areas. The current existing SSAFS are also situated in this area. It is for these reasons and the fact that DASU are looking to site the new SSAFS in this area, that the study area is that covered by the nda_wcsa_ge.shp shape file as well as the surrounding land. The study area is demarcated in Figure 2.1.

2.5 RESEARCH METHODOLOGY

The main model which inspired and informed the methodology for this research is the study by Meaden (1987). His work sought to apply GIS to find optimal sites for trout farming in Britain. The main aim of that research was to develop a methodology to determine whether trout farmers in England and Wales were locating their farms in the areas most suited for this particular type of farming. The methodology aimed to help existing farmers to know how their location influences the profitability of their farms and also to provide emerging new farmers with a methodology that would help them choose an area best suited for trout farming.

A similar methodology to Meaden's is followed in this study. There are, however, some noteworthy differences. First, Meaden's study involved the classification of the entire land surface according to its suitability for trout farming, while this study focuses only on the rating of dams. Second, in Meaden's study the entire surface is divided up into a grid of cells and each of these cells is given a rating as to its suitability, that is raster data are employed. In this study grids of cells are not used; the dams and other themes are classified as whole items, i.e. they are in vector format. The third

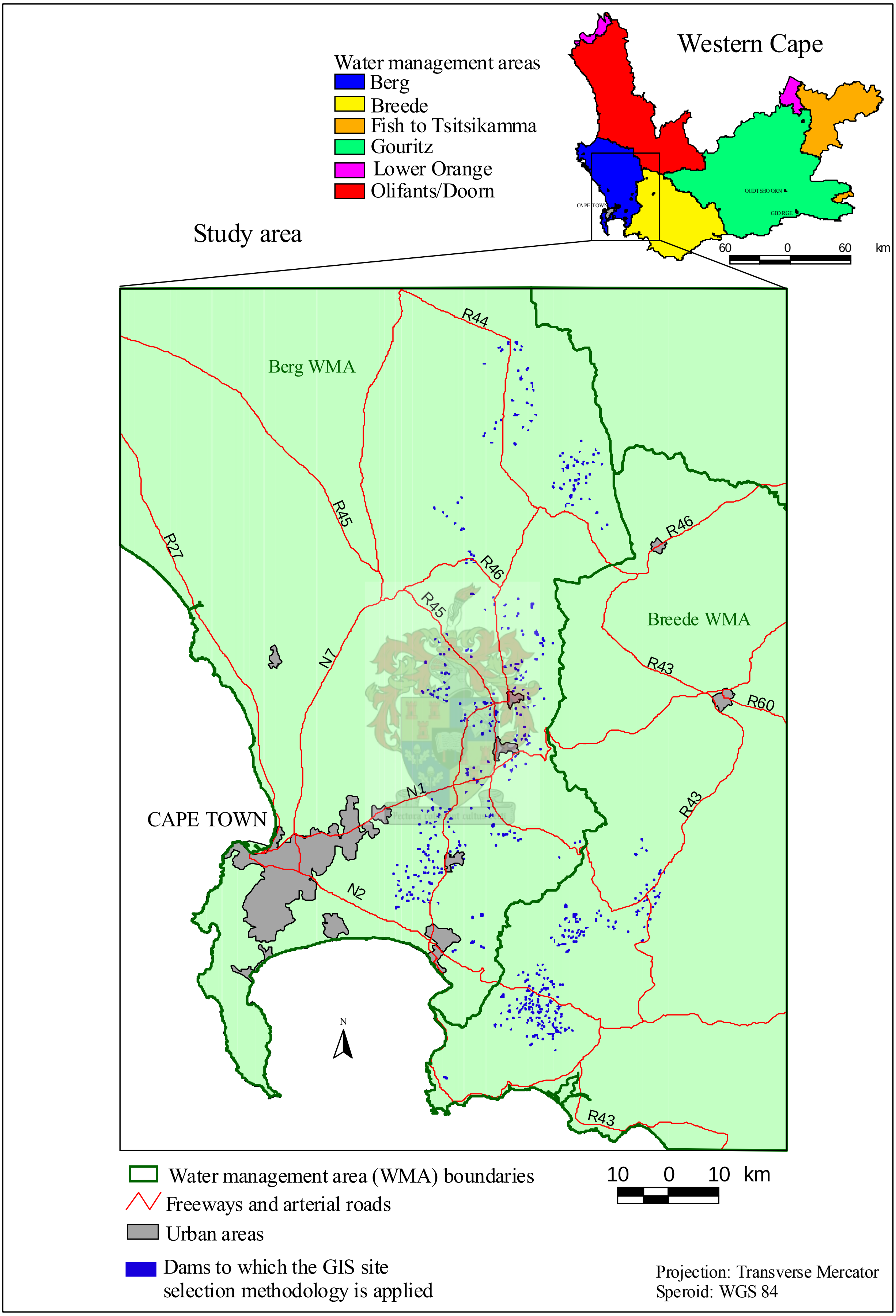


Figure 2.1: Study area for testing and illustrating the GIS site selection methodology

dissimilarity is that different variables and parameters are used to those of Meaden's study to classify the sites, as the sites are located according to the specific requirements of the SSAFS.

GIS software will be used to isolate those dams that are most suitable according to a hierarchy of variables that have the most influence on whether a dam is a suitable site for the SSAFS. The GIS software used in this study is ArcView GIS 3.2, developed by the GIS and mapping software company, Environment Systems Research Institute (ESRI) in Redlands, California.

The result is a GIS site selection methodology that produces maps showing the location of the dams as well as displaying their suitability for SSAFS according to variables that influence the success of the SSAFS. The maps can be used as a guide for finding new sites for the SSAFS. The methodology can also be adapted and/or improved to produce new maps showing sites suitable according to different variables and even different forms of aquaculture. The logic of the steps employed in this research is highlighted in Figure 2.2.

In the following chapter the GIS site selection methodology is implemented to find optimal sites for the SSAFS.

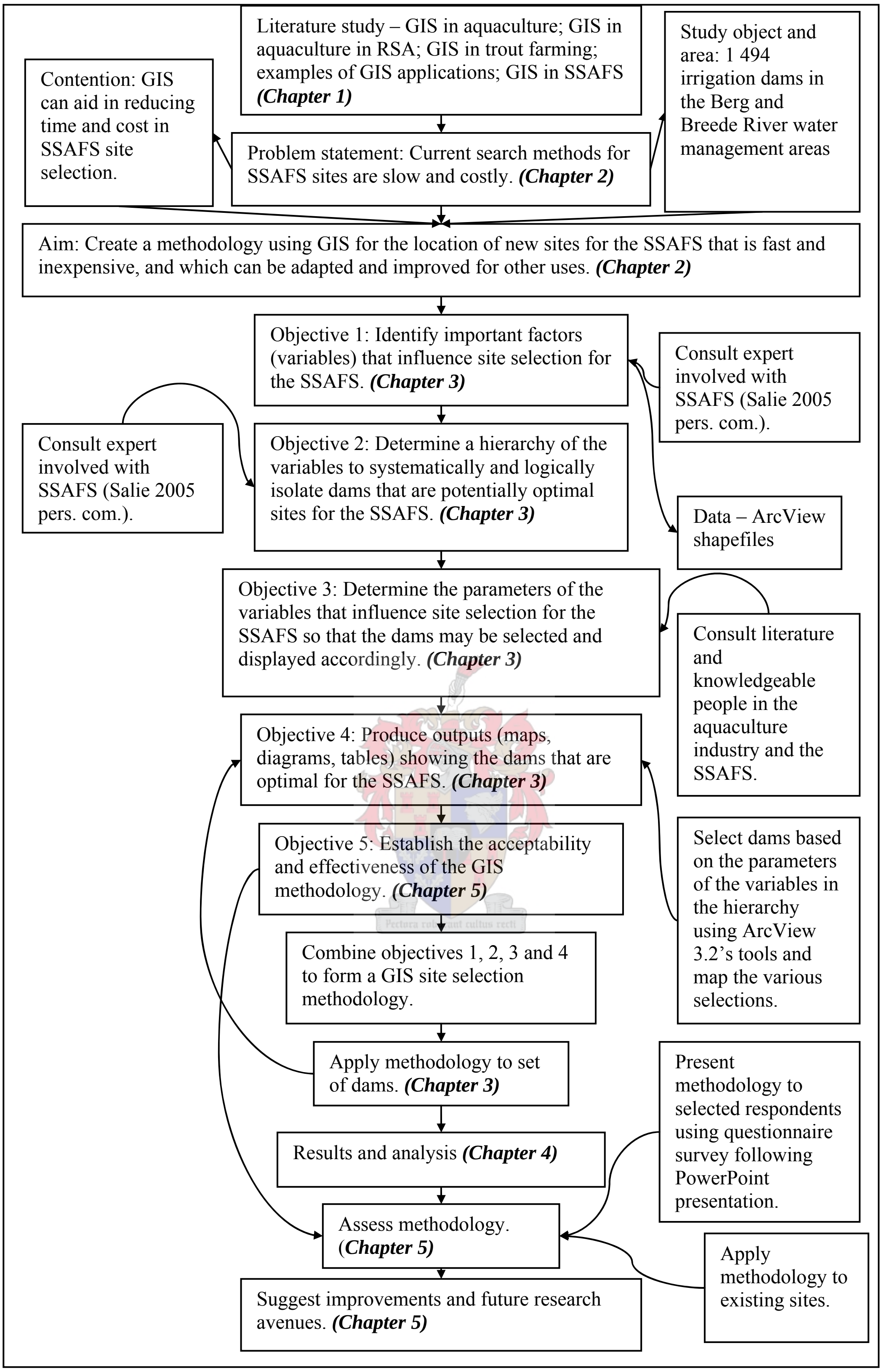


Figure 2.2: Research design for optimal aquaculture site selection using GIS

3 IMPLEMENTATION OF THE GIS SITE SELECTION METHODOLOGY

Objectives 1, 2, 3 and 4 combined form the GIS aquaculture site selection methodology. These objectives are pursued in this chapter to find optimal sites for the SSAFS.

3.1 VARIABLES THAT DETERMINE THE SELECTION OF DAMS AS OPTIMAL SITES FOR THE SSAFS

"To determine location suitability it was first necessary to establish those factors of production (production functions) which controlled trout farming, i.e. mostly physical and economic factors" (Meaden 1987: 33).

The first step, if a similar methodology to that of Meaden (1987) is used, is to determine those variables that have the most influence on the optimal location of sites for the SSAFS. This will fulfil the requirements of objective 1. These variables need to be mappable. In other words the variables need to be constant enough so that they can be mapped. Water quality is a good example. It is one of the most important variables that determines site selection for the SSAFS or any form of aquaculture, as confirmed by Swann (2005: 1): "To a great extent water determines the success or failure of an aquatic operation". Unfortunately water quality can change rapidly and regularly making it difficult to map. Consequently it makes more sense to isolate dams based on the other variables that can be mapped more easily, and then test the water quality of this smaller selection of dams. This aspect will be discussed in more detail in chapter 5. The variables that influence successful site selection most for the SSAFS and that are capable of being mapped, were determined through consultation with Salie (2005, pers. com.). Eight variables were distinguished as shown in Figure 3.1.

3.2 HIERARCHY OF VARIABLES THAT DETERMINE THE SELECTION OF DAMS AS OPTIMAL SITES FOR THE SSAFS

Once the first objective was completed the next step (objective 2) was to create a hierarchy or order in which variables would be arranged to select dams. The reason a hierarchy was developed is to sequentially select dams according to variables having decreasing influence on successful site location. In other words, a variable sieve is used to sift out those dams which have the most chance of being successful sites for the SSAFS.

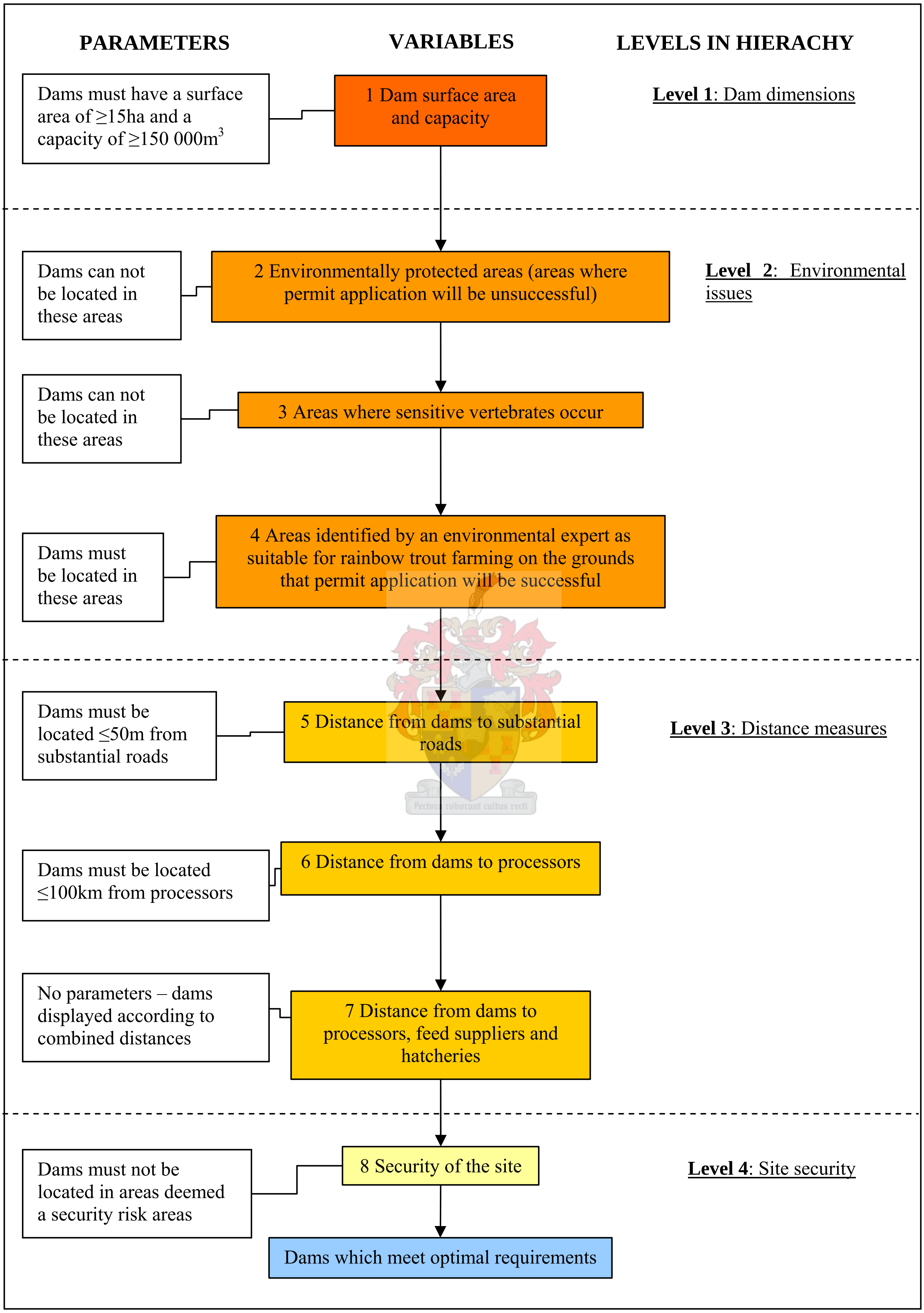


Figure 3.1: Hierarchy of variables for selecting optimal aquaculture sites for SSAFS

The hierarchy was determined through consultation with Salie (2005 pers. com.) and it is illustrated in Figure 3.1. The variables are indicated and numbered in order of decreasing influence from top to bottom. As the hierarchy is worked through in the direction of the arrows the potential of the dams to be successful SSAFS sites increases. The variables are also grouped in four levels of qualitative importance. Level 1 concerns dam dimensions. Level 2 relates to environmental issues and is less important, but still has a strong influence on site selection. Level 3 covers distance measures, while level 4 pertains to site security and is the least influential. Dams have to conform to the parameters of the variables in levels 1 and 2 otherwise the SSAFS site will fail. Dams do not have to conform to the parameters in levels 3 and 4, however they will show greater potential of succeeding as sites for the SSAFS if they do.

3.3 THE SELECTION OF DAMS AS SSAFS SITES ACCORDING TO THE PARAMETERS OF THE VARIABLES

In the following sections the hierarchy of variables is worked through. Parameters for each variable are applied and the dams are selected or eliminated accordingly. This fulfils the requirements of objective 3. The dams are then displayed on maps according to requirements of these variables, thereby fulfilling the requirements of objective 4.

3.3.1 Dam surface area, capacity and depth

The starting point in the selection procedure according to level 1 in the hierarchy of characteristics for new sites for the SSAFS is to isolate dams that have a large enough surface area, capacity and depth. According to Salie (2005, pers. com.), a dam must have a surface area of 15ha or greater, a capacity of 150 000m^3 or more, and a depth of 5m or deeper. The reason for this is that the floating cages need to be periodically moved around in a dam, because if the cages are left in one spot in the dam an entire season, the water quality around the cages can deteriorate (Salie 2005, pers. com.). Surface area and capacity of a dam are also important as the larger the dam the better chance of it having and maintaining good water quality. With regards to depth, the dam has to be deeper than 5m. The reason is that cages are suspended from floats on the surface of the water (see Figure 1.2) and a cage's draught is 5m, so in order for a cage to be suspended in the water and not rest on the bottom of the dam, the dam has to be deeper than 5m.

The dataset used was the shape file of the dams (Nda_wcsa_ge.shp) in the Berg and Breede River water management areas. This shape file is the most detailed dataset of dams available for the study area. The dataset comprises capacities and surface areas. Unfortunately data on depth were not available, so depth will have to be measured when the finally selected dams are inspected more closely through physical site visits. Dams with a surface area of 15ha or larger were selected first by using ArcView 3.2's query tool and the result was converted into a shape file. Next, a query was performed on the capacity field of this new shape file to isolate dams which have a capacity of 150 000m^3 or more. This was converted to a shape file named dam_area_cap.shp containing those dams having a surface area of 15ha or larger and a capacity of 150 000m^3 or more. This process reduced the original 1 494 dams drastically to 128 possible sites which could be subjected to further analysis. The selected and rejected dams are shown in Figure 3.2.

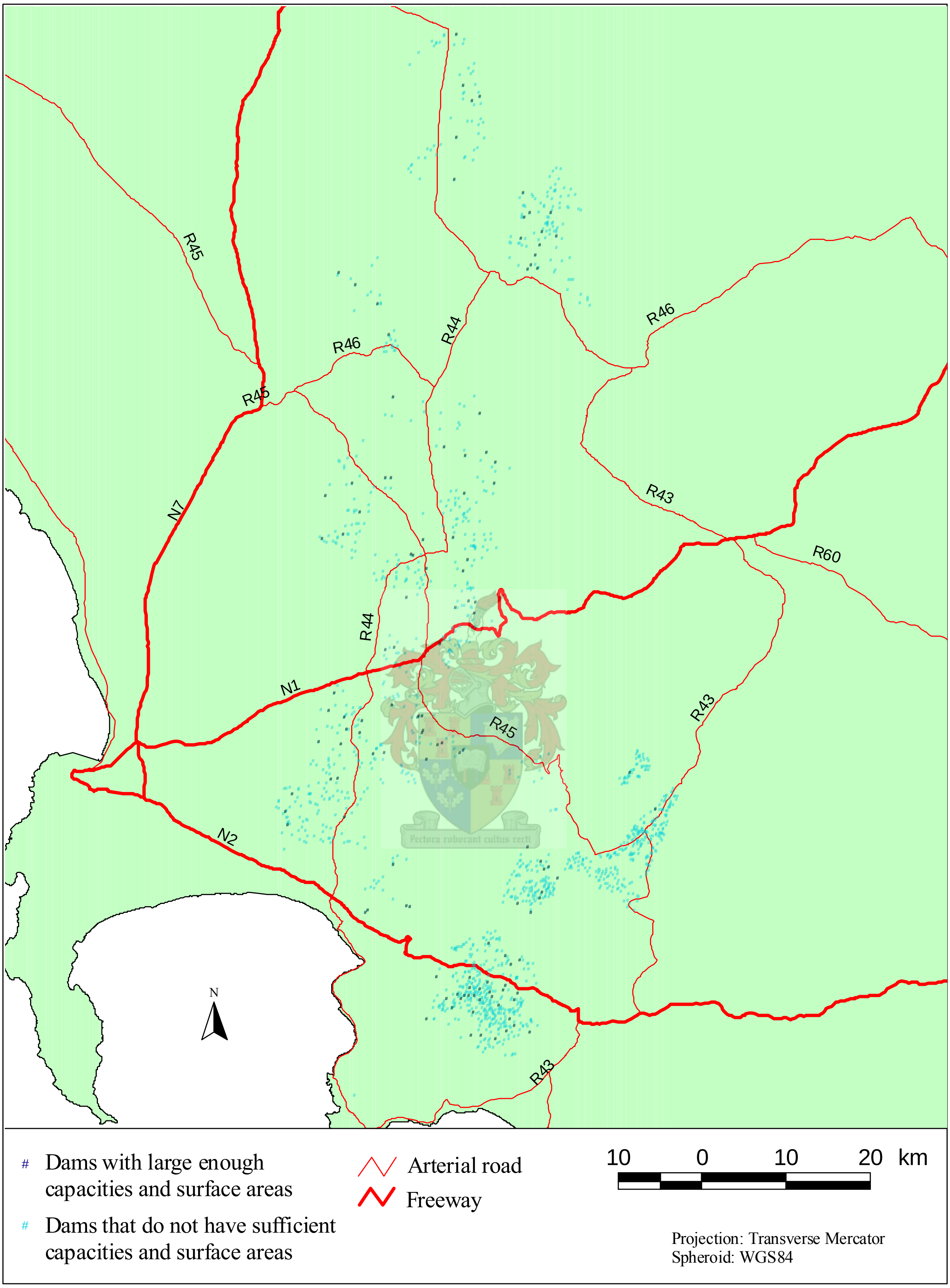


Figure 3.2: Dams with and without sufficient surface area and capacity for aquaculture

3.3.2 Areas where trout farming will or will not be allowed for environmental reasons

The second level in the hierarchy of variables is those areas where trout farming will not be allowed because they are either protected areas and/or environmentally sensitive. This is important as a permit is needed to start an SSAFS in a new location. "Moreover, it is often the case that governmental agencies involved with issuing new aquaculture permits need to perform spatial analysis on a proposed site to assess its potential environmental, economic and spatial impacts on other locations. This situation is analogous to the need for monitoring existing operations in terms of environmental and/or other impacts" (Aguilar-Manjarrez *et al.* 2000: 3). GIS can help in locating sites for the SSAFS that are not environmentally sensitive or protected, "[a]s noted by Osleeb & Kahn (1998), these decision support needs cannot be affectively addressed without the use of a GIS" (Aguilar-Manjarrez *et al.* 2000: 3). Through consultation with Impson (2005, pers. com.) and Hinrichsen (2004, pers. com.), three types of environmental areas have been distinguished, namely protected areas, areas that are environmentally sensitive with regard to certain threatened lower vertebrate species, and areas demarcated as being acceptable for trout farming on the grounds that they are not environmentally sensitive and/or protected and as such successful permit application is highly probable. Each is discussed in turn.

3.3.2.1 Protected areas

It is important to know which dams are located in protected areas where trout farming will not be allowed because, according to Salie (2005, pers. com.), the conservation status of the land on which the dam is located is one of the main factors determining the success or failure of a permit application.

Therefore ArcView shape files containing the different types of protected areas and their territory in the Western Cape were obtained from the Conservation Planning Unit (2002). The next step was to determine in which of these areas trout farming would be prohibited. To achieve this Stubbs (2005, pers. com.), chairman of the Western Cape Trout Farming Association, was contacted and asked who, if not himself, could provide this information. He suggested an employee of Aqua Eco, Mr E Hinrichsen. One of Aqua Eco's primary functions is to provide clients with assistance regarding aquaculture and the environment.

A list of the different protected areas, contained in the shape files obtained from the Conservation Planning Unit (2002), was sent to Hinrichsen (2004, pers. com.) for comment. These protected areas comprise conservancies, local authority nature reserves, South African national parks, national heritage sites, private nature reserves, protected natural environment areas, provincial nature reserves, sensitive wetlands, the West Coast Biosphere Reserve and the Kogelberg Biosphere Reserve. Hinrichsen (2004, pers. com.) highlighted all the areas that would not allow trout farming under any circumstances, namely all of the aforementioned areas except conservancies, private nature reserves and sensitive wetlands. These areas were selected and merged using ArcView's Geoprocessing Wizard to create a new shape file called prot_areas.shp containing the protected areas where trout farming would be prohibited.

3.3.2.2 Sensitive lower vertebrate areas

According to Impson (2005, pers. com.), one of the major detrimental affects that a trout farm can have on the environment is the fact that the trout can influence the existing indigenous lower vertebrate species (only lower vertebrates are included as it is mostly fish and amphibians which are at major risk from trout).Trout could escape into a river system and prey on the threatened species or disturb their natural habitat (i.e. compete for food sources). They do not even need to escape into the river systems as some of the threatened species are amphibious, such as frogs, and as such will be vulnerable as dams form an integral part of their habitat.

Therefore a shape file was obtained from Conservation Planning Unit (2002) consisting of all the areas in the Western Cape in which sensitive lower vertebrate species occur. Impson (2005, pers. com.) was consulted as to which of the species contained in the database of the shape file are vulnerable to trout farming specifically. Impson (2005, pers. com.) suggested that areas sensitive with regards to the microfrog, whitefish, western leopard toad, Cape kurper, Cape platana, Cape galaxias and Berg River redfin populations should be avoided when locating sites for trout farming. The sensitive lower vertebrate shape file was queried according to these species to create a new shape file called sens_areas.shp containing only these species (see Appendix D).

3.3.2.3 Environmentally suitable areas

While being consulted about areas where trout farming will not be allowed, Impson (2005, pers. com.) suggested that he would identify those areas in the study area where, in his professional opinion as an environmental expert, there would be little chance of not obtaining a permit for trout farming. Once these areas had been indicated on a map of the study area, they were digitized and a new shape file called Accept_tr_til.shp was created. Areas that are acceptable for rainbow trout farming are indicated in this shape file, as well as areas acceptable for Mozambique tilapia farming.

Although the latter is not necessary for the trout farming focus of this research, it is an added advantage, given that in the summer months Mozambique tilapia are farmed in the SSAFS. These demarcated areas are shown in Figure 3.3.

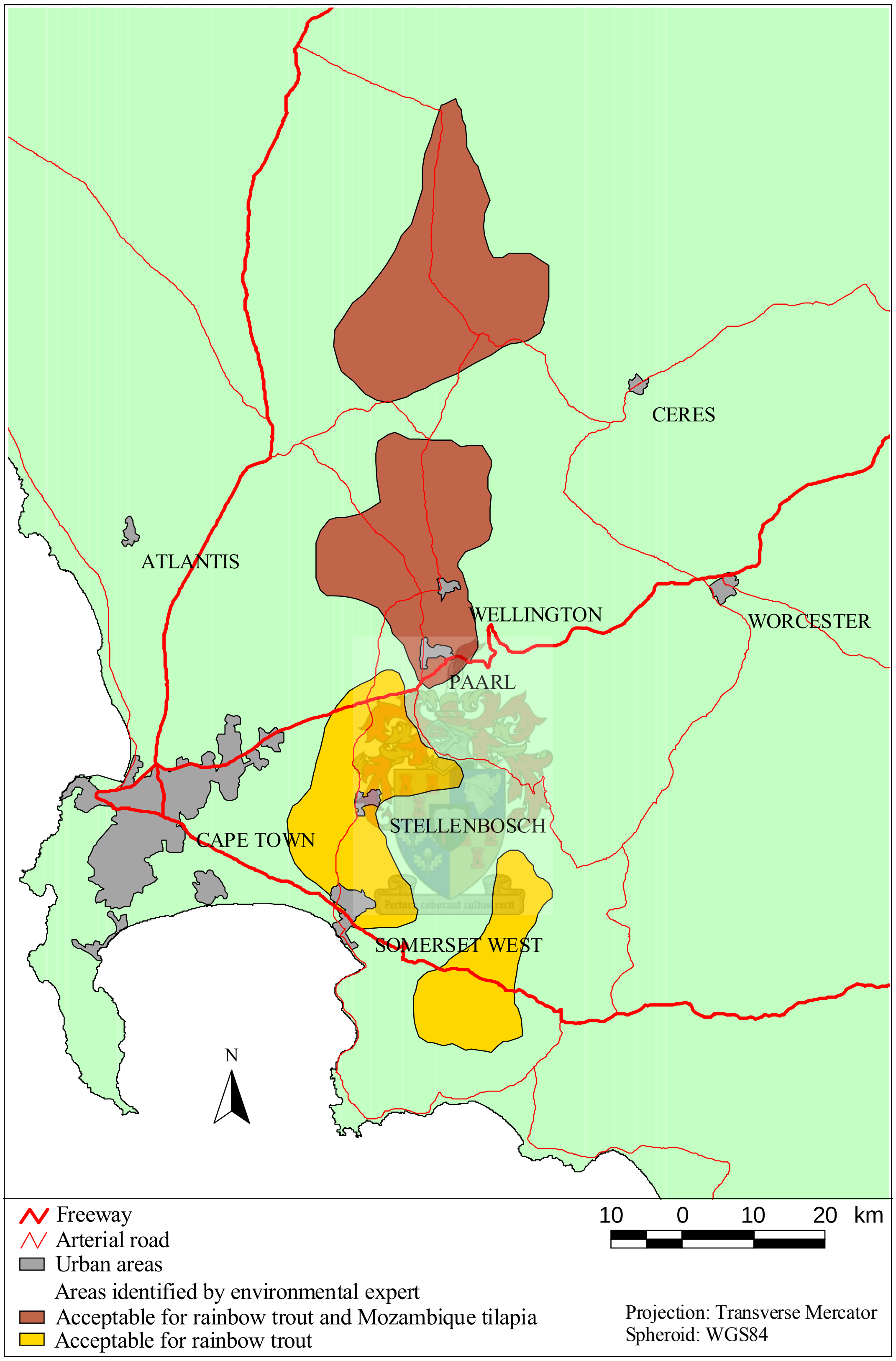


Figure 3.3: Areas suitable for rainbow trout and/or Mozambique tilapia farming as indicated by an environmental expert

3.3.2.4 Composite environmental areas

Once the protected areas, sensitive lower vertebrate areas and those areas indicated by Impson (2005, pers. com.) had been identified, it was necessary to determine which dams in the dam_area_cap.shp shapefile are located in these areas. The selection procedure involved a number of steps.

First the shape files prot_areas.shp and sens_areas.shp were merged to create a new shape file named Mg_prot_sens.shp, which contains all the protected areas as well as all the sensitive vertebrate areas. The next step was to select those dams in the dam_area_cap.shp shape file which intersected the Mg_prot_sens.shp shape file. This selection was inverted so as to find those dams which did not intersect the Mg_prot_sens.shp shape file (i.e. those dams which are not in protected or sensitive vertebrate areas). This selection was converted into a shape file called D_areacap_protsens.shp. The last step at this level of hierarchy of variables was to determine which of the dams in D_areacap_protsens.shp are located in the areas identified by Impson (2005, pers. com.) as suitable for trout farming. This was done by selecting all those dams of the D_areacap_protsens.shp that intersect the Accept_tr_til.shp shapefile and converting that shape file to a new composite shape file called D_areacap_protsensimp.shp. This shape file contains all the dams that have large enough surface areas and capacities, that are not situated in protected areas or areas where sensitive vertebrates occur and are in areas identified as being suitable for trout farming. Sixty-nine out of the original 1 494 dams qualified. The dams are plotted in Figure 3.4 which shows them in relation to protected areas, areas where certain sensitive vertebrates occur and areas identified as being suitable for trout farming. The fact that only 69 dams, just over half of the previous selection of dams in the hierarchy, are in areas where permit application will most probably be successful indicates how much impact environmental concerns have on locating sites for the SSAFS as well as other aquaculture types. The fact that the selection has been reduced so much also shows how much work can be saved by using the GIS site selection methodology.

In the previous sections the variables in levels 1 and 2 of the hierarchy were discussed. Dams have to conform to the parameters of these variables, otherwise they will be discarded. In the following sections levels 3 and 4 will be discussed. At these levels dams do not have to conform to the parameters of the variables to be included. The reason for this is that if they do not fulfil the requirements of the variables, it does not mean that they can not be used as SSAFS sites: it just means that they may not be successful sites.

3.3.3 Distance measures

The third level in the hierarchy of variables comprises distance measures. Increased distance between dams and places that need to be visited results in an increase in time and cost. The distances that have the most impact on whether a particular SSAFS would be successful or not are a

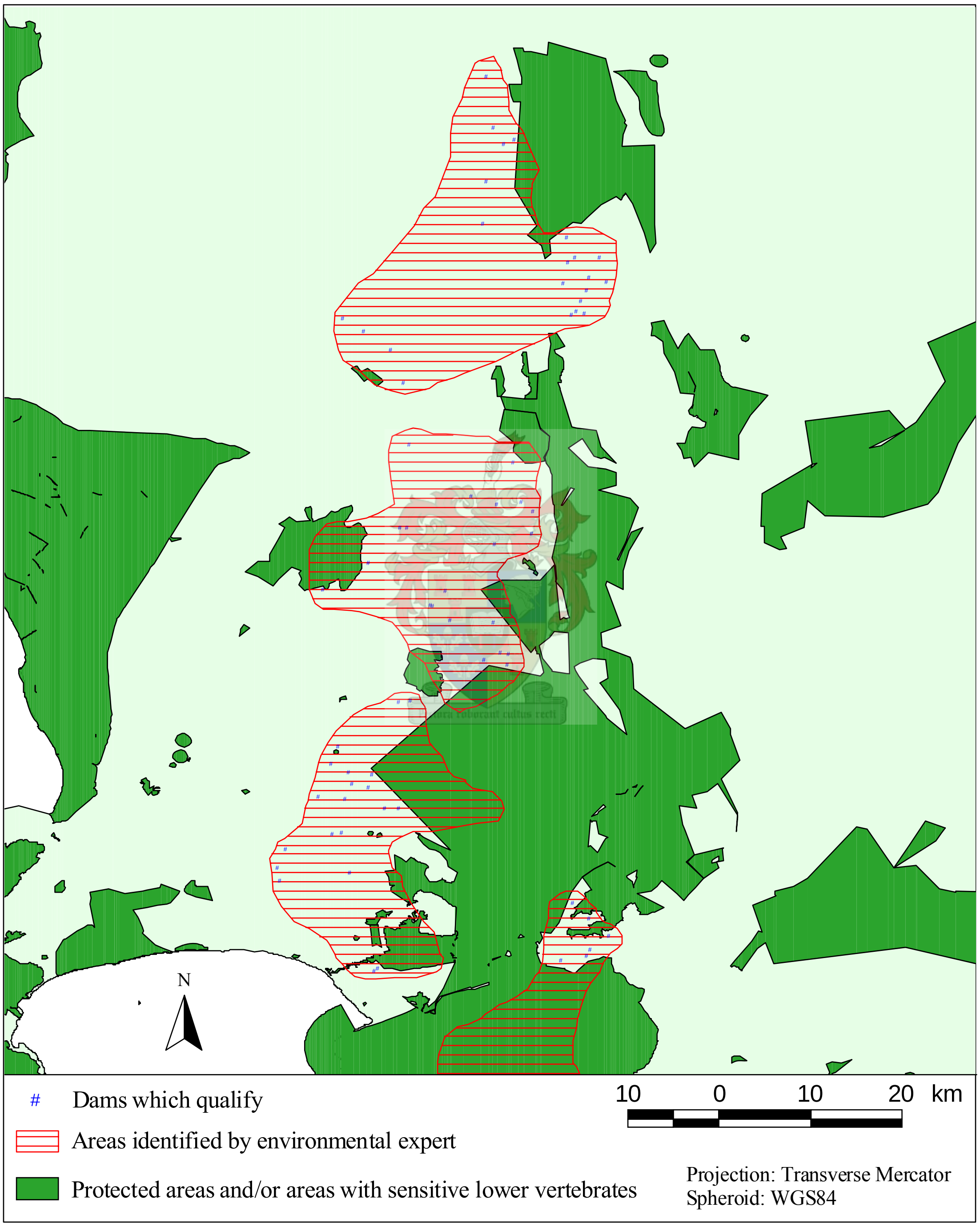


Figure 3.4: Location of dams that qualify for trout farming according to dam dimension and environmental criteria

dam's distance from a substantial road, the distance between a dam and its closest major processor (i.e. the potentially most frequented processors, namely Garon Foods, Three Streams Smokehouse, Franschhoek Fish House and Salmo Smokehouse), the distance between a dam and its closest major feed supplier (i.e. the potentially most frequented feed supplier, namely Aquanutro), and the distance between a dam and its closest major hatchery (i.e. the potentially most frequented hatcheries, namely the Stellenbosch University Trout Farm and Three Streams Smokehouse). At present all the fish produced by the SSAFS are processed by Three Streams Smokehouse (Stubbs 2005, pers. com.), however in this investigation other processors are included in case they will be used in future. These four distance variables are discussed in turn.

3.3.3.1 Distance from roads

The dams need to be 50 metres or closer to a road. This distance was decided upon by Salie (2005, pers. com.) for two reasons based on his experience. First is that fingerlings, when delivered to a dam, have to be transported from trucks into the dams. During this process the young fish are subjected to a lot of stress. Thus, the further the distance between the delivery vehicle and the dam, the more stress is placed on the fish and greater the chance of there being a loss of fish. The second reason is related to harvesting. When harvesting takes place, time is of the essence as the fish need to reach the processors before 09:00 so that the fish can be processed the same day. This reduces the risk of loss in quality of the fish. If the distance that the fish need to be carried between the truck and the dam is too great, the effort and time taken to harvest the fish will be increased, resulting in an increased risk of the fish not making the processors on time.

With this in mind a shape file of all the roads of South Africa was obtained and named Sa_road.shp. Only the roads of the Western Cape were needed, so the roads were clipped with the shapefile comprising the Western Cape boundary, WC.shp, to create a new shape file called WC_roads.shp. This shape file is made up of eleven different road types, namely arterial routes, main roads, national freeways, national routes, on-off ramps, other accesses, secondary roads, streets, hiking trails, track footpaths and roads under construction. WC_roads.shp was queried to select all the roads except for hiking trails, track footpaths and roads under construction. This resulting shape file was named Substantial_roads.shp. The reason for this excision of three types of road is that eight-ton trucks are used for harvesting as well as delivery of fingerlings. The road must be able to support an eight-ton vehicle (see Figure 3.5). These roads that can support such a vehicle are referred to as 'substantial roads'.

The D_areacap_protsensimp.shp shape file was queried to select all the dams within 50 metres or less from a substantial road. This selection was converted to a shape file named D_areacap_prsen_r50.shp. This shape file then contains the dams that have met the dimensional, the environmental and the proximity to a substantial road criteria. A total of 33 dams out of the original 1 494 dams passed through these selection sieves. These dams (as well as those farther than 50 metres from a substantial road) are plotted in Figure 3.6.

(Source: Kalied Salie)

Figure 3.5: Eight-ton truck on a substantial road during trout harvesting at Rustenberg farm's SSAFS, October 2004

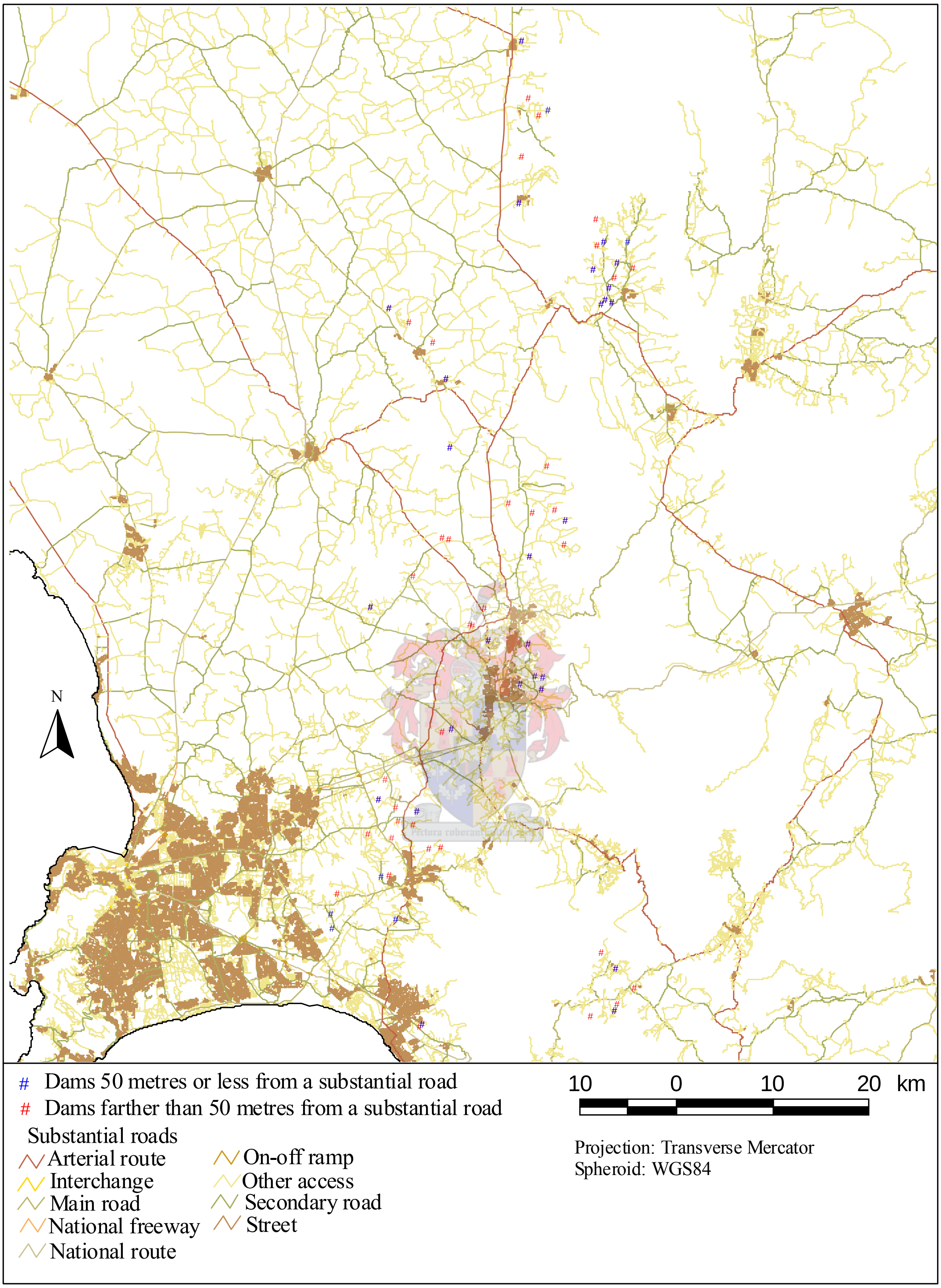


Figure 3.6: Location of dams that qualify for trout farming according to dam dimensional, environmental and proximity to substantial road criteria

3.3.3.2 Distance to fish processors

The distance between a dam and processors impacts on whether a dam will be a suitable site for the SSAFS. The reason is that processors start to process fish at the start of the day, usually about 09:00. It is preferable that, when trout are harvested, the load be received by a processor no later than 09:00. If the fish reach the processors after 09:00, they might not be processed the same day with the result that the quality of the fish may be compromised should the load stand overnight. Farmers of the SSAFS start harvesting fish at 06:00 and it takes roughly two hours to harvest, get the fish ready for transport and to pack the containers into the truck or trucks (Salie 2005, pers. com.). This leaves about one hour to travel to a processor. If a truck travels at an average speed of 100km/h, the closest processor should not be farther than 100km away if it is to be reached no later than 09:00.

With this in mind the point locations of the major processors in the Western Cape were determined. This was done by obtaining the physical addresses of the major processors and sending them to Map IT based in Pretoria where Morgan (2004, pers. com.) found the co-ordinates of the addresses and digitized them as points. These points were buffered by 100 kilometres using ArcView 3.2's Create Buffers function. The D_areacap_prsen_r50.shp shape file was queried using ArcView 3.2's Query Builder to see which dams lay within this 100km buffer zone (and those outside the zone). The dams are plotted in Figure 3.7. This selection was converted to a shape file and named D_areacap_prsenimp_r50_p100.shp. This shape file contains 32 dams, so only one dam did not fall within the 100km zone.

The final distance variable is a composite created from distances to processors, feed suppliers and hatcheries. It is covered in the following section.

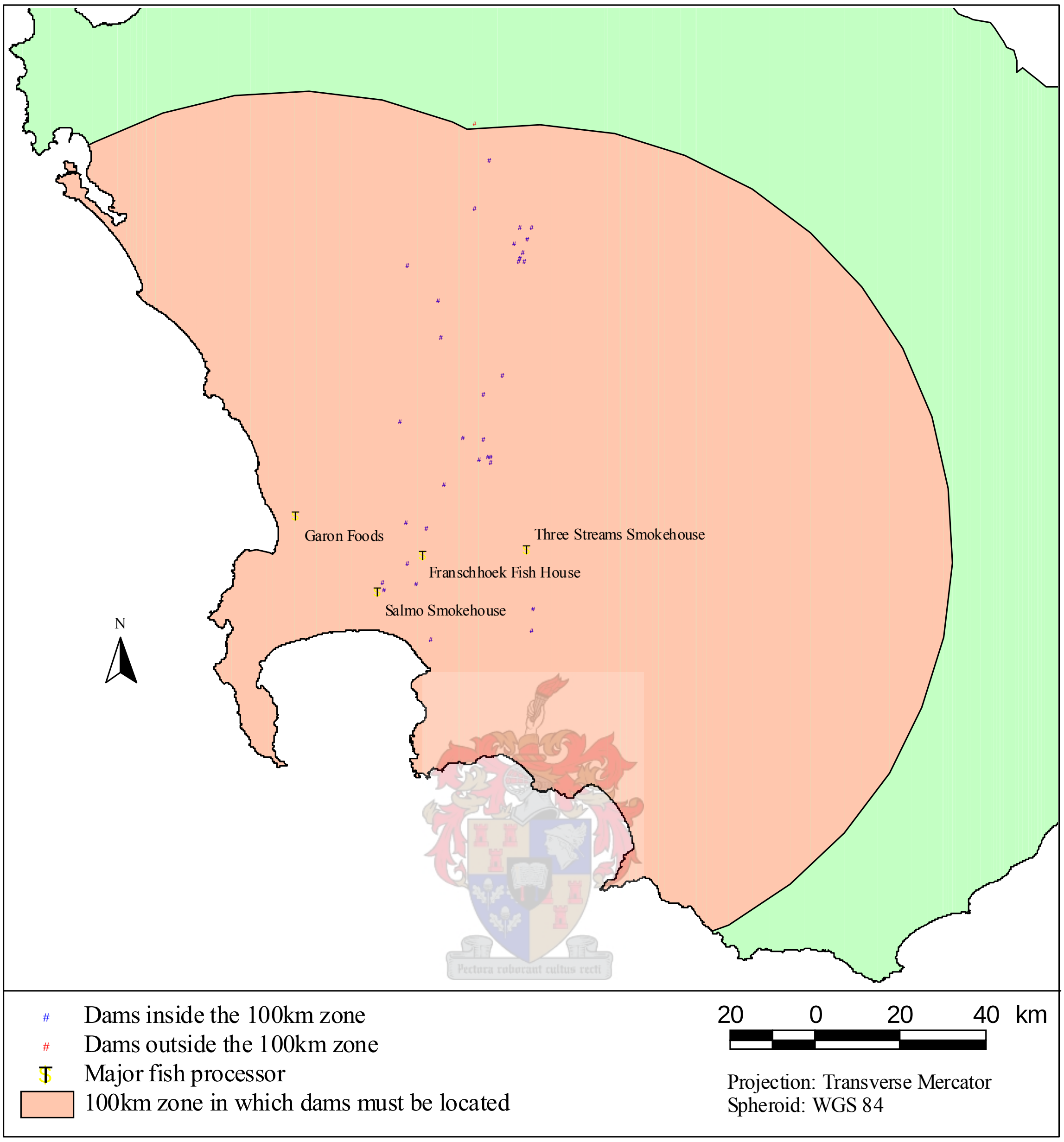


Figure 3.7: Dams in relation to the 100km zone around the major fish processors

3.3.3.3 Distance from the major processors, major feed suppliers and major hatcheries

In a business requiring the delivery of input supplies to its place of business and the transport of products to its clients, distance is a crucial variable which affects time and costs. The distances that influence the SSAFS are the distances between a dam and processors, feed suppliers and hatcheries (Salie 2005, pers com.). Consequently the last step at level three in the hierarchy of variables was to determine the distances between each dam and its closest processor, feed supplier and hatchery. This step does not aim to select (eliminate) any dams in the sieving process. It is done to aid in the choice of those dams already selected through the sieving process, by providing decision makers with a single distance measure. Decision makers can be provided with a table showing the distance measures as well as a map showing the location of dams which are displayed according to the composite distance measures. This was achieved in the following way.

First an Avenue script was used to determine the distance from each dam to each processor, feed supplier and hatchery. The script called View.CalulateDistance calculates distances from points in one theme to points in another theme. When the script is run, it adds fields to the shape files attribute table for each of the distances. This script was run on the D_areacap_prsenimp_r50_p100.shp file. As there are four processors, two hatcheries and one feed supplier, a total of seven fields were added to the table. Each of the new fields is populated with the relevant distances. Once this was done, it was necessary to determine which were the closest processors and hatcheries to each of the dams. This was not necessary with the feed supplier as there is only one. Three fields were once again added to the attribute table. These consisted of a field containing the distance between each dam and its closest processor, a field containing the distance between each dam and its closest feed supplier, and a field containing the distance between each dam and its closest hatchery. ArcView 3.2's Calculate tool was used to populate the one field with the minimum distance between each dam and each processor and the other field with the minimum distance between each dam and each hatchery. The distances in the feed supplier field created by the script were copied into the new field. The final step was to add yet another field. This field contains all three closest distances added together to create a total distance. This shape file with the added distances was called D_areacap_prsenimp_r50_p100_dis.shp. The 32 remaining dams could now be mapped as dots according to their total distances. Each dot represents a distance range: the bigger the dot the smaller the distance and the more the site is suitable with regard to distance (see Figure 3.8). By quick inspection of the map one can see which dams in the original set are not only suitable with regards to the other variables in the hierarchy, but also which of these have the least total distances. Each dam with its least combined distance and location in degrees, minutes and seconds (DMS) is listed in Table 3.1. (The complete distance information is available in Appendix A.)

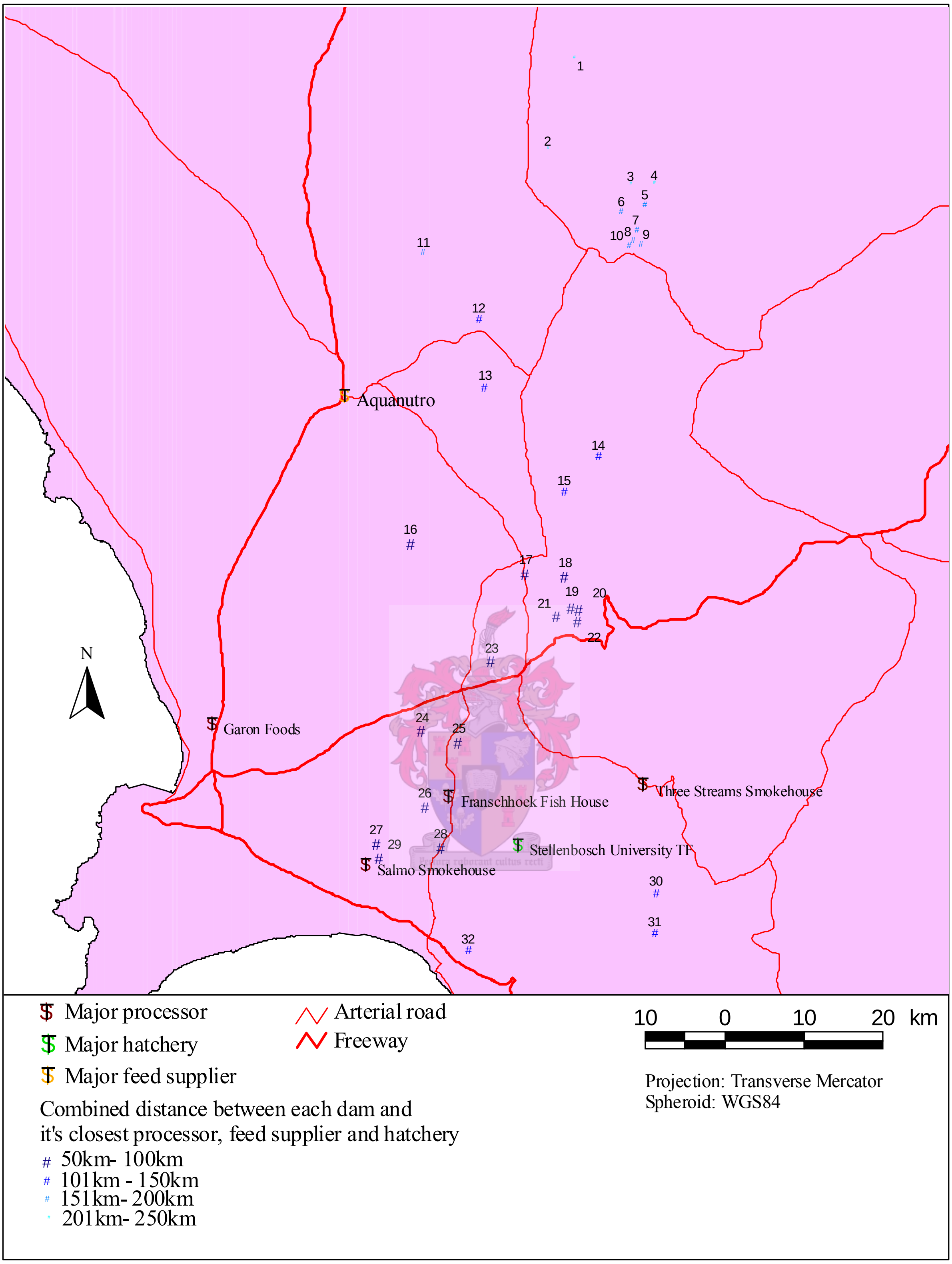


Figure 3.8: Location of dams that qualify for trout farming according to dam dimensional, environmental and all distance criteria

Table 3.1: Combined least distances of the dams and their co-ordinates

Dam number	Total combined least distances (km)	Latitude (DMS)	Longitude (DMS)
1	239.7	33° 4' 58"S	19° 2' 30"E
2	206.7	33° 11' 9"S	19° 0' 13"E
3	202.6	33° 13' 38"S	19° 6' 56"E
4	205.7	33° 13' 38"S	19° 8' 48"E
5	197.7	33° 15' 5"S	19° 8' 2"E
6	192.4	33° 15' 33"S	19° 6' 7"E
7	188.8	33° 16' 49"S	19° 7' 23"E
8	184.9	33° 17' 34"S	19° 7' 3"E
9	184.9	33° 17' 47"S	19° 7' 38"E
10	183.0	33° 17' 52"S	19° 6' 45"E
11	163.8	33° 18' 5"S	18° 49' 57"E
12	146.1	33° 22' 45"S	18° 54' 25"E
13	128.2	33° 27' 22"S	18° 54' 46"E
14	122.6	33° 32' 14"S	19° 3' 55"E
15	112.6	33° 34' 36"S	19° 1' 6"E
16	94.4	33° 37' 57"S	18° 48' 27"E
17	97.4	33° 40' 10"S	18° 57' 48"E
18	97.5	33° 40' 24"S	19° 0' 60"E
19	92.7	33° 42' 33"S	19° 1' 30"E
20	92.4	33° 42' 39"S	19° 2' 6"E
21	92.0	33° 43' 4"S	19° 0' 19"E
22	90.6	33° 43' 28"S	19° 2' 0"E
23	81.5	33° 46' 3"S	18° 54' 53"E
24	73.2	33° 50' 44"S	18° 49' 4"E
25	69.3	33° 51' 32"S	18° 52' 3"E
26	72.3	33° 55' 54"S	18° 49' 11"E
27	81.2	33° 58' 19"S	18° 45' 8"E
28	77.5	33° 58' 40"S	18° 50' 25"E
29	81.9	33° 59' 18"S	18° 45' 19"E
30	106.0	34° 1' 60"S	19° 8' 1"E
31	120.2	34° 4' 46"S	19° 7' 51"E
32	106.8	34° 5' 41"S	18° 52' 31"E

3.3.4 Site security

Level four in the hierarchy represents site security. Security refers to the risk of the fish grown out in the cages being poached by people who live in the surrounding areas. It also refers to possible vandalism or theft of equipment (e.g. nets, floats).

Security is an important consideration when starting an SSAFS, because a site shown to be optimal for SSAFS by all the parameters of the other variables may be sub-optimal if, when farming starts, the fish are stolen and/or property is vandalized. Current search methods for SSAFS sites often overlook security, or security can not be determined prior to farming. One SSAFS has failed specifically due to problems with security, to wit the SSAFS located at Genadendal was terminated as a result of vandalism by local youths (Salie 2005, pers. com.).

For the purposes of this study the security threat is measured by two surrogates, namely the population density and rate of unemployment of the people living around the dams. Population density is used as it is an indication of whether there are many or few people in an area close to the dams. The more people there are, the greater the likelihood of some of them stealing fish or vandalizing the site. The percentage unemployment is used to indicate whether there are many jobless people living in close proximity to the dam, on supposition that someone who is unemployed may be more liable to steal fish, to sell or eat.

Data for population densities and unemployment rates were obtained by manipulating the 2001 census data obtained from *SA Explorer Version 1.0* (Municipal Demarcation Board 2002), which was obtained from Stellenbosch University. The census data were grouped according to wards in a shape file called wards.shp.

Two new fields were added to the wards attribute table. The one field was populated with the population density (number of people per square kilometre) and the other with the percentage of people who were unemployed. It was decided arbitrarily that wards with a population density of more than 5 000 people per square kilometre and/or wards with an unemployment rate higher than 25 per cent would be considered risk areas.

Furthermore, it was necessary to determine a minimum distance at which the dams must be situated away from these risk areas to make them acceptable sites with regard to security. A distance of five kilometres was chosen as it is assumed that people would not travel farther than five kilometres to steal fish or vandalize equipment. The decision was also based on the assumption that unemployed and poor people would have to walk to the dams. A ten-kilometre return journey is probably a prohibitive distance if one is walking.

The next step was to determine which of the dams are situated farther than five kilometres away from the risk areas. This was achieved by using ArcView 3.2's select by theme function. A selection was done on the D_areacap_prsenimp_r50_p100_dis.shp shape file to see which of these dams were within five kilometres of the risk areas. This selection was inverted to single out those dams that are farther than five kilometres from the risk area. This selection was converted into a shape file and called D_areacap_prsenimp_r50_p100_dis_sec.shp. The 21 dams which are farther than five kilometres away from the risk areas are displayed in relation to the density and unemployment areas in Figure 3.9.

Site security is the final variable in the hierarchy of variables and completes the implementation of the GIS site selection methodology. The result is a selection of 21 dams. What does this result indicate? Is the GIS site selection methodology successful and useful? What does it say about the potential of the SSAFS and/or rainbow trout farming in the Western Cape? These questions are addressed in the following chapter.

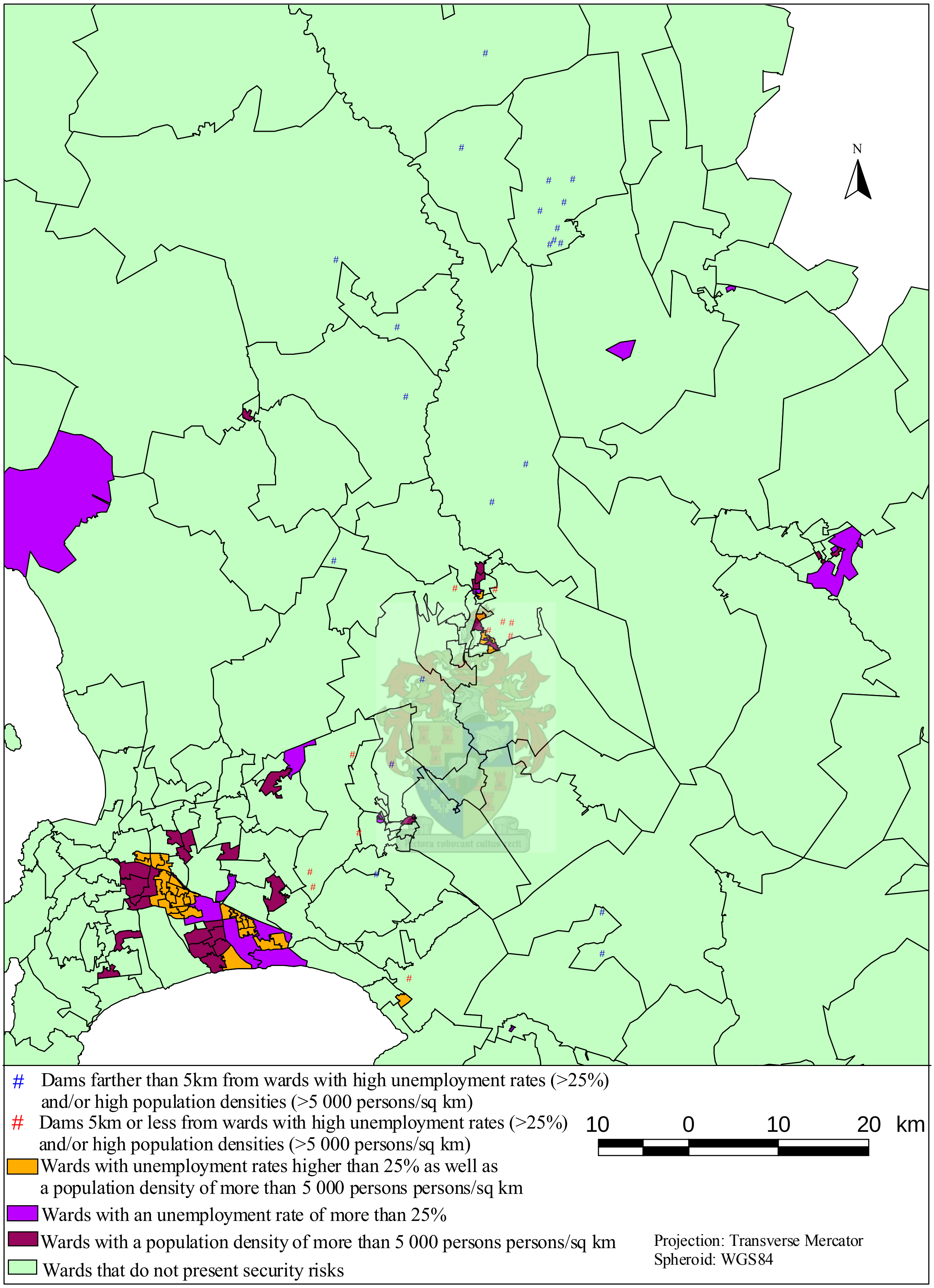


Figure 3.9: Dams in relation to areas of security risk

4 ANALYSIS OF RESULTS

In the previous chapter the GIS site selection methodology was applied to the dams in the dataset. The result is a selection of dams which conform to the parameters of the variables indicated in Figure 3.1. They are dams that:

- have large enough capacities and surface areas;
- are not in environmentally protected areas;
- are not in areas where sensitive lower vertebrates occur;
- are in areas determined by an environmental expert to be suitable for trout farming;
- are within 50 metres from a substantial road;
- are within a 100 kilometres of a fish processor; and
- are not in areas that are security risks.

Out of the original set of 1 494 dams, 21 (1.4%) have been isolated as optimal sites for the SSAFS. This final selection was made through the final step in the hierarchy of variables as depicted in Figure 4.1. The distances between each of these dams and their closest feed supplier, processor and hatchery have been attached to the dam file so that the dams with the least distances can be considered in a final selection decision. This information is provided in Appendix A.

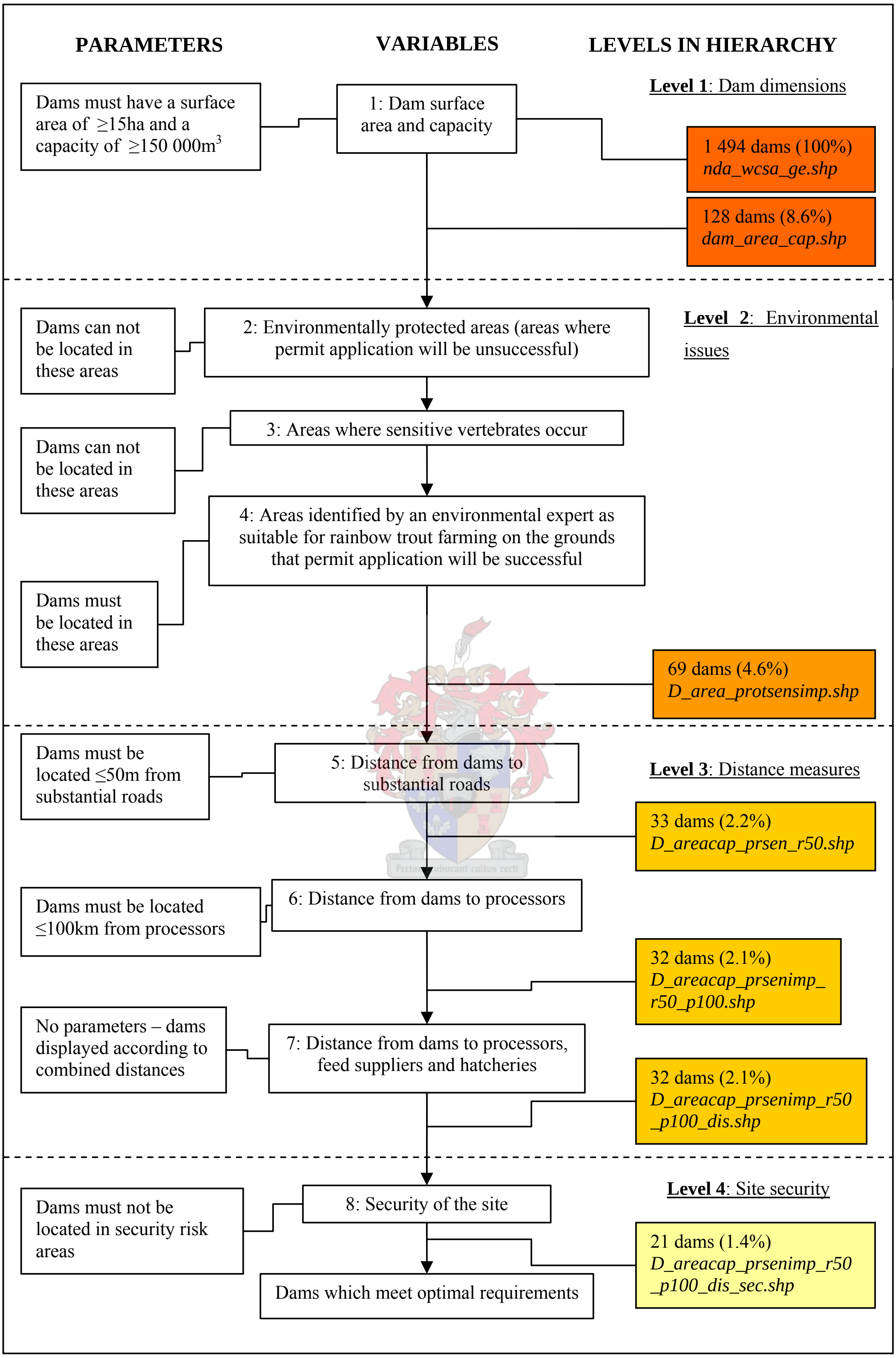


Figure 4.1: Elimination of dams according to the hierarchy of variables

The location of the final set of dams is shown in Figure 4.2. One can see how the dams meet the requirements of all the variables in the hierarchy although the substantial roads are not shown because they would clutter the map. In addition to Figure 4.2 another map (Figure 4.3) shows the location of the dams (to assist those who wish to do physical site visits to the dams in finding them more easily) by using their co-ordinates as listed in Table 4.1.

Table 4.1: Co-ordinates of the 21 optimal dams

Dam Number	Latitude (DMS)	Longitude (DMS)
1	33° 4' 58"S	19° 2' 30"E
2	33° 11' 9"S	19° 0' 13"E
3	33° 13' 38"S	19° 6' 56"E
4	33° 13' 38"S	19° 8' 49"E
5	33° 15' 5"S	19° 8' 2"E
6	33° 15' 33"S	19° 6' 7"E
7	33° 16' 49"S	19° 7' 23"E
8	33° 17' 34"S	19° 7' 3"E
9	33° 17' 47"S	19° 7' 38"E
10	33° 17' 52"S	19° 6' 45"E
11	33° 18' 5"S	18° 49' 58"E
12	33° 22' 45"S	18° 54' 25"E
13	33° 27' 22"S	18° 54' 46"E
14	33° 32' 14"S	19° 3' 55"E
15	33° 34' 36"S	19° 1' 6"E
16	33° 37' 57"S	18° 48' 27"E
17	33° 46' 3"S	18° 54' 53"E
18	33° 51' 32"S	18° 52' 3"E
19	33° 58' 40"S	18° 50' 25"E
20	34° 2' 0"S	19° 8' 1"E
21	34° 4' 46"S	19° 7' 51"E

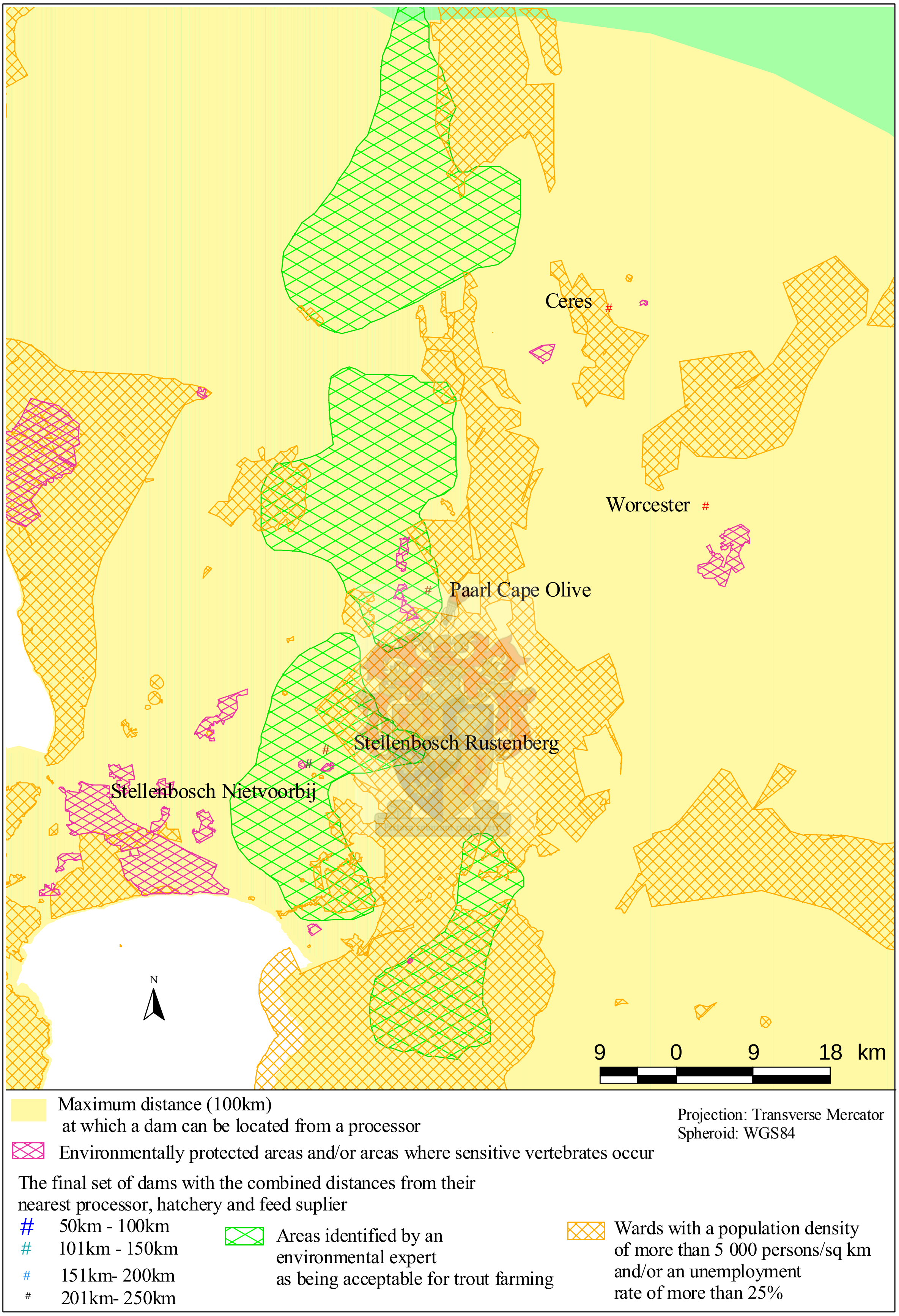


Figure 4.2: Dams selected using all variables except distance from roads

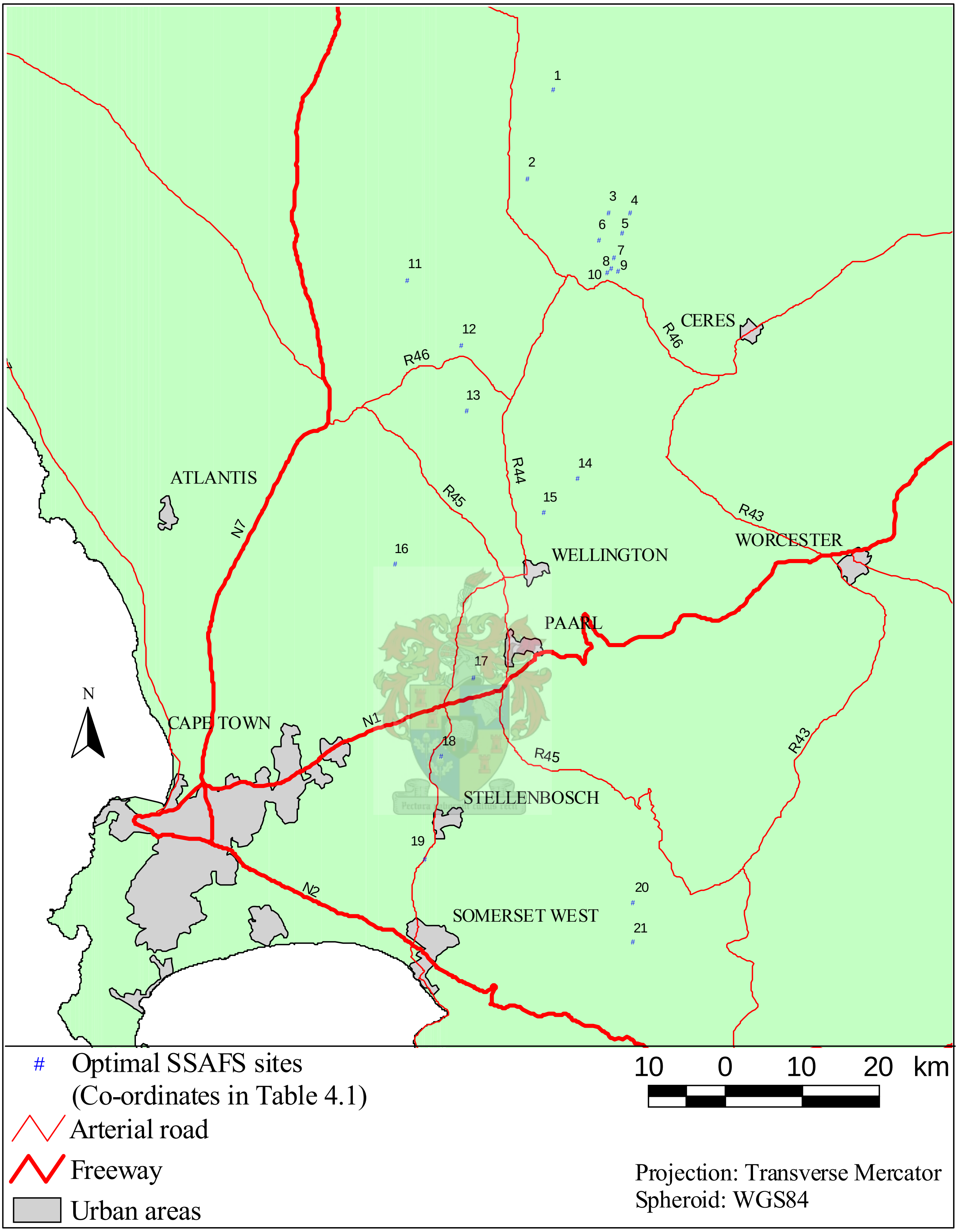


Figure 4.3: Location of optimal SSAFS sites

The GIS site selection methodology selected only 21 dams from a population of 1 494 dams as being optimal sites: a mere 1.4%. This raises a few questions. What does it say about the potential of dams for trout farming and/or other aquaculture in the Western Cape? What does it say about the GIS site selection methodology? Is it successful and useful?

An answer to the first question is that it appears that there are not many dams suitable for trout farming and/or other forms of aquaculture. Twenty-one dams out of close to 1 500 is not very encouraging. Alternatively it may indicate that the GIS site selection methodology is too strict. To test this contention, the methodology was applied to the five existing successful SSAFS sites to see if they would be included or excluded by the methodology. All five sites were excluded, thus indicating that the methodology is most probably too strict and as such not a true reflection of the potential of the study area for trout farming and/or other forms of aquaculture. This is dealt with in more detail in the following chapter.

Concerning the last question, the reduction of the number of dams to a handful suggests that the methodology is indeed useful as it will reduce the workload of physically investigating a large number of dams that would turn out to be unsuitable. This is illustrated graphically by Figure 4.4 where it is clearly evident how the original set of dams has been reduced significantly to a more manageable number. The better way of determining if the methodology is successful and useful is by asking potential users how they rate it. Such an exercise is reported in the following chapter.

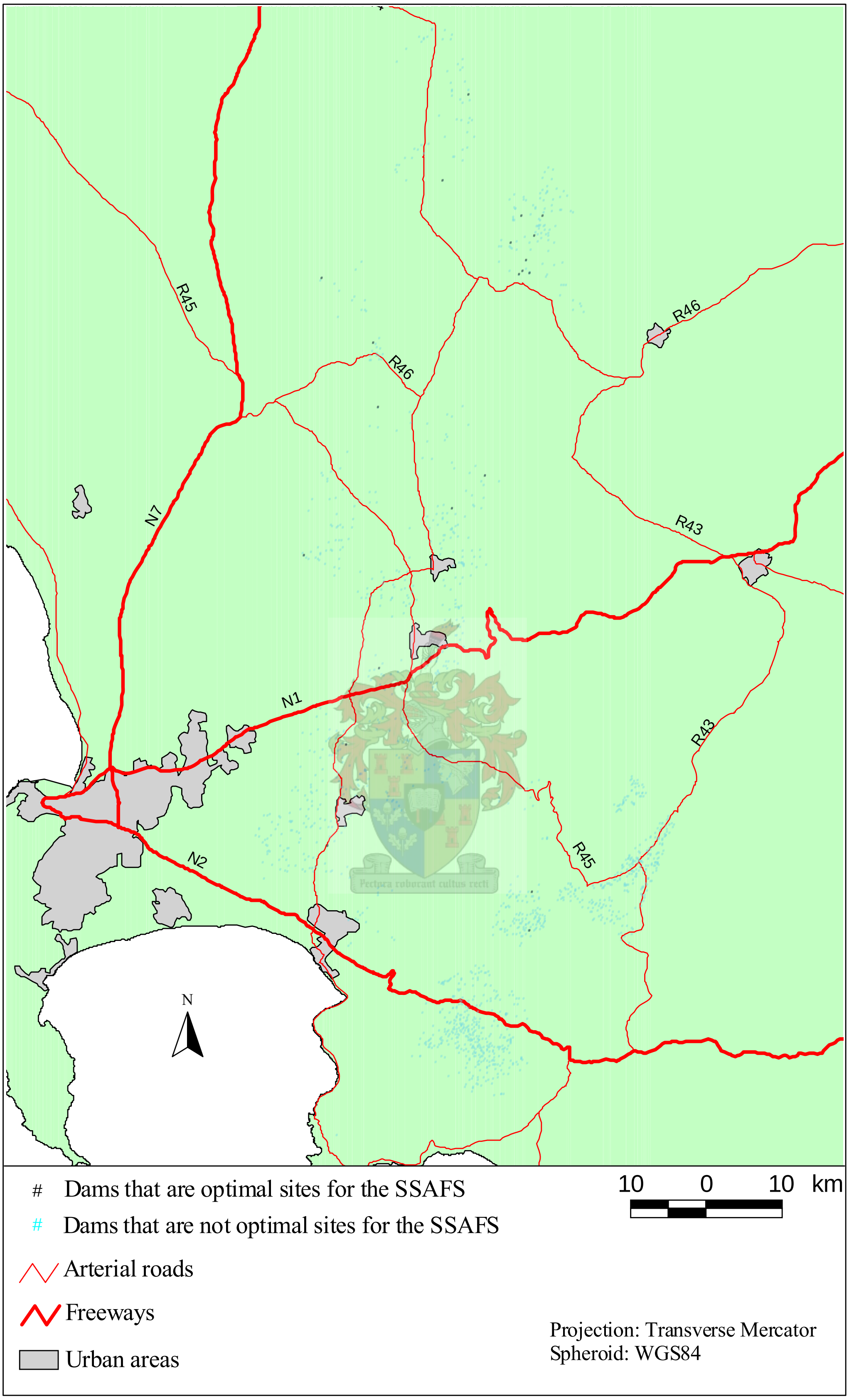


Figure 4.4: Optimal SSAFS sites in relation to the full set of dams

5 PUTTING THE GIS SITE SELECTION METHODOLOGY TO THE TEST

The raison d'être of this study was to create a GIS site selection methodology that is useful. In order for it to be useful it needs to work, preferably as well as possible. In order to do so, its strengths and shortcomings, and areas for improvement, need to be identified. In the following sections the GIS site selection methodology is assessed.

5.1 EFFECTIVENESS OF THE GIS SITE SELECTION METHODOLOGY

The preceding sections of this report addressed the study's first aim, i.e. to develop a GIS site selection methodology. This has been achieved by devising a procedure using a sieve of hierarchically ordered variables. The methodology is replicable and adaptable. Another part of the aim was that this methodology be an improvement (cheaper and faster) on the current methods employed to search for new sites for the SSAFS. Has this aim been achieved? This will be answered by measuring the effectiveness of the GIS site selection methodology. The verdict will then be provided as to whether the procedure indeed works faster and less expensively or not.

5.1.1 Measurement of effectiveness of the GIS site selection methodology

To determine if the GIS site selection methodology is an improvement on current search methods, some form of assessment device had to be developed to gauge the effectiveness of the methodology. A good way of determining the effectiveness of the methodology was to present it to people who would probably use it and ask them if it is an improvement on their currently used search methods. For this purpose a PowerPoint presentation giving an outline of the study and showing diagrams and maps generated by the method was set up (see Appendix C). A questionnaire (see Appendix B) for completion by the evaluators was compiled.

The PowerPoint presentation was made and the questionnaire administered to persons who were considered by the researcher and Salie (2005, pers. com.) as being in the best position to give the most perceptive and reliable feedback about the method. The respondents included persons who are directly involved in the search for new sites for the SSAFS, as well as others that could benefit from the research findings or who would find them interesting. The five persons who are directly involved in the SSAFS are:

- Mr H Stander, general manager and extension officer of DASU (Stander 2005, pers. com.);
- Mr K Salie, project manager and mentor of SSADP (Salie 2005, pers. com.);
- Dr D Brink, senior lecturer in the genetics department at SU and the head of DASU (Brink 2005, pers. com.);
- Mr B Sulvester, chairperson of HOFFC and manager of the Cape Olive SSAFS in Paarl (Sulvester 2005, pers. com.); and
- Mr P Page, director of HOFFC and chairperson of the Rustenberg SSAFS in Stellenbosch (Page 2005, pers. com.).

The four who are not directly involved in the SSAFS are:

- Mr D Impson, Scientific Services, Cape Nature (Impson 2005, pers. com.);
- Mr K Swart, aquaculture technician at Elsenberg Agriculture College (Swart 2005, pers. com.);
- Mr R Damonse, chairperson of Molapong Investments Pty Ltd at Dewdale Farm in Franschhoek; (Damonse 2005, pers. com.); and
- Mr G Stubbs, managing director of Three Streams Smoke House Pty and chairperson of the Western Cape Trout Farmers' Association (Stubbs 2005, pers. com.).

The PowerPoint presentation as well as the questionnaire were printed, and copies given to the respondents at the interviews. This was done as opposed to projecting the presentation on a screen because most of the respondents did not have ready access to such equipment. The copies were in black and white so the researcher explained the significance of the colours used in the maps. Should the GIS site selection methodology be used in future and similar presentations made, colour copies of the presentations are advisable. The added advantage of providing the respondents with paper copies of the PowerPoint presentation is that they could keep it and review it at their leisure. The PowerPoint presentation as well as the questionnaire was presented to the respondents in an interview format. In most instances the only people present were the interviewer (in this case the researcher) and the respondent. In two instances there were other people, who were interested in the GIS methodology, present at the interviews. They were also provided copies of the presentation and questionnaires, and also asked if they could provide input and responses. Only one of the three additional respondents answered the questionnaire, but asked to remain anonymous. For the sake of protecting this person's anonymity, his/her responses have been omitted from this report. Some of the respondents answered the questionnaire during the interview while others answered it at a later date via e-mail or telefax. If the GIS methodology is similarly assessed in future, one should insist that respondents answer the questionnaire during or at the end of the interview as this guarantees a response as well as reduces the time spent on collecting the responses afterwards. This course of action however rushed the respondents into giving answers which might have been poorly thought through. This was combated by providing respondents with a copy of both the PowerPoint presentation and the questionnaire, and asking them to review them in their own time and to make contact if they thought of additional responses.

The responses to the questionnaires and the additional information collected from the respondents are provided in the following sections.

5.1.2 The verdicts

The questionnaire (Appendix B) contains 12 questions. These questions were designed to inquire about the respondent's opinions on the methodology developed by the research, as well as to elicit suggestions for improvements to the methodology, if they believed this to be necessary. A synopsis of the responses to questions 1 to 10 and 12 is presented below. Following this, question 11 as well as the additional comments and suggestions made by the respondents are discussed in section 5.2.

5.1.2.1 Respondents' answers to the questions

Question 1: What are your current search methods of finding new sites for the Small-Scale Aquaculture Farming Systems (SSAFS)?

Stander (2005, pers. com.) replied that they find out about dams which might be possible sites through word of mouth. Salie (2005, pers. com.) had a similar response saying that they hear about dams, then do visual inspections and follow-up visits, and ask further questions about the sites.

Question 2: If you are not involved with the SSAFS, what are your methods for finding sites and are you applying them yourself or are you getting assistance?

The answers are similar to those for the first question in that dams are also reported by word of mouth. Stander (2005, pers. com.) mentioned that aquaculture entrepreneurs often approach him to either tell them whether their dam that they want to use is suitable, or for him to find dams that are suitable. Salie (2005, pers. com.) said that they can also consult topographic maps and get assistance from the relevant authorities. Stubbs (2005, pers. com.) is not directly involved with the SSAFS (except for processing fish for them) and as such does not search for sites for the SSAFS, so he does not know how they go about finding new sites for the SSAFS. He remarked that if it were up to him to find new sites, he would consult existing databases, if there were any, and then do physical site visits. Damonse (2005, pers. com.) replied that they find out about water sources "through the grapevine". They also check government databases for state-owned assets with suitable profiles (dams/water sources owned by the state that show high potential as sites for aquaculture). They then visit these sites for further inspection.

Question 3: Would you consider your current search methods as being too costly (financially)? Why?

The overall answer to this question appears to be that current search methods are too costly. Stander (2005, pers. com.) reported that the transportation involved in visiting sites is expensive (it costs him R3.80 for every kilometre that he travels using the University bakkie). Damonse (2005, pers. com.) also affirmed that transport to sites is expensive, especially as they often need special vehicles to negotiate rough terrains. Both Salie (2005, pers. com.) and Stubbs (2005, pers. com.) reported that the current search methods are too time-consuming, rather than too costly.

Question 4: Would you consider your current search methods as too time-consuming? Why?

The general opinion appears to be that their methods are too time-consuming. Stander (2005, pers. com.) contends, though, that their current search methods do not seem to be very time-consuming, as he has identified 25 sites in under a year. However, he believes this could be done much faster if the GIS site selection methodology were used. Salie (2005, pers. com.) admitted that their methods are too time-consuming as many of the possible sites communicated to them are not feasible and as such much time is wasted visiting them. Stubbs (2005, pers. com.) asserted that, as far as he is concerned, the current search methods for the SSAFS are inefficient, leading to time wastage, which in turn results in unnecessary expenditure. Damonse (2005, pers. com.) observed that their current search methods are time-consuming, especially the process of negotiating access to sites.

Question 5: Will you reach your target number of new sites in the envisaged time-span? If not, what are the major constraints in locating sites?

There were mixed responses to this question. Stander (2005, pers. com.) answered that he would reach his target number, as he has already located 25 sites, but added that not all of these sites would necessarily be statutorily approved. He stressed that the major time constraint is the statutory approval process. Salie (2005, pers. com.) provided the same answer as that of Stander (2005, pers. com.). Stubbs (2005, pers. com.) is of the opinion that as far as he knows they will not reach their target number of new sites for the SSAFS in the envisaged time-span as their search methods are too inefficient. Damonse (2005, pers. com.) answered in the negative, as searching for sites is not their priority.

Question 6: Do you think that the GIS methodology, if applied in future, would be less costly than your current search methods? Why?

Here the answer is a definite yes. Stander (2005, pers. com.) replied that it will definitely be faster and cheaper to use the GIS site selection methodology. Salie (2005, pers. com.) argued that it will eliminate unnecessary site visits, as dams which do adhere to the basic criteria can be isolated for further feasibility studies. Stubbs (2005, pers. com.) asserted that the GIS methodology looks to be more efficient than current search methods and as such would lead to time savings which would ultimately reduce costs. Damonse (2005, pers. com.) believes that if technology is applied as used in the GIS methodology, there will be a pre-visit source of information which will save time and money.

Question 7: Do you think that the GIS methodology, if applied in future, would be less time-consuming than your current search methods? Why?

The answers were positive. Stander (2005, pers. com.) held that it takes a long time to travel and find out about dams that are suitable. Salie (2005, pers. com.) affirmed that desktop studies (such as the GIS site selection methodology) will limit the need for personal communication and contacts, as well as physical site visits, thereby reducing the time spent on finding sites. Stubbs (2005, pers. com.) gave the same answer to this question as he did to question 6, as did Damonse (2005, pers. com.). Sulvester (2005, pers. com.) claimed that the use of this GIS site selection methodology and/or other GIS methodology will provide a database of information which can be expanded and used in the future. He remarked that the setting up of the database might be costly in the beginning, but in the long run it will save time and money.

Question 8: Would this GIS methodology be useful to you? Why?

Once again the answer is affirmative. Stander (2005, pers. com.) maintained that it would save time and money as “ideal dams” are identified straight away. Salie (2005, pers. com.) endorsed the methodology, as it presents a powerful tool to be used for future site selection and it combines multiple databases which can be accessed in future to find new sites for the SSAFS as well as other forms of aquaculture. Stubbs (2005, pers. com.) again gave the same answer to this question as he did to question 6. Damonse (2005, pers. com.) confirmed that for them it would be useful, as it could provide information needed in site identification. It could also serve as a database in the negotiations phase for planning purposes, funding procurement and convincing authorities of features of site suitability.

Question 9: What is your overall impression of the GIS methodology?

Stander (2005, pers. com.) claimed that it (GIS) is a wonderful technology and would be very useful in the future. Salie (2005, pers. com.) observed that the GIS methodology looks as though it will be useful and they are very keen to apply it to future site selection. Stubbs (2005, pers. com.) responded that it is very worthwhile. Damonse (2005, pers. com.) pronounced that it is useful and should definitely be a tool for aquaculture business planning.

Question 10: What access do you have to information technology?

Stander (2005, pers. com.) has access to the Internet, magazines, books, newspapers, telephone and telefax. Salie (2005, pers. com.) has access to his personal computer and the US network. Stubbs (2005, pers. com.) only has access to his personal computer, which has the basic software packages installed on it. Damonse (2005, pers. com.) has none besides a personal computer to manage work.

Question 11: Do you have any recommendations for improving the GIS methodology?

The answers to this question are dealt with in section 5.2 which reports specifically about improvements to the methodology.

Question 12: What do you suggest the next step is after the GIS methodology has selected optimal dams (e.g. physical visits)?

Stander (2005, pers. com.) suggested that a meeting should be set up with the people involved with the SSAFS project to provide them with the information obtained using the GIS site selection methodology and to discuss the outcome. Then there should be physical visits to the sites that were found using the GIS site selection methodology. Salie (2005, pers. com.) proposed that there should be physical visits to the sites and a listing of sites should be compiled. Databases must be compiled so that the work is recorded and less work/data collection is required in the future. Stubbs (2005, pers. com.) moved that there should obviously be site visits to the dams selected by the methodology after the GIS methodology has been implemented. Damonse (2005, pers. com.) advised that it should lead to the establishment of aquaculture businesses and results should be presented to potential investors and knowledge partners.

Overall the responses were positive. After reviewing the answers to the above questions the general opinion is that the GIS site selection methodology is useful in that it would aid decision makers in the future to make informed choices when locating SSAFS sites. It also seems that the general view is that the GIS site selection methodology is an improvement on existing site selection methods.

There were however additional comments and suggestions over and above those that were provided through the answers to the questionnaire. These are dealt with next.

5.1.2.2 Further comments and suggestions

Over and above the answers to the questions, most of the respondents also made additional comments and suggestions. Some respondents were, unfortunately, pressed for time and rather than answer the questions as set out, they gave overall impressions and short comments and suggestions. These were helpful as they often provided insights from different perspectives. All these comments and suggestions can be considered as recommendations for improvement to the GIS site selection methodology, so to avoid repetition, they are presented and discussed in the following section.

A suggestion made by Brink (2005, pers. com.) was that the methodology be presented at the 7th Bi-annual Conference of the Aquaculture Association of Southern Africa (AASA) in September 2005. To his knowledge, no presentations had been made about GIS being used in aquaculture at the six preceding conferences. Apart from being a novel contribution, it would also serve as a good opportunity to get feedback from conference delegates about the GIS site selection methodology.

The conference paper is an updated (it contains a summary of the results) and improved version (Steer & De Necker 2005) of the questionnaire presentation (Appendix C). The delegates were impressed and the consensus was that the GIS site selection methodology is useful and is an improvement on existing search methodologies. It is a valuable asset for aquaculture in South Africa.

5.2 RECOMMENDATIONS FOR IMPROVEMENT ON THIS STUDY AND FUTURE RESEARCH POSSIBILITIES

5.2.1 Recommendations for improvement on this study

The aim of this research was to create a methodology. Simply viewed, the methodology created by this research can be viewed as a recipe. In other words the aim was to devise a product which would not necessarily be used in its existing format, but rather it is used as a demonstration of what can be done. Granted, the research has generated results (a selection of 21 dams that are potential sites for the SSAFS) which can be used, but these results were produced by a methodology that was created by the researcher in a process that was severely limited by time, financial and resource constraints. The value of this research therefore lies not in the results produced, rather in the new methodology designed. None the less, it is important to highlight the shortcomings of this research and, should the methodology be used in the future with fewer constraints, to make suggestions as to how to improve it.

The suggestions and recommendations that follow come from the researcher and/or the respondents in the questionnaire survey. First, the answers to question 11 are dealt with.

Question 11: Do you have any recommendations for improving the GIS methodology?

Stander (2005, pers. com.) gave no suggestions for improvements to the methodology. Salie (2005, pers. com.) suggested that it should be duplicated for other candidate species. He also advocated that broader communities should have access to the methodology so that they too can initiate the site selection process. In other words it must be accessible so that people are able to use it. Stubbs (2005, pers. com.) agreed that, in its present form, it serves as a good example of what can be done with GIS in terms of site selection for aquaculture (in this case the SSAFS). He urged, however, that if it were to be really useful, the methodology should incorporate more accurate and up-to-date data and information, and the methodology should be expanded, perhaps to include more variables. Damonse's response was: "Yes. When planning a specific aquaculture project or the project investigation cycle, the GIS variables should be negotiated before the study commenced. The client must have an input in designing the terms of reference" (Damonse 2005, pers. com.).

As mentioned earlier, some respondents did not answer each question individually. Rather, they gave general impressions about the research and the GIS methodology, and then proceeded to offer suggestions on how to improve the methodology and to provide ideas for future research. One such respondent was Impson (2005, pers. com.). Overall he was impressed with the research and the GIS site selection methodology. One suggestion he had concerned the capacities of the dams. He argued that if the methodology was to be applied in future, capacities of the dams should be sufficient when they are at their lowest level, thus reducing the risk of the dam losing too much water, hence making it unsuitable for farming. Another of his suggestions related to water quality. In this methodology dam water quality was not included as a variable, as it varies too much and as such is not easily mapped. Impson (2005, pers. com.) mooted that one could include water quality in future as one could map the dams according to a predicted water quality. In other words, if the data for the surrounding river systems and soil compositions were available, one could predict what the water qualities of the dams would be and map them accordingly. This might not be very accurate, but it would give one an approximation. Brink (2005, pers. com.) contended that the step in the methodology whereby dams are selected on whether they are within 50 metres of a substantial road is unnecessary, because to his knowledge almost all the dams in the study area are accessible by substantial roads.

A suggestion that Impson (2005, pers. com.) as well as Brink (2005, pers. com.) made, was to apply the GIS site selection methodology to all the existing SSAFS. In other words, the existing sites would be compared with the 21 sites found using the GIS methodology. This is a good practical test of the GIS methodology. If the existing sites are excluded by using the GIS methodology, then either the current search methods may be shown to be less than stringent or the GIS methodology is too stringent. The exercise was applied to the five existing operational SSAFS in the study area. Their co-ordinates were acquired using a GPS and tabulated (see Table 5.1).

Table 5.1: Existing SSAFS sites in the study area and their co-ordinates

Existing SSAFS site	Latitude (DMS)	Longitude (DMS)
Stellenbosch Rustenberg	33° 53' 59"S	18° 53' 3"E
Stellenbosch Nietvoorbij	33° 54' 58"S	18° 51' 32"E
Worcester	33° 36' 10"S	19° 26' 16"E
Ceres	33° 21' 45"S	19° 17' 43"E
Paarl Cape Olive	33° 42' 21"S	19° 2' 1"E

Once done, the co-ordinates were used to display the point locations of the existing SSAFS by using ArcView's Add Event Theme tool. Thereafter, the points (existing SSAFS sites) were manipulated and classified using the GIS methodology in the same way as done with the original dataset of dams. The results (the dams are displayed accordingly in Figure 5.1) showed that when the sites

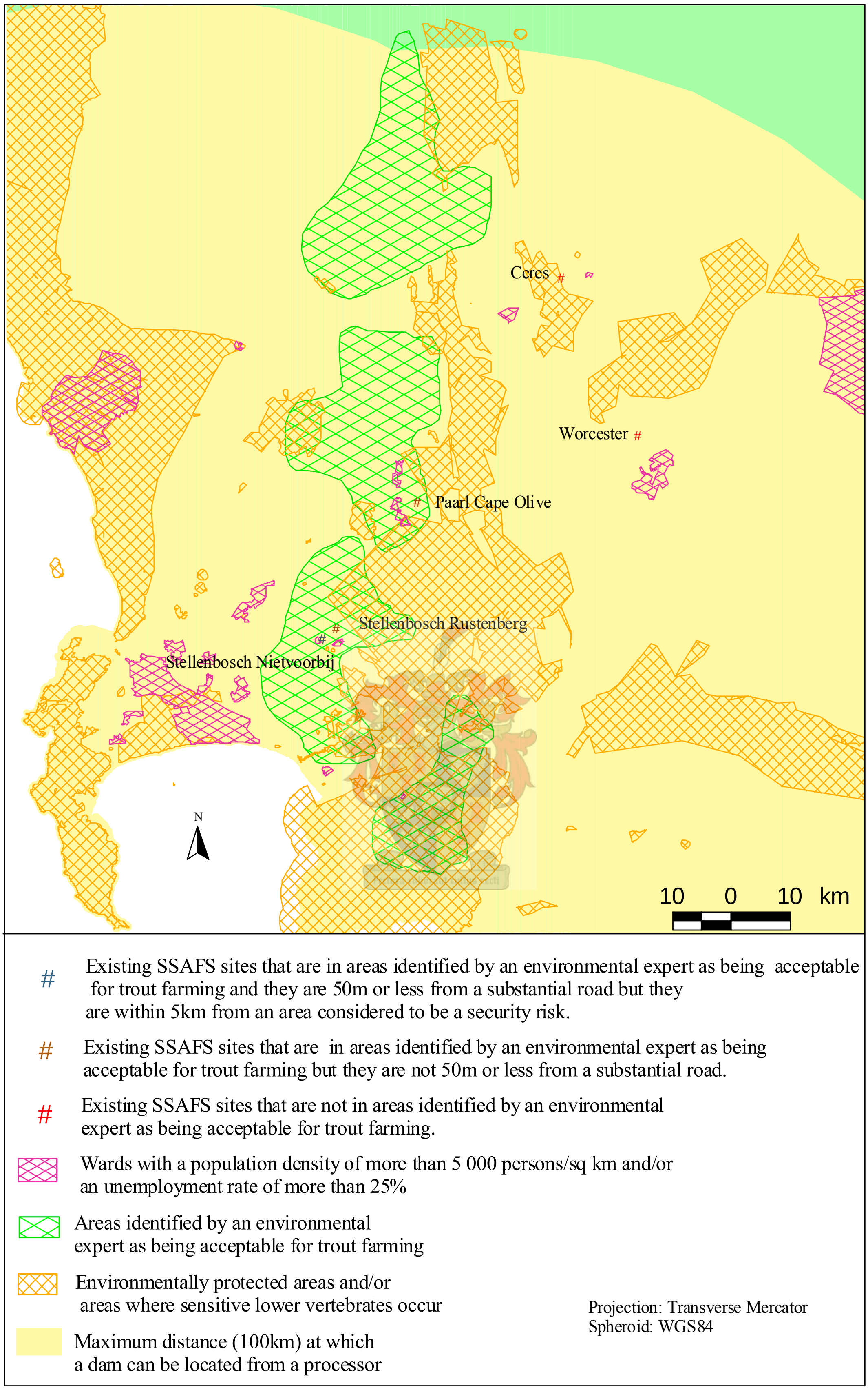


Figure 5.1: Suitability of existing SSAFS sites according to the GIS site selection methodology

were selected according to the hierarchy of variables (recall Figure 3.1), two were eliminated because they did not fall within the areas specified as being acceptable for trout farming by the environmental expert. A further two were eliminated as they are not within 50 metres from a substantial road and the remaining site was excluded as it was located 5 kilometres or less from an area considered by this methodology to be a security risk. Because none of the five existing SSAFS sites fulfils the requirements of the GIS methodology none would have been selected as sites suitable for further analysis. These existing SSAFS sites are however successful sites and the fact that they are excluded by the GIS site selection methodology could mean that the methodology is too stringent and/or it does not reflect reality. If the methodology is to be used and adapted in future, this must be taken into account and care should be taken not too make it too stringent. This can be achieved by using the methodology in conjunction with more fieldwork i.e. site visits. It is worth mentioning that it must also be remembered by decision makers that the GIS site selection methodology is a type of model. Therefore it can not possibly represent reality fully and as such should only be used as a guideline when searching for sites.

A suggestion for improvement to the methodology that was not suggested by the respondents concerns the analysis of distance between the dams and their major feed supplier, major hatcheries and major processors. The methodology uses straight line distances to determine shortest distances and the dams were classified accordingly. In reality the distances between the dams and other points will have to be travelled by road. The methodology will be more accurate and powerful if network analysis is employed to determine the least-cost paths between the dams and the various points. Husdal (2000) avers that: "One major application of network analysis is found in transportation planning, where the issue might be to find paths corresponding to certain criteria, like finding the shortest or least cost path between two or more locations, or to find all locations within a given travel cost from a specified origin".

Finally it is worth emphasizing an important suggestion made by some of the respondents. The suggestion revolves around the quality of data. Any GIS application is limited by the data used. The data used in this research are severely limited. They are limited in that some are dated; some do not have great detail; and some are inaccurate. The reason why these inferior data were used is that the researcher did not have the time or resources to obtain or collect better data. In some cases the data were, anyway, the best available. An example is the dataset of dams used to do the selection of sites. The reason this dataset was used is that it is the only dataset of dams that contains capacities and surface areas. The only reason a dataset with this level of detail exists, is that the detailed information about the dams was collected in 1990, as part of the Department of Water Affairs and Forestry (DWAF) Western Cape system analysis for hydrological modelling, by the company Ninham Shand. No other datasets of dams in South Africa, except for the larger reservoirs, have this level of detail, so if it did not exist, the first level of variables in the hierarchy would have been abolished. Improved application of this methodology will require care to be taken to obtain the most current, detailed and accurate data possible.

5.2.2 Future research possibilities

In terms of future research possibilities, this study will hopefully provide the template for more GIS applications in aquaculture in the Western Cape and the rest of South Africa. If this study is used as an example it can be adapted to find suitable sites for any of the species cultured in the country at the moment as well as those that may still be farmed. This study can also be adapted to develop a GIS application which can be used for the successful management of existing aquaculture sites. GIS can also be used to determine and monitor the impact of aquaculture on the environment. The list of the ways GIS can be useful in aquaculture is virtually endless. The only constraint in the use of GIS in aquaculture is the potential user's imagination and initiative. Hopefully this study will serve to stimulate this and as such promote the use of GIS in aquaculture.

From a geographical angle, this study can be taken further by doing a nearest-neighbour analysis of the dams to see whether they are clustered, regular or random (Toyne & Newby 1971). This could be useful as it may indicate relationships between the success of dams as sites for the SSAFS as well as other aquaculture and various aspects of their surroundings.

5.2.3 Concluding remarks

In summary, all the respondents felt that the GIS methodology developed by this research is useful and that it could be employed in future to make more informed choices when locating new sites for the SSAFS as well as for other aquacultural enterprises. The GIS site selection methodology is the first known attempt to adapt and improve Meaden's (1987) methodology. For it to be truly valuable it needs to be improved and expanded, and it must be tried and tested in practice. If this occurs, the GIS site selection methodology will help to overcome "[t]he most difficult obstacle in the way of the aspiring rainbow trout farmer [which] is finding and acquiring a satisfactory site for a fish farm" (Sedgwick 1995: 9).

[Word count 14 430]

REFERENCES

Aguilar-Manjarrez J & Ross GL 1993. Aquaculture development and GIS. *Mapping Awareness & GIS in Europe* 7, 4: 49-52

Aguilar-Manjarrez J & Ross GL 1995. GIS enhances aquacultural development. *GIS World* 8, 3: 52-56

Aguilar-Manjarrez J, Bolteb JP, Rossc LG & Nath SS 2000. Applications of geographical information systems (GIS) for spatial decision support in aquaculture. *Aquacultural Engineering* 23, 1-3: 233-278

Ali CQ, Ross LG & Beveridge MCM 1990. Microcomputer spreadsheets for the implementation of geographic information systems in aquaculture. A case study of carp in Pakistan. In Meaden GJ & Kapetsky JM 1995 (eds), *Geographical information systems and remote sensing in inland fisheries and aquaculture*. FAO fisheries technical paper 318 [online]. Available from: http://www.fao.org/DOCREP/003/T0446E/T0446E00.HTM [Accessed 16 May 2005]

ArcView 1999. *ArcView 3.2*. Redlands: Environmental Systems Research Institute, Inc

Blakely DR & Hrusa CT 1989. *Inland aquaculture development handbook*. Oxford: Fishing News Books

Brink D 2001. Aquaculture production in South Africa. Paper delivered at the African Feed Millers' Association (AFMA) symposium, Stellenbosch

Brink D 2003. Overview of aquaculture in South Africa. University of Stellenbosch, Stellenbosch

Clarke KC 1999. *Getting started with geographic information systems*. 2nd ed. Upper Saddle River: Prentice Hall

Conservation Planning Unit (CPU) 2002. [online] South Africa. Available from http://cpu.uwc.ac.za/ [Accessed 18 May 2005]

DeMers MN 2000. *Fundamentals of geographic information systems*. New York: John Wiley & Sons

Husdal J 2000. *Network analysis-network versus vector-a comparison study*. [online] UK: University of Leicester. Available from: http://www.husdal.com/mscgis/network.htm [Accessed 16 May 2005]

Huke RE 1985. The green revolution. *Journal of Geography* 84: 248-254

Kampusnuus 2004. Visboerdery help om plaaswerkers te bemagtig. 14 October: 4. Stellenbosch University, Stellenbosch

Kapetsky JM, Hill JM & Worthy LD 1988. A geographical information system for catfish farming development. In Meaden GJ & Kapetsky JM 1995 (eds), *Geographical information systems and remote sensing in inland fisheries and aquaculture*. FAO fisheries technical paper 318 [online]. Available from: http://www.fao.org/DOCREP/003/T0446E/T0446E00.HTM [Accessed 16 May 2005]

Kapetsky JM, Wijkstrom UN, MacPherson NJ, Vincke MMJ, Ataman E, & Caponera F 1990. Where are the best opportunities for fish farming in Ghana? The Ghana Aquaculture Geographical Information System as a decision-making tool. In Meaden GJ & Kapetsky JM 1995 (eds), *Geographical information systems and remote sensing in inland fisheries and aquaculture.* FAO fisheries technical paper 318 [online]. Available from: http://www.fao.org/DOCREP/003/T0446E/T0446E00.HTM [Accessed 16 May 2005]

Kent G 1997. Fisheries, food security, and the poor. *Food Policy* 22, 5: 393-404

Meaden GJ 1987. Where should trout farms be in Britain? In Meaden GJ & Kapetsky JM 1995 (eds), *Geographical information systems and remote sensing in inland fisheries and aquaculture.* FAO fisheries technical paper 318 [online]. Available: from http://www.fao.org/DOCREP/003/T0446E/T0446E00.HTM [Accessed 16 May 2005]

Middleton N 1996. The blue revolution? *Geography Review* 9, 4: 8-9

Municipal Demarcation Board 2000. *SA Explorer Version 1.0*. Hatfield, Municipal Demarcation Board

Nash CE 1995. Introduction to the production of fishes. In Nash, CE & Novotny, AJ (eds), *Production of aquatic animals: fishes*, pp1-20. Amsterdam: Elsevier

Nash CE & Novotny AJ (eds) 1995. *World animal science: Production of aquatic animals*. Amsterdam: Elsevier

Osleeb JP & Kahn S 1998. Integration of geographic information. In Dale VH & English MR (eds), *Tools to aid environmental thinking*, pp161-189. New York: Springer-Verlag

Pillay TVR 1993. *Aquaculture: Principles and practices.* Oxford: Fishing News Books

Sedgwick SD 1995. *Trout farming handbook* Sixth Edition. Oxford: Fishing News Books

Steer LA 2002. Location and suitability ratings of farm dams for the farming of *Cyprinus carpio* in Stellenbosch. Honours research report, Stellenbosch University, Stellenbosch

Steer LA 2003. GIS and trout farming: a review of the literature. Masters assignment, Stellenbosch University, Stellenbosch

Steer LA & De Necker PH 2005. Site selection for the small-scale aquaculture farming systems in the Western Cape: A GIS application. Paper presented at the 7th conference of the Aquaculture Association of Southern Africa. Rhodes University, Grahamstown

Swann L 2005. *A fish farmer's guide to understanding water quality*. [online]. Available from: http://aquanic.org/publicat/state/il-in/as-503.htm [Accessed 16 May 2005]

Toyne P & Newby PT 1971. *Techniques in human geography*. London: Macmillan Education

University of Stellenbosch 2002. Proposal to Alnet (Pty) Ltd., S.A on the development of Small-scale Aquacultural Farming Systems an initiative of the Division of Aquaculture, Faculty of Agricultural and Forestry Sciences, Stellenbosch University, Stellenbosch

PERSONAL COMMUNICATIONS

Beuster H 2003. Employee of Ninham Shand. Telephonically and via e-mail. Supplied data.

Brink D 2005. Senior lecturer in the Genetics department at SU and the head of DASU. Interviewed in 2005 about the GIS site selection methodology and consulted on various occasions about trout farming.

Damonse R 2005. Chairman of Molapong Investments Pty Ltd at Dewdale Farm in Franschhoek. Interviewed in 2005 about the GIS site selection methodology.

Hinrichsen E 2004. Employee of Aqua Eco, Three Streams Smokehouse. Consulted telephonically and via e-mail on various occasions with regard to general information about trout farming and conservation.

Impson D 2005. Employee of Scientific Services, Cape Nature. Consulted telephonically and via e-mail on various occasions with regard to general information about trout farming and conservation and interviewed in 2005 about the GIS site selection methodology.

Morgan T 2004. Employee of Map-it. Consulted telephonically and via e-mail. Supplied data.

Page P 2005. Director of HOFFC and chairperson of the Rustenberg SSAFS in Stellenbosch. Interviewed in 2005 about the GIS site selection methodology.

Salie K 2005. Project manager and mentor to the SSADP of DASU. Consulted telephonically and via e-mail on various occasions with regard to general information about trout farming, aquaculture and the SSAFS and interviewed in 2005 about the GIS site selection methodology.

Stander H 2005. General manager and extension officer of DASU. Consulted telephonically and via e-mail on various occasions with regard to general information about trout farming, aquaculture and the SSAFS and interviewed in 2005 about the GIS site selection methodology.

Stubbs G 2005. Managing director of Three Streams Smoke House Pty and chairperson of the Western Cape Trout Farmers Association. Consulted telephonically and via e-mail on various occasions with regard to general information about trout farming and aquaculture and interviewed in 2005 about the GIS site selection methodology.

Sulvester B 2005. Chairperson of HOFFC and manager of the Cape Olive SSAFS in Paarl. Interviewed in 2005 about the GIS site selection methodology.

Swart K 2005. Aquaculture technician at Elsenberg Agriculture College. Interviewed in 2005 about the GIS site selection methodology.

APPENDIX A: CO-ORDINATES AND DISTANCE MEASURES OF THE SELECTED DAMS

Dam no.	Distance to feed supplier (Aquanutro) (km)	Distance to processor (Franschhoek Fish House) (km)	Distance to processor (Three Streams Smokehouse) (km)	Distance to processor (Garon Foods) (km)	Distance to processor (Salmo Smokehouse) (km)	Distance to hatchery (Three Streams Smokehouse) (km)	Distance to Hatchery (Stellenbosch University Trout Farm) (km)	Total distance (km)	Distance to closest feed supplier (km)	Distance to closest processor (km)	Distance to closest hatchery (km)	Total closest distances (km)	Latitude (DMS)	Longitude (DMS)
1	55.0	95.2	92.3	100.4	106.7	92.3	99.8	641.8	55.0	92.3	92.3	239.7	33° 4' 58"S	19° 2' 30"E
2	43.7	83.1	81.5	88.6	94.5	81.5	88.0	560.8	43.7	81.5	81.5	206.7	33° 11' 9"S	19° 0' 13"E
3	50.8	82.1	75.9	93.1	94.9	75.9	85.3	558.0	50.8	75.9	75.9	202.6	33° 13' 38"S	19° 6' 56"E
4	53.8	83.4	75.9	95.6	96.5	75.9	86.1	567.3	53.8	75.9	75.9	205.7	33° 13' 38"S	19° 8' 48"E
5	51.3	80.4	73.2	92.7	93.5	73.2	83.1	547.4	51.3	73.2	73.2	197.7	33° 15' 5"S	19° 8' 2"E
6	47.8	78.3	72.3	89.5	91.1	72.3	81.5	532.7	47.8	72.3	72.3	192.4	33° 15' 33"S	19° 6' 7"E
7	48.8	77.0	70.0	89.6	90.1	70.0	79.7	525.2	48.8	70.0	70.0	188.8	33° 16' 49"S	19° 7' 23"E
8	47.7	75.4	68.6	88.2	88.6	68.6	78.2	515.3	47.7	68.6	68.6	184.9	33° 17' 34"S	19° 7' 3"E
9	48.6	75.5	68.2	88.7	88.7	68.2	78.1	516.0	48.6	68.2	68.2	184.9	33° 17' 47"S	19° 7' 38"E
10	47.0	74.7	68.0	87.4	87.8	68.0	77.6	510.5	47.0	68.0	68.0	183.0	33° 17' 52"S	19° 6' 45"E
11	21.6	68.6	74.8	67.5	77.6	74.8	75.9	460.7	21.6	67.5	74.8	163.8	33° 18' 5"S	18° 49' 57"E
12	22.4	60.2	63.5	65.0	70.8	63.5	66.4	411.9	22.4	60.2	63.5	146.1	33° 22' 45"S	18° 54' 25"E

Continued overleaf

Dam no.	Distance to feed supplier (Aquanutro) (km)	Distance to processor (Franschhoek Fish House) (km)	Distance to processor (Three Streams Smokehouse) (km)	Distance to processor (Garon Foods) (km)	Distance to processor (Salmo Smokehouse) (km)	Distance to hatchery (Three Streams Smokehouse) (km)	Distance to Hatchery (Stellenbosch University Trout Farm) (km)	Total distance (km)	Distance to closest feed supplier (km)	Distance to closest processor (km)	Distance to closest hatchery (km)	Total closest distances (km)	Latitude (DMS)	Longitude (DMS)
13	21.1	51.7	55.4	59.2	62.8	55.4	57.8	363.4	21.1	51.7	55.4	128.2	33° 27' 22"S	18° 54' 46"E
14	39.0	48.4	41.8	67.5	62.4	41.8	50.4	351.3	39.0	41.8	41.8	122.6	33° 32' 14"S	19° 3' 55"E
15	35.2	42.1	38.7	60.8	55.8	38.7	45.0	316.3	35.2	38.7	38.7	112.6	33° 34' 36"S	19° 1' 6"E
16	21.2	32.2	46.4	37.5	40.8	46.4	41.1	265.6	21.2	32.2	41.1	94.4	33° 37' 57"S	18° 48' 27"E
17	35.3	30.2	31.8	51.0	43.8	31.8	34.0	258.1	35.3	30.2	31.8	97.4	33° 40' 10"S	18° 57' 48"E
18	40.2	32.7	28.6	56.5	47.2	28.6	34.5	268.3	40.2	28.6	28.6	97.5	33° 40' 24"S	19° 0' 60"E
19	43.4	30.0	24.6	56.3	44.9	24.6	30.8	254.6	43.4	24.6	24.6	92.7	33° 42' 33"S	19° 1' 30"E
20	44.4	30.6	24.0	57.3	45.6	24.0	31.0	257.0	44.4	24.0	24.0	92.4	33° 42' 39"S	19° 2' 6"E
21	42.4	27.9	24.8	53.9	42.7	24.8	29.4	245.9	42.4	24.8	24.8	92.0	33° 43' 4"S	19° 0' 19"E
22	45.2	29.3	22.7	56.8	44.4	22.7	29.5	250.6	45.2	22.7	22.7	90.6	33° 43' 28"S	19° 2' 0"E
23	40.1	18.0	27.7	43.0	31.8	27.7	23.3	211.7	40.1	18.0	23.3	81.5	33° 46' 3"S	18° 54' 53"E
24	44.0	9.0	34.3	31.7	18.6	34.3	20.2	192.1	44.0	9.0	20.2	73.2	33° 50' 44"S	18° 49' 4"E
25	47.0	6.7	28.6	37.3	20.7	28.6	15.6	184.5	47.0	6.7	15.6	69.3	33° 51' 32"S	18° 52' 3"E
26	53.4	4.1	33.4	33.8	11.3	33.4	14.8	184.3	53.4	4.1	14.8	72.3	33° 55' 54"S	18° 49' 11"E

Continued overleaf

Dam no.	Distance to feed supplier (Aquanutro) (km)	Distance to processor (Franschhoek Fish House) (km)	Distance to processor (Three Streams Smokehouse) (km)	Distance to processor (Garon Foods) (km)	Distance to processor (Salmo Smokehouse) (km)	Distance to hatchery (Three Streams Smokehouse) (km)	Distance to Hatchery (Stellenbosch University Trout Farm) (km)	Total distance (km)	Distance to closest feed supplier (km)	Distance to closest processor (km)	Distance to closest hatchery (km)	Total closest distances (km)	Latitude (DMS)	Longitude (DMS)
27	56.8	12.8	41.4	29.1	2.8	41.4	21.5	205.9	56.8	2.8	21.5	81.2	33° 58' 19"S	18° 45' 8"E
28	58.9	6.8	31.9	38.0	11.5	31.9	11.7	190.8	58.9	6.8	11.7	77.5	33° 58' 40"S	18° 50' 25"E
29	58.7	13.5	41.4	30.4	2.0	41.4	21.2	208.6	58.7	2.0	21.2	81.9	33° 59' 18"S	18° 45' 19"E
30	78.3	33.7	13.9	70.5	44.2	13.9	21.9	276.3	78.3	13.9	13.9	106.0	34° 1' 60"S	19° 8' 1"E
31	82.3	35.7	18.9	72.1	44.7	18.9	23.6	296.3	82.3	18.9	18.9	120.2	34° 4' 46"S	19° 7' 51"E
32	72.4	19.8	34.1	48.2	19.0	34.1	15.5	243.0	72.4	19.0	15.5	106.8	34° 5' 41"S	18° 52' 31"E

APPENDIX B: QUESTIONNAIRE TO DETERMINE THE EFFECTIVENESS OF GIS SITE SELECTION METHODOLOGY

Current search methods

1. What are your current search methods of finding new sites for the Small-Scale Aquaculture Farming Systems (SSAFS)?

2. If you are not involved with the SSAFS, what are your methods for finding sites and are you applying them yourself or are you getting assistance?

3. Would you consider your current search methods as being too costly (financially)? Why?

4. Would you consider your current search methods as too time consuming? Why?

5. Will you reach your target number of new sites in the envisaged time-span? If not, what are the major constraints in locating sites?

GIS methodology developed by this study

6. Do you think that the GIS methodology, if applied in future, would be less costly than your current search methods? Why?

7. Do you think that the GIS methodology, if applied in future, would be less time-consuming than your current search methods? Why?

8. Would this GIS methodology be useful to you? Why?

9. What is your overall impression of the GIS methodology?

10. What access do you have to information technology?

11. Do you have any recommendations for improving the GIS methodology?

12. What do you suggest the next step is after the GIS methodology has selected optimal dams (e.g. physical visits)?

Thank you for your time and cooperation.

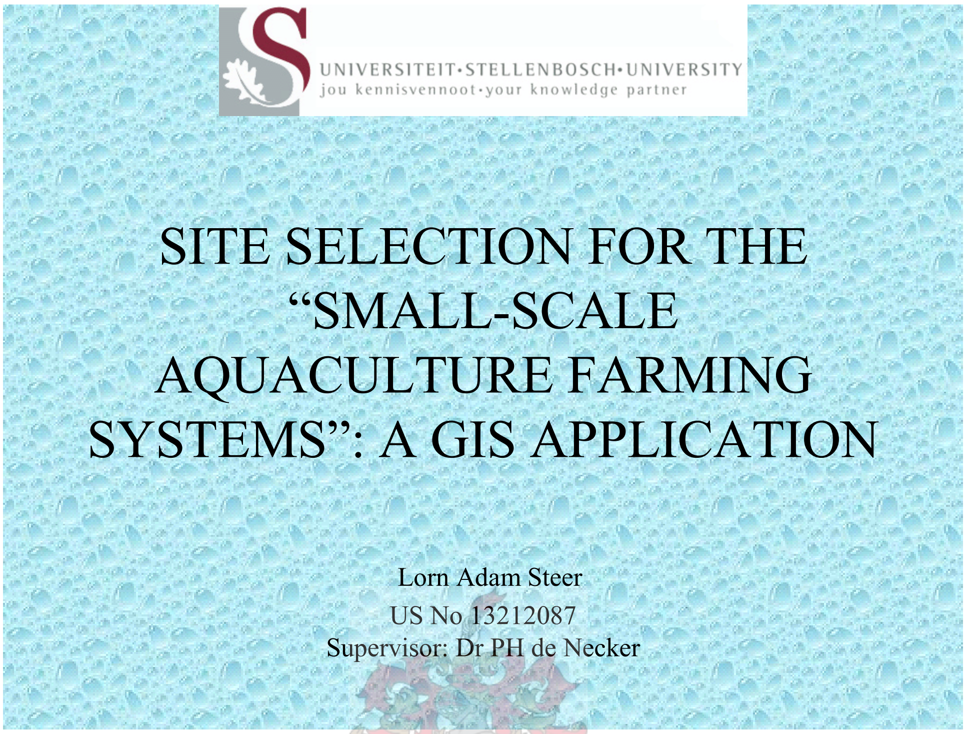
Adam Steer

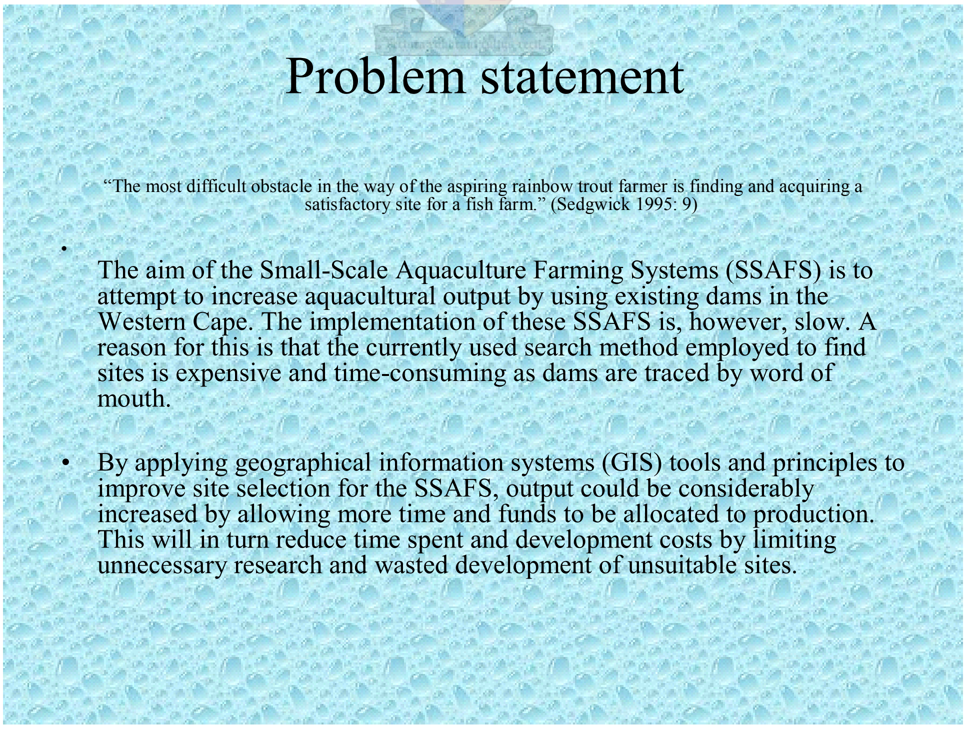
Cell No: 082 594 3613

Tel No: 021 887 2192

E-mail: asteer@absamail.co.za

APPENDIX C: POWERPOINT PRESENTATION OUTLINING RESEARCH AND DEVELOPMENT OF GIS METHODOLOGY *





* The original slides are in colour.

Aim

- To create a methodology using GIS for the location of new sites for the Small-Scale Aquaculture Farming Systems that is fast and inexpensive and which can be adapted and improved in the future.

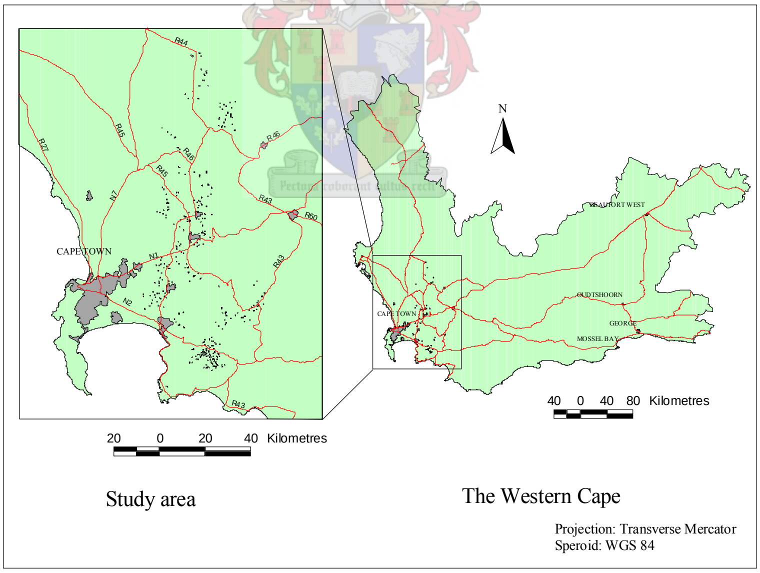
What is GIS?

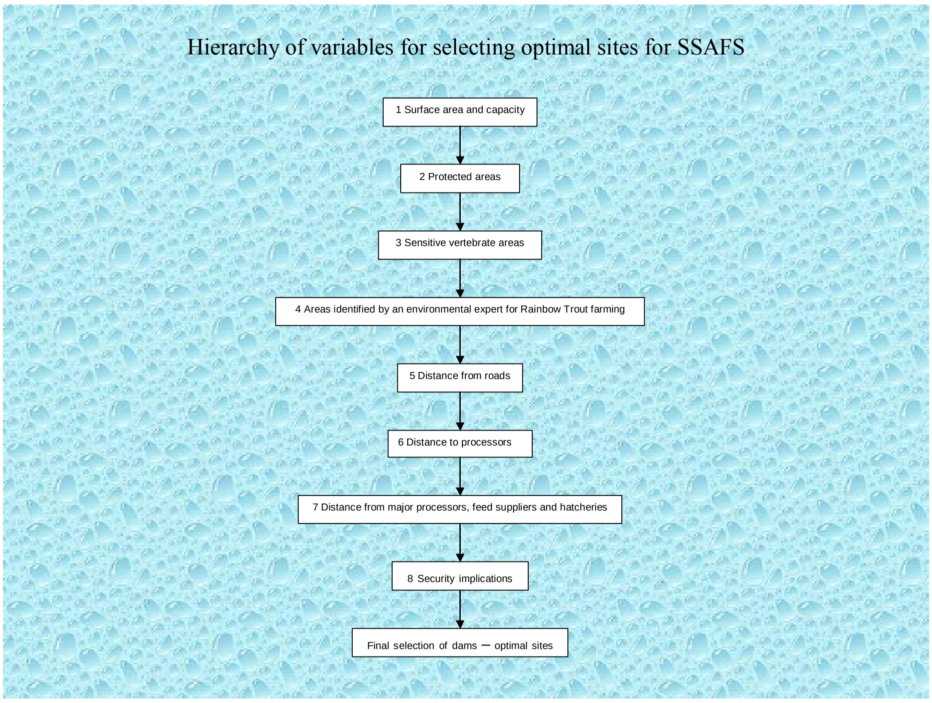
- "In the broadest possible terms, geographic information systems are tools that allow for the processing of spatial data into information, generally information tied explicitly to, and used to make decisions about, some portion of the earth" (DeMers 2000: 7).

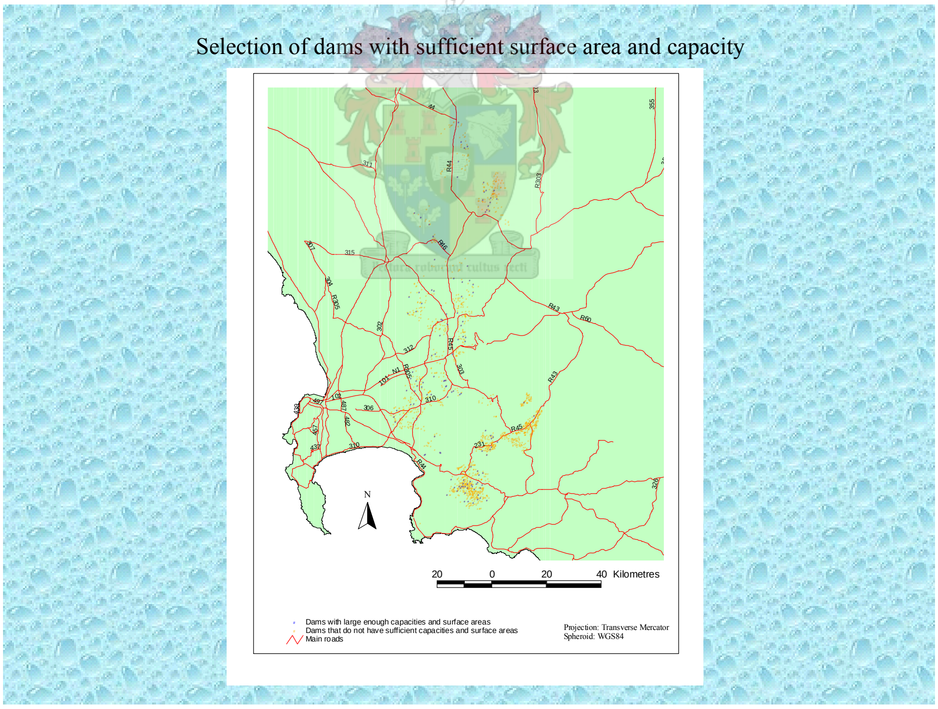
Objectives

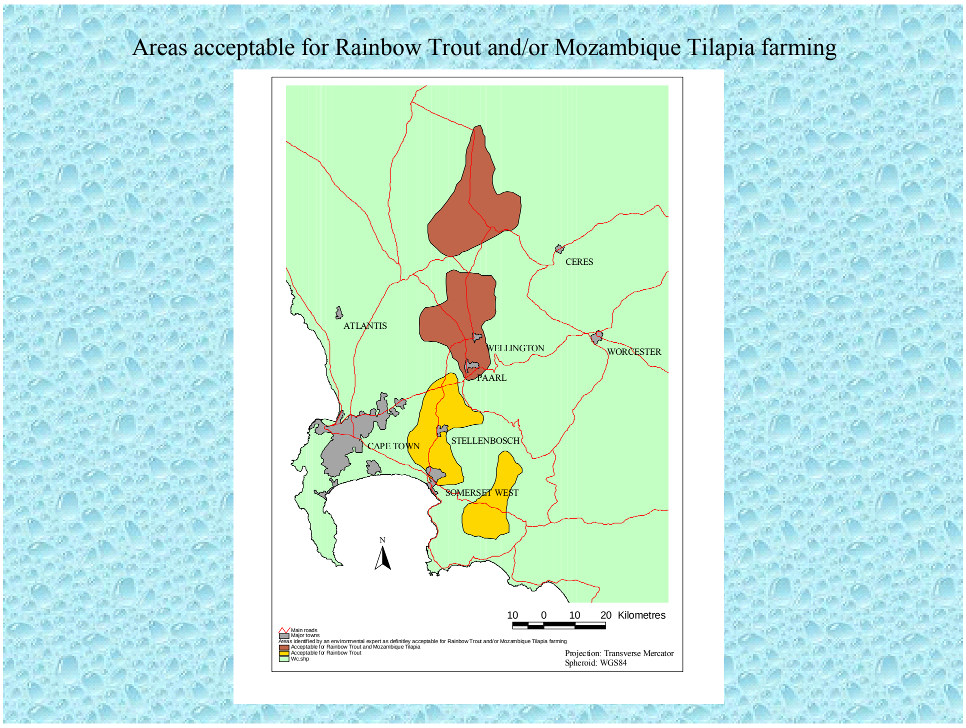
- *Objective 1*: Determine all the most important factors (variables) that influence site selection for the SSAFS.
- *Objective 2*: Determine a hierarchy of the variables to systematically and logically isolate dams that are potentially optimal sites for the SSAFS.
- *Objective 3*: Produce outputs (maps, diagrams, tables) showing the dams that are optimal for the SSAFS. Objectives 1, 2 and 3 combined, form a methodology which can be replicated and/or improved and adapted.
- *Objective 4*: Determine effectiveness of the methodology.
- *Objective 5*: Provide suggestions for further research and improvements to the methodology.

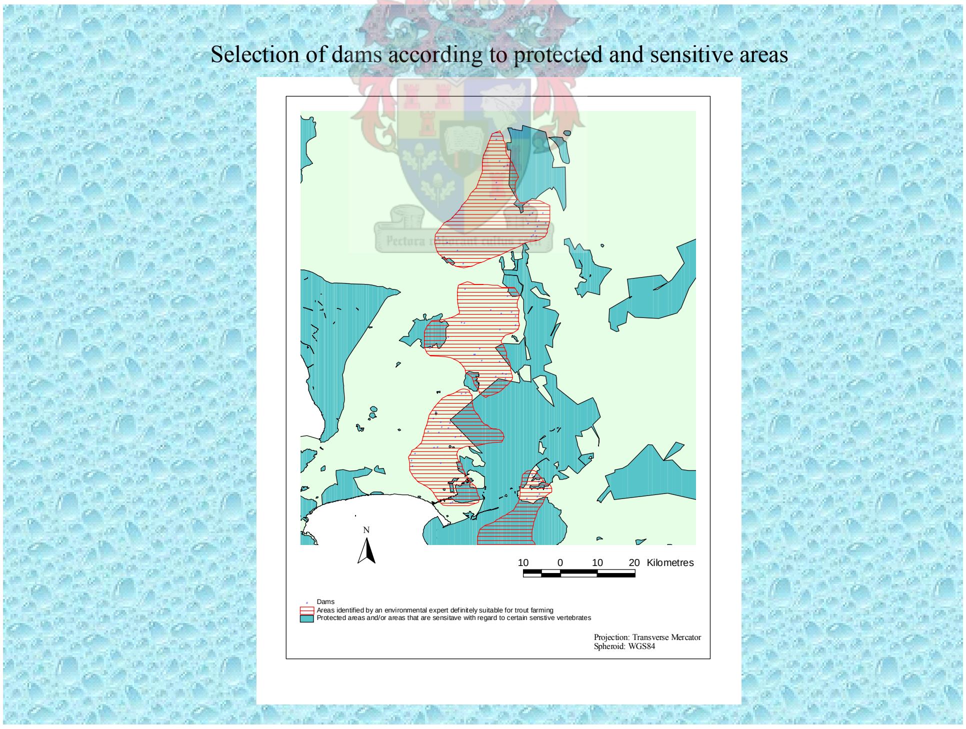
Study area for testing and illustrating the GIS site selection methodology



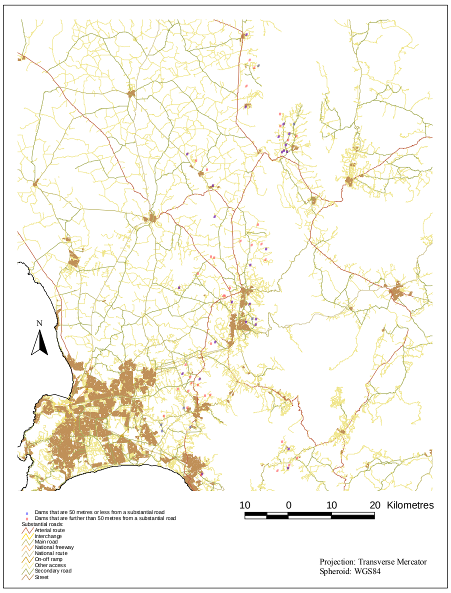

Hierarchy of variables for selecting optimal sites for SSAFS
1 Surface area and capacity
2 Protected areas
3 Sensitive vertebrate areas
4 Areas identified by an environmental expert for Rainbow Trout farming
5 Distance from roads
6 Distance to processors
7 Distance from major processors, feed suppliers and hatcheries
8 Security implications
Final selection of dams – optimal sites


Selection of dams with sufficient surface area and capacity
N
20 0 20 40 Kilometres
Dams with large enough capacities and surface areas
Dams that do not have sufficient capacities and surface areas
Main roads
Projection: Transverse Mercator
Spheroid: WGS84

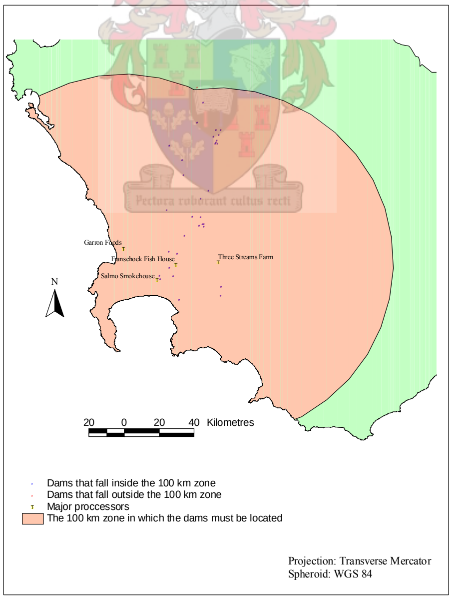

Areas acceptable for Rainbow Trout and/or Mozambique Tilapia farming
CERES
ATLANTIS
WELLINGTON
WORCESTER
PAARL
CAPE TOWN
STELLENBOSCH
SOMERSET WEST
N
10 0 10 20 Kilometres
Main roads
Major towns
Areas identified by an environmental expert as definitley acceptable for Rainbow Trout and/or Mozambique Tilapia farming
Acceptable for Rainbow Trout and Mozambique Tilapia
Acceptable for Rainbow Trout
Wc.shp
Projection: Transverse Mercator
Spheroid: WGS84

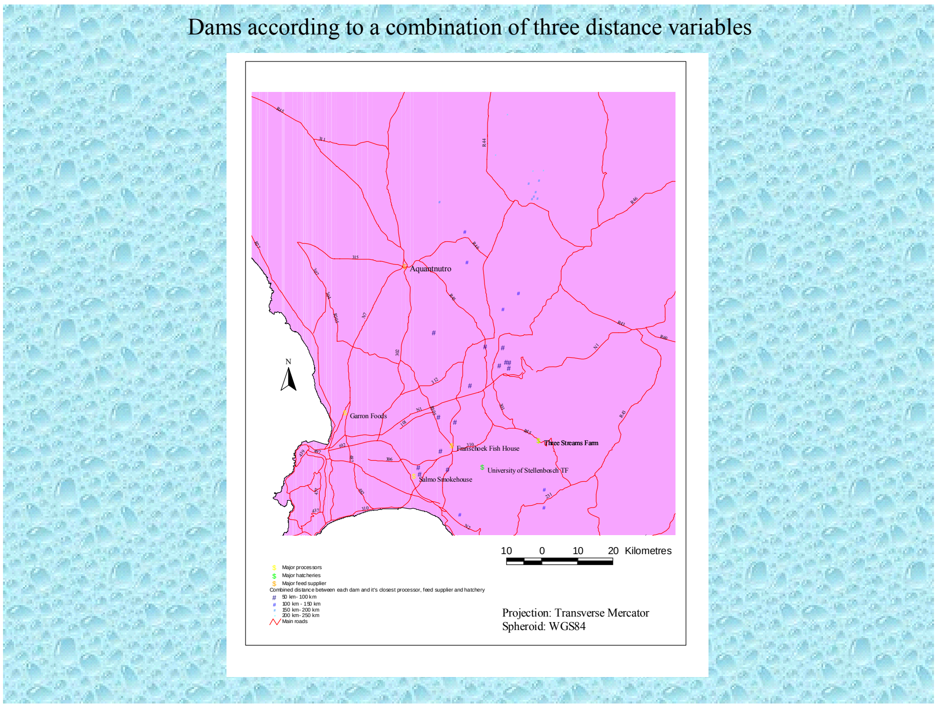

Selection of dams according to protected and sensitive areas
N
10 0 10 20 Kilometres
Dams
Areas identified by an environmental expert definitely suitable for trout farming
Protected areas and/or areas that are sensitave with regard to certain senstive vertebrates
Projection: Transverse Mercator
Spheroid: WGS84

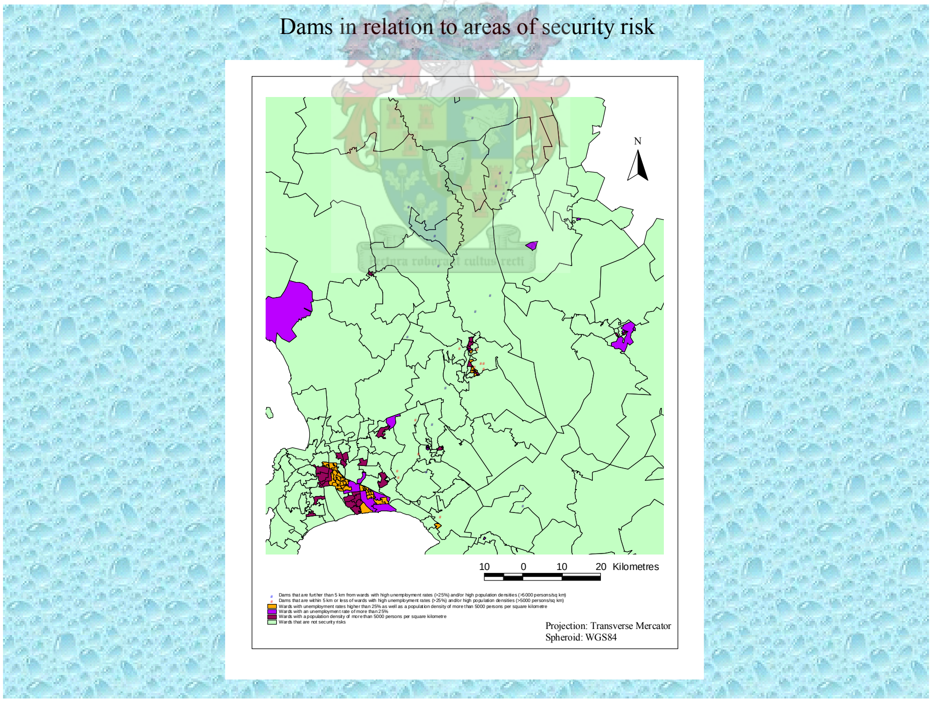
Selection of dams within 50 metres or less of substantial roads



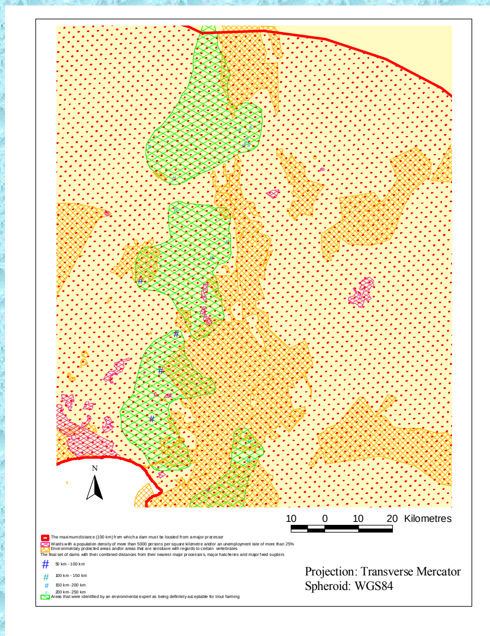
Dams in relation to major processors



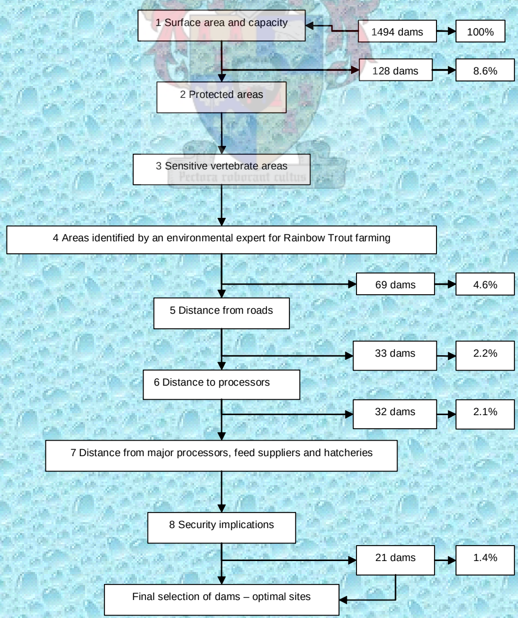

Dams according to a combination of three distance variables
Aquanutro
Garron Foods
Franschoek Fish House
Three Streams Farm
University of Stellenbosch TF
Salmo Smokehouse
N
10 0 10 20 Kilometres
Major processors
Major hatcheries
Major feed supplier
Combined distance between each dam and it's closest processor, feed supplier and hatchery
50 km- 100 km
100 km - 150 km
150 km- 200 km
200 km- 250 km
Main roads
Projection: Transverse Mercator
Spheroid: WGS84


Dams in relation to areas of security risk
N
10 0 10 20 Kilometres
Dams that are further than 5 km from wards with high unemployment rates (>25%) and/or high population densities (>5000 persons/sq km)
Dams that are within 5 km or less of wards with high unemployment rates (>25%) and/or high population densities (>5000 persons/sq km)
Wards with unemployment rates higher than 25% as well as a population density of more than 5000 persons per square kilometre
Wards with an unemployment rate of more than 25%
Wards with a population density of more than 5000 persons per square kilometre
Wards that are not security risks
Projection: Transverse Mercator
Spheroid: WGS84

Dams selected using all variables except distance from roads



Elimination of dams using the variable sieve



References

- DeMers MN 2000. *Fundamentals of geographic information systems*. New York: John Wiley & Sons
- Sedgwick, SD 1995. *Trout farming handbook* (Sixth edition). Oxford: Fishing News Books

Pectora roborant cultus recti

APPENDIX D: DAMS IN RELATION TO AREAS THAT ARE SENSITIVE WITH REGARD TO CERTAIN LOWER VERTEBRATE SPECIES