Using GIS as a means of Modelling Work Rates and as a Decision Support Tool in Alien Plant Control Management: the Case Study of the eMpofana River, KwaZulu-Natal Midlands

by
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ABSTRACT

The problems posed by alien invasive plants to our environment and the need for clearing and control has been highlighted by the Working for Water (WFW) programme. Alien plant control requires careful planning, including budgeting. To date, costing and budgeting in alien plant control has largely been a combination of experience on the part of weed 'experts', coupled with much guess work. Weed controllers have through experience calculated the amount of time (or the work rate), recorded as labour days, required for different control actions of different weed habits. These work rates are for weed clearance under ideal conditions and do not take into account the effect of factors such as gradient, access and distance to the weed infestation.

Factors affecting the work rate has been researched and modelled by researchers in both alien plant control and the timber industry. While the existing work rate model is useful in its present theoretical state, the model may be improved upon to make it more practical and applicable to the varying conditions of different areas.

This research built on existing theoretical research on alien control work rates, and concentrated on two main areas: the adaption and incorporation of the existing research on work rates into a Geographical Information System (GIS), and the creation and demonstration of a Spatial Decision Support System (SDSS) for the management of alien plant control. The eMpofana river in the KwaZulu-Natal midlands was selected as the study area, as there was an existing alien plant control programme.

Initially all factors, such as slope, access to weed infestations, terrain and penetrability of infestations, affecting the work rate in the research area were identified. An existing work rate model was then modified to account for the conditions of the research area. Regression analysis was used to derive the relationship between the various factors affecting work rate, creating a work rate model applicable to the study area.

Using the results of the regression analysis together with work rate figures adapted from an existing alien plant control programme, a SDSS for alien plant control along the eMpofana River was created. The use of the work rate model and the SDSS in the development of weed control programmes was demonstrated by examining four different management approaches, each having a different management objective. The SDSS provides a spatial component to weed control planning and costing that has thus far not existed.

What this research has achieved is the advancement of an alien control work rate model from a theoretical to a more realistic costing process. While some factors affecting work rate may not have been accounted for, the model does address the present inaccuracies in labour costing, and ultimately alien plant control costing. The research has highlighted the disadvantages of GIS in terms of affordability and expertise.

The model has wider uses than the eMpofana River, and is the ground work for the further development of a user friendly model applicable throughout South Africa. More effective project budgeting will decrease the likelihood of project failure and this will directly benefit long-term weed control efforts.

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List of Abbreviations

AL & RM	Agricultural Land and Resource Management
CAD	Computer Aided Design
DARC	Directorate Agricultural Resource Conservation
DBMS	Database Management System
DSS	Decision Support System
DEM	Digital Elevation Model
DTM	Digital Terrain Model
DWAF	Department of Water Affairs and Forestry
FU	Follow-Up Control
GIMS	Geographic Information Management Systems
GIS	Geographic Information System
IC	Initial Control
ICM	Integrated Catchment Management
NLP	National Landcare Programme
PPRI	Plant Protection Research Institute
RDBMS	Relational Database Management System
RDP	Reconstruction and Development Programme
RH	Rehabilitation
RMIS	Resource Management Information System
SDSS	Spatial Decision Support System
SQL	Structured Query Language
TIN	Triangulated Irregular Network
TON	Threshold Odour Number
USLE	Universal Soil Loss Equation
WFW	Working for Water

Declaration

I hereby declare that the work submitted in this dissertation is entirely my own unaided research unless otherwise stated, and that this document has not been submitted for any degree other than the Master of Science, or to any other university than the University of Natal, Pietermaritzburg. This dissertation comprises 50% of the M.Sc. obtained from the Centre for Environment and Development.

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CHAPTER 1
INTRODUCTION

The Working for Water (WFW) programme has highlighted the threat that alien invasive plants pose to our environment, and the importance of clearing and controlling these plants. The control of alien plants should not be attempted on an *ad hoc* basis, but should involve careful planning and implementing. Included in the planning is costing and budgeting. Much of the alien plant control costing to date has been one of educated guess work. While calculating herbicide, grass seed (for rehabilitation) and equipment costs is not difficult, it is considerably more demanding to estimate the time required to clear an infestation (or the work rate) (Loxton 1983 and Kluge & Erasmus 1991).

Inaccurate work rate estimating influences the labour costs, and in turn the budgeting for the entire project or programme. With labour costs accounting for a large portion of an alien plant weed control budget, mistakes with labour costing can seriously affect the continued operation of a project. Poor budgeting has many repercussions, both environmental and social. The temporary stoppage or premature end of a project may have dire consequences for the environment. Weeds will regenerate, and progress in clearing is delayed by many years (Loxton 1983). Similarly, workers and their families who depend for their livelihood on weed control, such as workers in the WFW programme, are severely affected by erratic earnings. It is thus important that the financial requirements of any weed control programme are adequately estimated from the start to ensure an even distribution of monetary resources during a budgeting cycle (Naudé 1999).

Alien plant control researchers have, through experience, derived labour days per hectare on 100% infestation for alien plant treatment. This has, to a degree, helped with labour costing. These work rates are for weed clearance under ideal conditions, and do not account for the effect that steep slopes, distance to the infestations and ability to access vegetation, have on the work rate.

While it is acknowledged by alien plant controllers that there are numerous factors, such as gradient and distance from the site of infestation, affecting the work rate, very little has been done to formalise these factors. The timber industry, and notably the work of de Laborde (1992), has created work rate tables for the different commercial tree species, and has also allowed for the influence of gradient and terrain on work rates. Goodall and Naudé (1998a) have used work from the timber industry to devise a work rate model for alien plant control. While the work rate model of Goodall and Naudé (1998a) goes a long way to solving the problem of calculating the work rate in alien plant control, it is nevertheless still, in practice, a difficult model to implement. The model is however easily adapted and incorporated into a Geographical Information System (GIS), where it can be used with ease. A GIS, particularly a grid based (or raster based) GIS lends itself to the work rate model as developed by Goodall and Naudé (1998a). Since alien plant management planning requires a mapping system in order to calculate the areas in hectares to be controlled, it follows that a system capable of calculating the unique property variables such as slope, distance to the infestations and ability to access vegetation would be highly beneficial. This is particularly important for the purposes of estimating the aforementioned variables interaction and resultant influence on the work rate of alien plant control. The ability of GIS to manipulate spatial data and its corresponding attribute information, to integrate different types of data in a single analysis and to operate at high speeds makes GIS highly suitable to this application.

To demonstrate the capabilities of the work rate model, the work rate values generated by the model need to be compared with work rate values derived from tables (so-called theoretical values). Goodall and Naudé (1998b) prepared a management plan, which included costings for weed clearance along the tributaries of the Mgeni River (the eMopfana, Lions and the Mgeni River, above Midmar Dam, KwaZulu/Natal). The work rate costing was conducted using the derived or theoretical labour days, without taking into account other factors, such as gradient, which could influence the work rate. This costing conducted by Goodall and Naudé (1998b) will be used as a comparison for the work rate values generated by the model developed in this study.

The original costings prepared by Goodall and Naudé (1998b) will be modified and integrated into a GIS in order to create a spatial decision support system (SDSS) to help alien plant control managers with the decision making process. Use of the SDSS will be demonstrated under several weed management approaches.

Both the work rate model and the SDSS have wider applications than the study area, and it is hoped that they will both be adapted for use throughout South Africa, from the national scale of the Working for Water programme to the farm unit. If weed control costing is calculated more accurately, it is foreseen that more effective weed control management will be practised with better budgeting, and a greater likelihood of projects being completed.

1.1 Aim and Objectives

The aim of this research is twofold: the development and incorporation into a Geographic Information System of a work rate model for alien plant control, initially for the eMopfana River, but ultimately applicable throughout South Africa; and the creation and demonstration of a Spatial Decision Support System for the management of alien plant control along the eMpofana River which can be adapted for use nationally.

The objectives are as follows:

1 (a) To identify all the factors, such as slope, access to weed infestations and penetrability of infestations, affecting the work rate in the research area.

(b) To adapt Goodall and Naudé's (1998a) work rate model for alien plant control according to the conditions of the research area.

(c) To incorporate the modified work rate model into GIS in order to develop a model that more accurately predicts work rate (and hence labour costs and ultimately budgeting for programmes) for alien plant control, through the inclusion of those factors identified as influencing the work rate.

2 (a) To create a database for alien plant control along the eMpofana River from the existing control programme by Goodall and Naudé's (1998b).

(b) To integrate the database with ArcView 3.1 digital data in order to create a SDSS for alien plant control.

(c) To demonstrate the use of the work rate model and the SDSS in the development of weed control programmes, by examining four different management approaches.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The following chapter places the concept of weed control planning and management in the context of the current practices in South Africa. The management of weeds can only be discussed once an understanding of the following has been gained: the definition of a weed, the threat posed by weeds in the South African environment, the current legislation concerned with the control of weeds, the methods of weed control and the phases of weed control that have been achieved. The chapter thus lays this grounding by beginning with brief discussions of each of the aforementioned factors. Following on from this is a discussion of the various management approaches to weed control in South Africa, and the various weed control initiatives underway. The discussion will then focus on the weed control planning done for Umgeni Water on the eMpofana River. Shortcomings of the approach followed will be highlighted, and the benefits of GIS for weed control planning will be introduced.

2.2 Weeds and Alien Invasive Plants

A weed is a plant growing where it is not desired, or a plant out of place (Klingman *et al* 1982). Plants are considered weeds when they interfere with the utilisation of land and water resources, or otherwise adversely intrude upon human welfare. Much of the research on weed control to date (Subcommittee on Weeds 1961, Klingman *et al* 1982, Loxton 1983, de Laborde 1992 and Zimdahl 1993) has focussed on weed control in commercial farming, particularly crop farming. Weeds are problematic in that they lower crop and animal yields, require controlling and thus increase the costs of production, result in poorer quality products, allow for less efficient use of the land and lower human efficiency (Zimdahl 1993 and Klingman *et al* 1982). Groves, as quoted in Goodall and Naudé, (1998a, p.109) refers to weeds outside of crop lands as environmental weeds and defines these weeds as undesirable, exotic plant species that invade vegetation and landscapes. The term 'alien plants' used in this study will refer to Groves` definition.

Alien plants are species which have accidentally or deliberately been introduced to a country or area (Directorate Agricultural Resource Council 1997). More than 900 alien (or foreign or exotic) plants occur in South Africa, and are very necessary in: feeding the people and livestock of our country, supplying fuel, providing raw materials for industry, etc. Some of these species include: grain crops, fruit and nut trees, timber trees, fodder plants for livestock, ornamentals for gardens and ground cover to help stabilise the soil (PPRI 1999). Alien plants *per se* are not necessarily a problem, but rather the invasive nature of some of these alien plants. Of the alien species, 161 are regarded as invasive, with 44 having been declared or proposed for declaration as noxious weeds, and 31 having been declared or proposed for declaration as invaders. While plants have been introduced to South Africa from various countries, those originating from Australia are particularly invasive (DWAF 1999). A few indigenous plants may even under certain conditions become invasive, such as the encroachment of thorn trees (*Acacia* spp.) on grassland.

2.2.1 Need for the Control of Alien Plants

In order to motivate for the control and management of alien plants, it is necessary to understand the problems caused by alien plants.

Disturbance of Natural Ecology

The survival of a natural community, consisting of plants and animals, depends on the interaction between the various species as well as the climate and the soil of the area. The community may be temporarily or permanently altered by a factor or event that disrupts this interaction. Some alien plants have such a marked and dramatic effect on a natural community that they are referred to as transformer species. They are able to suppress the growth of indigenous plants, resulting in a decrease in seed production and ultimately the elimination of the indigenous plants in the area.

Thus the plant biodiversity of the area will be reduced which in turn affects the animal and insect biodiversity. As the indigenous plants die off, there is an increase in organic matter which could lead to an increase in fire temperatures. Many alien plants are more fire tolerant than indigenous plants, thus while a hotter fire may damage alien plants, it can be highly destructive to fire sensitive indigenous plants, particularly those that have a shallow root system, such as many grass and herbaceous species. Alien plants can also smother plants that act as ground cover resulting in increased run-off and erosion. The end result is the disturbance and alteration of the ecological balance of an area (PPRI 1999, Stirton 1985 and Directorate Agricultural Resource Council 1997).

Increase in Land Management Costs

"Plant invaders in the countryside hamper farming and forestry operations, displace indigenous vegetation, disfigure scenery, and in some cases are fatally poisonous to humans, livestock and wild animals" (Stirton 1985, p 28). Plant invaders growing in open veld may be very dense, restricting access by humans, animals and machinery. Stock farming may become uneconomical in such areas as a result of the reduction in edible, grazing plants and the presence of poisonous species such as *Lantana* species. Thorny/spiny alien plants such as American bramble, mesquite and the *Hakea* species may also cause injury to livestock, and the leaves of *Opuntia* species, sticking to wool, may be responsible for the down-grading of that wool. The presence of such plant invaders thus results in less efficient use of the land, increased production costs, lower animal yields and/or poorer quality products (Klingman *et al* 1982, Stirton 1985 and Directorate Agricultural Resource Council 1997).

Furthermore, the presence of alien plants such as bugweed and American bramble may impede the movement of workers in plantations, especially during firefighting and trimming operations. In nature reserves, alien plants could hinder game viewing and need to be actively managed and thus place an added demand on the management budget (PPRI 1999).

Increase in Water Management Costs

Plant invaders in water-bodies pose a threat to aquatic ecosystems, irrigation works and hydro-electric installations. Water sports such as fishing, swimming, boating and water-skiing are disrupted by the presence of these plants. Clogged irrigation channels have been responsible for reduced water supplies to farmers, increased the risk of flooding and have provided breeding grounds for mosquitoes. The provision of drinking water and hydro-electric power is being threatened by the presence of invader plants in storage dams. These plants pollute the water, clog inlets, jam pumping equipment, and lower the water level through their high evapo-transpiration rates (Stirton 1985 and Directorate Agricultural Resource Council 1997).

Effect on Riparian Zone

The riparian zone is that "area of a river or flood plain in which water availability, determined by fluctuations in river flow or flood plain level, regulates plant growth and species distribution" (Ferrar 1989, p 94). According to Stirton (1985), the most threatened indigenous plant communities are those occurring in moist areas such as marshes, wetlands, stream and river banks, and seepage areas, where the competition by plant invaders is fierce. The existence of these alien plants along watercourses presents a number of problems. Alien plants use more water than indigenous plants, reducing the volume of flow, especially the dry season flow and Poulter 1995). The presence of alien plants also restricts the spreading of flood water, leading to increased erosion of the river channel and banks and resulting in an increase in the amount of silt and debris. The silt and debris may cause damage to downstream bridges and dams (Stirton 1985 and DWAF 1999).

2.3 Legislation

It is necessary to examine the legislation pertaining to the control of alien plants, since these Acts serve as the framework to all alien plant management strategies. The Acts are also important as they provide the recourse for legal action should land users contravene any of the laws. The Act that used to refer specifically to the control of alien plants is the Conservation of Agricultural Resources Act (No. 43 of 1983) which is administered by the Directorate of Agricultural Land and Resource Management. However, most of this Act has been repealed and replaced with the National Environmental Management Act (No. 107 of 1998) (Government Gazette 1998). At present the National Environmental Management Act has not laid down specific guidelines for the control of weeds and alien plants. Thus, the old regulations as specified by the Conservation of Agricultural Resources Act have been included, as to date, they still provide the most comprehensive directions for the control of alien plants and weeds. There are also a number of other acts that also deal, in varying degrees of detail, with the control of weeds. They are:

- Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act, No. 36 of 1947
- Agricultural Pests Act, No. 36 of 1983
- National Water Act, No 36 of 1998

2.3.1 Conservation of Agricultural Resources Act, No. 43 of 1983

The objects of Act 43 (section 3) are to "provide for the conservation of the natural agricultural resources of the Republic by the maintenance of the production potential of land, by the combatting and prevention of erosion and weakening or destruction of the water resources, and by the protection of the vegetation and the combatting of weeds and invader plants" (Government Gazette 1983, p 69).

In section 2(3) of Act 43, the minister is given the power to declare a plant a 'weed' or an 'invader plant' either throughout the Republic or within certain areas, if the plant is seen to be adversely affecting the natural resources. The presence of declared weeds is not permitted on land within an urban area, and where they occur on farm land, they must either be eradicated or effectively controlled. 'Declared invaders' is the term used for those invasive species that also have some commercial or other value. These species must be controlled if their occurrence is seen to be detrimental to the productive potential of the natural agricultural resources. The difference between a weed and an alien invader plant is sometimes difficult to define. Appendix 1 gives the main perceived differences between weeds and invader plants as proposed by the Directorate of Agricultural, Land and Resource Management at a workshop held at Roodeplaat in February 1999.

The term invader or weed also refers to the seeds of the plant as well as any vegetative part of the plant which reproduces itself asexually. All declared weeds and invader plants are listed in Government Gazette No 9238 (1984).

Should any of these weeds or invader plants occur on such land, the land user is to control them, according to Government Gazette No. 9238 (1984), by as many of the following measures as possible:

- The weeds/invaders must be uprooted, felled or cut off and destroyed by burning or by another suitable method.
- The weeds/invaders must be treated with a registered weed killer.
- Any other recognised method of treatment including biological control, that has as its objective the destruction of the weeds/invaders, must be applied.

The Act also covers a number of issues pertinent to weed control, which will be mentioned briefly. The prohibition of the spreading of weeds (section 5); the prescribing of control measures to land users for the conservation of agricultural resources (including the control of weeds and invader plants) (section 6); and the ordering of land users, by means of a direction, to adhere to a particular control measure (section 7) are all dealt with in the Act.

Section 8 of the Act looks at the establishing of schemes in which financial assistance in the form of subsidies may be given to land users for the conservation of agricultural resources (including the combatting of weeds and invader plants). Furthermore, the supply of weed killers as a means of combatting weeds or invader plants may be subsidised. Also, the rendering of services by the Department of Agriculture, including the use of weed killers, in order to combat weeds or invader plants may be subsidised.

Lastly, Act 43 covers the rendering of advice (including the control of weeds and invader plants) to the land user (section 10); the establishment of conservation committees in order to promote the conservation of the agricultural resources, including the control of weeds and alien plants (section 15); and the expropriation of land by the Minister of Agriculture if he is of the opinion that it is necessary for the restoration and reclamation of the natural agricultural resources of the land (section 14).

2.3.2 Other Acts Relevant to Weed Control

The Environmental Conservation Act, No. 73 of 1989

This Act is not specifically aimed at the control of weeds, but broadly to provide for the effective protection and controlled utilisation of the environment (Government Gazette 1989). Since alien plants pose a threat to indigenous plants and the environment generally, the control of alien plants is loosely covered by this Act. The usefulness of Act 73 lies primarily in its ability to lend support and act as a back up to the Conservation of Agricultural Resources Act.

The Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act, No. 36 of 1947

Act 36 deals with the registering of herbicides and pest control operators. The use of herbicides in South Africa is strictly controlled. According to the Act, chemicals must be tested and registered for use against particular plants or groups of plants before they can be recommended (PPRI 1999).

Agricultural Pests Act, No. 36 of 1983

The Act guards against the introduction and establishment of undesirable pests, including plants (CSIR 1998).

National Water Act, No 36 of 1998

The purpose of this Act is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways which take into account a number of factors, one of which is protecting aquatic and associated ecosystems and their biological diversity through the establishment of suitable institutions. While the control of alien plants is not referred to directly, maintaining biological diversity and protecting the ecosystem would entail the clearing and controlling of alien plants (Government Gazette 1998).

Contained within the national water resource strategy is the framework for regional or catchment level management, in defined water management areas. Catchment management agencies will be responsible for the development of a catchment management strategy for the water resources within its water management area. Integrated Catchment Management (ICM) will be expanded upon later in the chapter.

The National Water Act replaces a number of acts, or sections of acts, including sections of the Forest Act (Act No. 122 of 1984) relevant to the protection of water resources from afforestation. The sections included: the granting of afforestation permits and the conditions for permit approval, including the specifying of riparian zone widths and of a 50-metre buffer zone around wetlands. These sections have been replaced by the National Water Act's recognition of certain activities as responsible for reducing stream flow, and therefore needing control. At present, only plantation forestry is classified as such an activity, although other forms of land use are to be included in the near future.

Convention on Biodiversity (1992)

As a signatory to this convention, South Africa is obliged to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" (CSIR 1998, p 5).

2.4 Methods of Alien Plant Management and Control

Alien plant management is a combination of prevention, eradication and control. In some instances, eradication of a particular alien plant may be possible, in another instance the maintenance of an alien plant population at some level may be the goal of a weed manager (Zimdahl 1993).

2.4.1 Prevention

The prevention of a given species from contaminating an area is an important part of weed management, but also the most difficult. Eradication of most weed species is made almost impossible due to the following characteristics of weeds: their prolific reproductive capacity, special dissemination characteristics, dormancy and viability. Preventive control measures should be attempted wherever possible as a matter of principle. Since these measures are often extremely costly, prime attention needs to be given to those preventive measures that, for the effort expended, are likely to return the most favourable results (Subcommittee on Weeds 1961 and Fletcher 1983).

Preventive measures include being aware of the weed infestation potential of imported feed, seed, livestock or machinery. Section 5 of the Conservation of Agricultural Resources Act, No. 43 of 1983, deals with the prohibition of the spreading of weeds. The term prevention also includes preventing seed production by weeds and the vegetative spread of weeds. (Zimdahl 1993 and Directorate Agricultural Resource Council 1997).

2.4.2 Eradication

Once weeds or alien plants have established themselves, they need to be dealt with. Eradication is the complete elimination of all live weeds, parts of weeds and their seeds. It is usually easy to eliminate live plants because they can be seen. However, it may be difficult to eliminate seeds and vegetative reproductive parts in soil (Directorate Agricultural Resource Council 1997).

Eradication is desirable when the weed species is noxious, but may only be practicable if a weed infestation is confined to a limited area. Although eradication of weeds and alien plants is the ideal of land managers, in reality most land managers attempt to control or limit weed infestation through the use of a variety of techniques (Subcommittee on Weeds 1961, Klingman *et al* 1982 and Zimdahl 1993).

2.4.3 Control

A weed control programme may be the only viable measure when weeds are widespread and difficult or economically unfeasible to eliminate (Zimdahl 1993). There are several methods of controlling weeds/alien plants. They are: mechanical, chemical, biological and indirect or cultural control. Each of these methods have their advantages and disadvantages, and one may be more appropriate than another depending on the circumstances. The choice of method will be influenced by factors such as size and age of the plant, the habitat, the season, its ability to propagate, or even the availability of labour (Loxton 1983). In reality a combination of methods termed integrated control, is frequently used (PPRI 1999).

Mechanical Control

Mechanical control is defined as "causing severe damage to, or removal of, a plant by physical action" (PPRI 1999, p 25). Mechanical control is frequently used not to kill the plants, but to prepare them for the application of herbicides. It is not a cheap alternative to chemical control, and may often be more expensive.

Examples of mechanical control include:

- Uprooting/Hand Pulling
- Clear-Felling
- Slashing or Mowing
- Ringbarking
- Bark-Stripping

The advantage of mechanical control is that simple tools are used in mechanical control, thus little training and supervision are needed. Except for soil disturbance, mechanical control is not generally harmful to the environment. After the usable wood has been removed, where possible, the remaining brushwood is spread over the area to prevent soil erosion and to provide a micro-climate more suitable to seed germination than bare soil.

The disadvantage is that control is slow and labour intensive which makes it a costly procedure for areas greater than one hectare or for control of dense infestations. Disturbance of the soil results in the germination of weed seeds, and the possible erosion of soil on steep slopes (PPRI 1999).

Chemical Control

Chemical control is defined as "the control and suppression of plants through the action of chemicals (called herbicides) which are applied directly to the plant or to the soil close to it" (PPRI 1999, p 26). The importance of herbicides goes beyond their ability to kill or control weeds. They manipulate part of the chemical environment of plants which is more easily manipulated than the climatic, edaphic or biotic environment (Zimdahl 1993).

Used correctly, chemical control can be the most cost-effective method of control, and is indeed sometimes the only effective method. It is also less time consuming than mechanical control, for example slashing bushes by hand may require eight times the labour of spraying with a knapsack sprayer, although in many cases both methods are employed. Furthermore, herbicides pose little threat if the recommended doses are adhered to (PPRI 1999).

However, the expense in using chemical control is not just the cost of herbicides, but the added cost of the equipment for applying them and the training of operators. In many cases mechanical preparation of the plants may also be needed before herbicides can be applied.

There is always the possibility when using herbicides that the surrounding environment could become contaminated, especially as some herbicides are known to persist in the soil for as long as 18 months. In addition, herbicides can be hazardous to plants that are not targets, but are affected by inappropriate application or drift (Zimdahl 1993 and PPRI 1999).

Biological Control

Biological control is defined as the maintaining of another organism's population at a lower average density than would naturally occur due to the action of parasites, predators or pathogens. The objective of biological weed control is the reduction and long term stabilisation of weed density at sub-economic level, and not the eradication of weeds (Zimdahl 1993).

The spread of most plant invaders in South Africa is due to an absence of their natural enemies. Through the introduction of some of the plant's natural enemies termed biological control agents, it is possible to decrease the aggressiveness of the plant invaders (Fletcher 1983 and Stirton 1985). This achieved, for example, by the introduction of biological control agents which attack the flowers and seeds of the plant effectively reducing the seed production of the plant. Although the plant remains competitive, its overall invasive aggressiveness is reduced.

The advantage with biological control is there are no undesirable effects on the environment, since the organisms are released after extensive research and only effect the target plant. There is no environmental pollution from biocontrol organisms and no environmental or mammalian toxicity, as is sometimes the case with chemical control (Klingman *et al* 1982).Furthermore, biological control is often permanent weed management as once the organism is released, it is self-perpetuating with control continuing without further human intervention. (PPRI 1999 and Zimdahl 1993).

The disadvantage of biological control is that it is slow and results are not guaranteed. Biocontrol is also by its very nature a selective form of control, and cannot be used to control a complex of many weeds. Its usefulness is limited to where a single, aggressive weed is particularly problematic (PPRI 1999).

Indirect Control (Habitat Management)

Indirect control "employs techniques of environment manipulation that reduce or eliminate competition of weeds and prevent their introduction or spread while the desired use of the environment is maintained" (Subcommittee on Weeds 1961, p 120). Said differently, indirect control involves the use of an agent which is not aimed primarily at killing plants. Two types of indirect control, fire and utilisation will be discussed.

(a) Fire

The burning of grassland and bushveld is used as an important means of managing grazing land. Fire removes the excess dead plant material which would otherwise result in woody plants becoming more numerous and a decrease in the number of palatable plants. Burning also serves to control weeds. However, fire should always be used as a way of managing the whole landscape, and not purely as a method of weed control (PPRI 1999).

The advantage of using fire is that it is a relatively inexpensive and rapid method of weed control in that its implementation over large areas is straight forward. Fire can also, under ideal conditions of temperature, humidity and vegetation fuel load, kill large plants.

However, while fire may be a cheap and simple method of weed control, it can be difficult to control and dangerous to people, stock and property. Furthermore, the right time to burn is also the most dangerous, when the vegetation is at its driest. Also, if there is an insufficient amount of fuel, the fire may not be able to move through the stand. Thus, burning may not damage dense infestations of plants.

(b) Utilisation

"If a use can be found for an undesirable plant, this may be an incentive to harvest it and kill it at the same time. If it becomes a desirable plant, then it would be managed accordingly and would no longer be considered a weed" (PPRI 1999, p 29). For example, wattle is used for firewood, charcoal and building materials. The fruit of bugweed contains an alkaloid which could be used in the manufacturing of steroids, and the pods of mesquite are used to feed stock.

The advantage of finding a use for a previously unwanted plant is that the income received from the problem plant could be used to control it. In addition, a use is found for a plant, presently occupying unproductive land. The land is unproductive for various reasons but generally, if heavily infested by alien plants, the cost of clearing these plants outweighs the value to be gained by the property owner from such expenses. The property owner would be more inclined to manage the alien plant infestation if there was some economic benefit to gained from doing so.

However, the cost of harvesting the problem plants may exceed the benefits gained. Furthermore, by allowing people onto land in order to harvest the weeds, such as, the collecting of firewood, the landowner may increase the risk of fires, stock theft, etc. The cost of harvesting the plant may exceed the benefits, especially if the plant is not dense enough (PPRI 1999).

Integrated Control

The term refers to the use of two or more complementary control methods, with appropriate integration, to control a given plant in a particular situation. Mechanical and chemical control are frequently used together. Often mechanical means have to be employed to provide access to an infestation, to lower its height or to produce new growth prior to the use of a herbicide. Fire may be used to stimulate the germination of weed seeds prior to spraying (Klingman *et al* 1982).

2.4.4 Phases of Control

It is important that a weed control programme includes all three phases of weed control, namely: initial control, follow-up control and maintenance. Rehabilitation is an essential component in any weed control programme, and will also be discussed.

Initial Control

Initial control is aimed at removing the existing infestation. It is of short duration, but because of the amount of growth to be killed, it is frequently the most costly part of the programme. A number of control methods are often used together (PPRI 1999).

Follow-Up Control

This phase is aimed at killing those weeds that survived or were missed, as well as any regrowth (especially seedlings which have germinated) resulting from the initial control. Follow-up control can start any time from one month to a year after the initial control phase. The techniques employed in this phase include foliar sprays of regrowth as well as hand pulling of seedlings. The number of follow-up operations varies depending on many factors including: the species present, their densities, the weeds' physiologies and the seedbank.

Maintenance Control

Maintenance control is reached when the number of alien plants is very low, such that one worker is able to cover many hectares a day handpulling scattered alien plants. This control should occur once or twice a year, and is best done at the end of summer. Maintenance control aims to sustain low or reduced alien plant levels, with low annual inputs, both financial and in terms of labour. If maintenance control is neglected, the vegetation could revert to the follow-up level of control, resulting in higher control costs. Maintenance control is important in that it ensures that the vegetation remains in good condition (Goodall & Naudé 1998b and Campbell 1993).

Rehabilitation

The rehabilitation of areas cleared of weeds is an important part of an effective weed control programme, as disturbed areas are particularly susceptible to reinvasion. Rehabilitation should begin straight after the initial control phase, and can be conducted throughout the year, even in winter. Rehabilitation involves introducing a plant cover that will not only make the area productive again, but will also stop any further degradation that could occur as a result of the exposed soil surface (Goodall & Naudé 1998b and Campbell 1993).

2.5 Weed Management Systems

A weed management system should be designed for any weed situation, integrating all available weed management techniques, the sum of which has greater impact than any one component. Too often, weed-control activities are random in nature and narrow in perspective. They rely on traditional control procedures, rather than on a series of steps, planned on a continuing basis for a specific situation. The majority of work on weed management systems deals with weeds in crops and not environmental weeds. While it is accepted that weed control is a systematic process of reducing weed growth to an acceptable level and optimising land use, we do not yet have a clear definition of weed management (Subcommittee on Weeds 1961 and Zimdahl 1993).

Zimdahl (1993) has proposed six logical steps of weed management. They are:

2.5.1 Mapping

Before a management programme begins, an accurate map of weed infestations must be made. The weed species need to be identified as well as their location. Thus a weed management system must be designed to control specific weeds in specific places. If it is not possible to map every weed species, major weed species should be identified as well as those species likely to become problematic.

2.5.2 Prioritisation

It is not possible to do everything. Since money, time, labour and technology are often lacking, prioritising is necessary. Once the weed problem in an area has been assessed, those species and areas that pose the greatest threat to the environment will receive priority.

2.5.3 Development of an Integrated Weed Management System

This involves the selection of the best techniques or method for the weeds to be managed. The best weed management systems will not select a single method. All the techniques will be analysed and an integrated approach which includes two or more of the above mentioned methods will be chosen to manage the problem.

2.5.4 Implementation of Systematic Management

The weed management programme can begin once the manager has a map of the problem weeds and a management plan. Everything need not be accomplished in one season or with one technique. The programme should be systematic, meaning that the weed problem will be dealt with in a planned way over time.

2.5.5 Record Keeping and Evaluation

Records of the methods used and its successes must be kept. Record keeping will allow for successes to be repeated and will enable the manager to learn from mistakes. Evaluation should be over two to three years, and not just a week or month after a control was done.

2.5.6 Persistence

Success in weed management is not achieved after the application of one control technique. The seed bank, regrowth of treated weeds and new sources of infestation require continued attention and on-going treatment (Zimdahl 1993).

Randall (1998) has also proposed six steps in the management of weeds which are similar to Zimdahl's (1993). Randall's (1998) steps are given in the form of a flow diagram in figure 2.1 below.

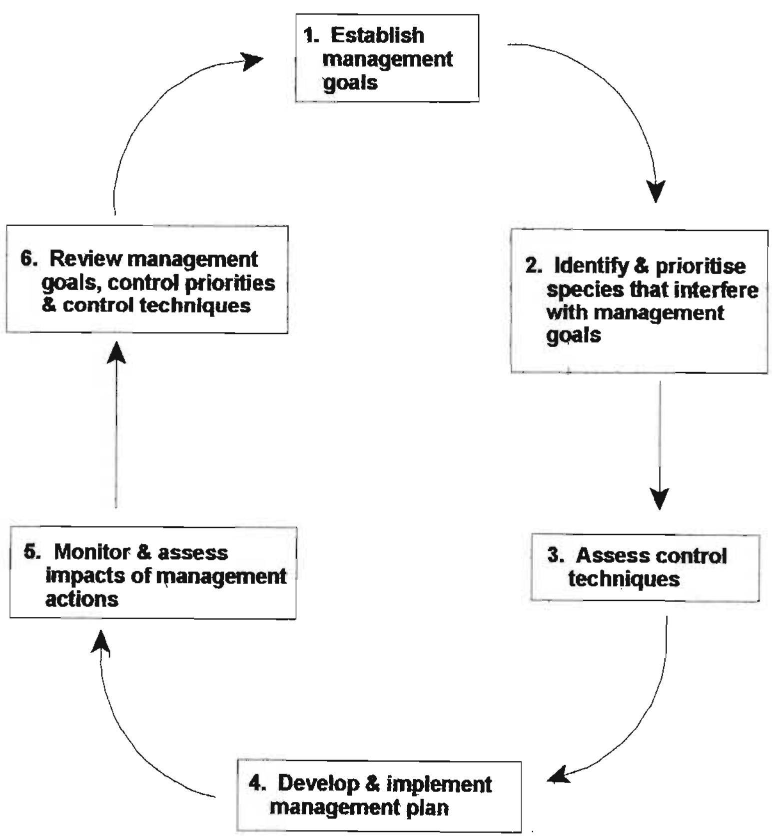

Figure 2.1: Flow diagram for adaptive approach to weed management (Randall 1998)

2.6 Alien Plant Control Initiatives in the South African Context

Alien plant control takes place at a number of scales, from the farm unit to national initiatives such as the Working for Water programme (WFW). Similarly, there are many organisations of varying scale that are involved with alien plant control. At a national level, the Working for Water programme is the most publicised programme, and is focussed primarily on the removal of alien plants. However, two other national initiatives, Integrated Catchment Management (ICM) and Landcare are also concerned with alien plant control, although not as their only objective. Both ICM and Landcare focus on the conservation and management of natural resources generally. The control of alien plants is one of many problems facing the conservation of resources.

2.6.1 Landcare

The aim of the National Landcare Programme (NLP) is the development and implementation of integrated approaches to natural resource management in South Africa which are efficient, sustainable, equitable, and consistent with the principles of ecologically sustainable development. The NLP is the responsibility of the Chief Directorate Agricultural Land and Resource Management of the National Department of Agriculture (Directorate of Agricultural, Land and Resource Management 1999a).

Landcare attempts to prevent degradation of the land (which includes soil erosion, soil nutrient loss, loss of biodiversity, lowering of the water table, etc.), while at the same time making use of the natural resources in such a manner that the users quality of life is improved (greater productivity, food security, job creation, etc.), but not at the expense of future generations Directorate of Agricultural, Land and Resource Management 1999a). In a document entitled 'Landcare and Desertification', alien plants along with soil erosion and soil degradation were mentioned explicitly as being areas of concern for the NLP.

At present, the South African Landcare initiative is at the development phase. A workshop was held in April 1998, attended by Landcare representatives from all the provinces. The aim was to develop a framework for Landcare South Africa which will enable each province to formulate a provincial strategy through the involvement of all stakeholders in that province (Smith 1998).

2 6.2 Integrated Catchment Management (ICM)

In a relatively 'water poor' country such as South Africa, it is necessary for our water resources to be managed in order to meet the growing demand for water. The Department of Water Affairs and Forestry (DWAF) has recognised that "water is most effectively managed within the geographic unit of the river basin or catchment, so that all aspects of the hydrological cycle and the impacts of land use on water in the catchment can be taken into consideration" (Umgeni Water & DWAF 1998, p 2). Water can no longer be managed as a separate entity. Activities such as agriculture, industry and the establishment of residential areas impact on water quantity and quality. Integrated Catchment Management (ICM) ensures that there is a sustainable balance within the catchment between the utilisation and the protection of all environmental resources. This is achieved through co-ordinating the management of land use activities within the catchment.

The Department of Water Affairs and Forestry has, with the passing of the new National Water Act, provided the legislation for the devolution of water management responsibilities through the development of ICM structures. Every major river will be represented by a catchment management committee who will decide on a catchment management plan and supervise its implementation. The catchment management plan is a holistic management strategy that considers the present state of the catchment and then develops management strategies in order to guide the use, conservation and control of the water resources in a catchment. Water use charges will be used to fund the development of catchment management strategies.

The Mgeni Catchment Management Plan

The Mgeni River catchment, of which the eMpofana River is a tributary, provides water to over 3.5 million people and supports approximately 65% of the total economic production and 40% of the population in KwaZulu-Natal (Umgeni Water & DWAF 1996). It is thus, one of the most heavily utilised catchments in South Africa and as a result the natural resources of the Mgeni River have been severely stressed. This has resulted in Umgeni Water, together with the Department of Water Affairs and Forestry, conducting a catchment management plan study of the Mgeni catchment.

The plan's objective is to "mitigate existing problems and prevent further deterioration in the catchment, enable the water resources to be sustainably managed and to provide sufficient water of adequate quality to meet basic needs while supporting economic development and maintaining the healthy functioning of the natural environment" (Umgeni Water & DWAF 1996, p 3). The plan is in line with the National Water Act, as well as the international trend towards Integrated Catchment Management (ICM) which views the entire catchment as an environmental unit, managing resource use and human activity. One of the issues identified as requiring urgent management in the Mgeni catchment is the reduced water availability due to alien vegetation, afforestation and irrigation (Umgeni Water & DWAF 1996).

The Mgeni catchment has been divided into six sub-catchments or management units. The research study area falls within the Midmar management unit. In each unit, preliminary objectives were formulated for the most important problems or issues. From these objectives, potential management strategies were devised which form the basis of the Catchment Management Plan. Strategies were put forward as a means of accomplishing the objective, one of which was the removal of alien invasive vegetation from river courses as well as the rehabilitation of the riparian zone (Umgeni Water & DWAF 1996).

2.6.3 Working for Water (WFW)

The WFW programme aims to clear alien vegetation from catchments within South Africa to improve water supply. At the same time it is also a poverty relief initiative, focussed on job creation particularly among the rural poor. The programme is funded by the Reconstruction and Development Programme (RDP) and managed by the Department of Water Affairs (DWAF) as a component of the National Water Conservation Campaign.

The government's concern is that in a relatively dry country such as South Africa, with very few good dam sites, we should be making every effort to maximise our water supplies. Alien vegetation in riparian zones is responsible for removing large volumes of water from catchments (Dye & Poulter 1995). Furthermore, alien plants constitute a fire hazard, have a negative effect on biodiversity, cause soil erosion and can increase the likelihood of flooding. By clearing catchments of alien plants, the flow in rivers and streams should increase as well as the reliability of the flow (DWAF 1996a). The increased stream flow should also result in an increase in water volumes in dams downstream of the cleared rivers. This strategy was identified by Prof. Kader Asmal who stated that clearing alien plants from catchments is a lateral-thinking way of building dams (DWAF 1997a).

In some catchments, clearing of alien plants has resulted in increased stream flow, and in some instances streams and springs that were dry have started flowing again. For rural people, and especially women, who have to walk great distances to collect water, the increased stream flow has reduced the burden of water collection (DWAF 1996b).

Apart from the conservation of water, the social benefits of the WFW programme have been great. In 1998/1999 Annual Report of the Working for Water programme, nearly 24 000 people were employed, 54% of which were women and 16% were youths (16 - 25 years) (DWAF 1999). One of the most important objectives of the programme is to not just create employment, but to provide people with the skills necessary to become independent contractors. The demand for a comprehensive training course, in which workers are taught general management and entrepreneurial skills, has been brought about by the move towards contract work. Training courses on life skills are also provided by the programme, and include financial management and first aid. Aside from employment, small-scale secondary industries, such as the production of charcoal making and building materials, have started to develop. Crèches for the workers children have also been established in nearly all of the projects, with equipment for the crèches and subsidised food being provided by the projects (DWAF 1997b).

One of the catchments presently being cleared of alien vegetation, as part of the WFW programme, is a section of the Mgeni catchment. These rivers (the eMpofana River, the Lions River and the Mgeni River above Midmar Dam) within the Mgeni catchment are the receiving streams of the Mooi-Umgeni Transfer Scheme. Thus these rivers are also being cleared of alien plants to allow for an increased flow of water in the river channels. On behalf of Umgeni Water, Goodall and Naudé (1998b) proposed a detailed costing and strategy for the clearing of the receiving streams of the Mooi-Mgeni Transfer Scheme. A summary of their methods has been included in Appendix 3.

2.6.4 The Mooi-Umgeni Transfer Scheme

The importance of the study area lies in the inter-basin transfer scheme proposed by the Department of Water Affairs and Forestry, in association with Umgeni Water. The scheme proposes moving water from the Mooi catchment to the Mgeni catchment (via the eMpofana and Lions Rivers) in order to meet the demand for water in the Durban and Pietermaritzburg metropolitan areas.

The movement of water from one catchment to another poses many problems, one of which is the increased volume of water leading to flooding and the inundation of farm land and infrastructure along certain sections of the river. In areas where the flow rate is rapid, existing terrestrial vegetation can be expected to be uprooted or die off, accompanied by erosion of the river channel. The uprooting of trees, such as black wattle, could lead to blockages in the river channel and the obstruction of flow of the river (Munro 1995a).

Thus the primary function of the clearance of alien plants along the eMpofana, Lions and Mgeni Rivers is to allow for an increased flow of water in these river channels. However, equally importantly, clearing the riparian zone will also meet the aims of the Working for Water Programme.

On the positive side, it has been noted that the increase in flow could off-set the use of water by the plantations in the area, and make more water available to farmers and the general community. The increase in the volume of water in the rivers could also dilute pollutants from fertilizer and manure (Munro 1995b).

There are a variety of alien species found in the riparian zone along the eMpofana River, a description of which may be found in Appendix 2. For each species, a brief description is given as well as an explanation of the problems the species presents to the environment, and finally their status with respect to the Agricultural Conservation Act, No 43 of 1983 is mentioned. The Appendix has been included in order to understand the importance of and the need for alien plant control and management.

The clearing of alien plants from the riparian zone of the eMpofana River must not be seen as solely meeting the objectives of the Mooi-Mgeni Transfer Scheme and the Working for Water programme, but needs to viewed in the broader context of the National Land Programme (NLP) and the Integrated Catchment Management (ICM), specifically the Mgeni Catchment Management Plan.

2.7 Shortcomings of Present Planning Approaches in Alien Plant Control

While effective control techniques exist for the control of alien plants, the actual implementation of these methods in controlling alien invasive plants has been poor Kluge *et al* 1991).

A number of reasons have been identified by Kluge and Erasmus (1991) and Loxton (1983) for this, including:

- no proper planning - alien plant control is generally done in an *ad hoc* manner.
- no follow-up - initial clearing should be followed-up for as long as there is a threat of re-infestation.

- short-term rather than long-term thinking - many attempts at alien plant control are aimed at 'solving' the problem in a few years, without accepting that control is an ongoing process.
- poor information on the real cost of control - apart from herbicide costs, little information exists on the cost of other aspects of alien plant control, such as labour. Often historical data is used for budgeting purposes.

Loxton (1983) has identified factors which need to be taken into consideration when budgeting for weed control. These factors as shown in table 2.1 below.

Table 2.1: Factors in Weed Control Budgeting (Loxton 1983)

VEGETATION	Species
	Density
	Area (ha)
	Height
	Location
TERRAIN	Slope/Access
	Carrier Volumes
	Transport - type and cost
	Equipment
	Method
LABOUR	Type - skilled/unskilled
	Number
	Task Rate (ha/manday)
	Unit Cost
METHOD	Overall treatment
	Spot treatment
	Stem injection
	Manual/Mechanical
	Aerial

In alien plant control, budgeting includes calculating: the volume and cost of herbicide, the mass and cost of grass seeds for rehabilitation, the amount and cost of equipment, and the number of labourers needed to clear the infestation and the cost of the labour. The following can be calculated with some measure of accuracy: herbicide volumes and cost, grass seed mass and cost as well as the necessary equipment requirements and costs. However, determining how long it will take to clear an infestation (work rate), and therefore the cost of labour is difficult. Labour costing has largely been an educated guess which is an area of concern in alien plant control planning. It is very important that the financial requirements of any weed control programme are adequately estimated from the start. Macdonald and Jarman (1985) believe that underestimating the requirements of an alien plant control could lead to programme failure and the possible discontinuation of the programme.

Temporary closure of alien plant control projects, such as the WFW projects, not only has a negative effect on the environmental, but also affects the income of the project workers. Project managers should ensure an even distribution of the budget throughout the year in order to prevent temporary project closure, as happened in September 1998 with the Central Umkomaas WFW (Naudé 1999). During this period, the project was put on hold for a few months and people, temporarily retrenched, struggled to survive. It is important that project costing and budgeting are conducted more correctly because of the dependence of the workers and their families on this source of income. Part of accurate budgeting includes realistic calculations of the project work rate and hence the labour costs.

Work rate, is expressed as labour days, and is the time it will take one person at work for 8 hours (including lunch and rest breaks) to complete a particular task (PPRI 1999). Clearly if there are four people working, the control time will be a quarter of the time it takes one person. PPRI have derived a table for labour days per hectare on 100% infestation for alien plant treatment (Appendix 3, Table A3.3). The number of labour days depends on the alien plant's habit as well as the particular treatment being applied in controlling the alien plant. The table, based on years of weed control experience, has taken some of the guess work out of predicting work rate.

It is however, the work rate under ideal conditions, in other words, where: the ground is relatively flat, the terrain is not particularly rocky or marshy, access vegetation is open and easy to move through, and the infestations are close to roads, so that little work-time is lost getting to the site of infestation.

Some answers to the question of work rates may be found in examining the work done by the forestry industry.

2.8 Work Rates

2.8.1 Work Rates in the Forestry Industry

The forestry industry in South Africa has done some work regarding calculating work rates as far as forestry is concerned. In 'Timber Harvesting Manual', de Laborde (1992), has created tables of the daily task rates (expressed as number of trees) for the different harvesting activities based on both tree height and trunk diameter at breast height (DBH). Daily task rate tables for wattle, eucalypt and pine felling have been created.

De Laborde (1992) differentiates between a normal daily task rate, as read from table, and an actual daily task rate which is the adjusted table value. The normal daily task rate (or the number of trees felled, debranched, etc.) may be decreased for a variety of reasons. For example, if poles are stacked in four different categories, the task rate is reduced by 15%. Along with the normal daily task rate, a maximum daily task rate is also provided, which should not be exceeded for risk of accidents and the health of the workers.

Such daily task rate tables are very useful in the timber industry where same species stands of trees of similar height and diameter at breast height (DBH) occur. However, the tables would be impractical for use in the removal of environmental weeds where there is frequently a mixture of tree species, and therefore great diversity in the height and the diameter at breast height (DBH) of the trees.

Slope is not only an important factor affecting the task rate in the timber industry, but is also relevant to the clearing of environmental weeds. Slope is seen as an impediment to chainsaw felling and cross-cutting in the timber industry. For the felling of wattle and eucalypts, the chainsaw operator's daily task rate is decreased by a factor, which is dependent on the slope of the ground and the diameter at breast height (DBH) of the tree. For the felling of pine trees, the daily work rate is given under two terrain conditions, light and difficult, as seen in table 2.2. The terrain conditions can be interpolated to cover most situations.

Table 2.2: Terrain Conditions for the Felling of Pine (de Laborde 1992)

TERRAIN CONDITIONS	DESCRIPTION
Light	1. Slope less than 15°. 2. Undergrowth, rocks and brush do not impede walking nor felling. 3. Felling faces are of such a length that chainsaw operator is required to change site up to 4 times only during normal daily task.
Difficult	1. Slope between 15° and 30°. 2. Undergrowth, rocks and brush impede felling. 3. Felling faces may be short, making it necessary for the chainsaw operator is required to change site 5 or more times only during normal daily task.

Slope needs to be included in the work rate costing for not only the timber industry, but also in alien plant removal. Obstructions to felling and walking, in the form of rocks or vegetation are also important in influencing the work rate of both the timber industry and the clearing of alien vegetation. Thus obstructions to movement and operations need to be factored into alien plant weed clearance.

As the timber industry is concerned with the speedy removal of trees, they have well-developed infrastructure in the form of roads. As little time as possible is lost in getting labour to and from the areas to be cleared. However, weeds frequently grow in inaccessible places, far from roads. Thus distance from a weed infestation to the nearest road is an important factor influencing the work rate clearance of environmental weeds. The further the weed infestation is from the nearest road, the longer it will take for labour and equipment to reach the site of clearance, and the less available time there is for clearing the weeds.

There was clearly a need to develop the concept of work rates for the control of alien plants. Goodall and Naudé (1998a) formally devised a means of calculating work rate based on the work done in the timber industry.

2.8.2 Work Rate in Alien Plant Control

While the effect of slope and terrain have been acknowledged by other alien plant controllers and the timer industry, Goodall and Naudé (1998a) have developed a means of calculating the work rate in alien plant control by accounting for the factors seen to affect the work rate. Four factors were identified by Goodall and Naudé (1998a) as impeding progress in weed clearance and thus were also influencing the work rates.

They are identified as:

- slope (X_1)
- terrain (rockiness) (X_2)
- vegetation (X_3)
- access time (X_4)

Each of the four factors was divided into categories and given a weighting according to their potential to impede weed clearance progress.

Slope was divided into the following four gradients each with a weighting:

- 0 - 15° (X_1 = 1)
- 16 - 25° (X_1 = 1.2)
- 26 - 35° (X_1 = 1.5)
- 36 - 45° (X_1 = 2)

Terrain was divided into the following three gradients each with a weighting:

- Not difficult ($X_2 = 1$)
- Moderately difficult ($X_2 = 1.2$)
- Very difficult ($X_2 = 1.5$)

Vegetation was classified according to its potential to impede operations and given a weighting:

- Short/open ($X_3 = 1$)
- Variable from open to closed ($X_3 = 1.4$)
- Thicket ($X_3 = 2$)

Access time is defined as the percentage labour-day lost in reaching and leaving areas. Three classes were identified and weightings were assigned as follows:

- Round trip up to 10% ($X_4 = 1$)
- Round trip 11 - 25% ($X_4 = 1.3$)
- Round trip more than 25% ($X_4 = 1.5$)

It is important to note that a work study has not been conducted to validate these values under field conditions.

Multiple linear regression analysis was used to determine the relationship between the factors identified by Goodall and Naudé (1998a) as impeding weed clearance progress (the independent variables) and the work rate (the dependent variable). The work rate or dependent variable is expressed as a correction to the work rate. The work rate correction will be examined in greater detail in the next chapter.

While the model formulated by Goodall and Naudé (1998a) is useful in its present theoretical state, the model may be improved by modifying and integrating it into GIS. The use of GIS allows for the more accurate calculation of the factors affecting work rate, particularly slope. Calculating slope without the use of GIS would require a large number of labourious measurements from topographical maps to calculate. The result is that in practice an estimate is taken in the field using broad slope categories. In addition, the use of GIS may not lend itself to small alien clearing programmes, since the cost benefits would not be favourable. Only with the large scale clearing of alien plants by projects such as the Working for Water programme has the demand for more accurate work rates become necessary, since the costs on this project run into many millions of rands. GIS will enable managers to more accurately calculate the labour and herbicide requirements for alien plant control. There are a number of other benefits of using GIS in alien plant control, including the running of scenarios and the production of maps for specific requirements on demand. Furthermore, while the initial capturing of data into GIS may be costly and time consuming, the model is in place to be re-used in subsequent alien control programmes, particularly follow-up control.

2.9 Geographical Information Systems (GIS)

A GIS can be defined as a computer-based system for capturing, storing, checking, manipulating, analysing and displaying spatially referenced data. The spatial referencing of information is the essential difference between a GIS and other databases (Aronoff 1989). Another important component in the definition of a GIS is the ability to manipulate and provide information, and not just data. Information is that which reduces uncertainty and enables decision making, while data is just the transmission medium. GIS provides a way of analysing data to aid the management and understanding of a wide variety of human and natural phenomena. A useful GIS should be able to assist in management decisions by providing a spatially referenced insight into a wide range of processes and activities (Chidley *et al* 1993 and Cinderby 1995).

2.9.1 Databases and Database Management Systems (DBMS)

Aronoff (1989) argues that the effective functioning of an organisationis dependent on accurate and timely information. A database refers to multiple related files, and a database management system (DBMS) is a way of storing the data in a meaningful way so that it can be extracted, sorted or queried (Chidley *et al* 1993). There are three data models that are used to organise databases: the hierarchical, the network and the relational models. Originally developed to handle the information needs of the business world, they have been adapted for use in the GIS environment.

In the hierarchical data model, the data are organised in a tree structure. While hierarchical systems are easy to understand and update, they are to a degree inflexible and restrictive in the type of query one may perform. Some of the inflexibility of the hierarchical data model is overcome with the network data model, although more extensive linkage information needs to be stored in a network database management system, adding to the size and complexity of the data files (Aronhof 1989).

Relational models are most commonly used to store attribute data in a GIS, and indeed, most modern DBMS are relational (Chidley *et al* 1993). The basic layout of the relational database management system (RDBMS) is the table or relation. The columns of the table are termed fields and the rows are called records (or tuples), with different fields containing different data types. In a RDBMS, a query can be made of any single table using any of the attribute fields, singly or together. Searches of related attributes stored in different tables can be made by linking two or more tables using any shared attribute, and is called a join operation. The query language is one of the most valuable features of a DBMS. It allows the user to retrieve information from the database based on certain criteria and in the format specified. The most commonly used language in RDBMS is standard query language (SQL) (Aranoff 1989).

A GIS's ultimate aim is to provide information that is needed and used by a person or organisation, i.e., it is a tool that aids the decision-making process. GIS contains an image or model of reality and is not just a means of storing cartographic data necessary for the drawing of maps. The modelling aspect of GIS is capable of creating new information for the decision-maker rather than merely retrieving information, previously encoded (Cinderby 1995).

2.9.2 Decision Support Systems (DSS)

A decision support system (DSS) "is a computer-based system that transforms and presents information in a form and manner designed to assist a manager make specific resource management decisions" (McCloy 1995, p 290). DSS were developed for business applications, but have more recently been applied to the management of the environment. DSS often include query functions, statistical analysis capabilities, spreadsheets, graphics and mapping functions to help the manager or end user evaluate the data in order to make more informed decisions.

According to Keen and Morton (1978), a DSS should:

- assist managers in making decisions to solve semi-structured problems
- support the manager's judgement rather than try to replace it
- improve the manager's decision-making effectiveness, rather than its efficiency

The figure 2.2 below illustrates the relationship between problem structure and the degree of support provided by the computer.

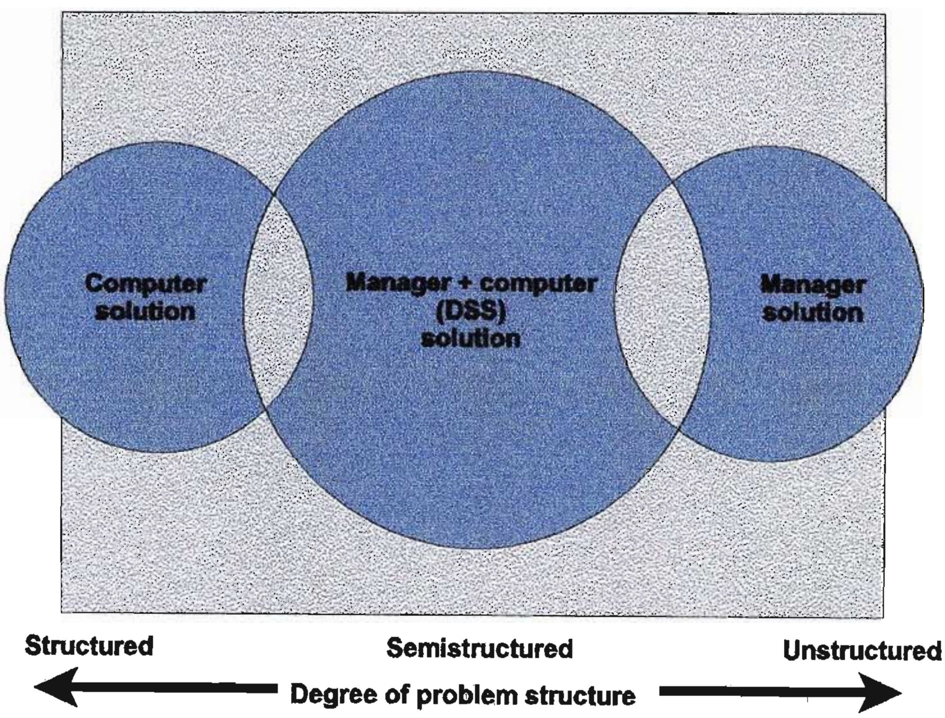

Figure 2.2: The DSS Focuses on Semi-Structured Problems (McCleod 1995)

The computer can be applied to the structured problems, while the manager deals with the unstructured problems which involve applying judgement or intuition. With semi-structured problems, the computer and the manager work together in solving problems (McLeod 1995).

A GIS is an example of a decision support system, and is also referred to as a spatial decision support system (SDSS) owing to its spatial component. A SDSS provides "a framework for integrating database management systems with analytical models, graphical display and tabular reporting capabilities, and the expert knowledge of decision-makers" (Maguire *et al* 1991, p 403/404).

The primary aim of this research is the creation of a SDSS for alien plant control along the eMpofana River, using Goodall and Naudé's (1998a) adapted work rate model.

2.10 GIS and Alien Plant Management & Planning in South Africa

While the following discussions are not related to work rates in alien plant control, they nevertheless deal with the use of GIS in managing alien plants, and therefore deserve a brief mention.

2.10.1 Working for Water Programme

A South African company, Geographic Information Management Systems (GIMS) has developed a project information management system for the Department of Water Affairs and Forestry's (DWAF) Working for Water programme. The system was designed to "keep track of projects, monitor progress and provide information necessary to manage the process" (Computer Graphics 1998, p 16). According to GIMS, the system brings together systematic data capture, reporting, modelling, monitoring and management tools. The system is based on ArcView 3.1 desktop GIS, which enables WFW managers around the country to access spatial data on their projects as well as provide central managers with up-to-date information on progress on a national scale.

2.10.2 Catchment Management with GIS

CSIR's Division of Forest Science and Technology (Forestek) has been involved in the design of a generic catchment management system to aid managers in their decision-making process. The Department of Environmental Affairs recognised the threat of catchment degradation from housing development, forestry, agriculture and recreation. Increasingly catchment managers are involved in conflicts over land use, with little access to information upon which they could make informed decisions. With an increasing population, pressures on the catchment areas, and the associated water resources will increase. There was thus a need to devise a catchment management system, using GIS, in order to help catchment managers in making their decisions (Richardson *et al* 1995).

2.11 Addressing the Shortcomings in Existing Alien Plant Control Management and Budgeting

As already mentioned, the most difficult aspect of alien plant control planning is the work rate, and hence labour costs. While the work rate model of Goodall and Naudé (1998a) goes a long way to addressing the problem of calculating the work rate in alien plant control, it is nevertheless still a cumbersome model to implement. The model needs to be adapted to include a spatial component and hence the need for a GIS.

The shortcomings of present weed control planning need to be highlighted and can best be shown by means of a case study. A management plan together with costing was carried out by the Goodall and Naudé (1998b) for weed clearance along the tributaries of the Mgeni River, the eMpofana and Lions Rivers and the Mgeni River (the receiving streams of the Mooi-Mgeni Transfer Scheme) above Midmar Dam. However, the costing for alien plant removal along the eMpofana, Lions and Mgeni Rivers was conducted using the derived (or theoretical) labour days (Appendix 3, Table A3.3) for each of the various tasks in alien plant control, but without taking into account other factors, such as gradient, which could influence the time taken to clear (or the number of labour days). It is the purpose of this research to use the existing costing as a means of comparing the improved work rates with the original work rates, in order to illustrate the shortcomings of present management approaches. Although costing exists for weed clearance along the eMpofana, Lions and Mgeni Rivers, above Midmar Dam, the study will confine itself to weed clearance along the eMpofana River

The integration of the original costings into a GIS, will also help with the decision making process in alien plant control. It is hoped that this research will enable more realistic budgeting for not only alien plant clearance along the eMpofana, Lions and Mgeni Rivers, but for large scale weed clearance projects, such as the Working for Water Programme, and for smaller farm units. If the costing in weed control is correctly estimated, it is anticipated that more effective weed control management can be expected with fewer programme failures and the greater likelihood of projects being completed.

CHAPTER 3
MATERIALS AND METHODS

3.1 Introduction

In order to effectively address the aims and objectives of this study, the methods have been divided into three phases: work rate modelling, data capture and GIS analysis. The work rate model of Goodall and Naudé (1998a) was taken as the starting point, in the development of a work rate model, suitable for predicting the work rate for alien plant control, and suited to the conditions of the research area. Data capture consisted of the creation of an alien plant control database from the budgeting conducted by Goodall and Naudé (1998b) and its integration into ArcView 3.1. Digital data was also captured and added to the existing data in ArcView 3.1. The GIS analysis involved the incorporation of the work rate model into ArcView 3.1 in order to create images of improved work rates for all the phases of alien plant control. A description of the study area has been provided for the purposes of orientation.

Since the costing and budgeting conducted by Goodall and Naudé (1998b) was used in the creation of the database for this research, a summary of the method by which they collected the data and conducted the costing for alien plant removal, along the eMpofana River, has been included in Appendix 3. Furthermore, in order to demonstrate the manner in which the work rate model has improved work rate calculations and costing for alien plant control, a comparison of an existing costing for work rate is required. The costing conducted by Goodall and Naudé (1998b), on behalf of Umgeni Water for the clearing of alien plants along the eMpofana, Lions and Mgeni Rivers (the receiving streams of the Mooi-Mgeni Transfer Scheme), was used for such a comparison as the raw data was still available.

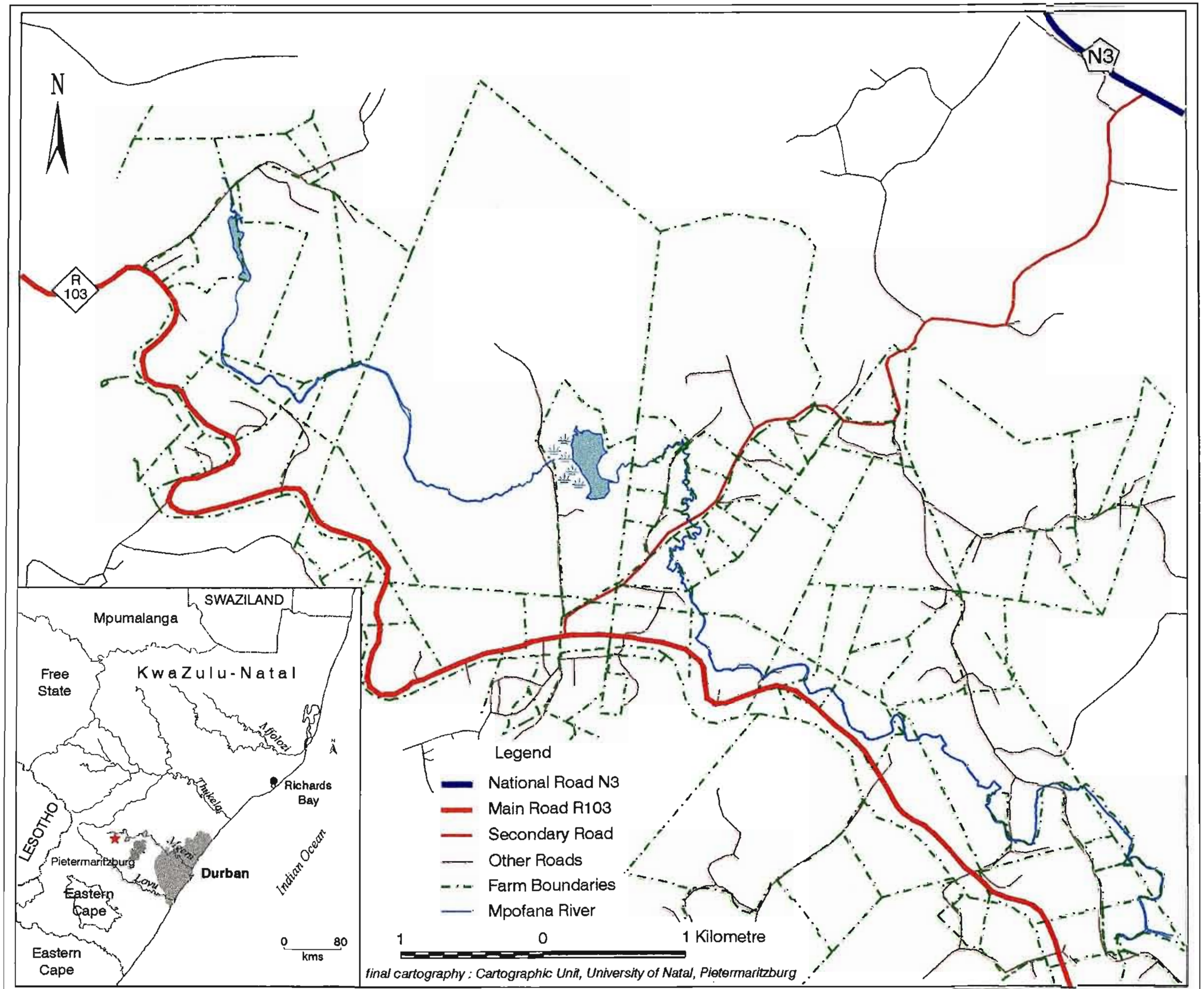

Figure 3.1: Map of Study Area

3.2 Study Area

The eMpofana River rises south of Nottingham Road, KwaZulu-Natal, South Africa, and is situated between latitudes 29° 21′ 40″ S and 29° 24′ 55″ S and longitudes 30° 01′ 40″ E and 30° 05′ 55″ E. Figure 3.1 shows the location of the study area. The river flows for 13,6 km in a south-easterly direction before joining the Lions River which in turn joins the Mgeni River. The riparian zone along the eMpofana River forms the area of study for this research.

According to Acocks (1988), the study area falls within the Natal Mistbelt Ngongoni Veld type, and coincides with Low and Rebelo's (1996) Short Mistbelt Grassland Biome. Based on Camp's (1999) division of KwaZulu-Natal into bioresource groups (BRG) (categorised mainly on climate and vegetation), the study area falls into BRG 5.2, or the Moist Midlands Mistbelt bioresource group, sub-group 2 - the Central Midlands.

The region is characterised by an average annual rainfall of between 900 and 1200 millimetres, occurring in summer. Temperatures may vary between - 2°C and 38°C, with an average of 17°C. The soils of the region are dystrophic as a result of the high rainfall. Topsoils are largely free-draining and high in organic matter, while yellow or red apedal subsoils are common. The terrain in the area is characterised by steep, broken valleys and hills with crests of moderate slopes (Low & Rebelo 1996 and Camp 1999).

The vegetation is a *Themeda*-dominated sourveld. However, large areas have been replaced by *Aristida junctiformis* as a result of intensive agriculture. While predominantly a grassland biome, patches of indigenous forest occur. Commercial forestry has replaced much of the grassland, and large areas have been invaded by exotics, notably *Acacia* spp., *Eucalyptus* spp. and American bramble (*Rubus cuneifolius*) (Acocks 1988, Low & Rebelo 1996 and Camp 1999).

This BRG sub-group has a very high agricultural potential, and is considered to be one of the areas with the highest climatic reliability in the country. The predominant activity within the area is farming, including dairy, beef, vegetable, trout, timber and stud farming. Tourism and recreation are also important activities (Munro 1995a and Camp 1999).

3.3 Work Rate Modelling

3.3.1 Introduction

In weed control costing and planning, much of the costing, such as the volume of herbicide and the equipment required, can be predicted with reasonable accuracy. However, the work rate is affected by a number of variables, and is less easy to estimate (Goodall & Naudé 1998a, de Laborde 1992 and Loxton 1983). Work rate models applicable to weed control have been developed by Goodall and Naudé (1998b) and by the timber industry, (de Laborde 1992 and Loxton 1983). It is necessary, for the purposes of a GIS-based weed control modelling approach, to develop these work rate models further, since they were not originally designed for a GIS. Goodall and Naudé's (1998a) work rate model for alien plant control was taken as the starting point, and were developed and modified with reference to the work of the timber industry to produce a workable model, suitable for predicting the work rate for weed control, and suited to the conditions in the research area. The model will take into account all possible factors influencing the work rate.

3.3.2 Work Rate Variables

In Chapter 2, four factors were identified by Goodall and Naudé (1998b) as impeding progress in weed clearance and thus having an influence on the work rates.

They were identified as:

- slope (X_1)
- terrain (rockiness) (X_2)
- vegetation (X_3)
- access time (X_4)

The work rate model devised by Goodall and Naudé (1998b) was used as the basis for this research. However, the following three adaptions to Goodall and Naudé's (1998b) model were made partly as a result of the particular characteristics of the study area.

Firstly, in a discussion with PPRI (*pers. com.* 1999), it was decided that for the purposes of this study, the terrain variable would be excluded. In the study area, evidence of the terrain (X_2) or rockiness variable is at an absolute minimum and will thus have a negligible measurable effect in terms of the aim of this study. However, it should be borne in mind that for areas that are more mountainous (eg. Western Cape), terrain would have a very real impact on the weed clearance work rate. The remaining three variables are considered as being important as factors hindering clearing operations in the study area and will manifest themselves in their influence on the work rates.

Secondly, it was also decided that, as vegetation is classified according to its ability to impede operations, the word 'penetrability' is more useful in describing the influence vegetation has on work rates. Following a discussion with PPRI (*pers. com.* 1999), American bramble was identified as being the most common access problem species in the study area. Thus, the density of American bramble was used to reflect penetrability, and use was made of the same vegetation (X_3) weightings used by Goodall and Naudé (1998b).

Thirdly, access time was converted to distance, as it is easier to work with distance rather than time in a GIS.

3.3.3 Adaption of Work Rate Variables

Each of the factors (slope, penetrability and access) is divided into a number of categories and given a weighting, expressed as a factor, according to the degree to which they affect the work rate. It is necessary to reiterate that no work study has been conducted to verify these values / weightings under field conditions.

Slope (X_1)

According to Goodall and Naudé (1998b), slopes are divided into four gradients, and weighted according to their effect on the work rate. This weighting for slope, or slope factor, is shown in table 3.1 below, and is adapted from the work of de Laborde (1992).

Table 3.1: Slope Factors

Slope	Factor
0 - 15°	$X_1 = 1$
16 - 25°	$X_1 = 1.2$
26 - 35°	$X_1 = 1.5$
36 - 45°	$X_1 = 2$

Penetrability (X_2)

The original weighting by Goodall and Naudé (1998b) for vegetation was: short/open ($X_3 = 1$), variable from open to closed ($X_3 = 1.4$) and thicket ($X_3 = 2$). In a feasibility study of a riparian zone rehabilitation programme, American bramble was identified as being the most common access problem species (Midmar Catchment Riparian Zone Rehabilitation Study 1997). American bramble is problematic on two accounts. It is a declared weed in terms of the Agricultural Conservation Act, No 43 of 1983 and thus needs to be controlled. Furthermore, it seriously impedes access to other weeds being controlled and consequently slows down clearing operations. For this reason, and following a discussion with the Plant Protection Research Institute (PPRI) (*pers. com.* 1999), it was decided that American bramble was the weed species most likely to impede movement in the study area, and was classified as follows, using the same weightings devised by Goodall and Naudé (1998b).

Table 3.2: Penetrability Factors

% Bramble (Penetrability)	Factor
0 - 5 % (low)	1
6 - 50 % (medium)	1.4
51 - 100 % (dense)	2

Distance of Weed Infestation from the Nearest Road (X_3)

The original access time according to Goodall and Naudé (1998b) is the percentage time taken up in reaching and leaving areas, and is divided into three categories, viz. a round trip of up to 10% (X_4 = 1), 11 - 25 % (X_4 = 1.3) and more than 25% (X_4 = 1.5).

For the purposes of this study, time was converted into distance from the weed infestation to the nearest road, as it is easier to use distance rather than time in a GIS. The calculation of distance factors was based on the following two assumptions:

- 6 hours of actual work (8 hours minus 1 hour for lunch, two 15 minute breaks for tea, and 15 minutes at the beginning and the end of the day for packing and unpacking)
- a constant walking speed of 4km/h regardless of terrain and considering that the workers will be carrying herbicide and equipment

Table 3.3 below shows how the distance factor was calculated. To calculate the distance factor, the round trip distance is needed. Using the walking speed of 4km/h, the walking time can be calculated, which is subtracted from the 6 hours of actual work to get the working time. The 6-hour working day is then divided by the working time to get the distance factor.

Table 3.3: Calculation of Distance Factors

Distance from road to polygon (km)	Round trip distance (km)	Walking time (hours)	Working time (hours)	Factor
0 - 0.6	0 - 1.2	1.2 ÷ 4 = 0.3	6 - 0.3 = 5.7	6 ÷ 5.7 ≈ 1
0.6 - 1.2	1.2 - 2.4	0.6	5.4	1.1
1.2 - 3	2.4 - 6	1.5	4.5	1.3
3 - 4	6 - 8	2	4	1.5
4 - 5	8 - 10	2.5	3.5	1.7
5 - 6	10 - 12	3	3	2

3.3.4 Modelling Method

Multiple Linear Regression

Regression analysis shows the relationship between an independent variable (or set of independent variables) and one dependent variable. It answers the question: to what extent can a dependent variable be explained and predicted by one or more independent variables? Regression analysis makes use of the 'least squares' method to calculate a straight line that best fits the data. It also gives an indication of the confidence or accuracy of the relationship. Simple linear regressions are used when there is only one independent variable, and multiple regression when there is more than one independent variable (Corel Quattro Pro 8 and Microsoft Excel 97).

While it is accepted that work rate in weed clearance is affected by a number of factors, including slope, terrain, etc., the exact nature of the relationship is not known. Regression analysis provides a means of predicting that relationship. Goodall and Naudé (1998b) made use of multiple linear regression analysis to determine the relationship between the factors they have identified as impeding weed clearance progress, namely slope (X_1), terrain (X_2), vegetation (X_3) and access time (X_4) (the independent variables), and the work rate (the dependent variable). The work rate or dependent variable is expressed as a correction to the work rate.

The general equation of their multiple linear regression was as follows:

$$Y = a + \sum_{n=1}^{m} \left(b_n X_n \right)$$

where: X_n = factors affecting work rate (namely slope (X_1), terrain (X_2), vegetation (X_3) and access time (X_4))

b_n = coefficient corresponding to each work rate factor

a = constant

Y = correction to work rate for conditions in the field (when Y>1)

As mentioned, the work rate or dependent variable is expressed as a correction to the work rate (Y). The work rates to be corrected are those shown in Appendix 3, table A3.3. For example, if wattle saplings of density 25% are to be brushcut, the number of labour days for 100% infestation according to the table is 57 labour days. Therefore the number of labour days on 25 % infestation will be 14.25. This value does not account for the possible factors affecting the work rate. If, for example, the correction to the work rate is 1.53, then the real number of labour days when slope, terrain, vegetation and access time are taken into account is:

14.25 x 1.53 = 21.8 labour days.

For the purposes of this research, multiple linear regression will also be used to determine the relationship between the factors identified as influencing the work rate in the study area, and the correction to the work rate. Furthermore, the outcome of a regression analysis lends itself for use in a raster or grid[1] GIS, as will be demonstrated later.

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1 There are two basic data structures used in GIS:

- vector structure is based on a series of co-ordinates or co-ordinate give the location of a point, line, node, segment or polygon
- raster (or grid) structure is based on cell values, in which each cell in a coverage has a specified value (Burrough 1996 and Maguire *et al* 1991).

Modelling Process

Once the three work rate factors in the research area had been identified and each had been broken down and weighted, the relationship between these work rate factors (the independent variables) and the correction to the work rate (the independent variable) needed to be determined. A multiple linear regression was run, adapted from the data provided by Goodall and Naudé (1998b), in order to determine this relationship between: slope, penetrability, and distance from the nearest road (the independent variables), and the work rate, expressed as correction to the work rate (the dependent variable). Advanced Regression in Corel QuattroPro 8 was used to run the regression equation. The result is given below:

$$Y = -2.004 + 1.058\,X_1 + 1.108\,X_2 + 1.031\,X_3$$

$$(r^2 = 0.914,\ df = 72,\ p < 0.001)$$

where: X_1 = slope factor

X_2 = penetrability factor

X_3 = distance factor

Y = correction to work rate for conditions in the field (when Y>1)

For more detailed results of the regression refer to Appendix 5.

The work rate model is now ready to be incorporated into ArcView 3.1 (as shown in section 3.6) in order to create a more realistic costing for the work rate in alien plant control.

3.4 Attribute Data Capture

3.4.1 Introduction

Since one of the aims of the research was to create a spatial decision support system for alien plant control managers, a database had to be created and incorporated into a GIS (ArcView 3.1). In 1998, Goodall and Naudé (1998a) costed the removal of alien plants along the receiving streams (eMpofana, Lions and Mgeni Rivers) of the

Mooi-Mgeni Transfer Scheme. Use was made of spread sheets to calculate the cost of clearing the alien vegetation, and ArcView3.1 was used to indicate the position, area and density of the weed infestations. Much of the base data for this research was gathered from the spreadsheets produced by Goodall and Naudé (1998b). This data was not in a form that was suitable for inclusion in a GIS model and thus had to undergo a number of transformations and additions to be of use for this study. The digital data was also available but needed some minor adaptions.

3.4.2 The Creation of the Database

The format of the base data received from Goodall and Naudé (1998b) consisted of detailed spreadsheets of the costing calculations for each polygon done in Quattro Pro 8 (Corel Corporation and Corel Corporation Ltd 1997). A number of steps were needed to extract the data from the spreadsheets, and create the database suitable for importing into ArcView 3.1 (ESRI 1998).

Firstly, the spreadsheets were adapted and updated. In order to express the data in the manner required for the model, values needed to be totalled. The labour, and herbicide had also to be updated in order to reflect current prices and costs. Appendix 4 gives the labour structure and wages and the herbicide and carrier costs for the weed control operation as at August 1999. The grass seed and phosphate costs are from 1998.

Secondly, new spreadsheets, compatible with ArcView 3.1 database format, were created. It was decided to make use of the same spreadsheet package used for the base data, namely QuattroPro Suite 8. The reason for this being that the newly created spreadsheets could be linked with those formulated by Goodall and Naudé (1998b), so that any changes to the original spreadsheets, such as an increase in the cost of herbicide or labour, would be automatically reflected in the new tables.

The original spreadsheets consisted of a number of spreadsheets within a single file. It was necessary to transform the data into a database form where a single file consisted of one spreadsheet with a number of fields or columns, and their corresponding records or rows. In addition, not all the costing calculations from the original spreadsheets were needed in this research, only the results of these computations were required. These results (such as the number of labour days for the initial control or the cost of herbicide for the follow-up control) formed the fields of the spreadsheet, with the particular entries for each of the polygons making up the records.

Thirdly, the link between the spreadsheets in Quattro Pro was removed by converting the figures in the newly created spreadsheets into absolute values.

Fourthly, the spreadsheets of absolute values were converted to dBase files (in this case dBase IV), a form suitable for importing into ArcView 3.1. Figure 3.2 gives the steps taken to create the dBase files from the original spread sheets.

The result was the following dBASE files which were imported into ArcView 3.1:

1. Weed Area per Species per Polygon
2. Weed Density per Species per Polygon
3. Initial Control: Volume & Cost of Herbicide Mix per Polygon
4. Initial Control: Theoretical Labour Days & Costs per Polygon
5. Rehabilitation: Mass & Cost of Grass Mix per Polygon
6. Rehabilitation: Theoretical Labour Days & Costs per Polygon
7. Follow-Up Control: Volume & Cost of Herbicide Mix per Polygon
8. Follow-Up Control: Theoretical Labour Days & Costs per Polygon
9. Complete Treatment: Volume & Cost of Herbicide Mix per Polygon
10. Complete Treatment: Theoretical Labour Days & Costs per Polygon

The original labour days and labour cost values, as calculated by Goodall and Naudé (1998b), are referred to as theoretical labour days and theoretical labour costs, as the values were generated from a table (see Appendix 3, table A3.3) The labour days and labour cost values produced by the work rate model are referred to as corrected labour days and corrected labour costs.

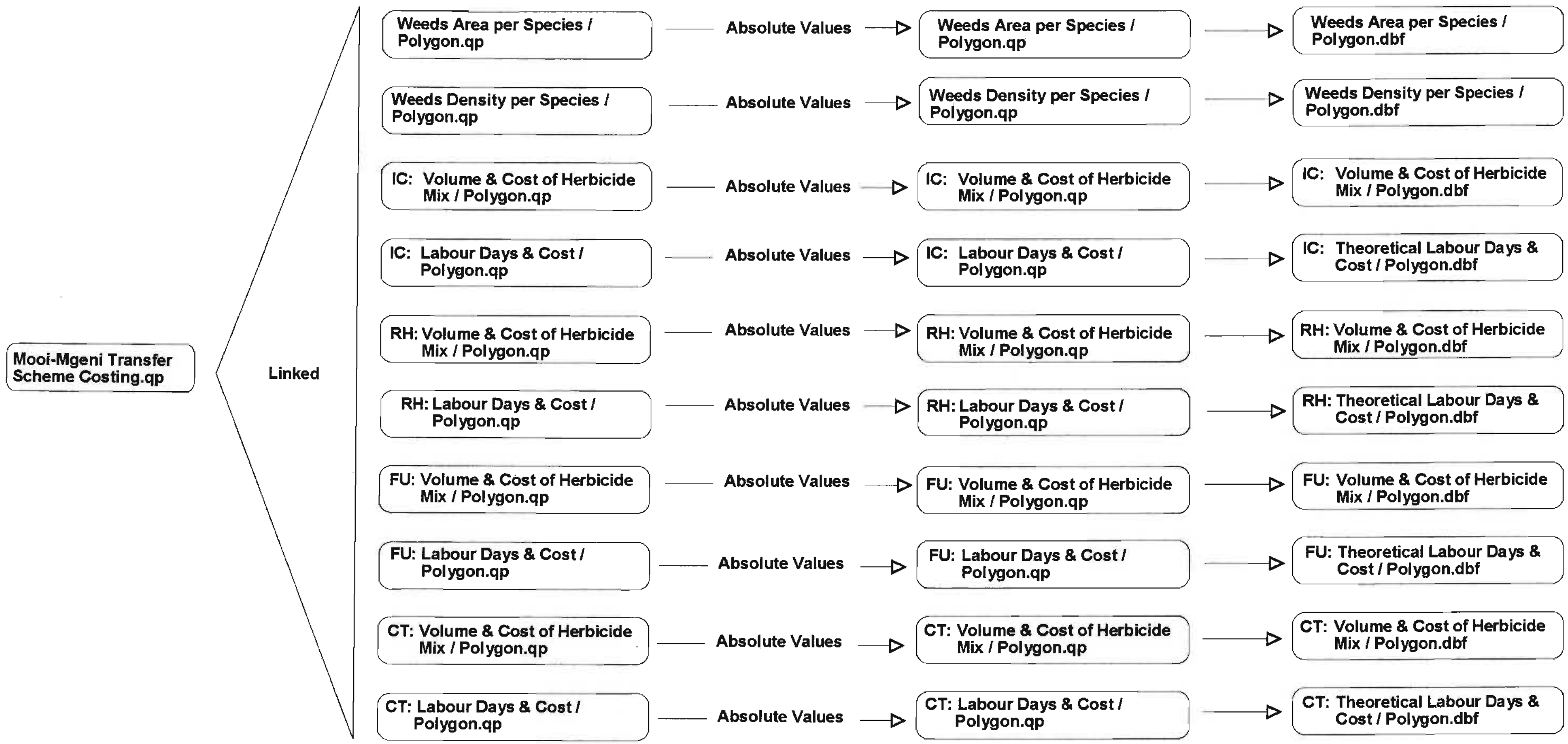

Figure 3.2: Creation of dBase files for use in ArcView

Legend
IC = Initial Control
RH = Rehabilitation
FU = Follow-up Control
CT = Complete Treatment

3.5 GIS Data Capture

3.5.1 Introduction

The digital data for the study area received from Goodall and Naudé (1998b) consisted of the weed polygons in ArcView 3.0 format, with a small attribute table containing data relating to the weed density per polygon, the area and perimeter of the polygon, and the farm name and subdivision number. The infrastructure, drainage and cadastral information was also available in CAD form (.UC). The .UC layers had to be converted to .dbf files, before being imported to ArcView 3.1 where they were converted into shape files. Some of the layers, such as the powerlines and the 30 metre buffer, were imported simply for display purposes, while others, notably the road layers, were required in the modelling process. In addition, the contour lines needed capturing in order to create the slope factor theme.

3.5.2 Contour Capture

The contour data was captured from the following 1 : 10 000 orthophotographs:

- 2930 AC 11 Michael house
- 2930 AC 12 Balgowan
- 2930 AC 17 Caversham

The orthophotographs were placed on a light table, and the required contours and the contour heights (in 5 metre intervals) were traced onto Decease double matt paper. The contours were traced in a strip approximately 500 metres wide on either side of the eMpofana River, not only to cover the weed infestations in the riparian zone, but also to enable the creation of a digital terrain model (DTM) of the river valley for display purposes. The cross hairs on the orthophotographs were also recorded, and are important in georeferencing the data so that the contours could be used with the existing digital data for the same area. The traced contours were then scanned and vectorised by Enviromap cc. As the contours had been saved as an ArcView project file (.apr), they were immediately available for use in ArcView 3.1.

3.5.3 Editing the Digital Data

Since the weed clearance costing conducted by Goodall and Naudé (1998b) was for the eMpofana, Lions and Mgeni Rivers, the weed polygon data for the Lions and Mgeni Rivers was deleted by removing the records from the weed polygon's attribute table. Otherwise the original digital data was clean and needed no further changes.

3.5.4 Integrating the Database with ArcView Digital Data

The database files were imported into ArcView 3.1, and were joined to the attribute table of the weed polygons theme. The polygons of weed infestations theme (referred to as weed polygons) was then copied a number of times, and by using the classification field in the legend editor, themes for some of the important fields, such as Volume of Herbicide for Initial Control, were created. Figure 3.3 shows the steps needed to create these themes. However, there are more data available for each polygon, as is shown in table 4.1 (Chapter 4), which could be expressed as themes.

Setting up a hot link between the features in a theme and external files, is another way of providing additional information on a view. Information that can be hot linked include: photographs, video clips, building floor plans and legal documents. Once a theme's hot links has been defined, clicking on one of the themes features with the Hot Link tool, automatically displays the file specified (in this case a photograph) as the hot link for that feature. To set up the hot link, a table, called image, was added to the weed polygons' theme attribute table and the pathname of the file containing the photograph was entered. The pathname of a photograph of each of the polygons could be added to the weed polygons' theme attribute table in order to further aid the decision-maker.

By integrating the database with the digital data, a spatial decision support system (SDSS) was created enabling alien plant control managers to query the data and thereby make informed decisions. While all the information pertaining to herbicide volumes and costs, and grass seed masses and costs may be used by the decision-

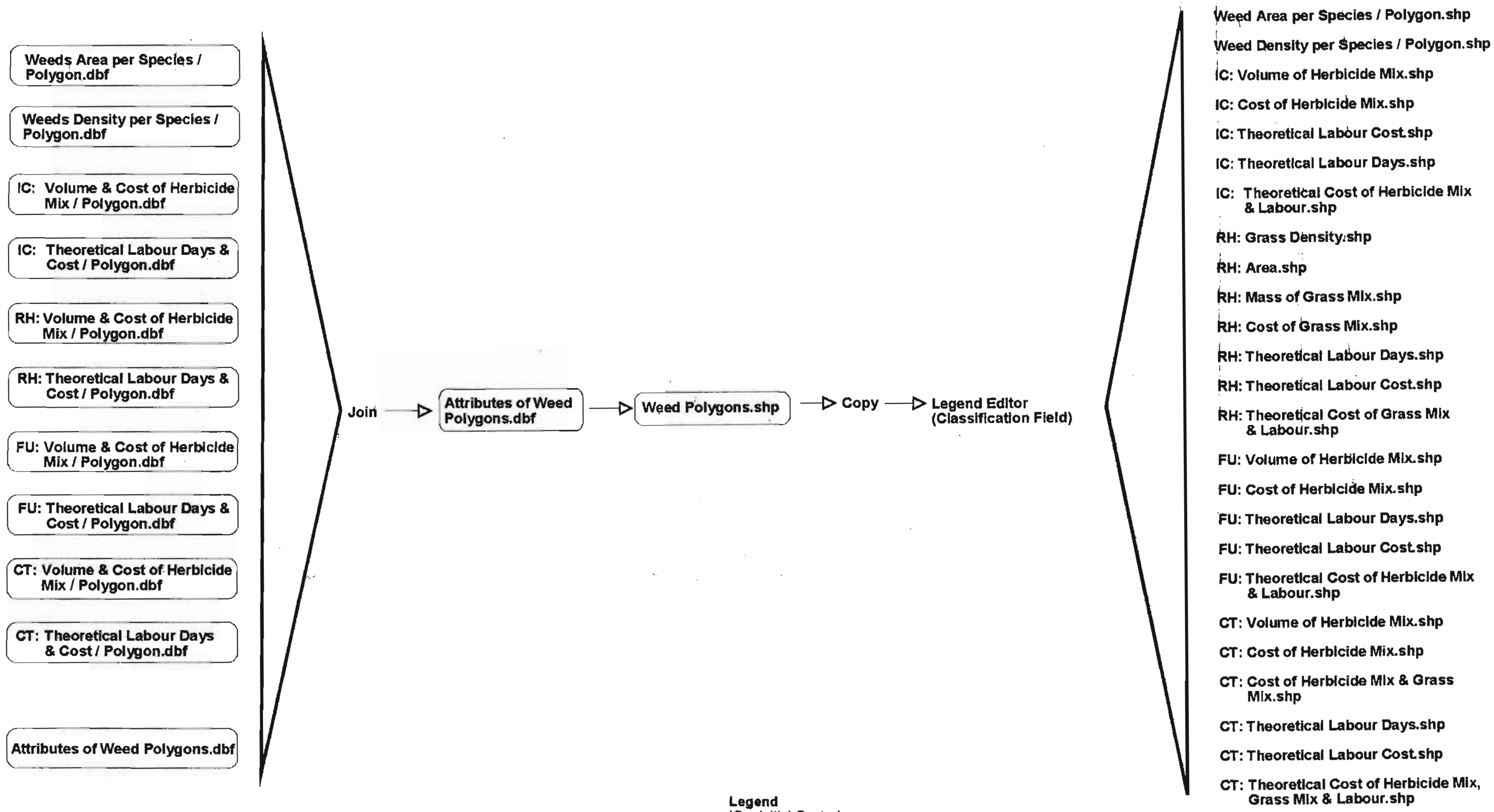

Figure 3.3: Creation of costing themes

Legend
IC = Initial Control
RH = Rehabilitation
FU = Follow-up Control
CT = Complete Treatment

maker as is, the work rate needs to be adjusted as it is at this stage being expressed under theoretical conditions. The work rate needs to be adapted to account for factors such as gradient, distance of infestation from the road and penetrability of weed infestation, in order to create a weed clearance model which most approximates reality.

3.6 GIS Analysis

3.6.1 Introduction

Slope, penetrability and distance were identified as the factors which impede the work rate in the study area. As mentioned in section 3.3.4, a regression equation lends itself for use in a raster or grid GIS. Each factor was dealt with individually and a grid theme created for each of the factors. The Map Calculator function in ArcView 3.1 was then used to combine the work rate factor themes using the regression equation above, in order to create a theme of the correction to the work rate.

3.6.2 Slope (X_1)

Figure 3.4 shows the steps taken to create the Slope Factor theme. The first step was to create a slope theme from the contours. To achieve this, a digital elevation model (DEM[2]) or digital terrain model (DTM) was created using a triangulated irregular network (TIN[3]) to represent the land surface. The DEM was then converted to a grid from which the slope theme was obtained using the ArcView 3.1 function, Derive Slope.

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2 A DEM is a digital representation of a continuous variable over a two-dimensional surface by a regular array of z-values referenced to a common datum. DEMs are typically used to represent terrain relief. Also referred to as digital terrain models (Maguire *et al* 1991).

3 A TIN is a surface representation derived from irregularly spaced sample points and breakline features. The tin data set includes topological relationships between points and their neighbouring triangles. Each sample point has an x, y co-ordinate and a surface, or z-value. These points are connected by edges to form a set of non-overlapping triangles used to represent the surface (Maguire *et al* 1991).

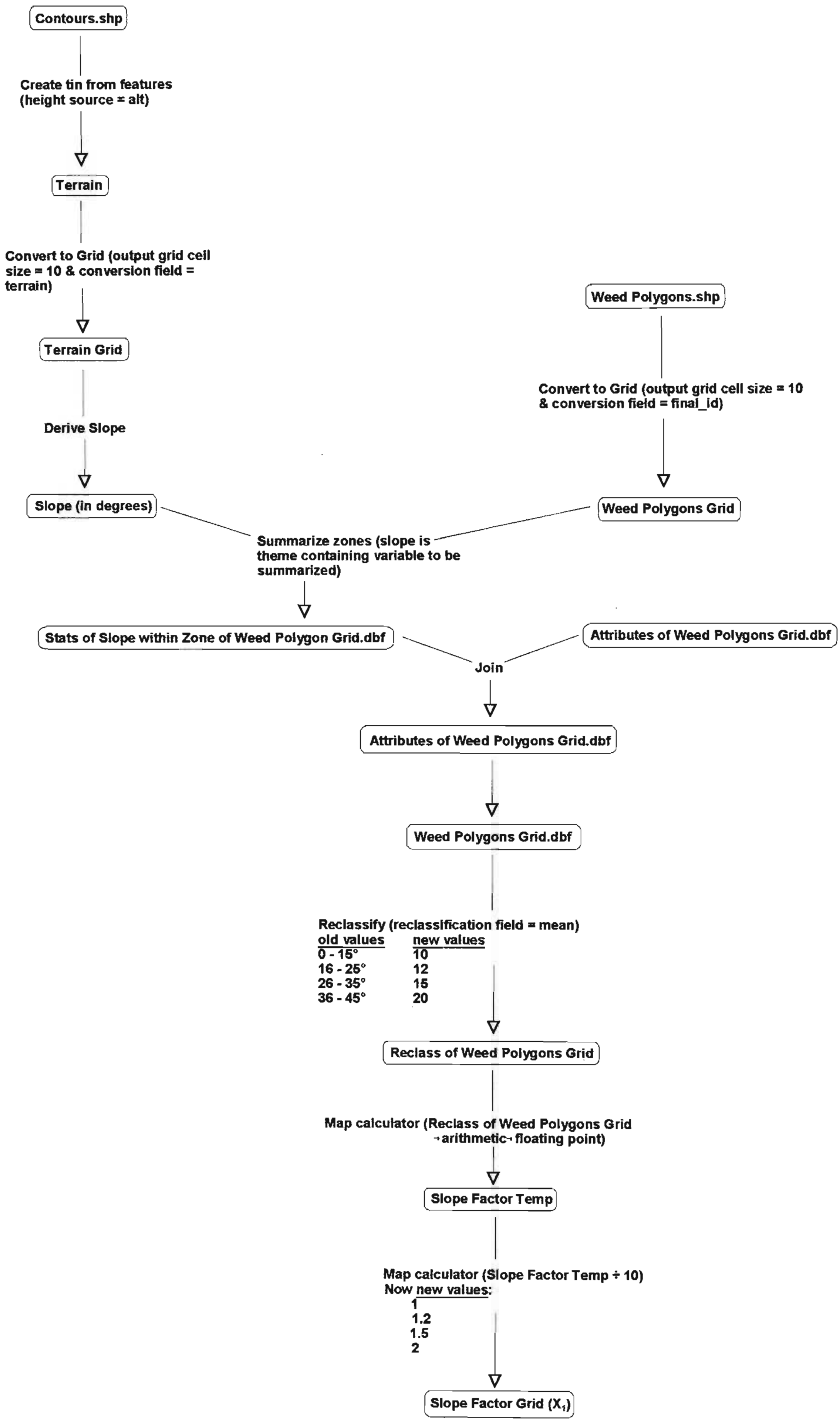


Figure 3.4: Creation of slope factor theme (X_1)

Next, in order to assign a slope factor to each polygon, the average or mean slope for each polygon was needed. The slope statistics (including the mean) for each polygon was obtained by using the Summarize Zones function in ArcView 3.1.

Thirdly, the weed polygons theme was converted to a grid, and its attribute table was then joined to the Statistics of Slope table.

Finally, the average slopes were reclassified according to table 3.1, to create the Slope Factor Grid theme. This involved a number of steps due to the fact that the average slope data is discrete and thus can only be stored as an integer grid theme, while the slope factors are real numbers (ArcView 3.1 GIS: The Geographic Information System for Everyone, 1996). This required reclassifying the average slope per polygon (grid) from degrees to factors which were multiplied by ten in order to convert them to integers. Table 3.4 shows the reclassification needed to create the Slope Factor Grid theme.

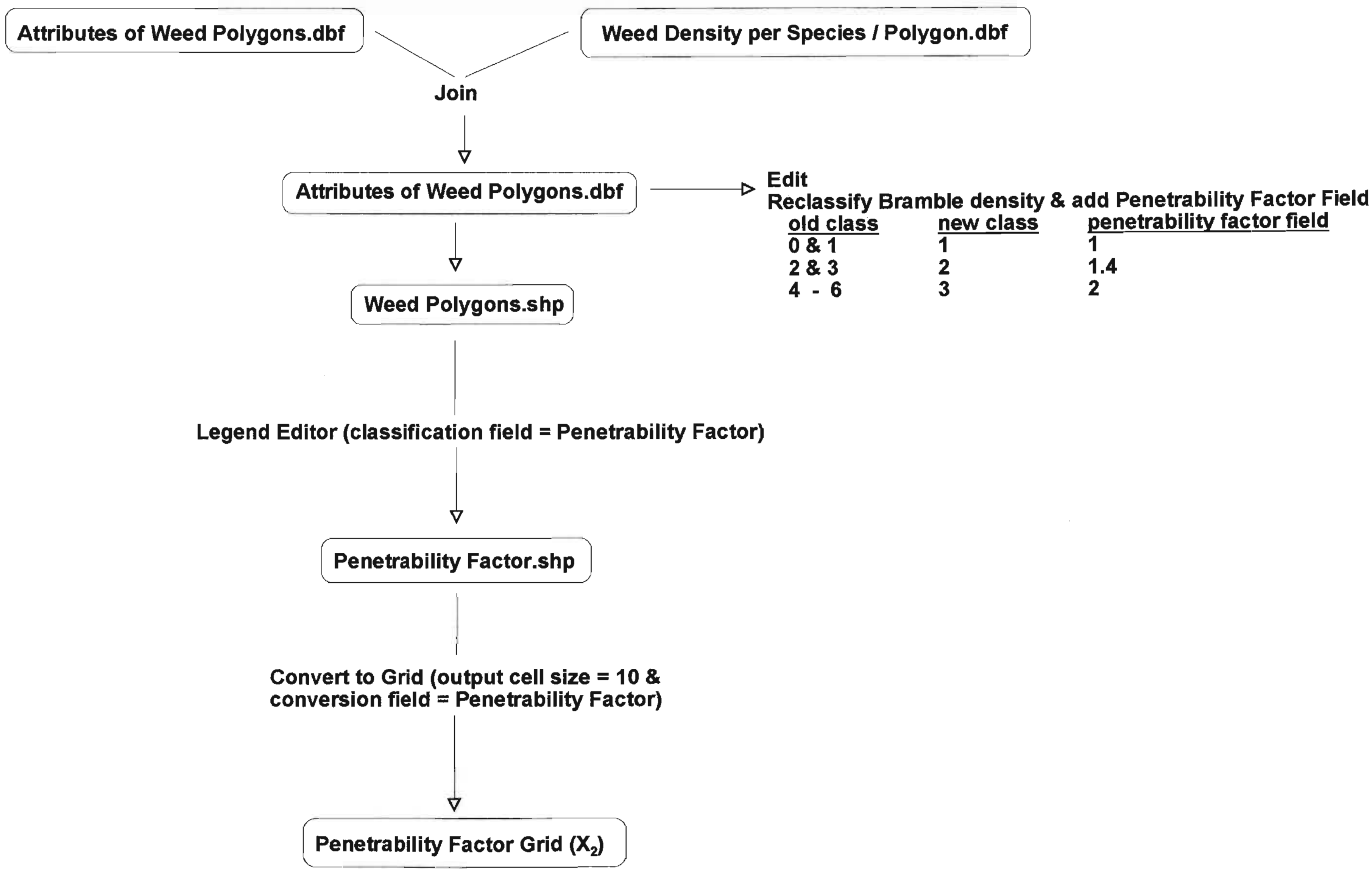
Table 3.4: Slope Reclassification from Degrees to Factors

Old values (in degrees)	New values (factor x 10)
0 - 15	1 x 10 = 10
16 - 25	1.2 x 10 = 12
26 - 35	1.5 x 10 = 15
36 - 45	2 x 10 = 20

Next, using map calculator in ArcView 3.1, the reclassified theme was converted to a floating point grid theme in order to display the slope factors which are real numbers. Finally, again using map calculator in ArcView 3.1, the floating point grid theme had to be divided by 10 so that the correct slope factors could be obtained.

3.6.3 Penetrability (X_2)

As already discussed, it was concluded that American bramble was the weed species most likely to impede movement in the study area. So penetrability is dependent on the density of American bramble. Figure 3.5 shows the steps taken to create the Penetrability Factor Grid theme. The Weeds Density per Species per Polygon table



·igure 3.5: Creation of penetrability factor grid theme (X_2)

(.dbf) which included American bramble had earlier been joined to the attribute table of the weed polygon theme. As shown in table 3.5, a new field was added to the attribute table of the weed polygon theme in order to reclassify the bramble density into low, medium and dense classes. A penetrability factor field was also added, and the reclassified bramble density was assigned the values, as shown in table 3.2, to create the penetrability factor theme.

Table 3.5: Reclassification of Bramble Density

Old Bramble Density Class	Percentage	New Bramble Density Class	Penetrability Factor (X_2)
0	0%	1 (low)	1
1	1 - 5%	1 (low)	1
2	6 - 25%	2 (medium)	1.4
3	26 - 50%	2 (medium)	1.4
4	51 - 75%	3 (dense)	2
5	76 - 100%	3 (dense)	2
6	> 100% (understorey weeds)	3 (dense)	2

A new theme was created from the weed polygon theme by selecting penetrability factor as the classification field from the legend editor. This was in turn converted into a grid theme in order to create the Penetrability Factor Grid theme.

3.6.4 Distance of Weed Infestation from the nearest Road (X_3)

The steps taken to create the Distance Factor Grid theme are shown in figure 3.6. The first step in creating the distance factor theme was to import the three access road layers from CAD into ArcView 3.1 and then convert them to shapefiles.
The next step was to combine the three road themes into one road theme, using a function called Merge Themes in X-Tools.

Thirdly, by using the Select by Theme function in ArcView 3.1, all polygons within 100 metres of the road were selected. A distance field was created in the attribute

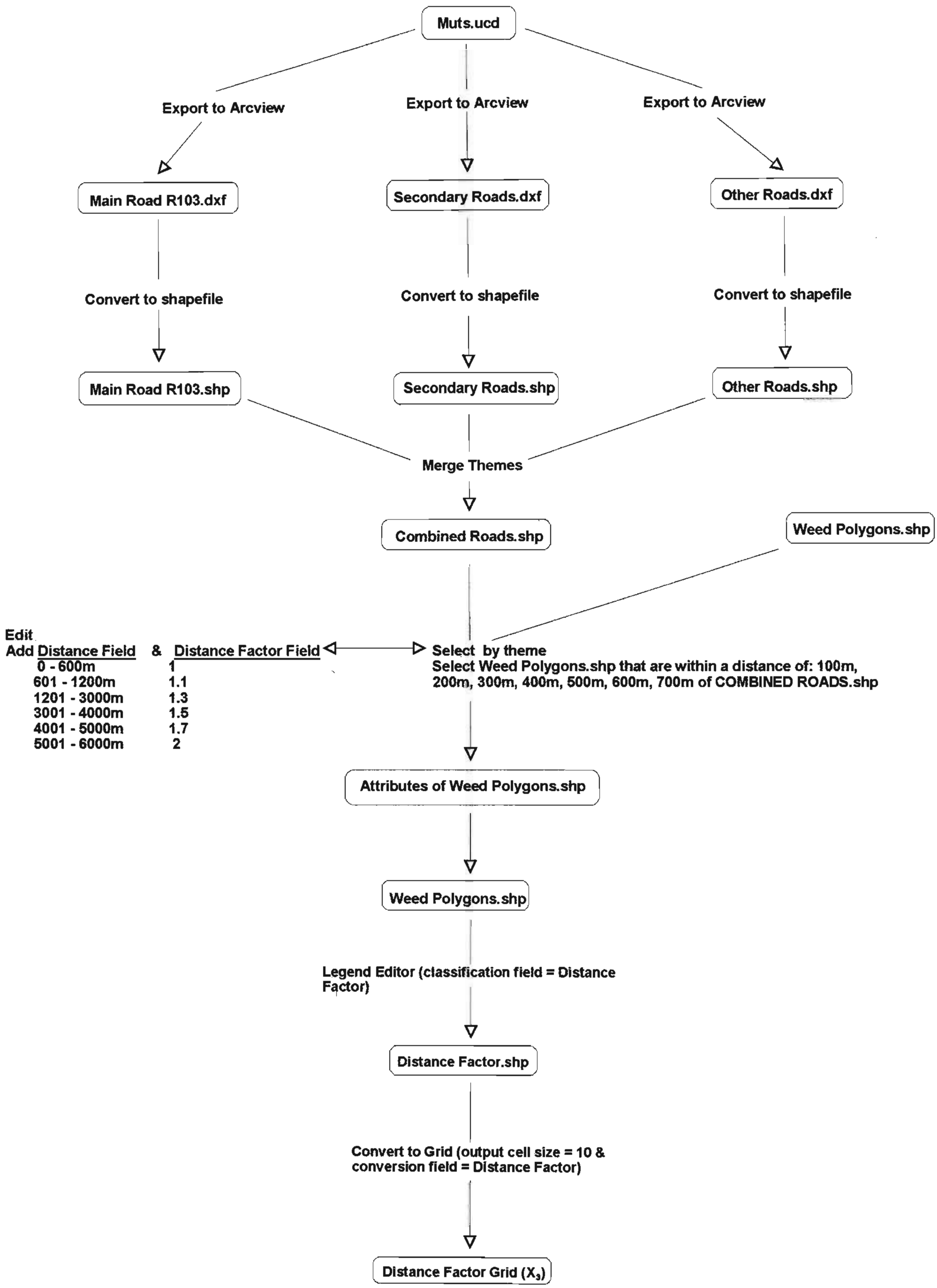


Figure 3.6: Creation of distance factor grid theme (X_3)

table of the weed polygon theme and the values were entered manually. This was repeated for all polygons within a distance of 200 metres from the nearest road, and increments of 100 metres up to the greatest distance of 700 metres. This meant doing a total of seven Select by Theme operations when the same result could have been achieved with two Select by Theme operations if the distances in table 3.3, viz., 0.6 km and 1.2 km had been used. However the usefulness in having this information will be demonstrated later. Next a distance factor field was added to the attribute table of the weed polygon theme and the factors were entered manually, according to table 3.3. Since there are only 176 records, it was possible to enter both the distance values and the distance factor values manually. It is however recommended that an Avenue script be written when working with larger data sets.

Once again, a new theme was created from the weed polygon theme by selecting distance factor as the classification field from the legend editor. This was also converted into a grid theme in order to create the Distance Factor Grid theme.

3.6.5 Corrected Work Rate

The final theme of the correction to the work rate was obtained by combining each of the factor themes, using the Map Calculator function in ArcView 3.1, according to the regression equation:

$$Y = -2.004 + 1.058\,X_1 + 1.108\,X_2 + 1.031\,X_3$$

where: X_1 = slope factor

X_2 = penetrability factor

X_3 = distance factor

Figure 3.7 shows the steps required to produce the Work Rate Correction Factor theme. It was not possible for the ArcView 3.1 function, Map Calculator, to do the whole calculation in one step. Instead three separate images of the coefficient multiplied by each of the factor themes:

- $1.058\ X_1$
- $1.108\ X_2$
- $1.031\ X_3$

had to be created first, and then added together with the constant term - 2.004.

Once the theme of the correction factor was created, the theoretical themes below (created as shown in figure3.3) were converted to grid themes. Each of these theoretical themes was multiplied by the correction factor theme, as shown in figure 3.8, in order to obtain the corrected theme in each case.

- Initial Control: Theoretical Labour Days per Polygon
- Initial Control: Theoretical Labour Costs per Polygon
- Rehabilitation: Theoretical Labour Days per Polygon
- Rehabilitation: Theoretical Labour Costs per Polygon
- Follow-Up Control: Theoretical Labour Days per Polygon
- Follow-Up Control: Theoretical Labour Costs per Polygon
- Complete Treatment: Theoretical Labour Days per Polygon
- Complete Treatment: Theoretical Labour Costs per Polygon

A summary of the research process is provided in figure 3.9. The base data in the form of spreadsheets and digital data was obtained from Goodall and Naudé (1998b), modified and then integrated into ArcView 3.1. The work rate modelling, based primarily on the work of Goodall and Naudé (1998a), had to be adjusted for the study area, and was then used to create a more realistic work rate model for alien

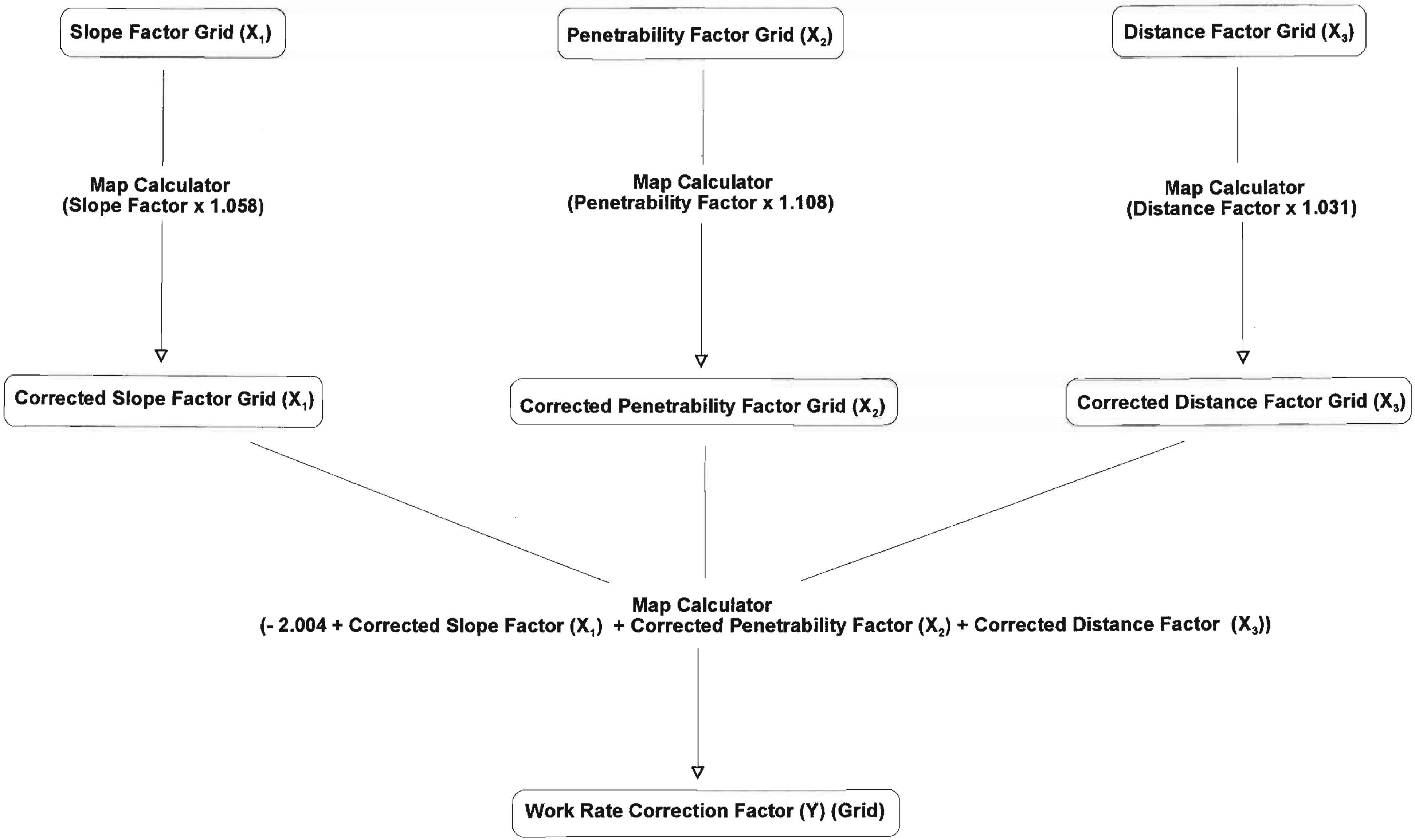


Figure 3.7: Creation of work rate correction factor (Y)

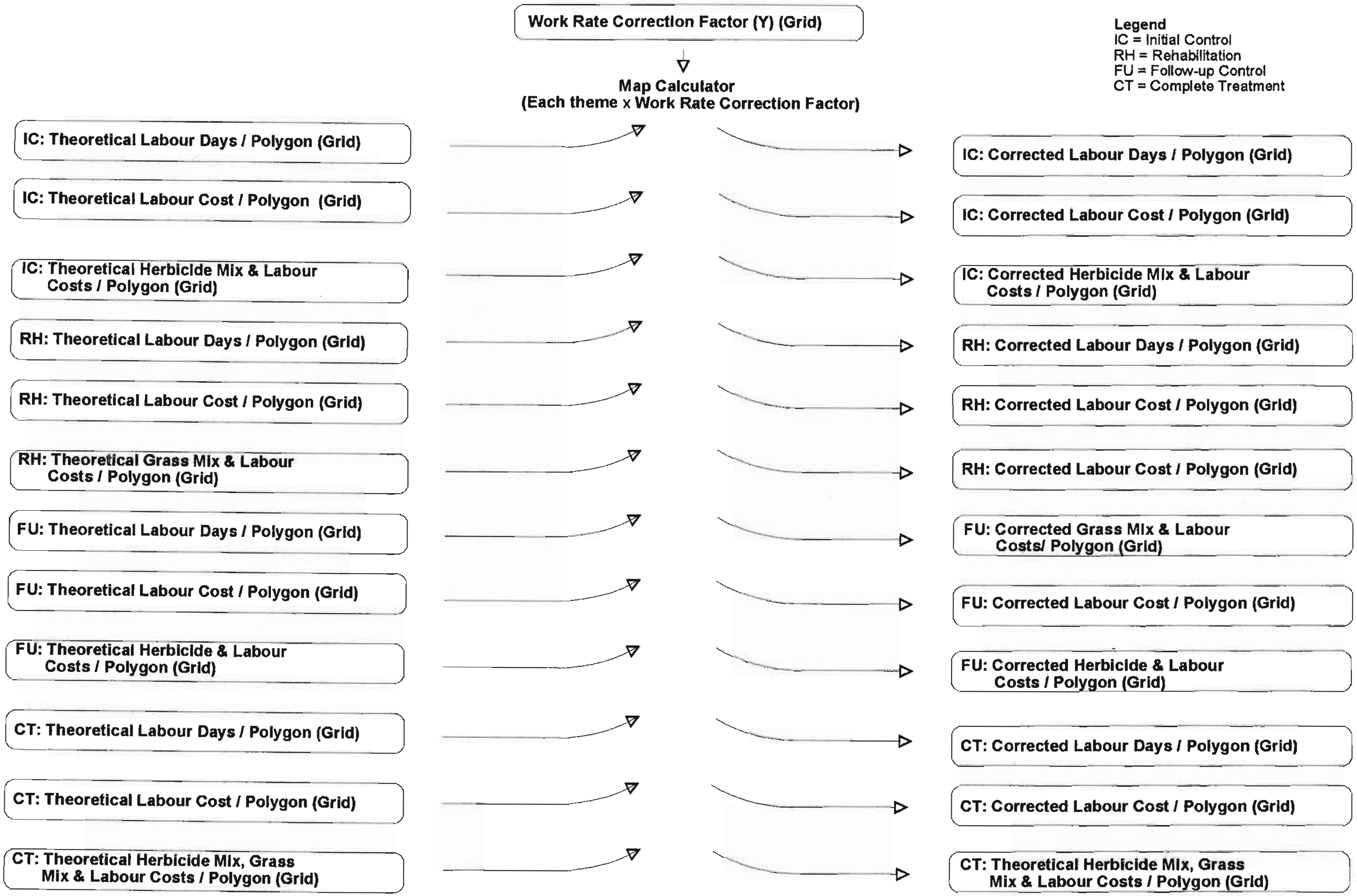


Figure 3.8: Creation of corrected themes

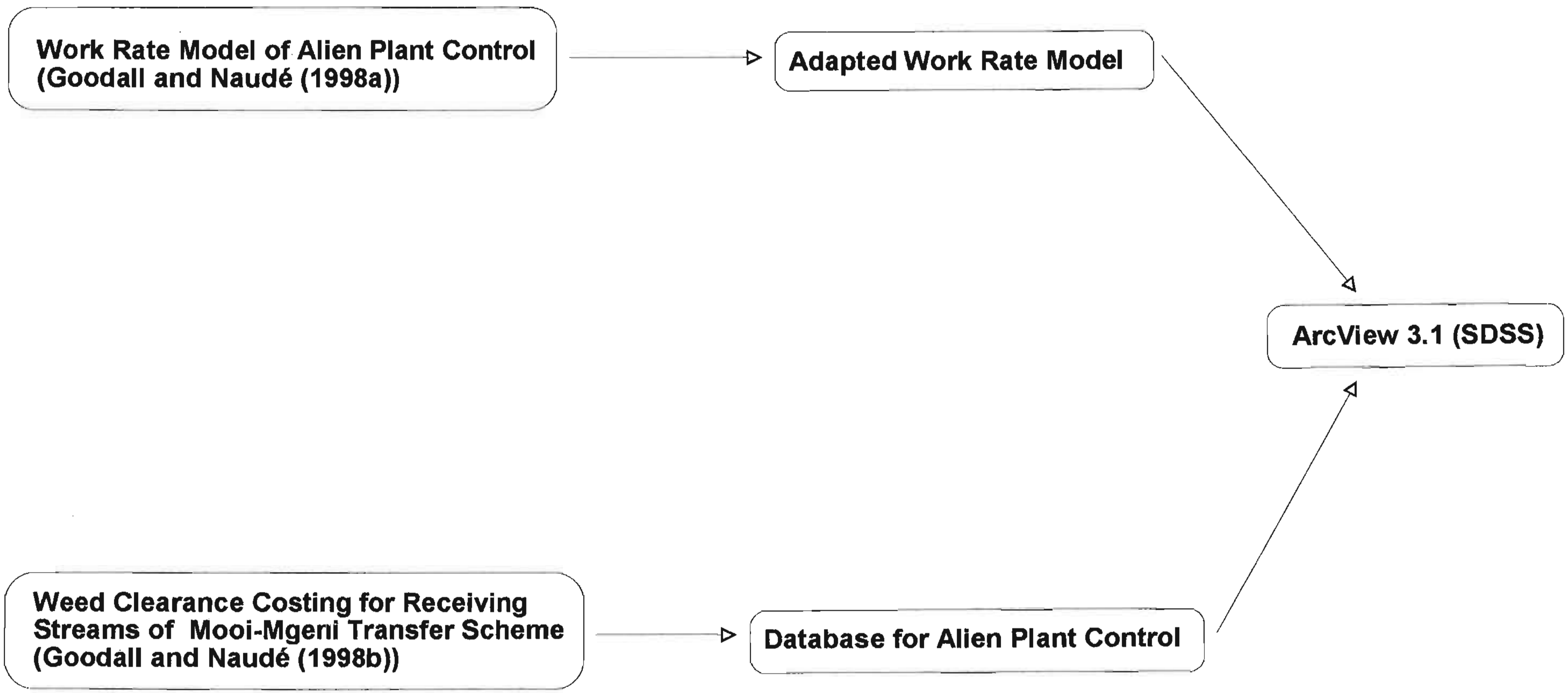


Figure 3.9: Summary of research process

plant control for the research area. The primary objective was to produce a spatial decision support system for weed control managers, and to create a work rate model. The merits and shortcomings of both the work rate model and the spatial decision support system will be discussed in the following chapter, Chapter 4.

3.7 Errors in GIS Analysis

A detailed examination of the errors in the GIS component of this research is beyond the scope of this thesis. However, a brief discussion has been included in order to emphasise the need, when using the model, to take into account and allow for possible errors, and resulting inaccuracies.

There are two major errors in spatial databases: positional errors and attribute errors.

3.7.1 Positional Errors

Positional errors occur when the location of a line, point or boundary is incorrectly located. They occur for a number of reasons including: the inaccuracy of the original paper map source, the inaccuracies introduced by humans when tracing data off an original map during the digitising process, and the creation of erroneous polygons caused by the random positional errors when overlaying two images (Chidley *et al* 1993 and Burrough 1996).

The possible positional errors in this research may have resulted from:

- inaccuracies in the original digital data from Goodall and Naudé (1998b)
- the use of distorted and/or out of date paper maps for the tracing of the contours lines
- imprecision, relating to the thickness of the pencil used for tracing and worker fatigue, caused by tracing
- the scanning and digitising of the contour lines

3.7.2 Attribute Errors

Attribute errors result from the incorrect classification of spatial features, and can be divided into two groups: continuous data attribute errors and categorical data attribute errors.

Continuous data attribute errors result from the interpolation of continuous scale data from sampling points. There are however techniques for estimating the confidence levels of the attributes.

In categorical data, the associated class at a point is either right or wrong. These data types are more commonly used in natural resource management and include soil and land cover attributes. Categorical data attribute errors result from the incorrect classification of an attribute to a particular class. While it is sometimes difficult to improve the accuracy of categorical information, there are methods for assessing the accuracy of these types of data sets (Chidley *et al* 1993 and Maguire *et al* 1991).

The possible attribute errors in this research may have resulted from:

- the use of contour lines to create a DEM and ultimately an image of continuous slope (continuous data attribute error)
- the use of an absolute category (weed polygons) as a means of classifying areas as having weeds, and therefore the surrounding areas as being weed free, may be subject to interpretation (categorical data attribute error)

While every effort is made to be accurate, possible errors must be borne in mind when using the data. Additional errors, apart from the GIS, are the surveying carried out by Goodall and Naudé (1998b), which provided some of the original data for this research. Then there are the possible errors with the model itself. These so-called weaknesses or limitations of the model will be examined in the following chapter.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Introduction

The results have been divided into two sections. The first section examines how the work rate model has changed and improved existing alien plant control costing, specifically work rate calculations and costings. This is achieved by comparing images of corrected labour days and costs with images of theoretical labour days and costs. Secondly, through the incorporation of an alien plant control database into a GIS, and by integrating the improved work rate values, a spatial decision support system (SDSS) for alien plant control managers has been created. The use of the SDSS is explored by examining its use in four different weed management approaches.

4.2 The Work Rate Model

The model was developed for the purposes of improving the alien plant control costing. There is a need to move from a theoretical costing process to a more realistic one by accounting for factors influencing work rate. The existing costing process has been modified in two ways: by its incorporation into a GIS (ArcView 3.1), and by the creation of a more realistic work rate for alien plant control through the inclusion of those factors identified as influencing the work rate. Work rate, is expressed as labour days, and is the time it will take one person at work for 8 hours (including lunch and rest breaks) to complete a particular task (PPRI 1999).

Existing costing for the clearance of alien plants along the receiving streams of the Mooi-Mgeni transfer scheme was used to demonstrate the effect that slope, penetrability and distance have on work rate. However, the particular data in this study is not the focus of the study, but rather its use in the development of the model. This model has wider uses than the eMpofana River, and forms the ground work for the further development of a work rate model applicable throughout South Africa which will give reliable costings for weed control projects.

4.2.1 Theoretical Versus Corrected Work Rate

The volume of herbicide and the mass of grass seed for rehabilitation, as well as their respective costs, is not affected by a change in work rate. Regardless of terrain, access or penetrability, the weed composition and density remain the same, and so the volume of herbicide and mass of grass seeds required for the treatment is unchanged. Therefore the work rate model is solely an adaption of the work rate or number of labour days, which also importantly affects the labour costs.

Thus, only the following themes, created in Chapter 3, figure 3.3, have been manipulated to reflect the effect of slope, penetrability and distance on labour days and ultimately on labour costs:

- Initial Control: Labour Days per Polygon
- Initial Control: Labour Costs per Polygon
- Rehabilitation: Labour Days per Polygon
- Rehabilitation: Labour Costs per Polygon
- Follow-Up Control: Labour Days per Polygon
- Follow-Up Control: Labour Costs per Polygon
- Complete Treatment: Labour Days per Polygon
- Complete Treatment: Labour Costs per Polygon

Since a change in labour costs will also affect the overall costing per polygon, it follows that the themes below have also altered:

- Initial Control: Herbicide Mix and Labour Costs per Polygon
- Rehabilitation: Grass Mix and Labour Costs per Polygon
- Follow-Up Control: Herbicide Mix and Labour Costs per Polygon
- Complete Treatment: Herbicide & Grass Mix and Labour Costs per Polygon

While it would be ideal to generate the theoretical and corrected images for each of the above theme, figures 4.1 and 4.2 have been selected, for demonstration purposes, to illustrate the difference between the theoretical labour days and the corrected labour days, after modelling for the effects of slope, penetrability and distance. Figures 4.5 and 4.6 have been chosen to show the difference between the theoretical labour cost and the corrected labour cost. By comparing the two images, the difference in theoretical work rate and corrected work rate is seen, although the visual display is influenced by the legend classification type. Although the classification type available to grid themes is either equal interval or standard deviation, it was found that neither displayed the data effectively, largely because of the existence of an outlier as shown in figures 4.1, 4.2, 4.5 and 4.6. The natural breaks classification type is best suited to this data, and was thus copied from the corresponding vector themes (before the conversion to grid themes) and manually entered for each of the grid themes.

The existence of an outlier has necessitated the creation of a class solely for the outlier. The outlier is as a result of a polygon of unusually large weed area coupled with a high percentage of saplings. Since the slashing and stacking of saplings requires a large number of labour days per hectare, the number of labour days (and labour costs) for clearance of this particular polygon is particularly large.

Figures 4.1 and 4.2 show the theoretical and corrected number of labour days for the initial control phase. It is possible to detect the changes in labour days from the images, however the use of histograms gives a much clearer presentation of the data. The histogram, created by ArcView 3.1, compares the number of cells with the different labour day classes as displayed in the image. As the number of cells remains constant, the changes in the number of cells within the different classes provides an overview of the modification in the number of labour days. Comparing figures 4.3 and 4.4, the histograms of their respective images, it can be seen that in the classes 0 - 1 and 5 -10 labour days there is a decrease in the number cells from the theoretical to the corrected number of labour days. There is very little change in both classes 1 - 3 and 3 - 5, but a significant increase in the number of cells in the class 121+. As already mentioned, the number of cells is constant for both histograms (and images). Thus, there has been a shift from the lower labour day classes to the intermediate classes to the highest labour day classes. A result that is not altogether surprising, since there has been a general increase in labour days across all the polygons.

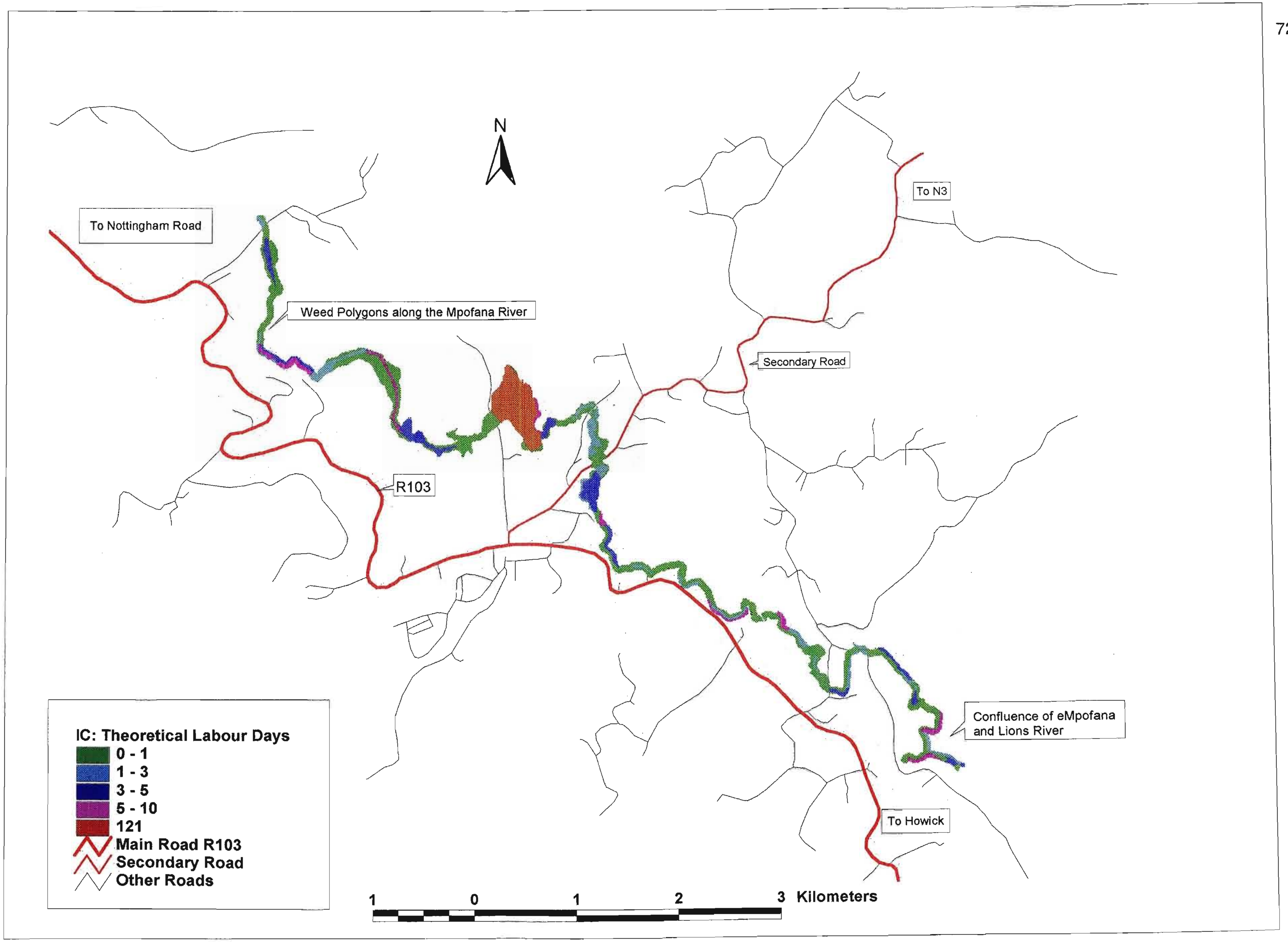


Figure 4.1: Initial Control: Theoretical Labour Days per Polygon

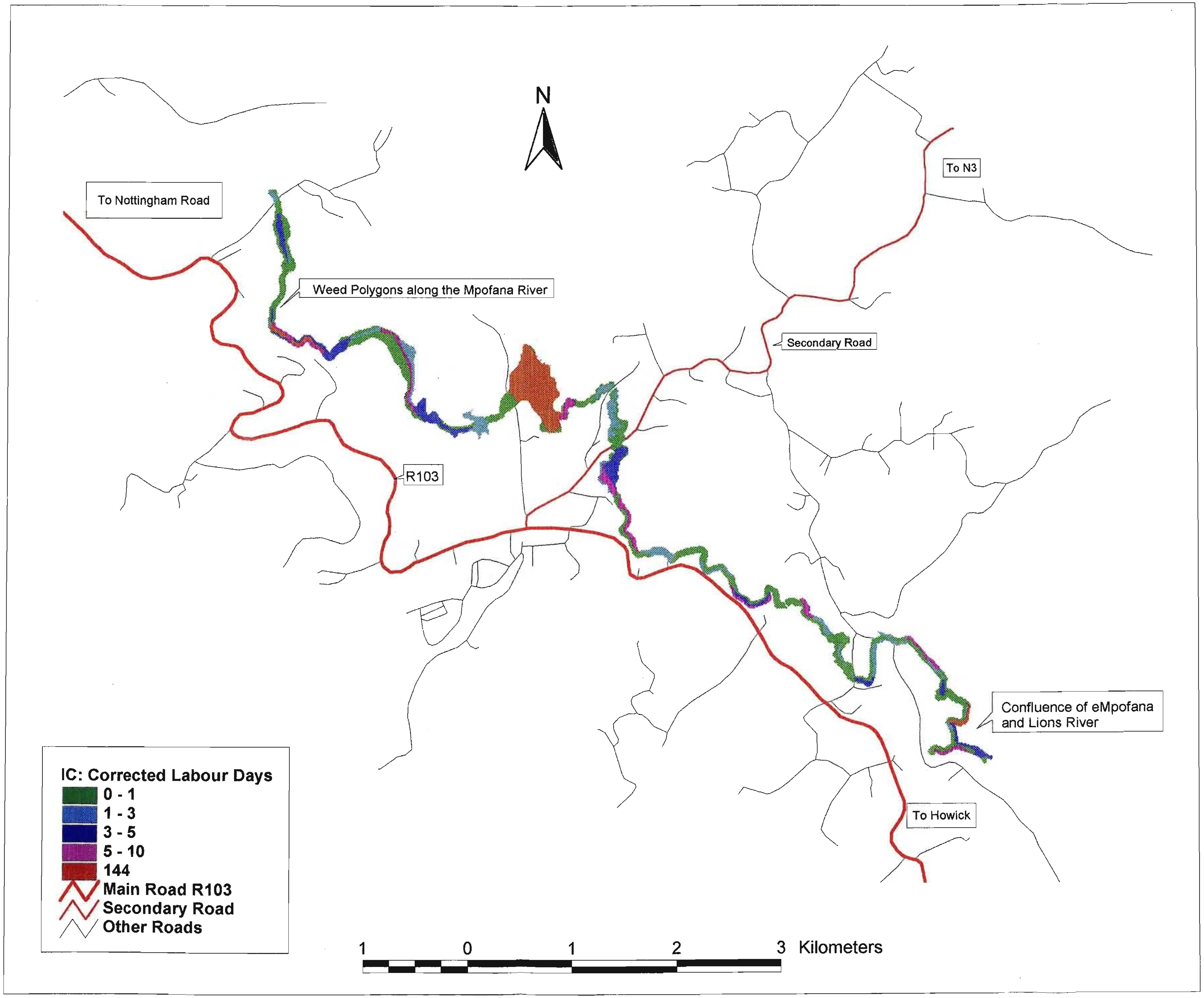


Figure 4.2: Initial Control: Corrected Labour Days per Polygon

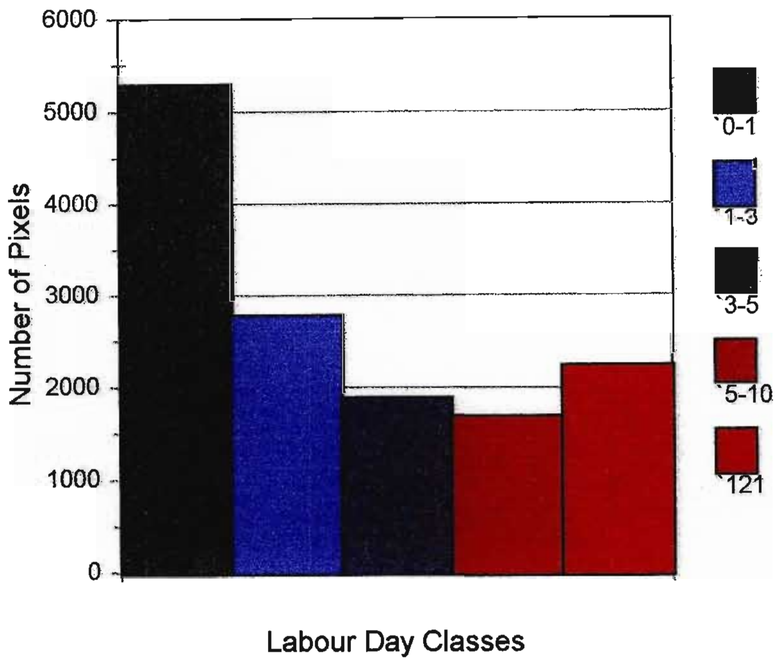


Figure 4.3: Theoretical Labour Days for Initial Control

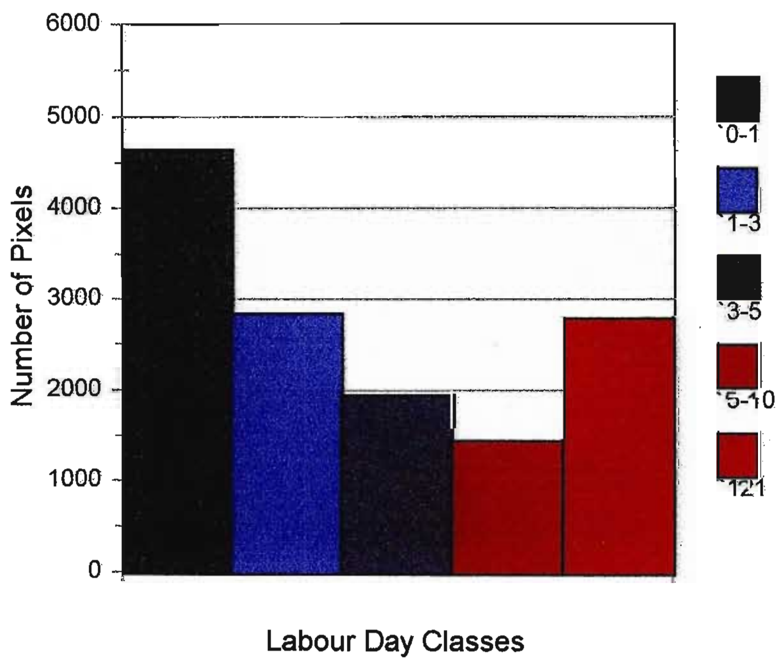


Figure 4.4: Corrected Labour Days for Initial Control

Figures 4.5 and 4.6 are of the theoretical and corrected labour costs for the initial control phase. Once again, changes in labour costs can be seen from the images, however the histograms present the differences more clearly. Comparing the histograms in figures 4.7 and 4.8, it can be seen that in classes R0 - R678 and R1 936 - R3 343 there is a significant decrease in the number of cells from the theoretical to the corrected labour costs. There is very little change in classes R679 - R1 935 and R3 344 - R6 615, but an increase in the class R6 616 - R 88 041. There is, as with the labour days, an overall shift from the smaller labour cost classes to the larger classes.

As this is a first attempt at the creation of a GIS work rate model, there are undoubtedly aspects that need improving upon. A true indication of the value of such a model will only be gained once a work study has been conducted.

4.2.2 Strengths and Weaknesses of the Model

Strengths

While the timber industry and many alien plant control managers acknowledge that the work rate is influenced by a number of factors, this is a first attempt at formalising and assimilating these factors into a GIS. It is also recognised that all the factors influencing the work rate may not have been accounted for. However, the model does attempt, by identifying as many of the factors as possible, to address the present inaccuracies in labour costing, and ultimately alien plant control costing. As labour is considered to be one of the major costs in alien plant control, it is important that it is correctly budgeted for. An under-budgeted project is likely to exhaust its financial resources before project completion. This results in temporary or even permanent closure of the project. A project that is suspended ultimately leads to greater costs as the weeds will regrow if consistent control, with annual follow-up operations, is not practised. More realistic costing in weed control will assist all weed managers and contractors, including emerging contractors, by allowing for better budgeting and possibly fewer project failures. Essentially the modelling allows for more realistic costings in what is ultimately an expensive exercise.

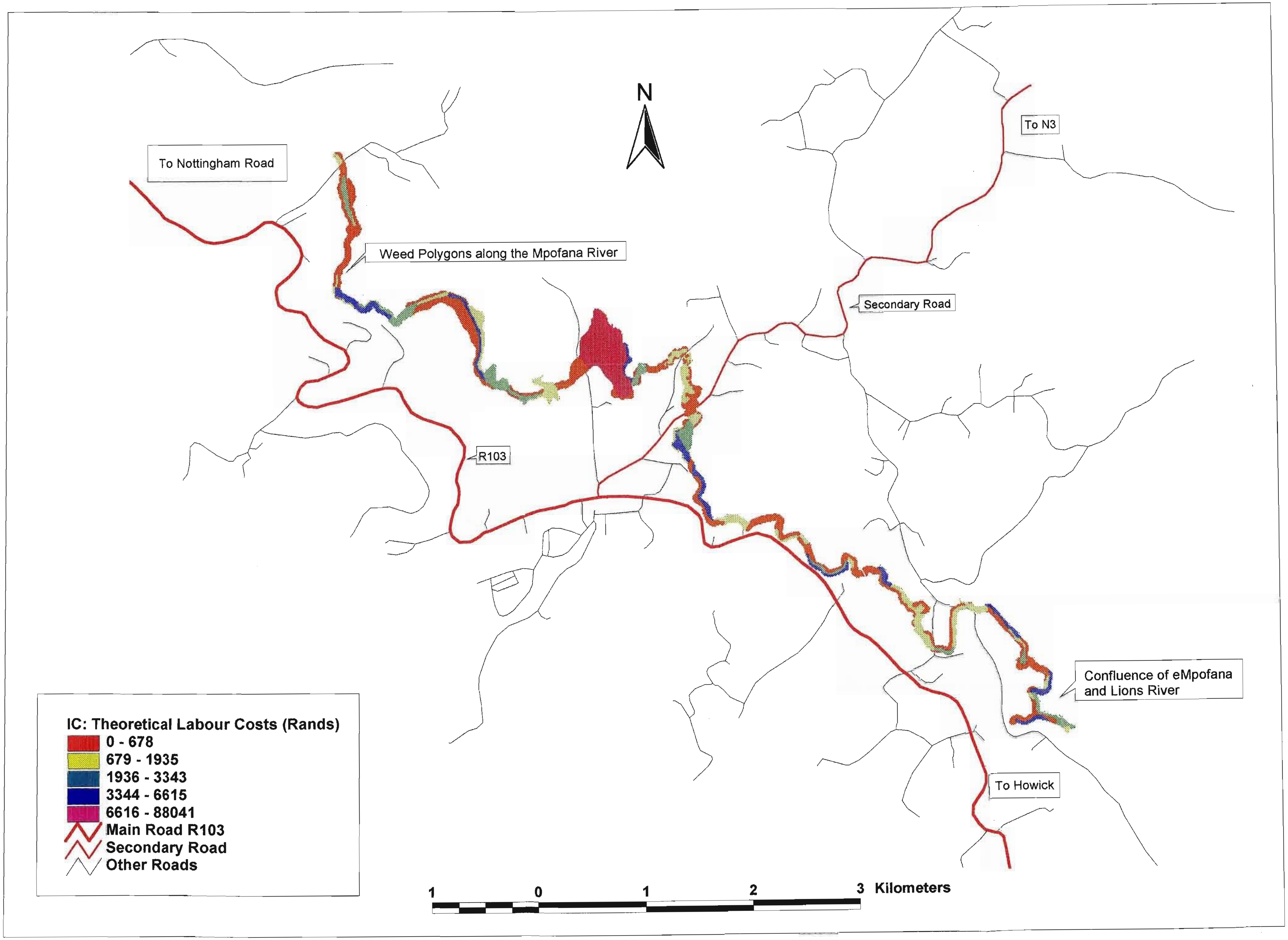


Figure 4.5: Initial Control : Theoretical Labour Costs per Polygon

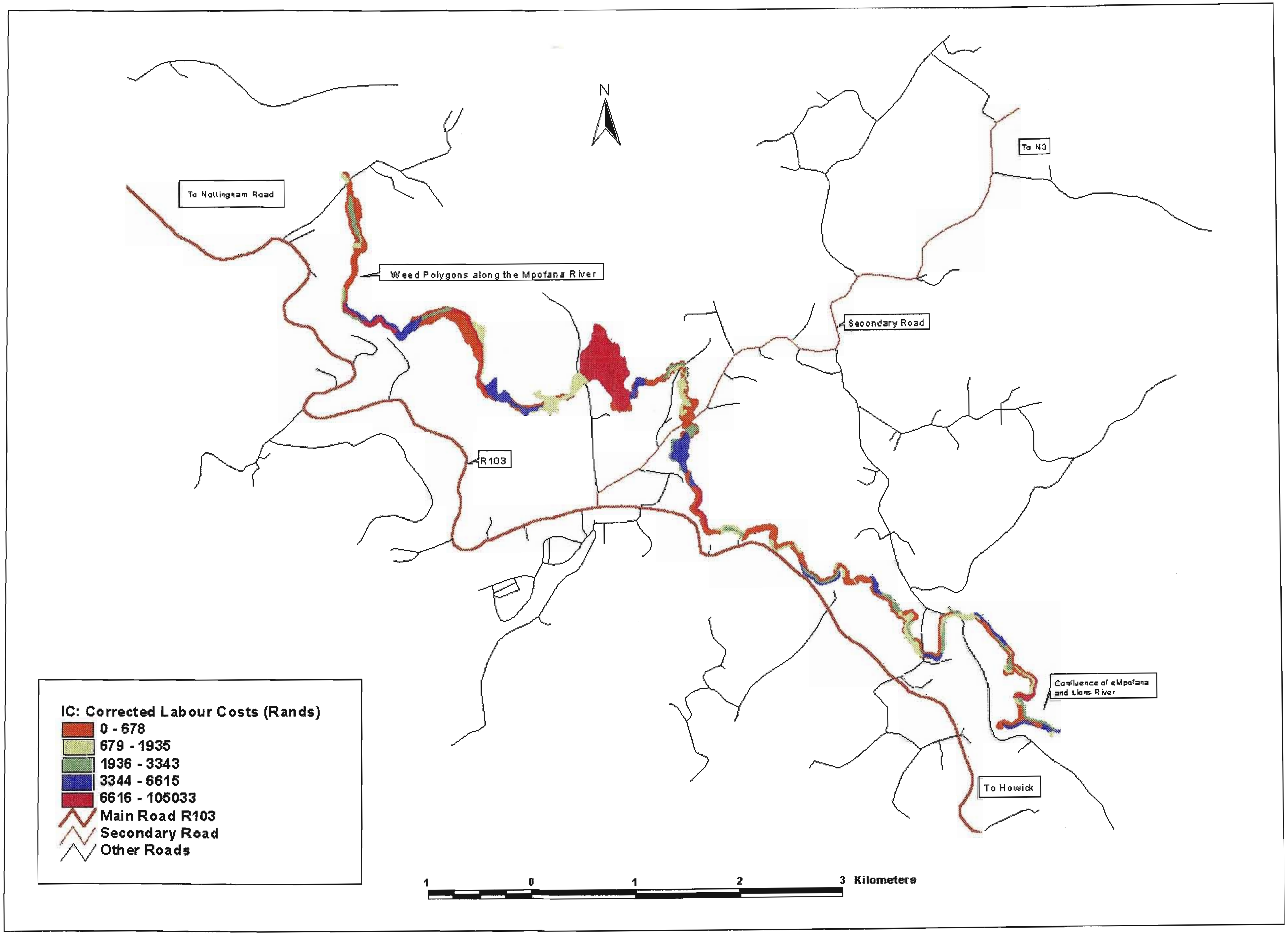


Figure 4.6: Initial Control: Corrected Labour Costs per Polygon

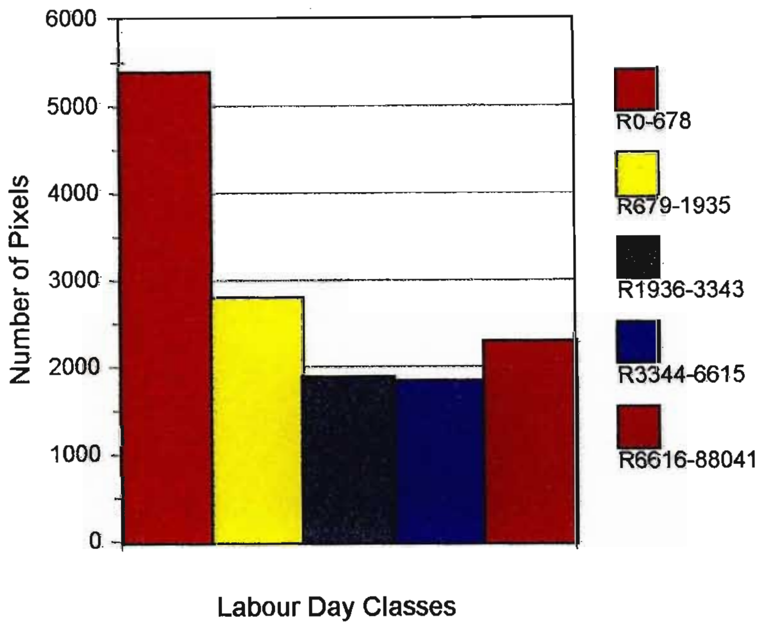


Figure 4.7: Theoretical Labour Cost for Initial Control

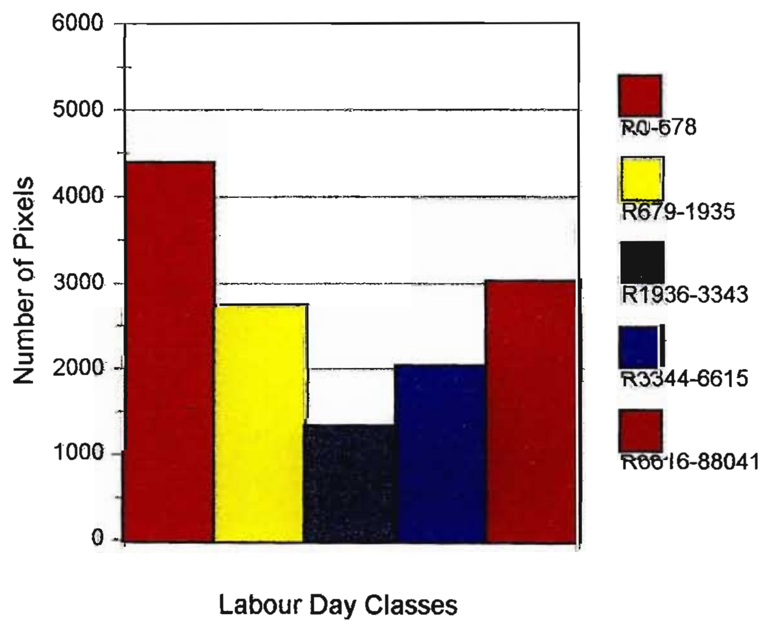


Figure 4.8: Corrected Labour Cost for Initial Control

The incorporation of the model into a GIS has a number of advantages, even though setting up a GIS may be time consuming and costly. It is hoped that ultimately, the cost of establishing such a GIS will be more than compensated for by the financial benefits of using such a model. The use of a GIS in the creation of a work rate correction factor theme enables corrections to the work rate merely by multiplying the correction factor theme by the labour days theme. This is considerably quicker than manually and individually multiplying the correction factor by the number of labour days in each of the polygons. Furthermore, any adjustments or updating to the work rate can be made instantly. The use of a GIS also allows for visualisation of the results of the modelling. It is thus the speed, the dynamic nature, as well as the visual capabilities of a GIS that makes it useful in work rate modelling.

Weaknesses

A first attempt at incorporating alien plant control work rates into a GIS is likely to result in a number of shortcomings with the model. One such weakness is that there is a likelihood that not all the factors influencing the work rate have been identified, and if they have, perhaps the relationship between the various factors is not linear as has been assumed.

A possible factor influencing the work rate of alien plant control that has been omitted is that the fewer the number of different weed species (especially with the same habit) in an infestation, the easier and quicker it is to control that infestation. Also, different species having the same treatment are easier and quicker to control. Thus two different tree species having the same treatment strategy is quicker to clear than two tree species having different strategies. So perhaps another factor influencing the work rate, which needs including in future, is the diversity of species and/or control treatments.

As previously stated, the relationship between the various factors influencing the work rate and the correction to the work rate was assumed to be linear. The results of the multiple linear regression will be more accurate if the data more closely matches a linear model (Corel Quattro Pro, Suite 8 and Matthews 1981). However, it is possible that the relationship between the distance factor and the correction to the work rate is an exponential relationship and not a linear one. In which case, the modelling would be inaccurate. The accuracy of the model can only be verified through the conducting of a work study, which is another shortcoming of the model as it is at present.

The study area itself was somewhat limited in terms of fully testing the capabilities of the model, in that the weed infestations were relatively accessible and the terrain was not particularly adverse. The maximum slope was a little over 20°, and thus only two of the four slope factor classes, namely:

- 0 - 15°slope = factor of 1
- 16 - 25° slope = factor of 1.2 were represented by this study.

Furthermore, there is a good network of roads in the study area, making the weed infestations easily accessible by road. The maximum distance of any weed polygon from the nearest road was only 700 metres, and thus only two of the four distance factor classes, namely:

- 0 - 600 metres = factor of 1
- 601 - 1200 metres = factor of 1.1 were represented.

There is a thus a great need to test the model on a larger area where there is a greater diversity of terrain and where the infestations are less accessible by road. However, due to the occurrence of bramble, in varying density, along the eMpofana River, all of the four penetrability factor classes were represented.

While there are a number of strengths and shortcomings with the modelling itself, the integration of the model into a spatial decision support system (SDSS) for alien plant control planning and costing needs to be assessed separately.

4.3 A Spatial Decision Support System (SDSS) for Alien Plant Control

There are a number of ways in which this system can act as a tool for decision-making. The manner in which the model is used depends largely on the management approach adopted. Four management approaches will be explored in this chapter in order to illustrate the capabilities of such a spatial decision support system:

- Clearing from source in a downstream direction
- Clearing to increase stream flow
- Clearing to contain areas and prevent further spread
- Clearing at the scale of the farm unit

However, the SDSS may be used in many more scenarios where the information could be printed as maps or simply viewed on screen.

4.3.1 Clearing from Source in a Downstream Direction

Stream flow carries the seeds and vegetative parts of weeds downstream where they may establish themselves and grow. The spread of weeds along a river is thus generally in a downstream direction, and it is logical that the clearing of weeds should occur in this direction. Umgeni Water's Riparian Rehabilitation Project is presently clearing the eMpofana River (as well as the Lions and Mgeni Rivers) using such a strategy. Figure 4.9 (a) and (b) show the eMpofana River close to its source, before and after the wattle saplings were cleared.

The management plan for clearance would be on a polygon by polygon basis, starting at the source of the eMpofana River, in a downstream direction. A knowledge of the surrounding infrastructure, (such as figure 4.10) would be essential to a manager. Figure 4.11, showing weed density would also be necessary for an initial assessment of the area. The advantage of viewing an image on screen, is that themes can be turned on and off as desired, unlike with a paper map. This allows for the user to produce a customised view, tailored to a particular purpose. A three

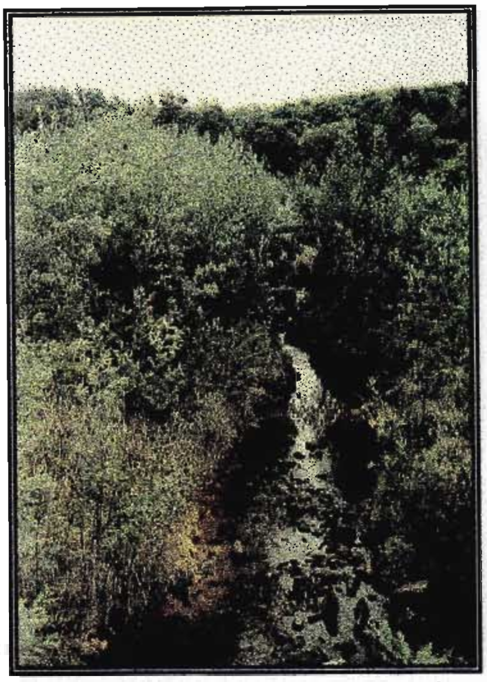


Figure 4.9(a): At the source of the eMpofana River before the wattle saplings were cleared.

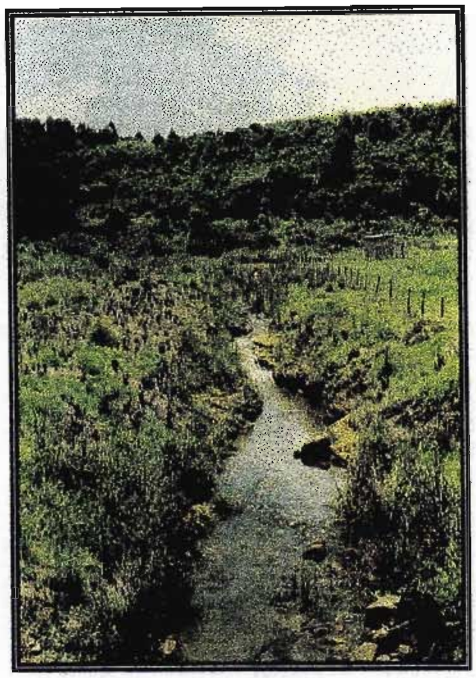


Figure 4.9(b): At the source of the eMpofana River after the wattle saplings were cleared.

dimensional view of the eMpofana valley was created using ArcView 3.1's 3-D Analyst in order to produce the slope factor image. This three dimensional image may be viewed on screen and can be rotated a full 360°, enabling the user to view the image at any angle.

Once the weed manager has orientated himself, he would need to familiarise himself with the control area. The weed control manager can access and express information from the SDSS in a number of ways. The following three will be explored:

- Accessing information using the identify tool
- Expressing information as a theme
- Querying data

Owing to the differing nature of vector and grid data, there are slightly different ways of accessing information within the SDSS. These differences will be explained for each of the above means of accessing the information.

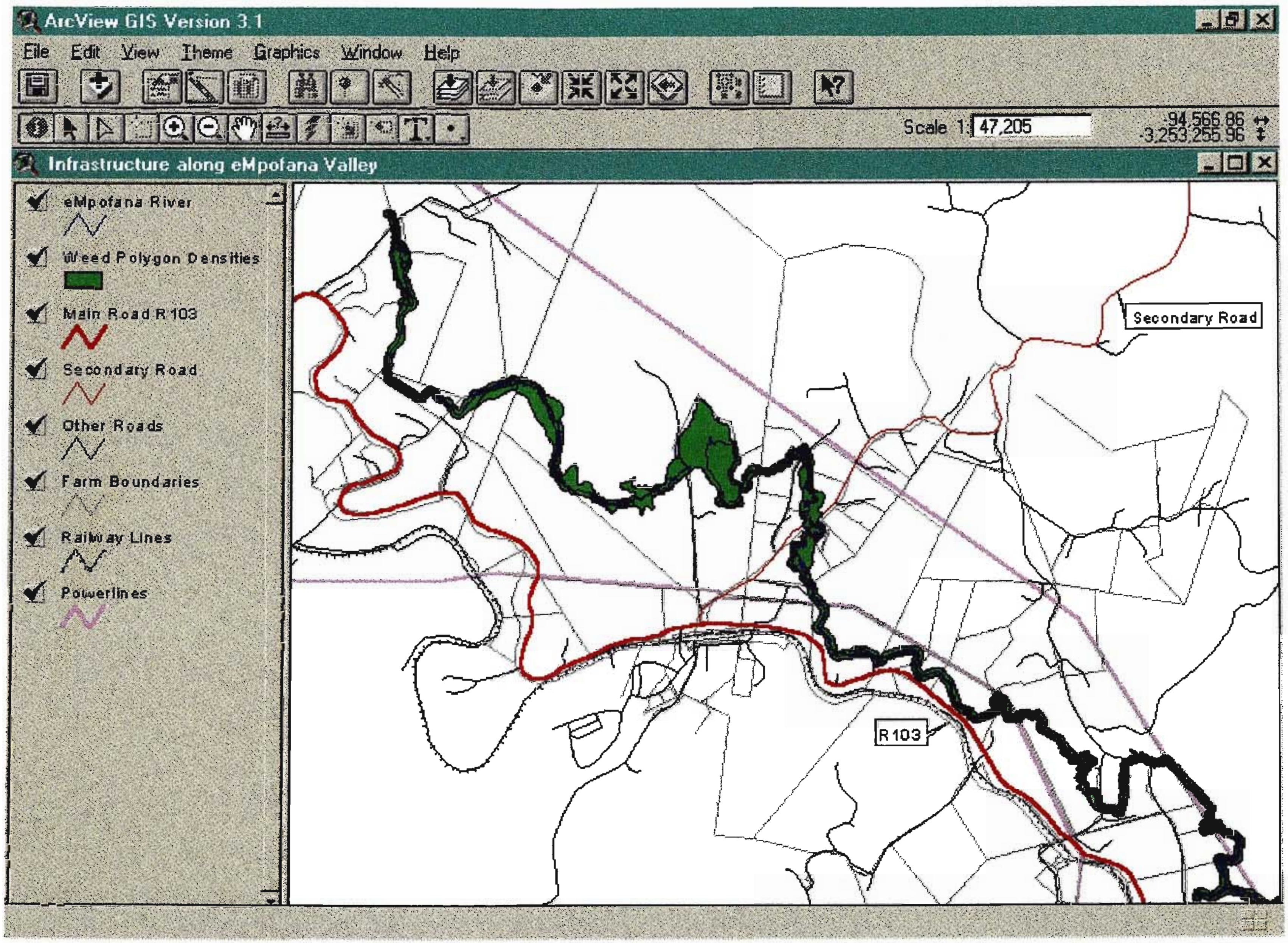


Figure 4.10: Infrastructure along eMpofana Valley

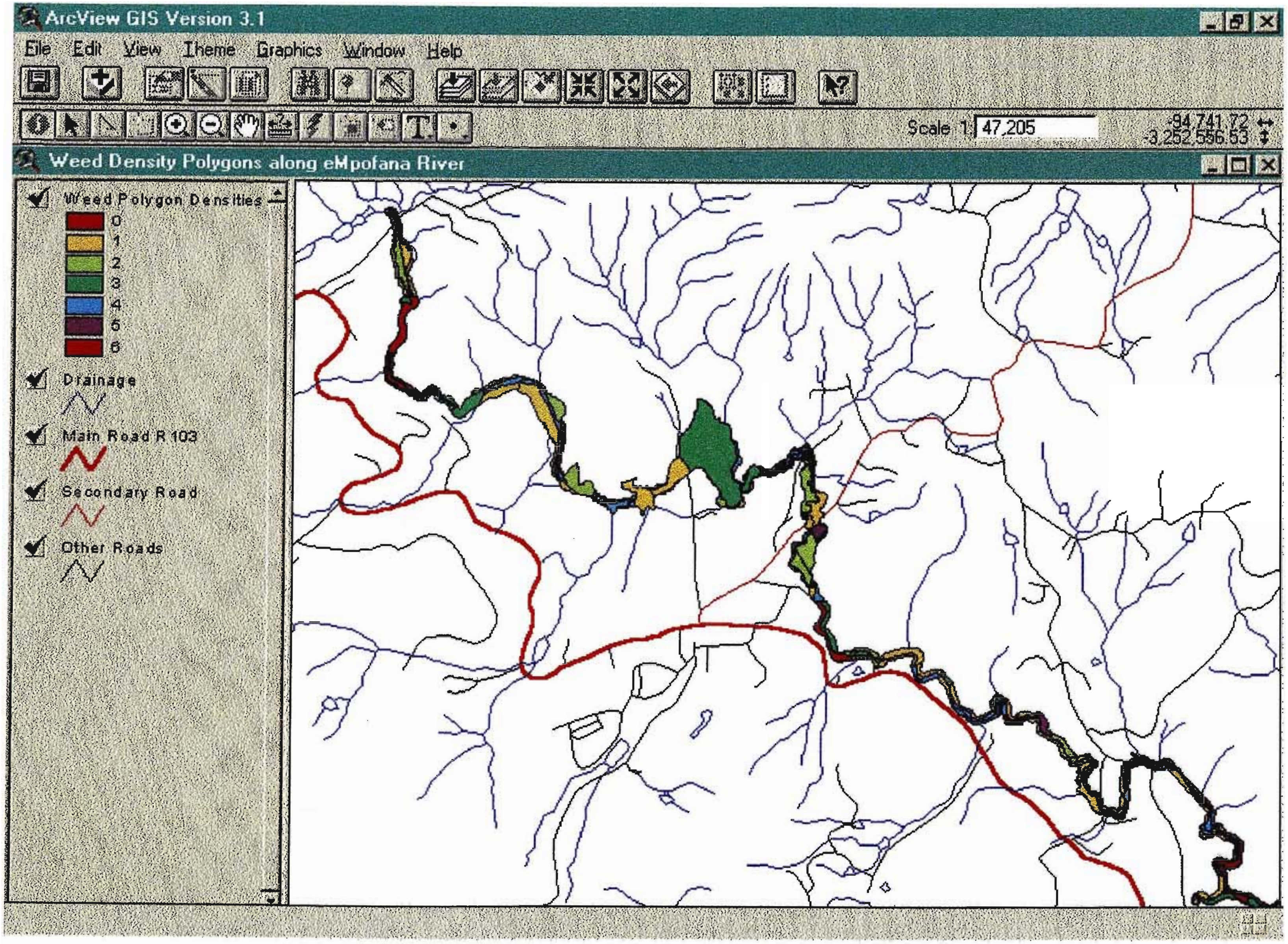


Figure 4.11: Weed Density Polygons along the eMpofana River

Accessing Information using the Identify Tool

Clearing, as already stated, would be on a polygon-by-polygon basis. With vector data, all the information stored in the themes attribute table (as shown in table 4.1) may be accessed by simply clicking on the identify tool. Figure 4.12 shows what one such query would look like on screen. The data for the polygon with final id 2 has been accessed with the identify tool. The view has been improved upon by the setting up of a hot link between this particular polygon and a photograph of the weed infestation in that polygon. When dealing with maps and tables, sight is often lost of the situation on the ground, and hence the need for photographs, and charts. With ArcView 3.1, charts (column and bar charts, pie charts, line charts, area charts and scatter charts) can be created as another means of visualising and representing the data.

When using the vector data, it must be borne in mind that the information reflects theoretical work rates (and therefore labour costs) rather than the corrected work rates (and labour costs). Owing to the manner in which the correction factor theme was calculated, the themes of corrected work rates (and labour costs) are grid data sets. It is not possible to access all the information displayed in table 4.1 from grid data as grid data storage involves the use of entire thematic coverages. Accessing information from grid data may only be achieved on a theme-by-theme basis, using the identify tool to determine the particular values (referred to as the z-values) of selected features for the active theme.

Expressing Information as a Theme

The use of the identify tool enables the weed manager to access information on a polygon-by-polygon basis. The manager may, however, wish to visualise some of the information for the entire project area. For vector data, the legend editor can be used to display the particular information as a theme, owing to the existence of an attribute table. For every field in the weed polygons attribute table (as shown in table 4.1), a theme can be created. Some of these themes have been created (see figure 3.3 of Chapter 3). Figures 4.13, showing the volume of herbicide mix for follow-up control, is an example of the type of images that can be generated using

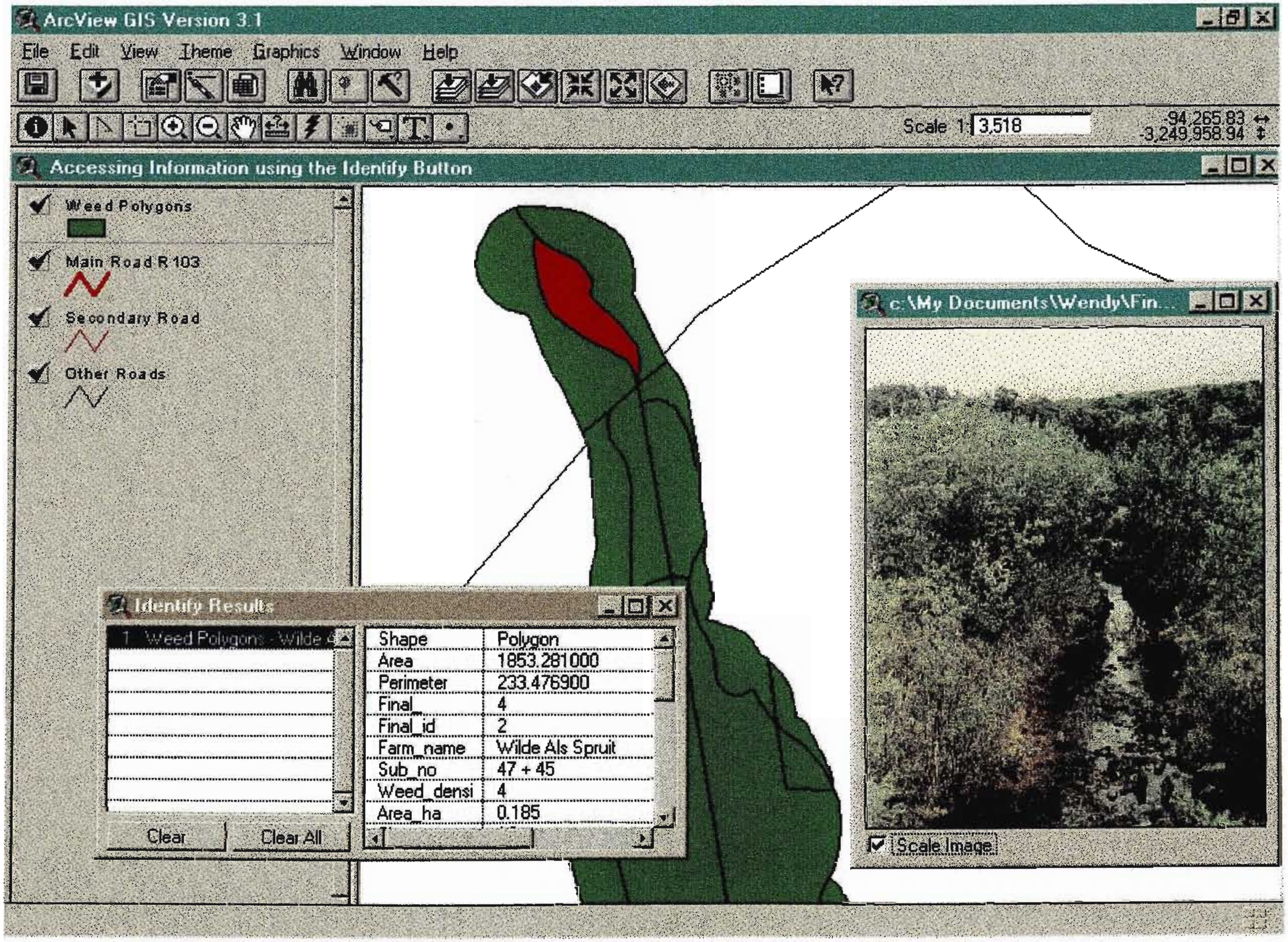


Figure 4.12: Accessing Information using the Identify Button

Table 4.1: Attribute Data for Weed Polygons

	INITIAL CONTROL	REHABILITATION	FOLLOW-UP	COMPLETE TREATMENT
1. GENERAL				
(a) Farm name (in which polygon falls)				
(b) Subdivision number of the farm (in which polygon falls)				
(c) Area of polygon (ha)				
(d) Perimeter of polygon (m)				
(e) Distance from nearest road (m)				
2. WEED CHARACTERISTICS	Weed species (habit & form) per polygon	n/a	Seedlings	
	Density of the individual weed species per polygon	Density of grass cover (& % grass cover) per polygon	n/a	
	Total weed density per polygon	n/a	n/a	
3. WEED AREA	Area of the individual weed species per polygon	n/a	n/a	
	Total weed area per polygon	Rehabilitation area per polygon	n/a	
4. TREATMENT STRATEGY	Weed treatment per polygon	Grass species and fertilizer per polygon	Spraying seedlings in every polygon using Garlon 4 (0.75%) with Actipron Super (0.5%) in water	
5. HERBICIDE/CARRIER VOLUMES	Volume of individual herbicide/carrier (Garlon 4, Actipron Super, Chopper, E-Blue, Diesel, Water) per polygon	n/a	Volume of individual herbicide/carrier (Garlon 4, Actipron Super, Water) per polygon for each of the follow-up years	
	n/a	n/a	Total volume of herbicide/carrier per polygon for each of the follow-up years	
	Total volume of herbicide/carrier per polygon for initial control	n/a	Total volume of herbicide/carrier per polygon for follow-up control	Total volume of herbicide/carrier per polygon for complete treatment
6. GRASS/FERTILIZER MASS	n/a	Mass of individual grasses per polygon	n/a	
	n/a	Mass of fertilizer per polygon	n/a	
	n/a	Total mass of grass and fertilizer per polygon (and complete treatment)	n/a	
7. LABOUR DAYS	Number of labour days per polygon for each treatment	n/a	Number of labour days per polygon for each of the follow-up years	
	Total number of labour days per polygon for initial control	Number of labour days per polygon for rehabilitation	Total number of labour days per polygon for follow-up control	Total number of labour days per polygon for complete treatment
8. COSTS				
(a) Herbicide/Carrier	Cost of individual herbicide/carrier (Garlon 4, Actipron Super, Chopper, E-Blue, Diesel, Water) per polygon	n/a	Cost of individual herbicide/carrier (Garlon 4, Actipron Super, Water) per polygon for each of the follow-up years	
	n/a	n/a	Total cost of herbicide/carrier per polygon for each of the follow-up years	
	Total cost of herbicide/carrier per polygon for initial control	n/a	Total cost of herbicide/carrier per polygon for follow-up control	Total cost of herbicide/carrier per polygon for complete treatment
(b) Grass/Fertilizer	n/a	Cost of grass/fertilizer per polygon for rehabilitation (and complete treatment)	n/a	Total cost of herbicide/carrier and grass/fertilizer per polygon for complete treatment
(c) Labour	n/a	n/a	Cost of labour per polygon for each of the follow-up years	
	Cost of labour per polygon for initial control	Cost of labour per polygon for rehabilitation	Total cost of labour per polygon for follow-up control	Total cost of labour per polygon for complete treatment
(d) Total Costs	Total cost of herbicide/carrier and labour per polygon for initial control	Total cost of grass/fertilizer and labour per polygon for rehabilitation	Total cost of herbicide/carrier and labour per polygon for follow-up control	Total cost of labour, herbicide/carrier and grass/fertilizer per polygon for complete treatment

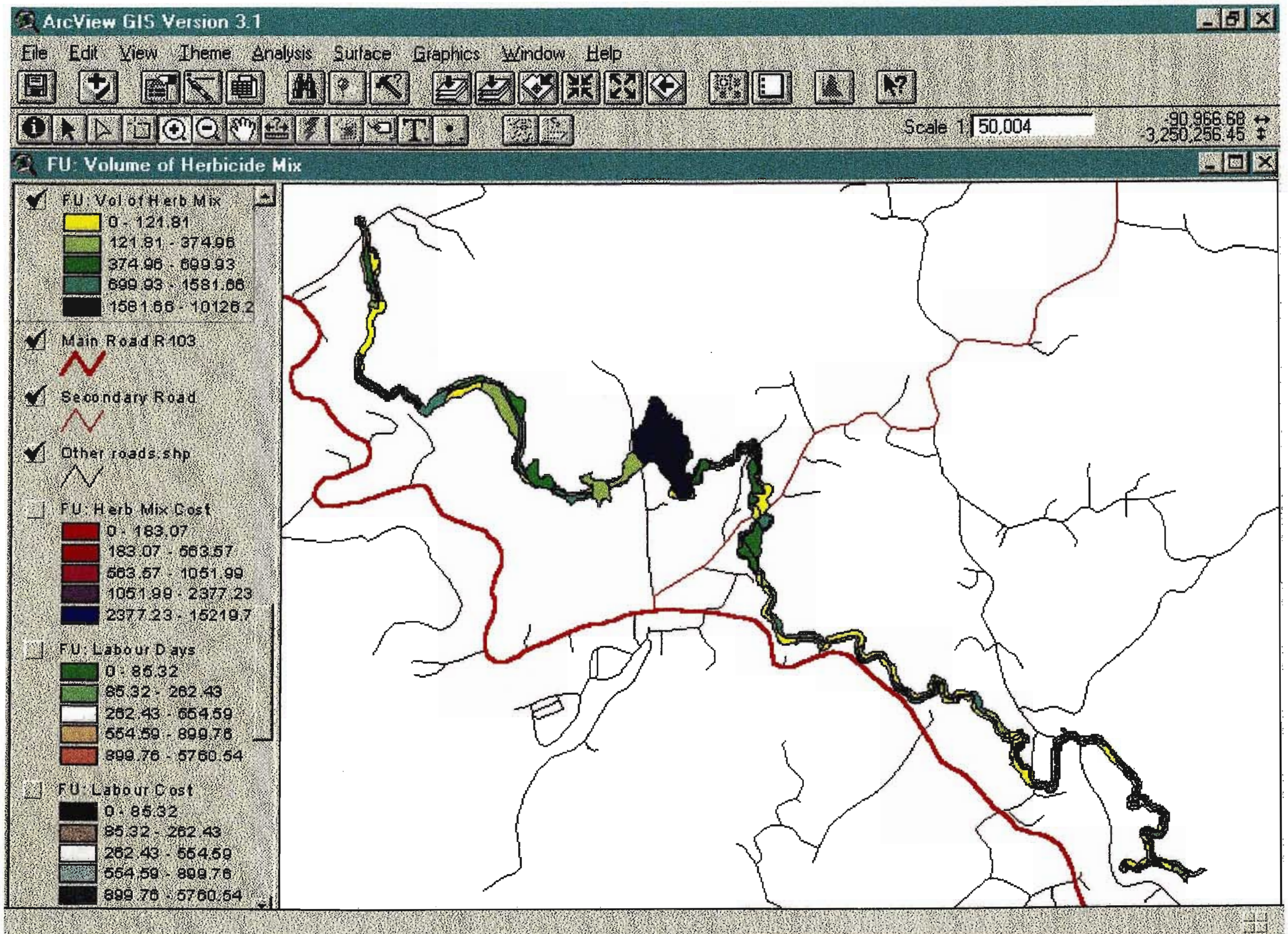


Figure 4.13: Volume of Herbicide Mix per Polygon for Follow-Up Control

editor, and either viewed on screen (as in figure 4.13) or printed as a map.

All themes except the labour days and labour cost themes can be generated from the vector data. The themes for corrected labour days (and costs), in grid data form, have however already been created, as shown in figure 3.8 of Chapter 3.

Querying Data

The manager may also perform certain queries on the information in order to access particular information not displayed in the above themes. This is done by using the query builder function if the data is vector, or the map query function if the data is grid. For vector data, a query can be performed on any field in the attribute table.

Examples of the sorts of queries a weed manager may perform are as follows:

- Which polygons, during the initial control, will take more than 5 labour days to clear?
- Which polygons are more than 300 metres from the nearest road? (This query demonstrates the usefulness of identifying polygons at increments of 100 m from the nearest road, mentioned in Chapter 3, as it allows for greater flexibility in posing queries).
- Which polygon will require more than 50 kilograms of grass seed and fertilizer mix for rehabilitation?
- Which polygons, in the first year of follow-up, will require more than 200 litres of herbicide and carrier mix?
- Which polygons have a total treatment cost (labour, herbicide and grass seed costs for initial control, rehabilitation and follow-up control) of more than R3 500?

The following two important queries will be looked at in more detail in order to demonstrate the capabilities of the model using the query builder function:

- (a) siting a water quality monitoring point to monitor diesel
- (b) wood utilisation

(a) Siting a Water Quality Monitoring Point to Monitor Diesel

In the treatment specified by Goodall and Naudé (1998b), diesel (used as a carrier for herbicide) was only prescribed for the treatment of wattle trees and saplings so as to limit the possible negative impacts on the environment. Since the impact of large volumes of diesel entering the river system is not known, the use of diesel should be kept to a minimum.

The manager would have to ascertain where large volumes of diesel were to be used in weed control, and establish a water quality monitoring point downstream of those areas to monitor the amount of diesel entering the river. According to Kempster (pers. com. 1999[4]), there is not a specific guideline for the control of diesel in water. However, there are two general guidelines:

- the Oil and Grease limit of the old special effluent standard of 2.5 mg/L (prevents toxicity to man, but an unpleasant taste and odour exists at this concentration)
- the limit for the Threshold Odour Number (TON) in the new SABS specification 241 (1999) standard is 5 units, which is approximately equal to 0.025 mg/L (which is 100 times less than the old special effluent standard for oil and grease)

It is recommended that the more stringent standard of approximately 0.025 mg/L proposed by the SABS specification 241 (1999) be adhered to. However, it is not possible to determine what volume of diesel, when applied as a carrier for herbicides in the control of weeds in the riparian zone, would result in a diesel concentration of

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0.025 mg/L in the river water.

The only way the manager could ensure the conservation of river water quality would be to identify the polygons requiring large volumes of diesel as a carrier in weed control, both in the initial control and the follow-up phase. He would use the query builder function in ArcView 3.1 to pose the following query:

[[Diesel volume] >= 100L

The water quality downstream from these polygons would then need to be measured in order to ascertain whether the concentrations met the standards of the SABS specification 241 (1999). If the concentration was over the limit, the manager would have to take measures to ensure that monitoring points be established at polygons where concentrations of diesel were lower than first identified. It is thus recommended that polygons, in which a lower concentration of diesel is to be used for weed control, be identified for monitoring from the out-set.

In figure 4.14, the red-coloured polygons are those polygons that have been identified as requiring monitoring in the initial control phase of weed control. The areas downstream of these polygons would only require monitoring while the weeds immediately upstream were being sprayed, thus any equipment could be moved downstream to the next site of concern.

(b) Wood Utilisation

In the report by Goodall and Naudé (1998b), it was proposed that certain tree species could be used for firewood, as well as the making of charcoal, pulpwood, matchwood, etc. The manager may decide that the selling of the felled wood may help off set the cost of clearing. The decision to do so would depend on the cost and effort in transporting the wood. It is important that the cost of harvesting the trees does not exceed the value gained from the felled wood. The decision to fell and

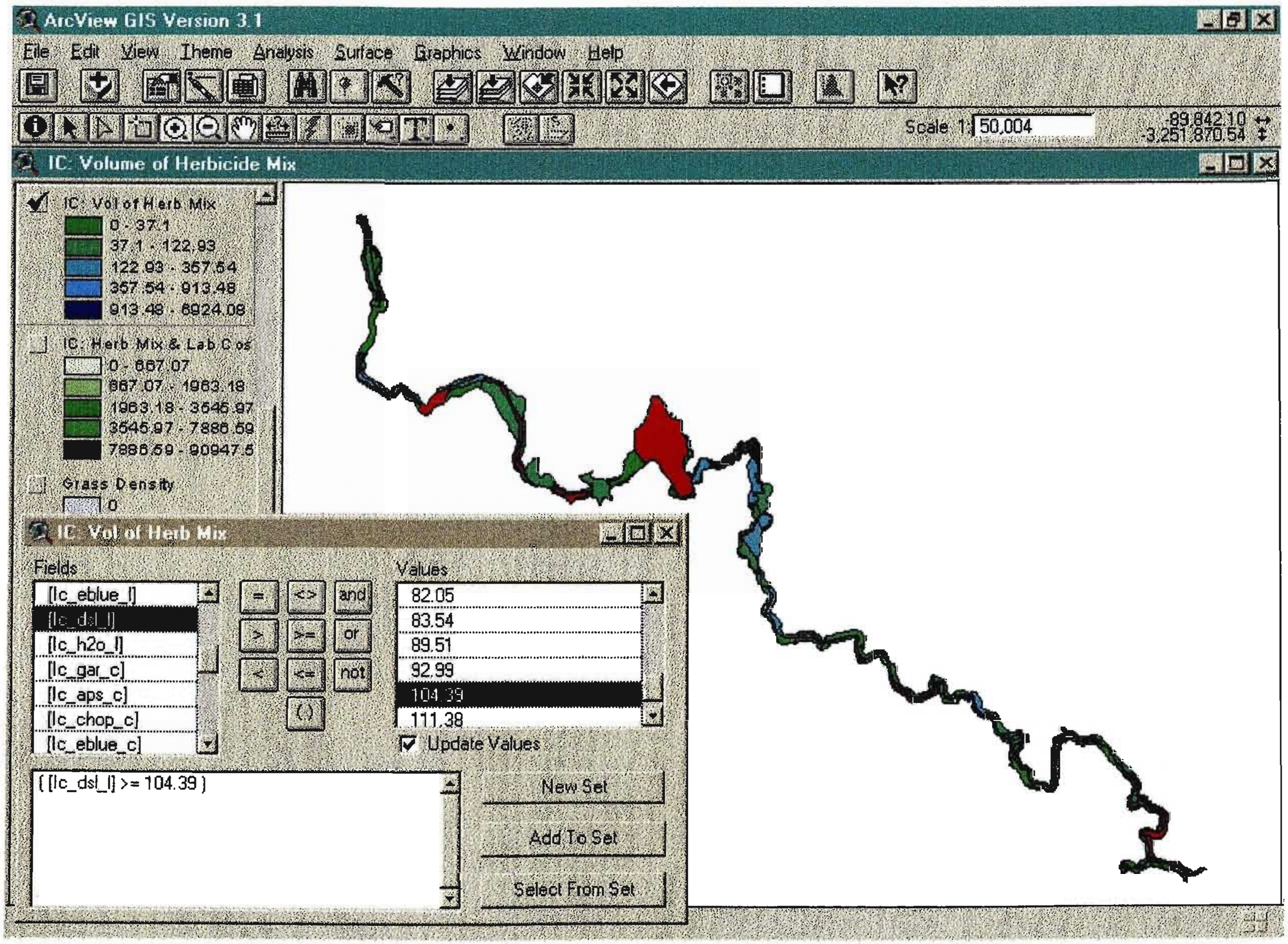

Figure 4.14: Polygons identified for the possible siting of water quality monitoring points

Figure 4.15: Harvested wood left in situ for the local inhabitants to remove at their own cost

leave in situ (as shown in figure 4.15) for the local inhabitants to remove at their own cost, or to fell and remove for sale would depend on a two important factors:

- the density of infestation, and
- the proximity to a road.

The decision would be made on a polygon basis, using the following query.

[[[Wattle tree density]>=4] or [[Gum tree density]>=4]] and [[Distance]<=300][5]

Note that the density class 4 and above represents 51% to 100% infestation. The density of the trees in a polygon is significant in that the greater the density, the higher potential yield. Density is also important because it means the trees will be close together and the stems straighter than trees in more open stands; an important factor in commercial forestry. However, the amount and quality of wood is variable, as the trees are self-seeded and unmanaged (Midmar Catchment Riparian Zone Rehabilitation Study 1997).

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5 **and** operator is used when both expressions must be true, and
or operator is used when at least one expression must be true.

In figure 4.16, the polygons that could be considered as sources of wood are coloured red, and are derived as described above.

4.3.2. Clearing to Increase Stream flow

Dye and Poulter (1995) found that stream flow in afforested catchments is affected by the presence or absence of invasive exotic trees in riparian zones, and that substantial increases in stream flow may be expected where dense infestations of such trees are removed. Clearing of invasive alien trees is costly and justification is often needed for the expense of clearing operations. An increase in stream flow is an obvious justification for the removal of alien invasive plants. However, not all alien plants use more water than the natural vegetation they replace, but generally, trees use more water than grasses or shrubs. The greatest impacts occur when evergreen plants replace seasonally dormant vegetation. So where grasslands are invaded by alien trees, there is an increase in water usage by the vegetation, resulting in reduced run-off into the streams and rivers (CSIR 1998).

Thus if the aim of the manager is to increase stream flow in a river, priority would be given to the removal of mature trees. It is these mature trees that are responsible for the greatest loss of water, as compared to young trees, saplings and seedlings. The density of infestation as well as weed species, together with budget and time are important factors in determining the approach adopted for weed clearance.

For the immediate increase in stream flow, polygons containing a high density of mature trees should be identified for control. Thus polygons with tree density classes 4 to 6, or 51% to 100% tree cover (see table 4.2), will be targeted for the first phase of the control operation. Figure 4.17 shows a patch of wattle trees growing along a stretch of the eMpofana River. The trees will require controlling, and the debris in the river will need to be removed to allow for an increased volume of water in the river channel.

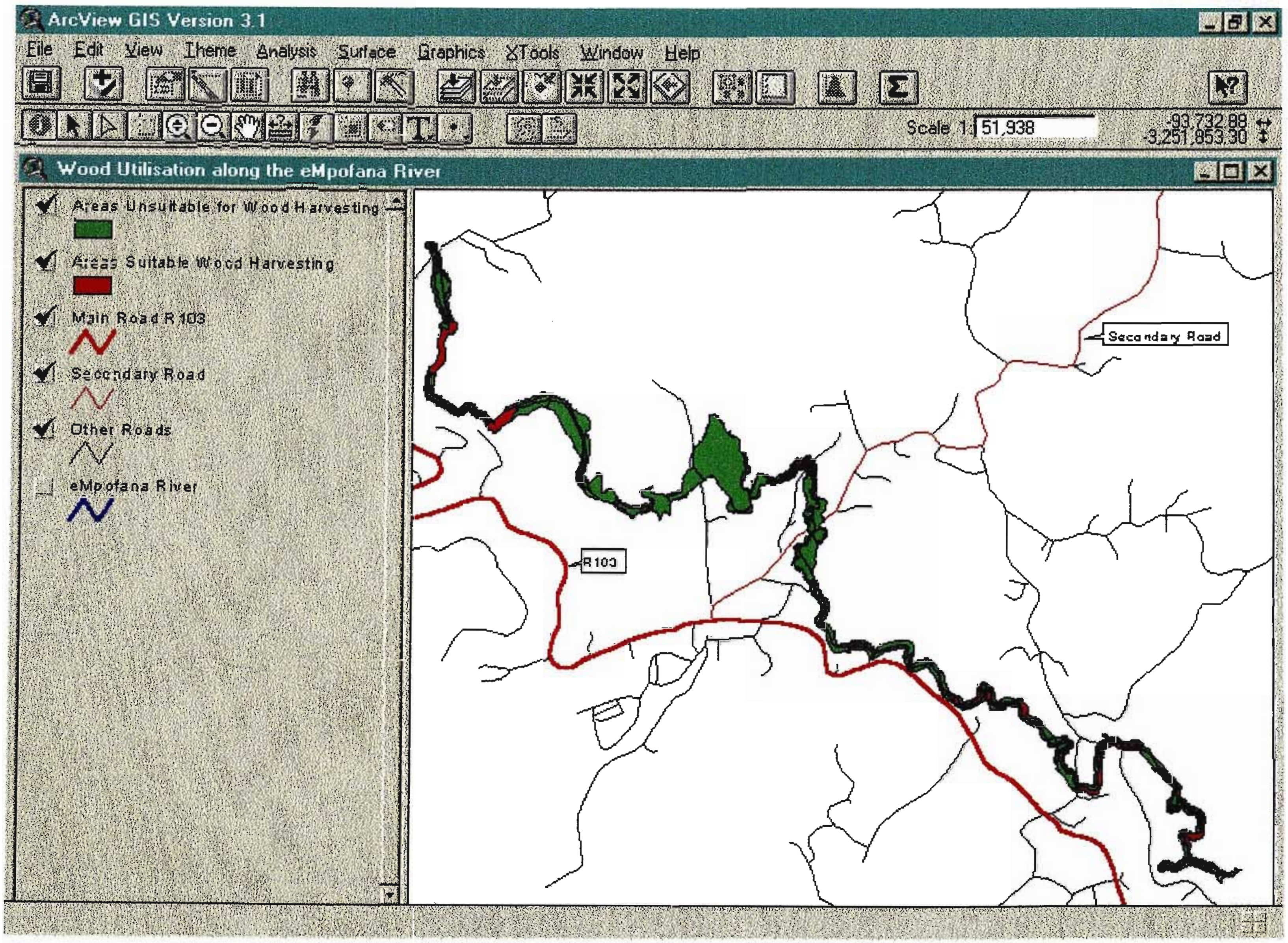


Figure 4.16: Polygons Suitable for Wood Harvesting

Figure 4.17: eMpofana River with mature wattles growing along banks & debris in river channel.

Table 4.2: Density and Percentage Cover

Density Class	Density	Percentage
0 & 1	Low	0 - 5%
2 & 3	Medium	6 - 50%
4 - 6	High	51 - 100%

This would involve using the query builder function in ArcView 3.1 to construct the following query:

[[wattle tree density] >= 4] or [[gum tree density] >= 4] or [[pine tree density] >= 4] or [[poplar tree density] >= 4] or [[willow tree density] >= 4] or [[syringa tree density] >= 4]

Figure 4.18 shows, on screen, the polygons (coloured red) containing the trees that will require clearing, as well as the attribute table with the records of those particular polygons highlighted in red. However, it must be remembered that the labour days

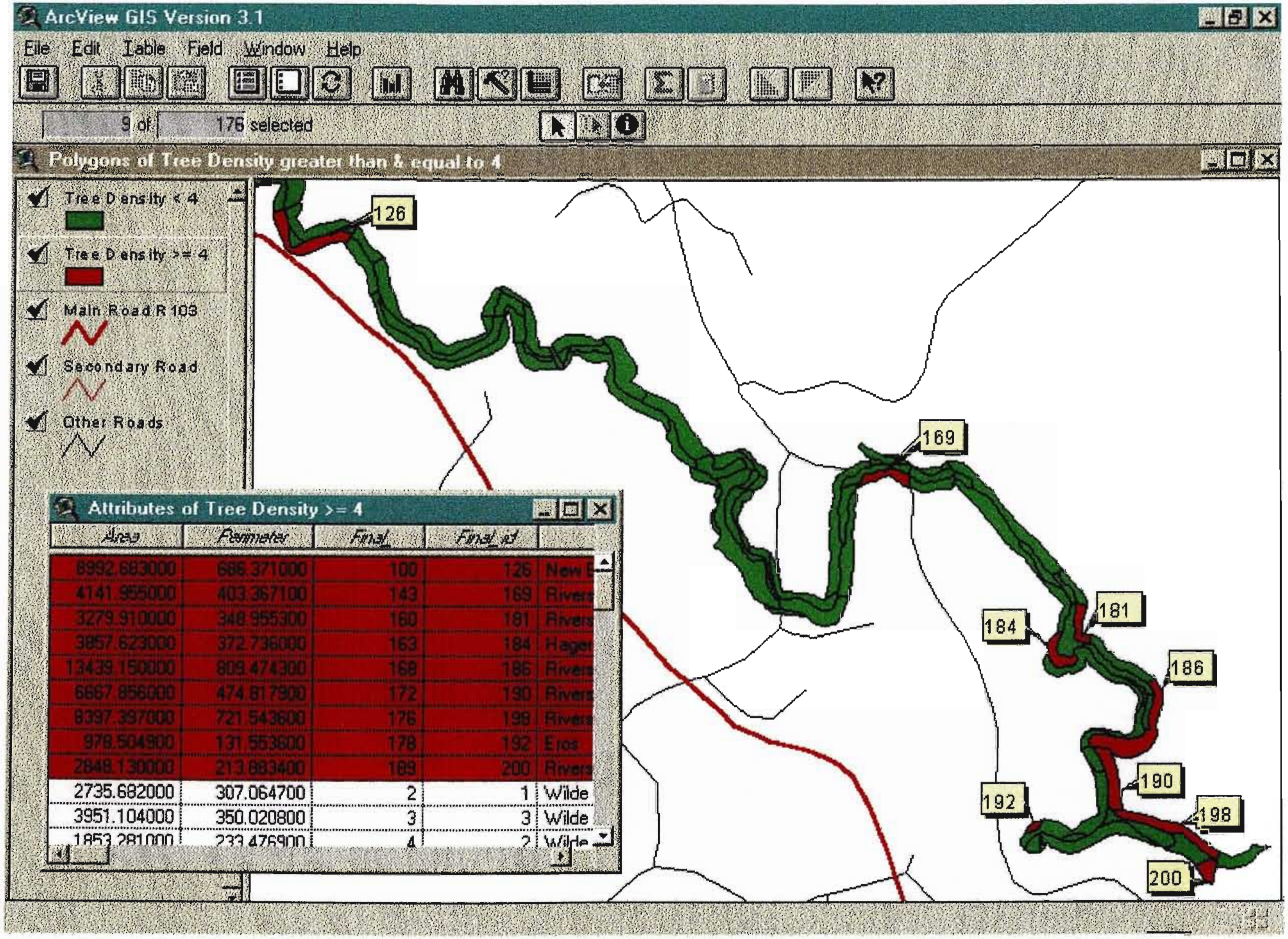


Figure 4.18: Polygons to be cleared in First Phase to increase Stream Flow

and labour costs in the attribute table are the theoretical values. For the corrected work rate figures, the manager would have to refer to the particular grid themes. At this stage the database is not detailed enough to provide herbicide costs, herbicide volumes, labour days and labour costs for the removal of only the trees from the polygons. However, if the long term goal is to clear the river of all weeds, it may make economic sense to remove all the weeds from those particular polygons at the same time that the trees are being removed.

The second phase would involve clearing those polygons containing a medium density of trees, i.e., polygons with a tree density class of 2 and 3 (or 0 to 5% tree cover).

The query would look as follows:

[[[wattle tree density] >= 2] and [[wattle tree density] <= 3]] or [[[gum tree density] >= 2] and [[gum tree density] <= 3]] or [[[pine tree density] >= 2] and [[pine tree density] <= 3]] or [[[poplar tree density] >= 2] and [[poplar tree density] <= 3]] or [[[willow tree density] >= 2] and [[willow tree density] <= 3]] or [[[syringa tree density] >= 2] and [[syringa tree density] <= 3]]

The third phase would involve clearing those polygons containing a low density of trees, i.e., polygons with a tree density class of 0 and 1 (or 0% to 5% tree cover).

The query would look as follows:

[[wattle tree density] <=1] or [[gum tree density] <= 1] or [[pine tree density] <= 1] or [[poplar tree density] <= 1] or [[willow tree density] <= 1] or [[syringa tree density] <= 1]

A variation on control strategy would be to concentrate on the more commonly occurring tree species, for example wattle and gum, repeating the above three phases.

4.3.3 Clearing to Contain Areas and Prevent Further Spread

If the manager's aim is to limit the expansion of the weed infestation, low density infestations consisting of seedlings, saplings and bushes of would be targeted first as they are most likely to expand. Clearing of small patches of light infestation is also encouraging to the weed controller as results are quickly achieved. Trees would be the last to be controlled as they are considered fairly stable. The weed clearing operation would consist of the following four phases, as shown in table 4.3:

Table 4.3: Phases for Clearing to Contain Areas and Prevent Further Spread

Phase	Strategy
Phase 1	Clear polygons containing low density seedlings, saplings and bushes (density class = 0 & 1)
Phase 2	Clear polygons containing medium density seedlings, saplings and bushes (density class = 2 & 3)
Phase 3	Clear polygons containing high density seedlings, saplings and bushes (density class = 4, 5 & 6)
Phase 4	Clear polygons containing trees of all densities

Again, the database is not detailed enough to provide herbicide costs, herbicide volumes, labour days and labour costs for the removal of particular weed habits from the polygons. It is therefore recommended that while seedlings, saplings and bushes of low density are being removed from a particular polygon, all other weeds regardless of habit or form be removed at the same time, and likewise for the other phases. This strategy would also be more cost effective in the long run. Thus if it were decided that the bramble in figure 4.19 needed clearing, the wattle trees in the background would also be cleared at the same time.

Figure 4.19: A section of the eMpofana River, with bramble in the foreground and wattle in the background

The query for the first phase of clearing to contain areas and prevent further spread would look as follows:

[[Wattle sapling density] <= 1] or [[Wattle seedling density <= 1] or [[Gum sapling density] <= 1] or [[Gum seedling density <= 1] or [[Poplar sapling density] <= 1] or [[Poplar seedling density <= 1] or [[Willow sapling density] <= 1] or [[Syringa sapling density] <= 1] or [[Syringa seedling density <= 1] or [[Bugweed (<=1.5m) density] <= 1] or [[Cotoneaster (<=1.5m) density] <= 1] or [[Bramble density] <=1]

Figures 4.20 represent the clearing in the first phase of the operation. The extent of the alien plant invasion is evident by the fact that almost every polygon is indicated (coloured red) as requiring clearing. Thus the strategy of clearing to contain and prevent further spread will not be effective as the invasion has gone past the point of containment. Another strategy would therefore be required in this case.

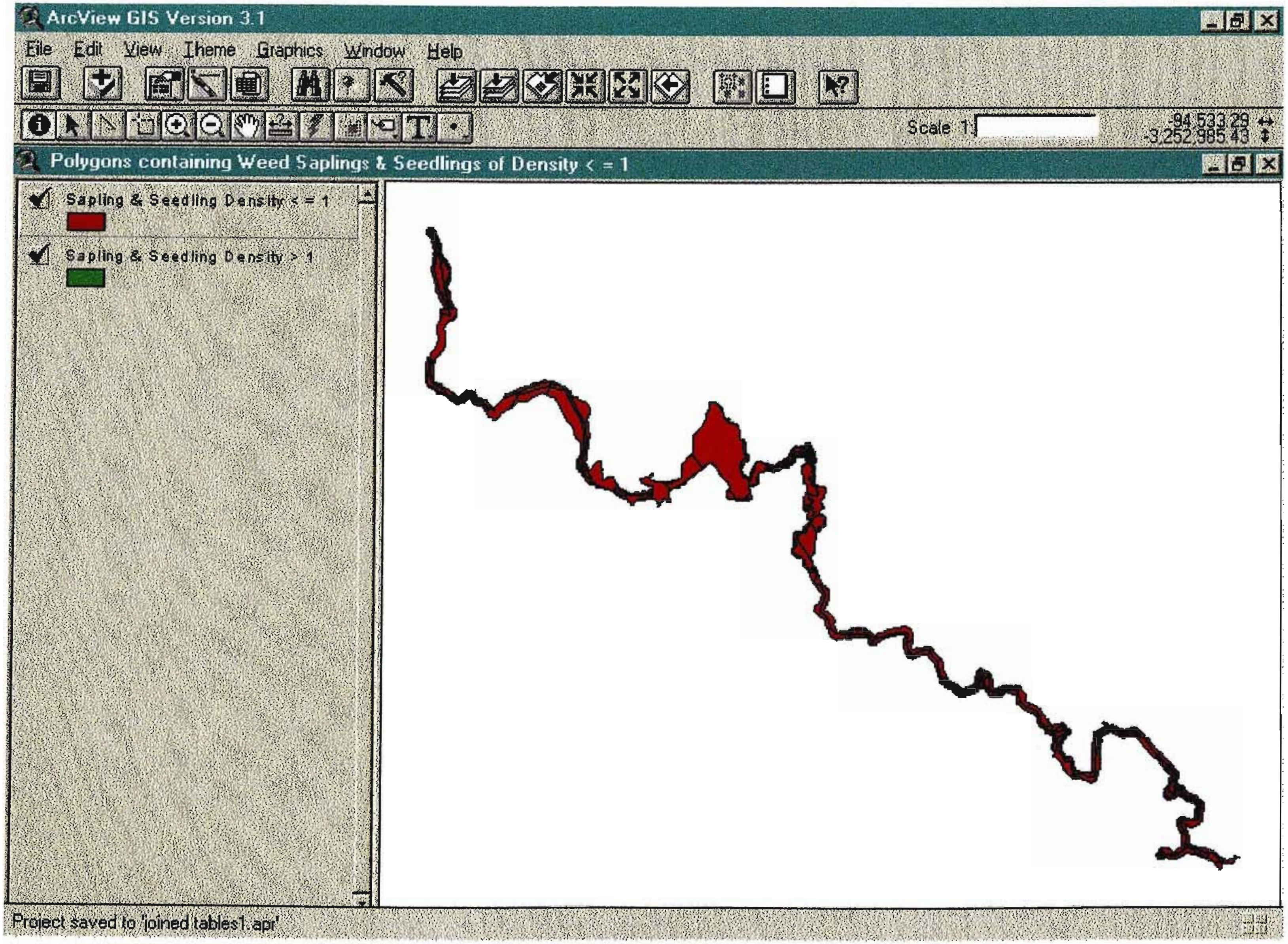


Figure 4.20: Polygons to be Cleared in First Phase of Clearing to Contain & Prevent Further Spread

4.3.4 Clearing at the Scale of the Farm Unit

The expense of setting up a GIS may prohibit the use of the SDSS by individual farmers. However, if a SDSS could be set up as part of integrated catchment management, individual farmers would be responsible for clearing alien plants on their own farms, but would be given access to the SDSS. The integrated catchment management committee would be responsible for providing farmers with access to the SDSS.

Within a catchment, individual farmer should aim to attain the maintenance level of control on their farms. Rehabilitation of land should also be an important priority. The clearing of alien plants can take many years, depending on funds and size of the infestation. It is important not to be overly ambitious, and attempt to clear too much in one year. The systematic reduction of the weed infestation requires steady progress with control (Campbell 1993). It is also important that follow-up control is practised. According to Loxton (1983), a backlog of at least two to three years is created for every year that weed control is neglected. Figure 4.21 (a) shows an infestation along the eMpofana River prior to clearing, and figure 4.21 (b) shows that

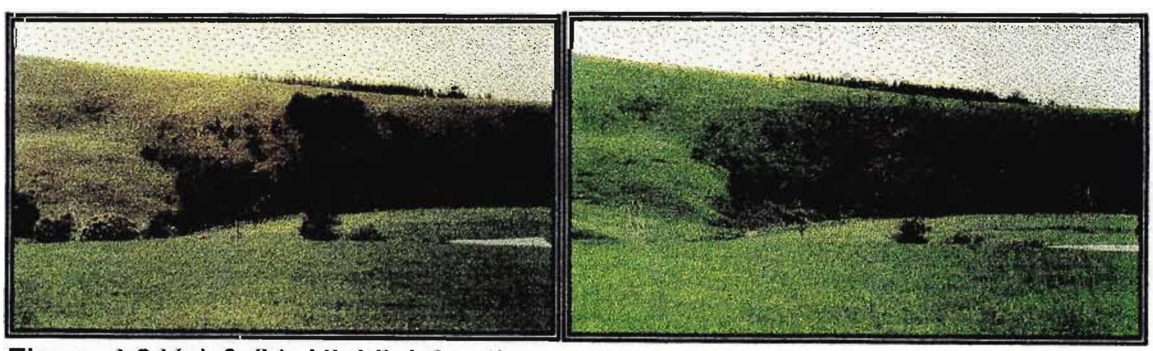


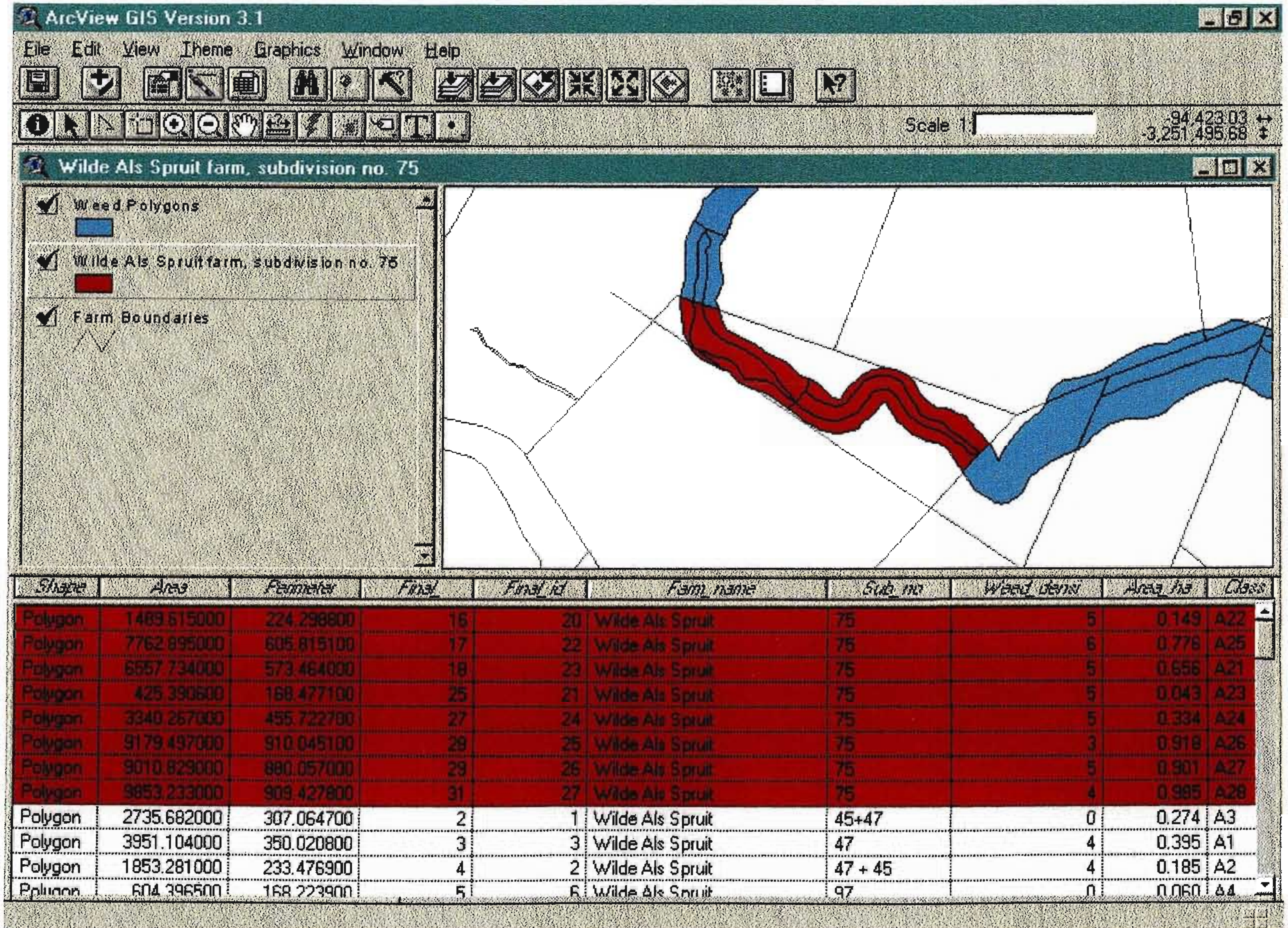
Figure 4.21(a) & (b): Highlighting the importance of follow-up control

same area after the initial control. The regrowth and / or areas that were missed in the initial control are evident, thus illustrating the necessity of follow-up control.

Normally it is best to begin with the light infestations as these are the areas most likely to expand. They are also comparatively easy and inexpensive to control. However, in the case of infestations along water courses, treatment should ideally begin at the top of the river and continue in a down stream direction. While there may well be infestations elsewhere on the farm, this research will confine itself to looking at weed control along the eMpofana River.

It is recommended that the patches of infestation be used to divide the farm into units for control (Campbell 1993). Due to the manner in which the initial surveying was conducted, the weed infestation along the river has already been divided into polygons which will serve as the control units. While clearing the weed polygons, it is necessary to start at the edge of the polygons and work inwards.

Figure 4.22 has been selected as example of the use by individual farmers of the SDSS. The farmer on Wilde Als Spruit, subdividion number 75 would be able to access the information regarding the weed infestation on his particular farm, and could use this information to make more informed decisions regarding costing, strategy and planning. He could if he wished, investigate the necessity of setting up a water monitoring station, to monitor the amount of diesel entering the river. Wood utilisation is also another area of interest to the farmer, as the selling of wood may help towards the cost of clearing.



Shape	Area	Perimeter	Final_	Final_id	Farm_name	Sub_no	Weed_densi	Area_ha	Class
Polygon	1469.615000	224.298800	16	20	Wilde Als Spruit	75	5	0.149	A22
Polygon	7762.895000	605.815100	17	22	Wilde Als Spruit	75	6	0.776	A25
Polygon	6557.734000	573.464000	18	23	Wilde Als Spruit	75	5	0.656	A21
Polygon	425.390600	168.477100	25	21	Wilde Als Spruit	75	5	0.043	A23
Polygon	3340.267000	455.722700	27	24	Wilde Als Spruit	75	5	0.334	A24
Polygon	9179.497000	910.045100	28	25	Wilde Als Spruit	75	3	0.918	A26
Polygon	9010.829000	880.057000	29	26	Wilde Als Spruit	75	5	0.901	A27
Polygon	9853.233000	909.427800	31	27	Wilde Als Spruit	75	4	0.985	A28
Polygon	2735.682000	307.064700	2	1	Wilde Als Spruit	45+47	0	0.274	A3
Polygon	3951.104000	350.020800	3	3	Wilde Als Spruit	47	4	0.395	A1
Polygon	1853.281000	233.476900	4	2	Wilde Als Spruit	47 + 45	4	0.185	A2
Polygon	604.396500	168.223900	5	6	Wilde Als Spruit	97	0	0.060	A4

Figure 4.22: Weed Polygons on Wilde Als Spruit farm, subdivision no. 75

He may also wish to view any of the following important themes to help with planning and costing:

- Initial Control: Labour Days per Polygon
- Initial Control: Labour Costs per Polygon
- Initial Control: Volume of Herbicide Mix per Polygon
- Initial Control: Cost of Herbicide Mix per Polygon
- Rehabilitation: Labour Days per Polygon
- Rehabilitation: Labour Costs per Polygon
- Rehabilitation: Mass of Grass Mix per Polygon
- Rehabilitation: Cost of Grass Mix per Polygon
- Follow-Up Control: Labour Days per Polygon
- Follow-Up Control: Labour Costs per Polygon
- Follow-Up Control: Volume of Herbicide Mix per Polygon
- Follow-Up Control: Cost of Herbicide Mix per Polygon
- Complete Treatment: Labour Days per Polygon
- Complete Treatment: Labour Costs per Polygon
- Complete Treatment: Volume of Herbicide Mix per Polygon
- Complete Treatment: Cost of Herbicide Mix per Polygon
- Complete Treatment: Cost of Labour, Herbicide Mix & Grass Mix per Polygon

While there are many benefits to gained by the use of the SDSS in alien plant control, shortcomings do exist. Both the strengths and the weaknesses of the SDSS will be examined.

4.3.5 Strengths and Weaknesses of the Spatial Decision Support System (SDSS) for Alien Plant Control

Strengths

The use of a GIS in the costing of weed clearance work rates is useful for a number of reasons. It provides a spatial component to weed control planning and costing that has thus far not existed. The visualisation that a GIS provides is useful in that it reveals patterns and trends that one would not ordinarily observe from tables. Thus the added spatial component of a GIS, helps with visualisation and ultimately better decision making. Contractors would find this an invaluable tool in budgeting for the clearing of alien plants, especially if the system is customised, so that the user does not have to be a GIS expert. It would also be helpful to emerging contractors who could benefit from better budgeting and realistic tendering.

The system is also dynamic and adaptable, so that while the setting up of the GIS is costly, the advantage is that it can be reused and updated. According to Aronoff (1989), the ability of GIS to: manipulate spatial data and its corresponding attribute information, to integrate different types of data in a single analysis and to operate at high speeds are unequalled by any manual method. Even once maintenance level has been attained, the system can be used to monitor weed control. Once the digital data has been captured and the database built, analysis and queries can be performed with almost instantaneous results.

Weaknesses

Probably the greatest deterrent in using a spatial decision support system is the cost, time and financial resources required. As a result, only large organisations and / or programmes, such as Working for Water, would be able to afford such a system. However, the average farmer and even small scale contractors may find it too costly. The creation of partnerships between large organisations / programmes and farmers, may offer a solution to the problem. Resources could be shared and the various parties could work together towards a common goal. A further advantage to such an arrangement, is that it overcomes the problem of unskilled people not being able to make use of a GIS.

While the system is useful as is, a knowledge-based system, or expert system, would ultimately be ideal, and would provide better decision support to weed managers. At present the system is somewhat rigid, and it is envisaged that a knowledge-based system would provide greater flexibility. For example, it would be more desirable for the system to provide a variety of control treatments, especially in terms of follow-up control and the choice of the number of follow-up years. This research has made use of the 5 follow-up years prescribed by Goodall and Naudé(1998b), however this can be limiting and a system is required where more options are available. This also refers to the use of a variety of herbicides and the structure of the work teams.

While the modelling has offered an improvement on existing weed management costing, there are a number of ways in which the model could be improved upon. Similarly, the spatial decision support system has added a spatial component as well as a greater measure of flexibility to weed control planning. However, there are also ways in which the spatial decision support system could be modified and developed. These will be examined in the following chapter.

CHAPTER 5
RECOMMENDATIONS AND CONCLUSION

5.1 Introduction

A model is an approximation of reality and thus needs to be tested and refined. As this is a first attempt at incorporating a work rate model for alien plant control into a GIS, certain adjustments may be required to improve on it. It is very important that a work study be undertaken to test and verify the relationship between the three work rate factors namely: slope, penetrability and access, and to possibly include other factors that have been omitted unwittingly. It is anticipated that the use of this model will allow for more realistic work rate costing in alien plant control. Similarly, the SDSS for alien plant control will undoubtedly enable managers to make more informed decisions regarding the planning and control of alien plants. However, as mentioned in the previous chapter, the greatest deterrent to the use of the SDSS, is probably the expense of a SDSS, coupled with the lack of GIS expertise.

5.2 Recommendations

5.2.1 Work Rate Model

As this is a first attempt at a work rate model, it is recommended that a work study be carried out to test the model in order to make possible changes and adjustments. As the research area was not particularly mountainous, a first step would be to apply the model in a more mountainous area where the rockiness factor, identified by Goodall and Naudé (1998a), can be tested. The terrain conditions (slope factor) as well as the accessibility (distance factor) also need to be more varied in order to fully test the model. The results of a work study may lead to the addition or elimination of work rate factors and/or the adaption of work rate factors for different physical conditions. The weighting of the individual factors may also need adjusting for different locations. As the relationship between the various factors influencing the work rate (especially the distance factor) and the correction to the work rate was assumed to be linear, it may be necessary to adjust the regression equation in order to more accurately reflect the relationship between the factors affecting work rate.

Another factor identified and not accounted for in this research is that the number of species (especially with the same habit) in an infestation is directly proportional to the ease and speed of control of that infestation. Also species that have the same treatment are easier and quicker to control. Thus it is recommended that the diversity of species and/or treatments in controlling those species be considered as another possible factor affecting the work rate.

5.2.2 A Spatial Decision Support System (SDSS) for Alien Plant Control

The first recommendation relates to the first phase in creating a decision support system, namely data capture. The creation of the database for the decision support system was limited by the initial inputting into spread sheets. The original spreadsheets, as created by Goodall and Naudé (1998b), consisted of a number of spreadsheets within a single file. The data needed to be transformed into a database form where a single file consisted of one spreadsheet with a number of fields or columns, and their corresponding records or rows. From the outset, it would be better to create a database that could easily be incorporated into a GIS.

It is furthermore recommended that the treatment strategy as demonstrated in table 5.1 be used, as it has removed some of the redundancies found in the treatment strategy proposed by Goodall and Naudé (1998b) (see Appendix 3, table A3.2). By simplifying the treatment strategy it deduces the number of calculations for the herbicide, grass and labour costing.

Probably the greatest deterrent in using a SDSS is the cost, time and financial resources required. The average farmer and even small scale contractors may find it too costly to establish a SDSS. It is therefore recommended that large organisations and / or programmes, who have the financial resources and expertise, form partnerships with smaller organisations and farmers. Resources and skills could be shared, enabling the various parties to work together in their efforts to control and manage alien plants. Furthermore, farmers and small scale contractors would be able to make use of the SDSS without needing to be GIS experts.

Table 5.1 Species or Groups of Species with Same Treatment

SPECIES	STRATEGY	CHEMICAL TREATMENT				
		Technique	**Herbicide**	**Wetter**	**Dye**	**Carrier**
Logs in river/dam	Extract & cut logs, remove	n/a	n/a	n/a	n/a	n/a
Pine, ornamental & dead trees	Fell, debranch & cross-cut into logs, do not treat stumps, stack brush, remove					
Pine & ornamental saplings	Brushcut, stack brush					
Pine seedlings	Hand pull					
Wattle trees	Fell, debranch & cross-cut into logs, treat stumps (as indicated), stack brush, debark pulp logs only, remove	Total stump	2% Garlon 4	n/a		Diesel
Wattle saplings	Brushcut, treat stumps (as indicated), stack brush					
Peach & mulberry	Slash, treat stumps (as indicated)					
Cotoneaster > 1.5 m	Slash, treat stumps (as indicated), stack brush					
Cotoneaster < 1.5 m	Spray (as indicated)	Foliar spray				
Gum trees	Fell, debranch & cross-cut into logs, treat stumps (as indicated), stack brush, debark pulp logs & good poles only, remove	Cut stump	7.5% Chopper	n/a	n/a	Water
Gum saplings	Brushcut, treat stumps (as indicated), stack brush					
Poplar & willow trees	Fell, debranch & cross-cut into logs, treat stumps (as indicated), stack brush, remove	Cut stump	5% Chopper	n/a	n/a	Water
Poplar & willow saplings	Brushcut, treat stumps (as indicated), stack brush					
Syringa trees	Fell, debranch & cross-cut into logs, treat stumps (as indicated), stack brush, remove	Cut stump	3% Chopper	n/a	n/a	Water
Syringa saplings	Brushcut, treat stumps (as indicated), stack brush					
Wattle, gum, poplar & syringa seedlings	Spray (as indicated)	Foliar spray	0.75% Garlon 4		n/a	Water
Bugweed > 1.5 m	Slash, treat stumps (as indicated)	Cut stump	1.25% Chopper	n/a	n/a	Water
Bugweed < 1.5 m & American bramble	Spray (as indicated)	Foliar spray	0.5% Garlon 4		n/a	Water

While the SDSS for alien plant control is useful as is, it is recommended that a knowledge-based system (or expert system) would provide better decision support to alien plant control managers, and therefore needs to be developed in the near future. The present SDSS is somewhat prescriptive, and is limited by its lack of flexibility. Ideally, a greater variety of control options both in terms of herbicides and work teams are required. It is anticipated that a knowledge-based system would enable greater adaptability, allowing for better decision making.

There is a further recommendation that refers specifically to the user-friendly nature of ArcView 3.1. While ArcView 3.1's querying and visualisation on screen are easy to use and very effective, the laying out of images is problematic. To a user who wishes to work on screen and is not in need of a paper map, the use of ArcView 3.1 presents few problems. However, if a manager should wish to print a particular view to give to a contractor or farmer, ArcView 3.1's lay out function is difficult to work with and preparing an image for printing is frequently time consuming, as the researcher discovered. It is therefore recommended that until a newer version of ArcView is produced in which the problem with the lay out has been remedied, the user should import the view into another graphic presentation software package, such as Corel Draw in order to manipulate the lay out and print the image.

5.3 Conclusion

Work rate is influenced by a number of factors, as has been acknowledged by the timber industry and alien plant control managers. This is however a first attempt at formalising and incorporating these factors into a GIS. While some factors affecting work rate may not have been accounted for, the model does attempt to address the present inaccuracies in labour costing, and ultimately alien plant control costing. Since labour is regarded as one of the major costs in alien plant control, it is important that it is accurately budgeted for.

What the work rate model has achieved, is the advancement from a theoretical to a more realistic costing process. Factors influencing weed control costing have been taken into account at a level of detail that is impossible for a subjective observer.

Simple data has been transformed into a model that enables an alien plant control manager to accurately predict the work rate and hence to budget more efficiently. This model has wider uses than the eMpofana River, and is the ground work for the further development of a user friendly model applicable throughout South Africa, which will give reliable costings for weed control projects, so long as the initial survey work is carefully and accurately done.

The SDSS was developed to aid the decision-making process with both the planning and the management of weed control projects. The SDSS has not only incorporated the database of alien plant control costing, but has also included the work rate model to enable more realistic predictions for labour costing. It provides a spatial component to weed control planning and costing that has thus far not existed. Contractors and managers would find this an essential tool in alien plant control budgeting, especially if the system is customised, so that the user does not have to be a GIS expert.

The incorporation of the model into a GIS has some disadvantages in terms of affordability and expertise. It is hoped that the flexibility, in terms of reusing and updating, and the visualisation capabilities of a GIS will compensate for the cost in establishing such a SDSS.

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APPENDICES

APPENDIX 1: Perceived Differences Between Weeds and Invader Plants

WEEDS	INVADERS
Alien plants that serve no known useful purpose.	Alien plants that can serve a useful purpose if contained to specific areas.
Completely 'out of place' and unwanted on any land because of undesirable characteristics and effects.	Only 'out of place' when invading undisturbed land without human interference.
Plants that can be classed as harmful, unwanted, a menace, constantly problematic to control, useless, plants that should therefore for all intents and purposes be eradicated.	Plants that can be classed as problem plants outside the areas where they serve a useful purpose but that should not necessarily be eradicated.
Plants that should not be allowed to spread or to be propagated in any way or be used in trading of any kind.	Plants that can be allowed to be propagated under managed conditions and that can be used in trading for specific purposes.

(Directorate of Agricultural, Land and Resource Management 1999b)

APPENDIX 2: Alien Plants found along the eMpofana River

2.1 American bramble (*Rubus cuneifolius)*

Description

American bramble also known as blackberry originates from North America. It is a deciduous shrub, characterised by curved prickles on its stems and serrated-edged leaves. The flowers are white and the fruit changes in colour from green to pink to black. American bramble is one of a number of exotic brambles invading overgrazed grassland, often hybridizing with one another and indigenous species (Henderson *et al* 1987).

American bramble was introduced into this country for its fruit in the late nineteenth century. Since then, it has spread rapidly especially in the KwaZulu-Natal midlands and the Mpumalanga area where it favours the temperate climates and high rainfall of these areas (PPRI 1999).

Problem/Threat

American bramble is very adaptable, amongst trees a tall form occurs and a short form occurs in grassland. Hence, it is able to invade forest edges, plantations and grasslands. The occurrence of American bramble in the veld limits livestock movement and reduces grass production, especially in dense patches of infestation. In plantations, American bramble restricts the movement of workers and equipment. It is an extremely difficult weed to eradicate, spreading both vegetatively and by birds feeding on the berries. Control usually involves mechanical and chemical means (PPRI 1999 and Henderson 1995).

Status

American bramble is a declared weed in terms of the Agricultural Conservation Act, No 43 of 1983. Herbicides such as glyphosate and triclopyr are registered for the control of this weed. In addition, American bramble is the subject of biocontrol investigation (Henderson 1995).

2.2 Bugweed *(Solanum mauritianum)*

Description

Bugweed originates from South America, growing up to 8 metres in height. Its leaves are hairy and shaped like tobacco leaves. Bugweed flowers are purple in colour, and the fruit, found in clusters of 20 - 80, is initially green becoming soft and yellow when ripe. Small, rounded seeds are found within the fruit, with an occurrence of as many as 250 seeds per fruit. The bugweed seeds are spread by birds, monkeys, bush pigs, bush buck and duiker. The dispersal of bugweed is further aided by the preference by birds for bugweed fruit over the fruit of indigenous plants (PPRI 1999).

Problem/Threat

Bugweed is common in moist inland areas, especially in timber plantations and along forest margins. Its occurrence in plantations is problematic because the hairs on the leaves may irritate the skin or result in respiratory problems, which will hinder the movement of workers. In addition, bugweed is regarded as a hazard to young forestry plantations because birds, which are attracted to the bugweed fruit, perch on and break the growing points of young pine trees, affecting the future conformation of these trees (Henderson &Musil 1987 and Bromilow 1995).

The fruit fly that attacks fruit in orchards has been found to breed in the bugweed fruit. Furthermore, the predilection developed by birds for bugweed fruit, has meant that birds no longer bother to seek out and distribute the fruits of indigenous plants (Henderson & Musil 1987). Bugweed is also known to invade roadsides, wastelands, watercourses and urban open space (PPRI 1999 and Henderson 1995).

Status

Bugweed is a declared weed in terms of the Agricultural Conservation Act, No 43 of 1983. It is the subject of a herbicide registration and biocontrol investigation (Henderson 1995).

2.3 Cotoneaster (*Cotoneaster francetii* and *C. pannosus*)

Description

Cotoneaster originates from Asia, and is used for ornamental purposes and hedging. It is an unarmed shrub growing up to 3 metres high with arching branches. *C.francetii* has small grey-green leaves and pinkish flowers, producing orange-red, berry-like fruit. While *C. pannosus* has larger dull green leaves and white flowers which produce deep red fruit (Henderson 1995).

Problem/Threat

Cotoneaster invades grassland, forest margins, kloofs, riverbanks and rocky outcrops. It invades by means of seed which is often spread by birds from garden or road-side plantings (Henderson & Musil 1987).

Status

Unknown.

2.4 Eucalyptus spp

Description

The eucalyptus species have been grouped together because the similarities between the species results in a similar method of control for all eucalyptus species. Eucalyptus trees were introduced from Australia for a variety of reasons including: the provision of timber, as a source of firewood, for ornamental purposes, to provide shelter, for the bee-keeping industry and to bind sand dunes.

Problem/Threat

Eucalyptus trees have invaded water courses where they have seriously affected the flow of rivers and streams. They are also capable of invading forest gaps, plantations, fynbos and road sides. Eucalyptus trees are spread from fine wind-blown and water-borne seed. They also coppice when cut (Henderson 1995).

Status

Herbicides have been registered in the use against eucalyptus species (Henderson & Musil 1987).

2.5 White Mulberry (*Morus alba*)

Description

White mulberry was introduced from Asia, and is cultivated for its edible fruit. It is a deciduous tree growing up to 15 metres high, with a dense, rounded canopy. Its leaves are light green, turning yellow in autumn. The flowers are green and fruits are white, purple or black in colour.

Problems/Threats

White mulberry invades savanna, grassland, roadsides, riverbanks and urban open space. It is spread by birds who feed on its fruit, and coppices when cut.

Status

It has been proposed that Mulberry be declared a weed (Henderson 1995).

2.6 Ornamental trees

Description

Ornamental trees include plain, cyprus, oak, etc.

Problems/Threats

While being exotic, they are not particularly invasive and are thus not considered problematic. They have been grouped together because of their similar methods of control.

Status

Unknown.

2.7 Pinus spp

Description

The pine species have been grouped together as was done with the eucalyptus species and ornamental trees, because of the similar methods of control for all pine species. The pine species were introduced for timber and originate from several continents including North America, Central America and Europe.

Problem/Threat

Pine species invade by means of seed spread by wind and rodents. They invade forest margins and gaps, grasslands, fynbos and road cuttings (Henderson 1995).

Status

Cluster pine (*Pinus pinaster*) has been declared an invader plant except where it is cultivated commercially, and is the subject of a herbicide registration. It has been proposed that *Pinus canariensis*, *P. elliottii*, *P. halepensis*, *P. patula*, *P. pinea* and *P. radiata* be declared invader plants (Henderson 1995).

2.8 Grey Poplar (*Populus x canescens*) and Matchwood Poplar (*P. deltoides*)

Description

Grey poplar was introduced to South Africa from Europe and Asia in the 1920's. It is a deciduous or semi-evergreen tree, growing up to 35 metres in height. Its bark is white/grey in colour with horizontal dark lines, and its leaves are dark green and shiny above but white to green beneath. Grey poplar was cultivated to provide timber and shelter, for ornamental purposes, and for donga reclamation.

Problem/Threat

Grey poplar invades vleis, water courses and dongas. It coppices when cut and suckers profusely from the roots, frequently producing dense stands of saplings around a few mature trees. This hybrid does not however produce seed, but is nevertheless difficult to control (Henderson 1995 and Bromilow 1995).

Although grey poplar is considered the problematic of the poplar species, matchwood poplar (*P. deltoides*), a timber species which is planted along streams and in wetlands, will also need to be cleared from along the river course. It coppices when cut, sometimes suckers from the roots and also spreads from seed (Henderson 1995 and Henderson & Musil 1987).

Status

Unknown.

2.9 Syringa (*Melia azedarach*)

Description

Syringa was imported from India late last century for ornamental purposes. Today, parts of the plant are used for the making of insecticides, while its soft, attractive wood makes it suitable for cabinet making.

Syringa is a deciduous tree growing to a height of 20 metres. Its leaves are oval in shape with serrated edges, and the flowers are lilac in colour and heavily perfumed. The syringa fruit consists of a green berry which becomes yellow and wrinkled, and contains three seeds (PPRI 1999 and Henderson 1995).

Problem/Threat

Syringa has invaded large parts of the country because it is drought resistant and tolerates mild frost, and can thus withstand a range of growing conditions. Syringa coppices, even from stumps cut to ground level and burned, and is thus difficult to control. It spreads by means of its berries which are carried by water and birds. The berries are poisonous to some animals, including ruminants and chickens. Syringa competes with and replaces indigenous plants, especially along water courses. It also invades savanna, roadsides, urban open spaces and wasteland (Henderson 1995, Bromilow 1995 and PPRI 1999).

Status

It has been proposed that Syringa be declared a weed (Henderson 1995). At present, there is at least one herbicide registered for use as a basal stem treatment. The herbicide is mixed with diesel and painted onto both the stem and stump (Bromilow 1995).

2.10 Wattle

Wattle includes black wattle (*Acacia mearnsii*), silver wattle (*A. dealbata*), green wattle (*A. decurrens*) and blackwood (*A. melanoxylon*). They have been grouped together because of their similar methods of control.

Wattle (Acacia mearnsii, A. dealbata and A. decurrens)

Description

Black wattle was introduced into South Africa from Australia initially to provide firewood and shelter, but was later commercially cultivated for its bark, pulp, firewood and the mining industry. Originally planted in KwaZulu-Natal, it is now widespread and still spreading due to natural invasion and commercial planting. Whilst black wattle is undeniably an economic plant, it is however problematic when it grows outside of commercial plantations (PPRI 1999).

Black and silver wattle are the most serious invaders, and may appear difficult to tell apart. The difference being the even distribution of the glands on the rachis of silver wattle, as compared to the irregular distribution on black wattle. Furthermore, green wattle is more frost tolerant than black wattle, and thus occurs at higher altitudes than black wattle. Silver wattle is also grey-green in colour, whereas black and green wattle have darker green leaves. While the leaves of green wattle are longer and more openly arranged than the leaves of black and silver wattle. Green wattle is not very common, and together with silver wattle, may have been introduced by mistake. Neither silver wattle nor green wattle is planted commercially (Bromilow 1995).

Problem/Threat

Wattle is a problem on agricultural land because it reduces the grazing capacity of the land by competing with and replacing grassland. The exposed soil under the trees is then easily eroded. Wattle also invades forest gaps, roadsides and water courses. The impact of wattle and other weed species on the volume of flow in water courses has been highlighted by the work of Dye and Poulter (1995), who demonstrated how the removal of these alien plants from water courses can significantly increase the volume of water in these rivers and streams. Wattle also forms dense stands along river banks, frequently replacing indigenous plants and leading to instability on the river banks (PPRI 1999 and Henderson 1995).

The spread of wattle is largely by means of its seeds, which can remain viable for many years. It coppices readily and produces root suckers. Wattle seeds are known to have a lifespan of over 50 years. Furthermore, the soil below an old tree may contain over 20 000 seeds per square metre. Thus, the potential for spread, and the problems of control are great (Stirton 1985).

Wattle may be controlled by a combination of mechanical and chemical methods, but may require many years of follow-up operations to remove seedlings. Burning is one means of depleting the seed store as it stimulates germination. The seeds are dispersed by run-off, and hence the occurrence of wattle in many drainage channels and river courses. Thus when controlling an infestation, it should be kept in mind that sources of seed may well exist upstream of the immediate control area (PPRI 1999).

Status

In terms of the Agricultural Conservation Act, No 43 of 1983, black wattle and green wattle have been declared invader plant except where black wattle is cultivated commercially. Black, silver and green wattle are the subjects of herbicide registrations and the use of biocontrol agents which attack their seeds is under investigation (Henderson 1995).

Blackwood (Acacia melanoxylon)

Description

Blackwood was introduced from Australia as a forest replacement species in the Knysna forest. As indigenous trees where felled, so they were replaced with blackwood. It is an unarmed, evergreen tree growing up to 20 metres in height with a straight trunk and dense, cylindrically-shaped crown. The leaves are dark green and elongated in shape, and the flowers are pale yellow. Blackwood seeds are black, almost encircled by reddish seed stalks, and contained in reddish-brown pods (Henderson 1995).

Problem/Threat

In spite of its highly invasive nature, blackwood has a number of useful features. It is a fast-growing evergreen tree with a well-formed cylindrical crown which makes the tree useful as a forest replacement species, as a tree for shelter belts and as an ornamental in gardens. Furthermore, blackwood yields a good timber which is similar in appearance and qualities to that of indigenous stinkwood. Blackwood is used extensively in the manufacture of furniture, as well as fences, bridges, boats and gunstocks.

However, blackwood is difficult to control because of vigorous regrowth from stem coppice, root sucker and regeneration from seed. The seedbank in the soil can be very large with seeds lying dormant for many decades before germination occurs. The tough, hard skin of the seed protects the seed from predators and decay. Birds act as effective dispersal agents for the seeds. Blackwood grows best in moist and cool conditions and is most common in forests, on forest margins and along water courses. It competes vigorously with indigenous forests and riverine woodland trees (Stirton 1985 and Henderson 1987).

Status

In terms of the Agricultural Conservation Act, No 43 of 1983, blackwood is a declared invader, and the use of biocontrol agents which attack the seeds is under investigation (Henderson 1995).

2.11 Weeping Willow (*Salix babylonica*)

Description

Weeping willow was introduced to South Africa from Asia to provide shade, for ornamental purposes, as fodder, for the control of erosion and for the bee-keeping industry. Weeping willow is a deciduous tree and can grow to 18 metres in height. Its branches hang vertically, almost to the ground, and its leaves are long and slender. Its flowers are white and almost always female.

Problem/Threat

Weeping willow invades watercourse and in so doing decreases the volume of flow in these rivers and streams. It spreads vegetatively from detached branches and coppices when cut (Henderson 1995).

Status

Unknown.

APPENDIX 3: Weed Control Costing conducted by PPRI for Alien Plant Removal and Clearing of the eMpofana River

3.1 Field Work

The initial data collection was conducted by the Plant Protection Research Institute in 1997. Data was recorded on a survey sheet as shown in figure A3.1, and the weed areas (polygons) were sketched accurately onto 1:10 000 orthophotographs for digitising later. Each of the polygons was assigned a polygon number (referred to as a class number) during surveying. Later a unique reference number was given to each polygon for the inputting into the GIS system, ArcView 3/Arcinfo. The polygon areas were later determined using ArcView 3/Arcinfo. The Q_2 + 10 m^3/sec flood line (or the one in two year flood line with an increased stream flow of 10 m^3/sec) and a 30-metre buffer zone were superimposed onto the 1:10 000 orthophotographs. Polygons were classified as either Q_2 + 10 m^3/sec or 30 metre, the latter being chosen when the 30 metre line fell outside the Q_2 + 10 m^3/sec flood line.

Four different types of vegetation 'type' or polygon type were identified and recorded on the survey sheet. The polygon types included: weed areas (W), forestry plantations (F), orchards (O) and indigenous forests (IF). A survey was conducted for weed areas and orchards only.

A weed density for the whole polygon was recorded next using the density classes in table A3.1. Class 1 is the maintenance control level and is therefore the level managers should aim to achieve, since eradication of alien invasive plants is virtually impossible. Class 0 is necessary as it is important that weed free areas are recorded and that managers ensure these areas remain as such. Where the weed infestation is dense and another stratum of weeds exists, weed cover may exceed 100%, hence the need for class 6. Grass cover within the polygon was also recorded using the density classes 0 to 5.

Figure A3.1: Survey Sheet for Clearing of Receiving Streams of Mooi-Mgeni Transfer Scheme

SURVEY SHEET: : FARM NAME : SUB No.:

MAP No. : PAGE No. : SURVEYORS: DATE:

POLYGON NO.							
POLYGON AREA *(Ha)* (from mapping)							
POLYGON TYPE (W, F, O, IF)							
HABITAT RANKING							
MY PRIORITY RATING (management goals)							
GRASS COVER (use weed density classes 0 - 5)							
WEED DENSITY CLASS (0, 1, 2 ,3, 4 ,5, 6)							
Wattle trees (*Acacia* species)							
Wattle saplings							
Wattle seedlings							
Gum trees (*Eucalyptus* species)							
Gum saplings							
Gum seedlings							
Pine trees (*Pinus patula* , *P. taeda* & *P. elliottii*)							
Pine saplings							
Pine seedlings							
Poplar trees (*Populus deltoides* & *P. canescens*)							
Poplar saplings							
Poplar seedlings							
Willow trees (*Salix babylonica*)							
Willow saplings							
Syringa trees (*Melia azedarach*)							
Syringa saplings							
Syringa seedlings							
Jacaranda trees (*Jacaranda mimosifolia*)							
Jacaranda saplings							
Jacaranda seedlings							
Bugweed (>1.5m) (*Solanum mauritianum*)							
Bugweed (<1.5m)							
Peach (all heights)(*Prunus persica*)							
Mulberry (all heights) (*Morus alba*)							
Lantana (> 1.5 m) (*Lantana camara*)							
Lantana (< 1.5m)							
Cotoneaster/Pyracantha (>1.5 m)							
Cotoneaster/Pyracantha (<1.5m)							
Bramble (all heights) (*Rubus cuneifolius*)							
Hyacinth (only in dams) (*Eichhornia crassipes*)							
Kariba weed (only in dams) (*Salvinia molesta*)							
Planted trees (*Platanus*, *Cypressus*, *Quercus*)							
Ornamental saplings							
TOTAL							

Weed density classes: **0** = 0%, **1** = 1-5%, **2** = 6-25%, **3** = 26-50%, **4** = 51-75%, **5** = 75-100%, **6** = > 100% aerial cover. W = watercourse; F = Forestry; O = Open veld; IF = Indigenous forest (PPRI, 1997)

Table A3.1: Density Class for Alien Plants and Grass

Density Class	Percentage
0	0%
1	1 - 5%
2	6 - 25%
3	26 - 50%
4	51 - 75%
5	76 - 100%
6	> 100% (understorey weeds)

Finally the percentage cover of the individual weed species, including their age classes (tree, sapling and seedling) and growth habits (tree and shrub) was recorded. Trees are classified as plants of height greater than 5 metres with a trunk diameter at breast height (DBH) greater than 10 cm. Saplings refer to plants greater than one metre but less than or equal to 5 metres in height, with a stem diameter at breast height (DBH) less than 10cm. Seedlings are young woody plants less than or equal to one metre in height. Shrubs refer to plants such as bramble and lantana that have numerous thin stems not exceeding 3m in height when growing in the open.

Percentage cover was later converted to density classes using the above classes. The percentage of dead trees and the number of logs/trees in the river/dam was also recorded, as they would also require removing.

3.2 Mapping

Mapping consisted of two parts. Firstly, the following cadastral information, infrastructure and drainage was digitally captured by Enviromap cc using 1 : 10 000 orthophotographs:

- roads, including: the national road (N3), the main road (R103), secondary roads and other roads (mainly farm roads)
- railway line
- powerlines
- farm boundaries and sub boundaries
- eMpofana, Lions and Mgeni Rivers
- other streams and drainage
- 30 metre buffer
- Q_2 + 10 m^3/sec flood line
- grid

The capturing of the data involved delineating, scanning and vectorising.

Secondly, the mapping of the weed infestations carried out in the field work needed to be digitised. Again the orthophotographs were scanned and vectorised. The area and perimeter of each of the polygons were calculated. Area is particularly important in costing.

3.3 Manipulation of Data and Costing

Weed species and their growth habits were allocated weed cover percentages during the survey. In order to work with the data, the individual weed cover percentages were expressed as an area-based value representing 100% cover, using the following formula:

Condensed area (ha) of 100% cover of weed$_x$ per polygon

$$= \% \text{ of } \mathbf{Weed_X} \times \text{ Polygon Area}$$

Grass cover was also recorded using the 0 to 5 classes. As with the weed cover percentages, so the grass cover required for rehabilitation was converted to area equivalent values, using the following formula:

$$\textbf{Rehabilitation area (ha)} = \text{Polygon Area} - (\%\text{class} \times \text{PolygonArea})$$

3.4 Phases of Control

The costing for the clearance of alien plants along the eMpofana, Lions and Mgeni Rivers was broken down into three phases, viz., initial control, rehabilitation and follow-up control.

3.4.1 Initial Control

Strategy

Since initial control is aimed at removing the existing infestation, the following strategy was proposed by PPRI:

- the preparation of plants for treatment, e.g. felling and removing debris,
- the herbicide application technique, e.g. foliar spray and stump treatments, and
- the type as well as concentration of the herbicide to be applied, e.g. Garlon 4 and Chopper.

Since each species has its own characteristics, different treatments for their removal were required. However, this is not always possible, especially when treatment occurs on such a large scale. Furthermore, since the object of this clearance is to remove all vegetation obstructing the increased flow of water in the Mooi-Mgeni system, some plants will not have been certified for control, according to the Fertilizer Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act 36 of 1947). In such a case, off-label treatments were used, based on research.

The treatment for the removal of plants along the eMpofana River has been proposed by PPRI and is based on years of experience. As new registered herbicides become available, the treatment may be modified. The treatment specified was the most cost effective, and will have the least impact on the environment. For example, diesel (used as a carrier) has only been prescribed for the treatment of wattle trees and saplings. The impact of large volumes of diesel entering the river system is not known, and thus the volumes should be kept to a minimum. In addition, the report proposed that certain tree species could used for firewood, as well as the making of charcoal, pulpwood, matchwood, etc.

The strategy for the treatment and removal of each alien species (including both form and habit) as proposed by PPRI is shown in table A3.2 below.

Table A3.2: Strategy for the Treatment and Removal of Alien Species (Goodall & Naudé 1998b)

WEED	STRATEGY	CHEMICAL TREATMENT				
		Technique	Herbicide	Wetter	Dye	Carrier
Dead standing trees	Fell & cut logs, remove. Stack brush. Do not treat stumps.	n/a	n/a	n/a	n/a	n/a
Logs in river	Extract, cut logs, remove.	n/a	n/a	n/a	n/a	n/a
Wattle trees	Fell, cut logs. Debark pulp logs only. Remove logs. Treat stumps. Stack brush.	Total stump	2% Garlon 4	n/a	E-Blue 1%	Diesel
Wattle saplings	Brushcut. Treat stumps. Stack brush.	Total stump	2% Garlon 4	n/a	E-Blue 1%	Diesel
Wattle seedlings	Spray	Foliar spray	0.75% Garlon 4	Actipron Super 0.5%	n/a	Water
Gum trees	Fell, cut logs. Debark pulp logs & good poles only. Remove logs. Treat stumps. Stack brush.	Cut stump	7.5% Chopper	n/a	n/a	Water
Gum saplings	Brushcut. Treat stumps. Stack brush.	Cut stump	7.5% Chopper	n/a	n/a	Water
Gum seedlings	Spray	Foliar spray	0.75% Garlon 4	Actipron Super 0.5%	n/a	Water
Pine trees	Fell, cut logs, remove. Stack brush. Do not treat stumps.	n/a	n/a	n/a	n/a	n/a
Pine saplings	Brushcut. Do not treat stumps. Stack brush.	n/a	n/a	n/a	n/a	n/a
Pine seedlings	Hand pull.	n/a	n/a	n/a	n/a	n/a
Poplar trees (Grey & Match Poplar)	Fell, cut logs, remove. Treat stumps. Stack brush.	Cut stump	5% Chopper	n/a	n/a	Water
Poplar saplings	Brushcut. Treat stumps. Stack brush.	Cut stump	5% Chopper	n/a	n/a	Water
Poplar seedlings	Spray.	Foliar spray	0.75% Garlon 4	Actipron Super 0.5%	n/a	Water
Willow trees	Fell, cut logs, remove. Treat stumps. Stack brush.	Cut stump	5% Chopper	n/a	n/a	Water
Willow saplings	Brushcut. Treat stumps. Stack brush.	Cut stump	5% Chopper	n/a	n/a	Water
Syringa trees	Fell, cut logs, remove. Treat stumps. Stack brush.	Cut stump	3% Chopper	n/a	n/a	Water
Syringa saplings	Brushcut. Treat stumps. Stack brush.	Cut stump	3% Chopper	n/a	n/a	Water
Syringa seedlings	Spray.	Foliar spray	0.75% Garlon 4	Actipron Super 0.5%	n/a	Water
Bugweed > 1.5 m	Slash. Treat stumps.	Cut stump	1.25% Chopper	n/a	n/a	Water
Bugweed < 1.5 m	Spray.	Foliar spray	0.5% Garlon 4	Actipron Super 0.5%	n/a	Water
Peach (all sizes)	Slash. Treat stumps.	Total stump	2% Garlon 4	n/a	E-Blue 1%	Diesel
Mulberry (all sizes)	Slash. Treat stumps.	Total stump	2% Garlon 4	n/a	E-Blue 1%	Diesel
Cotoneaster > 1.5 m	Slash. Treat stumps.	Total stump	2% Garlon 4	n/a	E-Blue 1%	Diesel
Cotoneaster < 1.5 m	Spray.	Foliar spray	2% Garlon 4	n/a	E-Blue 1%	Diesel
American bramble (all sizes)	Spray.	Foliar spray	0.5% Garlon 4	Actipron Super 0.5%	n/a	Water
Ornamental trees	Fell, cut logs, remove. Stack brush. Do not treat stumps.	n/a	n/a	n/a	n/a	n/a
Ornamental saplings	Brushcut. Do not treat stumps. Stack brush.	n/a	n/a	n/a	n/a	n/a

Labour

PPRI has through years of experience derived the time required for the completion of various tasks in weed control. This is recorded as labour days per hectare on 100% infestation, and is shown in table A3.3.

Table A3.3: Labour Days per Hectare for Alien Plant Treatment

Habit	Action	Code	Labour days/ha (LDH) on 100% infestation
Trees	Fell, debranch and cross-cut into logs	tfe	20
	Stack brush	tst	30
	Debark logs/poles	tdp	53
	Remove logs/poles	tre	30
	Herbicide stumps	ths	2
Saplings	Slash/brushcut	ssl	57
	Stack brush	sss	40
	Herbicide stumps	shs	5
Bushes	Slash/brushcut	bsl	33
	Stack brush	bss	10
	Herbicide coppice	bhc	4
	Herbicide stumps	bhs	5
Seedlings	Handpull	sha	3
	Herbicide foliar	shf	0.5

It is possible to calculate the number of labour days required for the particular treatment of a certain species in a given area. For example, to calculate how long it will take to fell, debranch and cross-cut (fte) 0.2 ha (condensed area of 100% weed cover) of wattle trees:

Number of labour days = fte labour days x condensed area
= 20 LDH x 0.2ha
= 4 labour days

If there are 12 labourers, then the actual number of labour days with the team is divided by 12, giving a third of a labour day.

Costing

The herbicide mix and labour costs have been updated. The new figures can be found in Appendix 4(a) and(b).

3.4.2 Rehabilitation

Strategy

Rehabilitation is an important part of weed control as disturbed areas are particularly vulnerable to reinvasion. PPRI proposed the following strategy for rehabilitation:

- preparing the soil by hoeing the annual weeds which have established themselves since initial control,
- raking the soil in preparation for
- sowing of the grass and fertilizer.

Usually when rehabilitating sites cleared of weeds, brushwood and plant debris are spread to reduce soil erosion from the bare surface. Since the primary reason for the clearing of weeds along the eMpofana, Lions and Mgeni Rivers is to allow for the increased flow of water in the river channels (Mooi-Mgeni Transfer Scheme), PPRI recommended the removal of all debris and that the area be rehabilitated through the sowing of grass seeds.

The establishment of a grass layer will serve to protect the soil surface, inhibit the growth of weed seedlings, provide a fuel load for the control of seedlings, and ultimately provide grazing. *Eragrostis curvula* (3kg/ha) and *Eragrostis teff* (4kg/ha) were selected for this purpose. *E. curvula* was chosen because it establishes easily, is inexpensive and is readily available. Although indigenous, it is inclined however to be invasive, and so the sowing rates were dropped so that other local grass species would establish themselves in the gaps once the *E. teff* died off. Super phosphate (10.5%) will be applied to the soil at a rate of 300kg/ha, and meal is to be added to the seed mix to aid with the spreading of the small seed quantities at the correct concentration over a large area.

Labour

Table A3.4 shows the number of labour days per hectare for each of the rehabilitation activities.

Table A3.4: Labour Days per Hectare for Rehabilitation Activities

Action	Labour days/hectare
Hoeing	25
Raking	15
Sowing grass and fertilizer	5

Costing

The cost of the different grass seeds species and the fertilizer can be found in Appendix 4(c).

3.4.3 Follow-Up Control

An 80% mortality is expected after the initial control. Thus follow-up control is aimed at killing those weeds that survived or were missed, as well as any regrowth resulting from the initial control. All follow-up control operations will involve the spraying of seedlings using 0.75% Garlon 4 with Actipron Super (0.5%) in water.

Unlike with predicting the follow-up weed area, it is impossible (except by conducting a survey) to determine the mixture and density of species likely to be present at each follow-up. Although most of the weed seedlings present in the follow-up control will be those found in the original infestation, PPRI has chosen to refer to the unknown composition of weed seedlings as 'mixed weed seedling density'. A linear regression model was used to predict follow-up requirements based on mixed seedling covers.

In conducting follow-up control, it is necessary to know how many years it will take to reduce all alien invasive species to the maintenance target of 5% cover, if the area is treated once per annum. In deciding on this Years To Maintenance (YTM) figure for each polygon of infestation, the weed expert relies on experience while considering a number of factors including: the species present, their densities, the weeds' physiologies and the seedbank. Once the YTM value has been established, the future mixed weed seedling densities may be calculated, using the formula:

$$\mathbf{Msc}_{\mathbf{pm}} = \frac{\mathbf{C_x} - \mathbf{C_1}}{\mathbf{F_x}}$$

where: Msc_{pm} = annual decrease of 'mixed weed seedling' density
C_x = weed density of initial infestation
C_1 = weed density of class 1 (maintenance target)
F_x = number of follow-ups

It was decided that five follow-up operations, i.e., a YTM of 6 years, would be required before maintenance control would be reached in the clearing of alien plants along the receiving streams of the Mooi-Mgeni Transfer Scheme. The number of labour days and the volume of herbicide mix was then calculated for each of the five follow-up operations, using table A3.5.

Table A3.5: Table used in the Calculation of Follow-Up Labour Days and Herbicide Mix (values expressed as %)

		YTM1	YTM2	YTM3		YTM4			YTM5				YTM6				
Density Class	Initial Cover		F1	F1	F2	F1	F2	F3	F1	F2	F3	F4	F1	F2	F3	F4	F5
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
2	25	5	15	20	10	20	15	10	25	20	15	10	25	20	18	15	10
3	50	5	10	20	10	30	20	15	35	25	15	10	40	30	20	15	10
4	75	5	20	30	20	40	30	20	50	40	30	15	60	50	40	30	15
5	100	5	20	40	20	50	30	20	60	50	30	15	70	60	50	30	15

APPENDIX 4(a): Breakdown of Labour Structure and Costs

Labour Type	Daily Wage (Rands)	Number of Workers
Supervisor	70	1
Chainsaw Operator	45	2
Brushcutter Operator	45	2
Herbicide Applicator	40	3
Labourer	30	12
Total	230	20

(H. Howe 1999[6])

[6] Mr Horace Howe, EcoGuard Distributors (PTY) LTD, 28 Laurel Crescent, Merrivale, 3291, South Africa.
Tel: 033 - 3306985

APPENDIX 4(b): Cost of Herbicide & Carrier per Litre

HERBICIDES	**COST (Rands)**
Garlon 4	171.47
Chopper	170.50
WETTER	**COST (Rands)**
Actipron Super	6.50
CARRIERS	**COST (Rands)**
Water	0.20
Diesel	2.19
DYE	**COST (Rands)**
E-Blue	128.60

(H. Howe 1999[7] and R. Heathcote 1999[8])

7 Mr Horace Howe, EcoGuard Distributors (PTY) LTD, 28 Laurel Crescent, Merrivale, 3291, South Africa. Tel: 033 - 3306985

8 Mr Richard Heathcote, SA Cyanamide, Crompton Road, Winterskloof, South Africa. Tel: 033 - 3434102

APPENDIX 4(c): Cost of Grass & Phosphate per Kilogram

Grass/Phosphate	**Cost (Rands)**
Eragrostis curvula	14.00
Eragrostis teff	5.50
Super phosphate (10.5%)	1.03

(Goodall & Naudé 1998b)

APPENDIX 5: Advanced Multiple Regression of Factors Affecting Work Rate

Slope	Penetrability	Distance	Factor
1.0	1.0	1.0	1.000
1.0	1.4	1.0	1.587
1.0	2.0	1.0	2.667
1.0	1.0	1.1	1.137
1.0	1.4	1.1	1.633
1.0	2.0	1.1	2.733
1.0	1.0	1.3	1.430
1.0	1.4	1.3	1.727
1.0	2.0	1.3	2.867
1.0	1.0	1.5	1.750
1.0	1.4	1.5	1.950
1.0	2.0	1.5	3.000
1.0	1.0	1.7	2.097
1.0	1.4	1.7	2.323
1.0	2.0	1.7	3.133
1.0	1.0	2.0	2.667
1.0	1.4	2.0	2.933
1.0	2.0	2.0	3.333
1.2	1.0	1.0	1.280
1.2	1.4	1.0	1.680
1.2	2.0	1.0	2.800
1.2	1.0	1.1	1.320
1.2	1.4	1.1	1.727
1.2	2.0	1.1	2.867
1.2	1.0	1.3	1.517
1.2	1.4	1.3	1.820
1.2	2.0	1.3	3.000
1.2	1.0	1.5	1.850
1.2	1.4	1.5	2.050
1.2	2.0	1.5	3.133
1.2	1.0	1.7	2.210
1.2	1.4	1.7	2.437
1.2	2.0	1.7	3.267
1.2	1.0	2.0	2.800

APPENDIX 5: Advanced Multiple Regression of Factors Affecting Work Rate (cont.)

Slope	Penetrability	Distance	Factor
1.2	1.4	2.0	3.067
1.2	2.0	2.0	3.467
1.5	1.0	1.0	1.750
1.5	1.4	1.0	1.950
1.5	2.0	1.0	3.000
1.5	1.0	1.1	1.800
1.5	1.4	1.1	2.000
1.5	2.0	1.1	3.067
1.5	1.0	1.3	1.900
1.5	1.4	1.3	2.100
1.5	2.0	1.3	3.200
1.5	1.0	1.5	2.000
1.5	1.4	1.5	2.200
1.5	2.0	1.5	3.333
1.5	1.0	1.7	2.380
1.5	1.4	1.7	2.607
1.5	2.0	1.7	3.467
1.5	1.0	2.0	3.000
1.5	1.4	2.0	3.267
1.5	2.0	2.0	3.667
2.0	1.0	1.0	2.667
2.0	1.4	1.0	2.933
2.0	2.0	1.0	3.333
2.0	1.0	1.1	2.733
2.0	1.4	1.1	3.000
2.0	2.0	1.1	3.400
2.0	1.0	1.3	2.867
2.0	1.4	1.3	3.133
2.0	2.0	1.3	3.533
2.0	1.0	1.5	3.000
2.0	1.4	1.5	3.267
2.0	2.0	1.5	3.667
2.0	1.0	1.7	3.133
2.0	1.4	1.7	3.400
2.0	2.0	1.7	3.800
2.0	1.0	2.0	3.333
2.0	1.4	2.0	3.600
2.0	2.0	2.0	4.000

APPENDIX 5: Advanced Multiple Regression of Factors Affecting Work Rate (cont.)

Regression Statistics

Multiple R	0.956
R Square	0.914
Adjusted R Square	0.910
Standard Error	0.221
Observations	72.000

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	3.000	35.472	11.824	241.248	0.000
Residual	68.000	3.333	0.049		
Total	71.000	38.805			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95.00*	*Upper 95.00*
Intercept	-2.004	0.176	-11.406	0.000	-2.354	-1.653
slope	1.058	0.069	15.278	0.000	0.920	1.197
penetrability	1.108	0.063	17.456	0.000	0.982	1.235
distance	1.031	0.076	13.624	0.000	0.880	1.182