AN INFRASTRUCTURE POTENTIAL COST MODEL FOR INTEGRATED LAND USE AND INFRASTRUCTURE PLANNING

by

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SUMMARY

The purpose of the bulk infrastructure potential cost model is to provide a tool for planners to ensure the incorporation of bulk infrastructure cost considerations into the early, land suitability assessment phase of the integrated development planning process. In practice, infrastructure planning has generally tended to follow land use planning with infrastructure costs seeming to play no role in the generation of land use strategies. The output of the model is in the form of potential cost maps which facilitates the relative comparison of infrastructure costs for different density scenarios.

Bulk engineering services infrastructure relating to water, sanitation and electricity have been included in the model. The theoretical underpinning of the model is threshold analysis. There are three essential elements of the bulk infrastructure cost model: threshold, density and cost. The manner in which the three pillars are incorporated into the model is through capacity analysis. The density levels set, convert into the number of additional person units required, which in turn translate into infrastructure capacity demand. Existing infrastructure network and facility design capacities are compared with current utilisation of infrastructure in order to quantify the capacity supply situation. The comparison of capacity demand with capacity supply determines whether or not additional infrastructure is required. If infrastructure is required, the required infrastructure investment is calculated. The resulting relative costs are mapped and incorporated into a wider land suitability assessment model to identify suitable land for low income residential development.

The models are contextualised as Spatial Planning Support Systems, supporting a specific planning problem, with a strong spatial component, incorporating a multicriteria evaluation and cost model and being loosely-coupled with GIS.

It is shown that although bulk infrastructure potential costs can be incorporated into the land suitability assessment process to enhance the land delivery decision making process, it is preferable to keep the cost analysis separate from the analysis of the more "softer" issues.

Conclusion are made in relation to a number of key developmental issues: the sprawl/densification debate, land and housing policy issues, sustainability, integration, affordability and bulk services contribution rates.

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CHAPTER 1: INTRODUCTION

1.1 Problem statement

The government's undertaking to build a minimum of 1 million low cost houses over a five year period, the rapid urbanisation of South African cities and initiatives to restructure these cities into more compact, integrated urban forms, present tremendous challenges to those responsible for managing urban growth, particularly in an environment of limited financial resources. Confronted with problems of the proliferation of informal settlements on the periphery, excessive journey-to-work distances, inadequate infrastructure and too few job opportunities, urban managers must look for new ways to keep pace with urbanisation and effectively plan for the future. The challenge to accommodate this fast expanding urban population on an ever decreasing supply of well located land, in a sustainable manner, contributing to improving quality of life, is considerable. Whether residential development is accommodated on vacant land on the urban periphery, as infill development on vacant land within the developed urban area or as redevelopment at higher residential densities, the need exists to assess the relative suitability of areas for development. The need for the delivery of suitable land exists, however, financial resources are limited and therefore prioritisation is essential so that the most suitable land is developed first. The strategic identification of suitable land for low income residential development is the first step in the land delivery process, crucial for addressing the housing needs of the low income urban population.

Housing delivery cannot proceed without land delivery. Land delivery cannot proceed without the identification of land. Quality of life and sustainability cannot be achieved unless the land identified is suitable land. Relative land suitability assessment is essential in an environment of limited funds in order to prioritise the allocation of funds. An integrated, multi-disciplinary approach in the assessment of land suitability is crucial as a wide range of criteria influence what is considered to be "suitable" land.

The three major determinants of land suitability are accessibility to urban opportunities, physical environmental aspects impacting on safety and health and infrastructure capacity. The Reconstruction and Development Programme (RDP)(African National Congress 1994: 24) is clear that land for housing must be suitably located geologically, environmentally, and with respect to economic opportunities and social amenities. The White Paper on Housing (Republic of South Africa 1994: 52)calls for effective and integrated development by, amongst others, optimising the use of existing physical and social infrastructure. In the section regarding general principles relating to land development, the Development Facilitation Act (Republic of South Africa 1995: 10) reiterates the promotion of efficient and integrated land development by promoting the location of residential and employment opportunities in close proximity to or integrated with each other and by optimising the use of existing resources including such resources relating to land, bulk infrastructure, roads, transportation and social facilities.

A considerable amount of research has concentrated on the relationship between land use planning and transportation planning, with increased accessibility being a major goal. On the implementation side, major strategic and structure planning exercises conducted in metropolitan areas in South Africa have had a strong bias towards the integration of land use and transportation planning. Geotechnical impacts and constraints on development suitability have been widely recognised in the research field and have received prominent attention from an implementation perspective particularly as a result of informal settlement locating in areas prone to flooding and on dolomitic and undermined land.

An overview of the relevant literature has revealed a paucity of research regarding the interrelationship between land use planning and infrastructure planning. In practice, infrastructure planning has generally tended to follow land use planning and play no role whatsoever in the generation of land use plans. At most, the literature indicates the use of infrastructure cost assessment at the evaluation stage of land use planning, although in practice in South Africa, no evidence has been found for the infrastructural assessment of land use alternatives. The costing of bulk infrastructure has typically been reactive to land use planning. Strategic land use plans are prepared without due consideration of infrastructure costs and only once a final plan has been selected, bulk infrastructure planning commences reactively, as part of the implementation process, so as to optimise the provision of services in relation to the pattern of employment and population as set out in the plan.

In the South African context particularly, the incorporation of infrastructure capacity aspects into the land use planning decisions, at the land use plan generation stage, is crucial so that cost effective considerations are built into the plan proactively. Infrastructural investment was historically allocated in an imbalanced manner in accordance with racial policy, with some areas receiving massive investment and others, very little, resulting in areas with additional capacity which could be utilised at minimal additional cost. It is, however, not only political factors which make the incorporation of infrastructural aspects important but also the nature of infrastructure provision. It is not cost effective to expand infrastructure facilities in a continuously incremental manner but to construct facilities on an almost once-off basis, at considerable initial cost, but with considerable capacity. The knowledge of the location and amount of existing capacity is an essential input into the land use planning process. Not only is the additional capacity important but also an indication of the relative potential cost of extending and expanding the existing infrastructure.

A consideration of existing bulk infrastructure spare capacity at least gives some indication of areas which would theoretically be more suitable to develop in terms of cost on the basis of existing infrastructure still having some potential to accommodate additional demand. It is argued that the inclusion of only existing capacity consideration is not a sufficient indicator of suitability and that potential costs, incorporating existing capacity considerations, are a preferable indicator of development suitability. Size, current development characteristics or future potential demand of an area, supplied by particular infrastructure facilities, significantly affect the actual capacity conditions. There may be a significant volume of spare capacity in a particular facility or pipe but the catchment area is large with a significant proportion of undeveloped land, which means that theoretically the available spare capacity has to go a long way. On the other hand, a more fully developed, small catchment area, with less spare capacity, may be able to cope with far greater densities and may thus be more suitable for development. In addition, areas currently not served by any infrastructure, i.e. usually currently undeveloped parts of the area, are more or less excluded from a capacity analysis whereas a consideration of potential costs would differentiate suitability between currently unserved areas. Furthermore, infrastructure costs vary with location according to local land use, geotechnical, environmental and built conditions, making the role of Geographical Information Systems (GIS) appropriate and important in the model.

1.2 Purpose

The purpose of the study is to develop a strategic bulk infrastructure potential cost model as a decision support tool for planners and development decision makers to ensure the proactive incorporation of bulk infrastructure cost considerations, in the form of spatially comparative potential costs, in the early, land suitability assessment phase of the integrated planning process, to enhance the integration of land use and infrastructure planning.

1.3 Relevance

1.3.1 Support for enhanced decision making

Decision makers need to be able to make informed decisions and be aware of the implications of decisions before implementation. Planners and engineers need to understand the critical interrelationships between their disciplines. Stakeholders need to understand how technical factors impact on their choices and how their choices impact on issues such as cost and how their own situation relates to the wider area. There is thus a need to transform data into decision making material with what-if testing capabilities and graphic and spatial presentation facilities. With an integrated approach particularly, complexities in the urban process and relating to lack of familiarity between disciplines, need to be simplified and the data inputs and outputs between various disciplines need clarification and integration. The bulk infrastructure potential cost model is a means to achieve this desired mutual understanding and facilitates the determination of impact before actually embarking on a specific plan of action.

1.3.2 Integrated development planning context

Recent changes in the planning environment in South Africa, with the concurrent changes in philosophy, terminology and scope, require that prior references to land use plans, structure plans, strategic planning and land suitability assessment, be contextualised and made relevant within current planning practice. Due to the fact that a new planning practice is emerging in response to the legal requirements of the Local Government Transition Act for Integrated Development Plans (Republic of South Africa 1996) and of the Development Facilitation Act for Land Development Objectives (Republic of South Africa 1995), various methodologies and interpretations are being developed, debated and tested throughout the country. The manner in which existing and developing technical processes support the planning process is likewise in the process of being tested and adapted. It is thus not possible or feasible at this stage, neither is it the intention of this study, to rigorously position the bulk infrastructure cost model or overall land suitability assessment within an accepted and tested integrated planning process methodology. Suffice to say that the model and land suitability assessment as part of land use planning, can broadly be positioned in the spatial thread of the integrated planning process, playing an important role in informing the Spatial Framework part of the Development Framework through the Situational Analysis and Spatial Assessment (Figure 1.1).

1.3.3 Contribution to integration and sustainability

Recent government policy and legislation calls for development to proceed in an integrated manner in order to achieve sustainable development. As in the case of "sustainability", the word "integration" means different things to different people and these differences in interpretation are manifesting in the outcomes of so-called integrated process. It is not the purpose of this paper to debate the concepts of integration and sustainability. What is presented in this paper is intended to contribute to the achievement of integration, by focussing on certain aspects of the civil engineering profession which relate to certain aspects of the town planning profession, as they both relate to certain phases in the integrated planning process. These aspects are integrated and their interrelationships clarified, by means of a bulk infrastructure potential cost model which extracts appropriate information from one field of expertise, compiles, adapts, applies, analyses and presents the information in a way appropriate to another field of expertise, thus bridging a gap or facilitating "integration" between two disciplines. This in turn contributes towards sustainable development in that bulk infrastructure capacity and cost considerations are incorporated into the integrated development planning process so that the best use is made of existing or cheaper infrastructure facilities without unnecessary expenditure being incurred.

1.4 Definition of key terms

1.4.1 Bulk infrastructure

"Infrastructure" is a term commonly understood to mean the physical system of, mostly publicly or sometimes privately provided, services which provide a systematic framework for human living arrangements (Longley 1998: 53) or which allows a society to function (Rainer 1990: xxiii). Infrastructure first became necessary in response to poor public health conditions in urban areas that developed as a direct results of the industrial revolution towards the end of the nineteenth century (Rainer 1990: xxiii). Water and sewer systems were developed first followed by transportation, electric power and telephone systems (Rainer 1990: xxiii). More recently, information systems and the transfer of digital information, have also been included in the definition of infrastructure (Longley 1998: 53). Whereas the interaction between land use and transportation has been better developed in terms of theory and transportation cost modelling, the interaction of land use and water, sanitation and electricity systems is not well developed. For this reason, for the purposes of this study, infrastructure is defined as water, sanitation and electricity reticulation, storage and treatment facilities. Transportation infrastructure (including stormwater which is mostly related to road infrastructure), telecommunication and information infrastructure do not form part of the terms of reference of this study.

Institutionally, infrastructure is provided and operated at many different levels ranging from international, to national, provincial, regional, metropolitan and local levels. On the one extreme, water and electricity infrastructure conveys hydro-electric power and water into South Africa from Zimbabwe and Lesotho respectively. At the other extreme, water infrastructure conveys water from the pipe in the street to the tap in your house. "Bulk" infrastructure, for the purpose of this study refers to metropolitan level bulk infrastructure which relates to the reticulation, treatment and storage infrastructure operational from the edge of the particular settlement or township, up to and including storage and treatment facilities which that particular metropolitan authority is responsible for. Detailed definitions for each particular service are included in chapter 6.

1.4.2 Cost

"Cost" has been defined as "a sacrifice that must be made in order to do or acquire something. The nature of the sacrifice - i.e. what is given up - may be tangible, objective or subjective, and may take one or more of many forms such as money, goods, leisure time, income, security, prestige, power or pleasure (Spencer 1983). In this study, the cost has been confined to monetary or financial cost. Financial costs can be further distinguished. Financial costs can be expressed as average or marginal costs. Average cost is the total cost divided by the total number of units of output whereas marginal cost is the additional cost of producing one more unit of output (Van Ryneveld 1995: 2). For the present study, the cost of supplying additional infrastructure required to support a particular scenario population is divided amongst the additional people in that particular area and the cost expressed as an average per capita cost. Financial costs can further be distinguished as historical or current replacement costs. Due to the effect of inflation and the long time over which the infrastructure has been developed, the two are very different. In the present study, the concern is with additional infrastructure required and costs are calculated at 1995 prices. A third distinction in financial costs is between capital and operating costs. Capital costs are the initial once-off costs of providing physical water, sanitation or electricity infrastructure. Operating costs refer to routine maintenance and other costs incurred in keeping the service operational (Van Ryneveld 1995: 2). Only capital costs are included in the present study. A fourth distinction is between full utilisation costs and average current utilisation costs. Because additions to the bulk infrastructure system are made incrementally in advance of need, infrastructure is often not fully utilised (Van Ryneveld 1995: 2). Costs will be very different if average current usage rather than actual current usage is assumed. In the present study, actual usage and spare capacity is calculated resulting in more accurate cost estimates than if average usage was assumed.

1.4.3 Potential costs

The term "potential" has been used to indicate that the calculated costs are for some possible future scenario population number. The model is intended for use at the strategic planning level while alternative development scenarios are being tested and developed therefore responding to density and location specific "what-if" type questions.

1.4.4 Land suitability

Land identification comprises two aspects: land availability and land suitability. The current study relates to the land suitability component. Land suitability assessment is an essential task in the land identification component of the land delivery process in that it is a way of quantifying land development constraints and opportunities and thus assists in the supply side aspects of land use planning (McDonald & Brown 1984). Land availability deals with the selection of land for participation in the analysis. Land availability assessment provides the land options whereas land suitability assessment evaluates and prioritises those options. The "land options" can be all the land in the study area as in the present study or can be limited to a number of selected land parcels such as vacant stands within the built-up area or undeveloped open space. The criteria for the selection of "available land" predominantly relate to the physical/legal land entity aspects and existing land uses. The land availability assessment results in go/no go results which means the land is either in or out of the further land identification process. Land suitability assessment on the other hand, arranges participating land areas along a continuum of relative suitability or into discreet relative suitability classes.

1.5 Research methodology

It is submitted that Developmental Research, as propounded originally in relation to social work research (Thomas 1978), is the appropriate methodology choice for this study which has the development of a model of a component of the urban system as its aim.

The aim of Developmental Research is to develop a technology which is the technical means by which policy objectives are achieved (Thomas 1978: 484). As such, Developmental Research is seen to provide interventional innovation in so far as it provides technologies to assist in achieving "political" goals and objectives (e.g. compact cities, increasing accessibility). As applied to social work, social technologies are the technical means by which social work objectives are achieved. Related to urban planning, urban planning technology is the technical means by which urban planning objectives are achieved. Types of technology include physical frameworks, models, computer technology (e.g. GIS), information systems.

By its very nature, the results of Developmental Research are flexible, with different technologies being more appropriate at different times and under different circumstances. As new techniques become available and more funds become available - so the technology is adjusted to suit the particular conditions.

Developmental Research has its roots in typical Research and Development methodology which proceeds through a process from research to development to diffusion and finally to adoption. Developmental Research is distinguished as comprising the initial phases of analysis, development and evaluation while the remaining phases of diffusion and adoption, concerned with the utilisation of the innovation, are excluded as Developmental Research but included as Utilisation Research (Thomas 1978: 487).

The analysis phase precedes the development phase and comprises the steps of problem analysis and identification, review of existing technology being used to address the problem or related problems, technological feasibility study, selection of objectives and selection of information sources (Thomas 1978: 489). In the development phase, the interventional innovation is created. Through a series of operational steps, data relevant to the development objective are transformed and shaped into a new product. The development phase comprises the steps of: gathering and evaluating technological resources, designing the technology and preparing a prototype. The evaluation phase is involved with appraisal and possible revision of the innovation including testing of the product with pilot implementation (Thomas 1978 p 496).

1.6 Structure

The document structure broadly follows the Developmental Research methodology outlined before (Figure 1.2). Chapters 1 to 3 relate to the first phase - analysis - of the Developmental Research methodology where the problem is articulated, a solution proposed in terms of a purpose or objective of the study, accompanied by an assessment of literature regarding current theory and practice and available technologies (Figure 1.2). Chapters 4 and 5 comprise the development phase of Developmental Research where, in the case of land suitability assessment, the existing technology of multicriteria evaluation is adapted for the purpose of land suitability assessment using GIS, and, in the case of the bulk infrastructure potential cost model, a technology is developed from scratch to ensure that bulk infrastructure costs are incorporated into the land suitability assessment process. Chapters 6 to 8 relate to the third and final phase of the Developmental Research methodology - evaluation. The models adapted and developed in chapters 4 and 5 are implemented on a test basis in order to evaluate their success in practice(Figure 1.2)

After the introductory comments relating to problem analysis, purpose, relevance and project methodology in chapter 1, chapter 2 presents an investigation of approaches to land suitability assessment from the literature. Chapter 2 concludes that multicriteria evaluation together with GIS technology is the most feasible existing technology to be utilised to undertake the land suitability assessment component of the present study. Land suitability assessment is the overall framework within which the bulk infrastructure

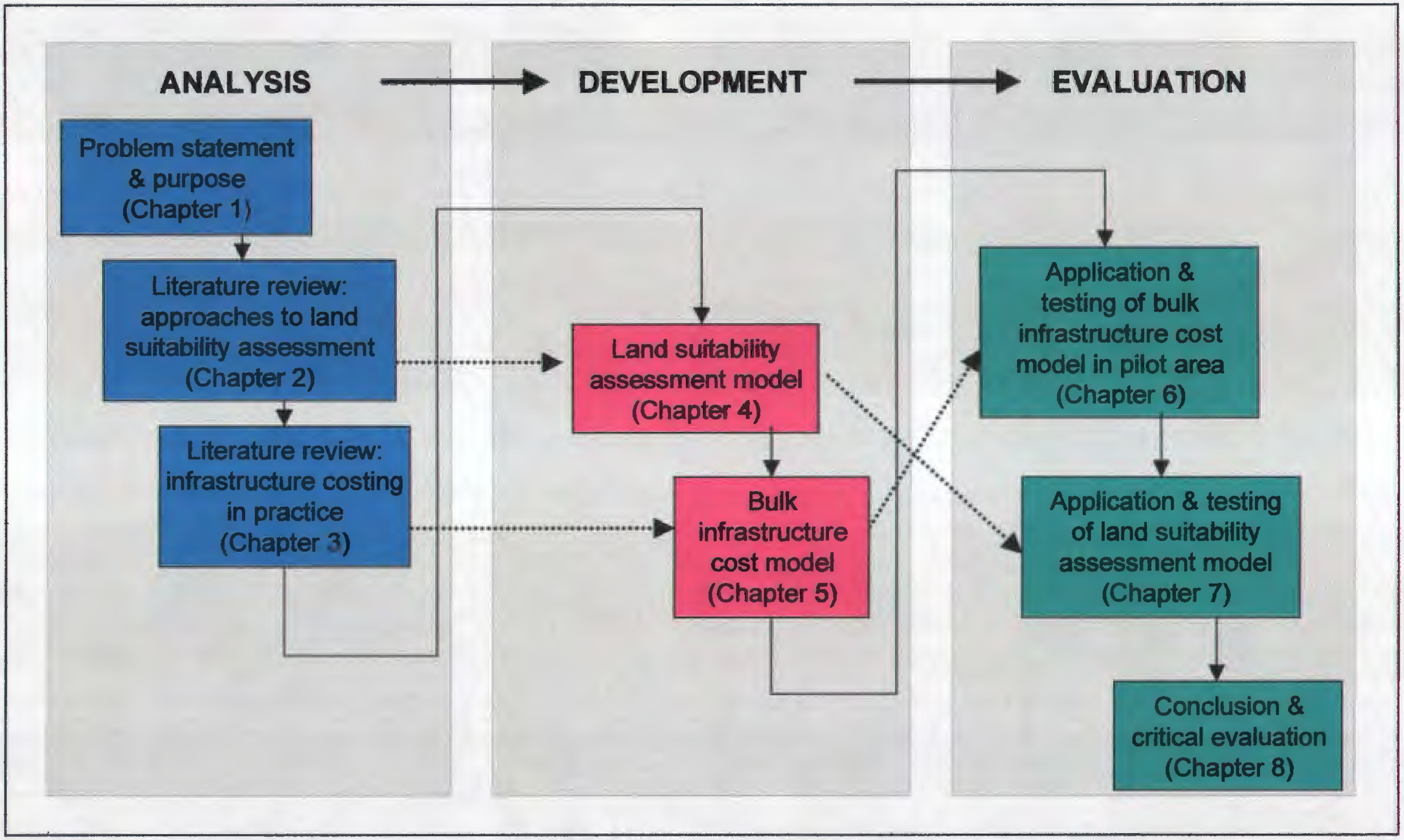


Figure 1.2: Structure of the document in relation to the Developmental Research methodology

potential cost model fits.

Chapter 3 is concerned with a literature review of engineering services infrastructure costing in practice. The purpose of the chapter is to provide an overview of predominantly South African sources of infrastructure costing related exercises. The purposes, assumptions and outcomes of these studies are reviewed in relation to the present study. It is concluded that other than transportation costs, engineering services costs are included in very few practical costing exercises and that when they are included, it is simply done on the basis of fixed per person rates, with existing capacity and locational factors playing no role whatsoever.

The land suitability assessment methodology used in the identification and prioritisation of land for low income residential development is described in chapter 4. After contextualising the land suitability assessment methodology as a Spatial Decision Support System, the multicriteria evaluation process is described in relation to land suitability assessment and GIS. The land suitability assessment methodology provides the framework within which the bulk infrastructure potential cost model operates. Bulk infrastructure cost criteria are generated and quantified within the bulk infrastructure potential cost model and slotted into the land suitability assessment model in order to enhance the suitability assessment process by ensuring that relative infrastructure costs are taken into account in the decision making process.

The conceptualisation and design of the bulk infrastructure potential cost model is presented in chapter 5. The model is contextualised within the theoretical framework of threshold analysis followed by a description of the generic bulk infrastructure potential costing methodology applicable to water, sanitation and electricity costing.

Chapter 6 presents the results of applying the bulk infrastructure potential cost model in the study area. The calculation of each individual cost is explained and presented spatially and the results discussed. Individual costs are amalgamated to obtain a water, sanitation and electricity cost and finally, all costs are overlayed to obtain a final bulk infrastructure potential cost surface for the study area. The role of GIS in the bulk infrastructure potential cost model is also detailed in chapter 6.

In chapter 7, the results of applying the overall land suitability assessment methodology in the study area are given. The results of the application of the land suitability assessment model excluding all bulk infrastructure considerations are compared and contrasted with the results obtained when bulk infrastructure capacity and cost considerations are included in the land suitability assessment.

Conclusions are given in chapter 8 in relation to the original intention of the study, the achievements, shortcomings and further application of the bulk infrastructure potential cost model, implications for densification and the cost of sprawl debate, implications for sustainability and integration, land suitability assessment implications, land and housing policy implications for the study area and finally the implications for the use of GIS in such a modelling exercise.

1.7 Study area

In order to test and evaluate the land suitability assessment and bulk infrastructure potential cost models, the models were applied in the Greater Pretoria Metropolitan Council (GPMC)area (Figure 1.3). The reasons for the choice of study area were data quality and availability, familiarity with the area and complexity of the area in terms of bulk infrastructure systems and development.

The study area is situated in the northern part of Gauteng Province and is one of four metropolitan councils in the province. To the north and northwest it borders with the Eastern District Council of North West Province. The entire eastern boundary is shared with the Eastern Gauteng Services Council. The south western part of the study area shares a boundary with the Western Services Council while the southern boundary borders with the North East Rand Metropolitan Council.

The study area is about 130 000 hectares in extent, stretching over a distance of 65 kilometres from north to south and over 50 kilometres from east to west (GPMC 1997c: 28). The study area comprises three metropolitan substructure areas of the Town Council of Centurion in the south, the City Council of Pretoria in the centre and the Northern Pretoria substructure in the north (Figure 1.3).

CHAPTER 2: APPROACHES TO LAND SUITABILITY ASSESSMENT

2.1 Introduction

Evaluation of options in order to make a choice is a universal problem applied to all aspects of life from personal decision making to public decisions. In the field of land use planning, evaluation techniques have been developed to assist in the process of choice between various options. Cost-benefit analysis (Lichfield 1966; Schofield 1987), threshold analysis (Malisz 1969; Kozlowski 1971; Simpson 1977), planning balance sheet method (Lichfield et al 1975), participation methods (Manheim et al 1975), multi-attribute utility theory, potential surface analysis (Smith 1974) and multicriteria evaluation (Voogd 1984; Buckley 1988; Massam 1988; Voogd 1988), are some of the techniques which have been developed and applied in land use planning to evaluate and assess various options.

Although the techniques to be discussed fall under the general term "evaluation techniques" and are useful for evaluating alternative options, some are more appropriate for evaluating alternative projects, others, for evaluating alternative plans and yet others for evaluating alternative locations for a particular land use. Land suitability assessment is more particularly concerned with the relative evaluation of alternative locations for particular land uses and thus the spatially oriented techniques are more appropriate and directly applicable. These techniques have been given greater emphasis in the literature review. The various evaluation techniques are by no means mutually exclusive and therefore the techniques, more directly appropriate to evaluating projects and plans, have also been included in the discussion in order to give an understanding of the underpinnings, origins and emergence of the more spatially related evaluation techniques, more appropriate to land suitability assessment.

In the literature there is evidence of a progressive development of techniques, each in response to the shortcomings of the previously developed techniques. Prior to World War II, there was a strong orientation towards financial trade-off analysis where cost-effectiveness and cost-benefit analyses dominated, although the methodology was not utilised extensively in the planning profession (Nijkamp, Rietveld & Voogd 1990). It was only in the late 1960's that the planning balance sheet approach was developed by Lichfield (1966) which evolved over the years from an extension of cost-benefit analysis into a comprehensive general framework for plan and project evaluation (Lichfield 1985). The attention of planners was only really gained with the development of the goals-achievement matrix by Hill in the late 1960's and early 1970's. A strong spatial emphasis, specifically aimed at addressing planning issues, was introduced in the form of overlays, threshold analysis and potential surfaces in the late 1960's and early 1970's (Malisz 1968; McHarg 1969; Smith 1974), although Keeble (1952) had introduced his sieve maps in the early 1950's.

The emergence of multicriteria evaluation was in many ways a culmination of the techniques which came before, in that all criteria types, quantitative and qualitative, could be accommodated, including preferences in the form of weighting. The technique was pioneered in the Netherlands by Voogd, Rietveld and Nijkamp in the late 1970's and early 1980's (Nijkamp 1979; Rietveld 1980; Voogd 1983; Nijkamp, Rietveld & Voogd 1990). Multicriteria evaluation has been applied from it's simple form (Shefer, Amir, Frenkel & Law-Yone 1997) to complex mathematical forms involving fuzzy logic (Xiang, Gross, Fabos & MacDougall 1992), utility function based optimisation (Malczewski & Orgryczak 1996) and interactive decision support systems (Teghem, Delhaye & Kunsch 1989).

The advent of GIS during the 1980's saw the re-emergence of overlay type techniques, only this time, much more was possible in terms of analysis, numbers of criteria included and accuracy (Whitley, Xiang & Young 1993). In addition, GIS technology has been combined with multicriteria evaluation to produce a powerful evaluation tool for land use planners (Jensen & Christensen 1986; Jankowski 1988; Janssen & Rietveld 1990; Carver 1991; Jankowski & Richard 1993; Lin, Wan, Li, Chen & Kong 1997).

Evaluation techniques have been compared, contrasted, critisised and praised by various authors (Lichfield, Kettle & Whitbread 1975; Hill 1990; Shefer & Kaess 1990; Nijkamp, Rietveld & Voogd 1990). This chapter examines the arguments presented and gives an overview of predominant evaluation techniques, highlighting the theoretical underpinnings and disadvantages and advantages of application. The chapter concludes with a section which compares and contrasts the techniques according to specific predefined criteria in order to focus the literature review very particularly on the techniques appropriate to land suitability assessment including the assessment of suitability from a bulk infrastructure perspective in the context of the current study.

2.2 Overview of techniques

2.2.1 Cost-benefit analysis

Cost-benefit analysis originated in the 1930's in response to the need to evaluate alternative actions in the design of water resource projects with the only goal being that of economic efficiency (Hill 1990: 3). Cost-benefit analysis is a technique for assisting with decisions about the use of society's scarce resources. It can either take the form of an "economic" cost-benefit analysis which deals with economic efficiency in the use of resources or "social" cost-benefit analysis, which deals with equity in the distribution of welfare between different groups in society. In both instances of "economic" and "social" cost-benefit analysis, everything is eventually reduced to monetary terms (Schofield 1987). The concept behind cost-benefit analysis derived from the theory of the firm and its profit motive where the most profitable projects are chosen on the basis of the relationship between monetary revenues and costs with capital invested (Hill 1990: 3). Marginal benefits must at least equal the marginal costs for the project to be profitable. The assumption is that in maximising economic efficiency, economic welfare is also maximised.

It is argued that this technique may have a chance of success in the private sector but that certain conditions applicable particularly in the public sector mitigate against success in that sector. These conditions relate to the existence of barriers to the flow of funds and resources, the fact that all costs and benefits cannot be expressed at market prices - some cannot even be quantified and the existence of external economies, diseconomies or other effects (Hill 1990: 4). A further drawback in the use of cost-benefit analysis in public sector decision making, particularly as related to the assessment of land suitability for low income housing, is that intangibles cannot be accommodated in the approach. Hill (1990: 5) remarks that the net effect is that those criteria which can be measured in monetary terms are implicitly treated as the most important whereas the intangible costs and benefits may indeed be the most significant.

Cost-benefit analysis is useful in comparing alternative actions to get to the same end result such as choosing the method to be used to build a particular bridge. It has limited application in providing guidance in investment prioritisation amongst various public sectors such as between a specific road project and a housing project. The monetary cost of providing engineering services infrastructure is important in the assessment of the suitability of land for development as is advocated in this study. There are, however, a whole range of other factors which need to be considered in the assessment ranging from accessibility to work opportunities to geotechnical conditions, some of which are related to cost but cannot be reduced to monetary terms.

Shefer and Kaess (1990: 101) summarise the criticisms of cost-benefit analysis as not resolving trade-offs between equity (political) and efficiency (economic/monetary), between quantifiable and non-quantifiable issues and between rational theory and irrational practice.

Variations on the basic cost-benefit analysis have been offered in the form of a poverty-oriented cost-benefit analysis which emphasise benefits relating to human development indexes in addition to those relating to gross domestic product (Clements 1995).

2.2.2 Balance sheet of development

A form of cost-benefit analysis, which is used to compare all the advantages and disadvantages of various options by means of a "balance sheet of development", was developed and applied by Lichfield during the late 1950's and 1960's (Lichfield 1956; Lichfield 1960; Lichfield 1966). It differs from the cost-benefit analysis as described above, in that it considers all identified benefits and costs, relating to all community goals in one enumeration, rather than the single goal of economic efficiency (Hill 1990:

6). The intention of this balance sheet is to enable choices that will maximise the achievement of a range of community goals. The purpose of the balance sheet is to make explicit the issues at stake so as to provide the framework for more rational and educated decisions to be made. The exact measurement of costs and benefits, while desirable, is not essential in this technique. A criticism of this method is that despite having a broader perspective than traditional cost-benefit analysis, it fails to recognise that costs and benefits can only be compared if they can be related to a common objective and not to a range of different objectives (Hill 1990: 9). The difficulty arises when an attempt is made to get an idea of the total picture - how does one compare how a significant cost concerning one objective is compensated for by a significant benefit relating to another objective. For instance, in land suitability assessment, if one area scores high in terms of geotechnical suitability but badly in terms of accessibility, how can that be compared to another area with bad geotechnical conditions and good accessibility?

2.2.3 Goals achievement matrix

Hill proposed an alternative evaluation procedure in the form of a goals achievement matrix (Hill 1990). The term goal is defined as "an end to which a planning course of action is directed" (Hill 1990: 10). For each goal, a cost-benefit analysis is undertaken. The costs and benefits are expressed either in tangible monetary terms, in tangible non-monetary but quantitative terms or as intangibles. Value judgements are built in terms of the weighting of each of the objectives. The method seeks to allocate benefits, i.e.,tendency towards achieving a goal, to groups within society by looking at the different mixes of goal satisfaction and full achievement for each option (Nijkamp, Rietveld & Voogd 1990: 149). It does not offer a single number outcome but makes explicit the performance of the alternative in relation to each of the goals set. A major disadvantage is that interaction and interdependence between goals is not registered therefore limiting its application in evaluating projects in different sectors/groups (Hill 1990: 25). A further critique is the problem of attaching numerical weights to the goals and to different groups in the community (Nijkamp, Rietveld & Voogd 1990: 149). The attractiveness of the method for many urban and regional planning practitioners is that no spurious impression of mathematical accuracy is given (Nijkamp, Rietveld & Voogd

1990: 149). In the 1970's, the multicriteria evaluation method emerged in response to the realisation that intangible effects and conflicts of interest play a major role in policy decisions (Nijkamp, Rietveld &Voogd 1990: 149).

2.2.4 Sieve and overlay evaluation

The traditional sieve map technique, has been widely used to identify areas which have physical constraints and thus no potential for development, and to sieve out those areas which are free of constraints and possess development potential (Keeble 1952). The technique has been criticised for only taking account of physical factors and also that it produced a single "blueprint" solution without testing alternatives (Smith 1974: 1). The sieve technique results in the total exclusion of certain areas from future development. Land is either deemed as "suitable" or "not suitable", there is no range or continuum of suitability possibilities which is essentially what suitability assessment is about. Map overlay, on the other hand, builds up a pattern of suitability by spatially superimposing criteria to form a composite map. McHarg (1969) introduced the technique from the perspective of an ecological planner. The basic proposition employed is that any location is the sum of historic, physical and biological processes which are dynamic and which constitute social values. Each area has an intrinsic suitability for land uses and some areas are suitable for multiple coexisting land uses.

It is emphasised that this technique does not produce a plan but that it contributes to the production of a plan by showing the implications that the land and its processes display for prospective development and its form (McHarg 1969). It is argued that the plan can only be developed once adequate information on the nature of demand, its location and resource characteristics, the capacities to realise objectives and the social goals of the community, is included (McHarg 1969). The emphasis of the overlay technique, however, is on ensuring that whatever plan is produced, it responds to an understanding of natural processes - it must "plan with nature" (McHarg 1969). A criticism of the technique centres around the fact that only natural, ecological factors are taken into account in the assessment. The point is that it was the express intention to take only these factors into account in this particular technique, while clearly stating that other factors also need to be incorporated, perhaps using other techniques, in order to undertake a complete evaluation.

The manner in which the technique was implemented originally was using colour and shading so that certain colours or shades of intensity indicate the level of suitability. A particular case study is described where each overlay was prepared in tones of grey and made into transparent negatives which were superimposed and photographed. The resulting photograph represented the summation with the darker shades indicating greater suitability (McHarg 1969). In the days before GIS, the technique was cumbersome and time consuming to apply but GIS significantly increases the efficiency and effectiveness of application of the overlay technique. The use of GIS in evaluation is discussed later under a separate heading.

Expanding on the basic procedure adopted by McHarg (1969), further mathematical developments have been proposed to improve the method (Hopkins 1977). The mathematical operations used in the simple overlay technique utilised by McHarg (1969) was the ordinal combination method which has been criticised due to the implied addition of ordinal scale numbers and due to the implied independence of factors (Hopkins 1977: 390). Two alternative mathematical operation methods are proposed to replace the ordinal combination method. A linear combination method is proposed to deal with the problem of summation of ordinal scale numbers and a nonlinear combination method proposed to mitigate the problem of the interdependence problem (Hopkins 1977).

Anderson (1987) further detailed seven methods for calculating land capability and land suitability but still using the intrinsic overlay and sieve approaches. The seven methods proposed differ in relation to mathematical procedure, the use of graphics, the inclusion of relative weighting and the consideration of interrelationships between criteria. The methods described and computerised in the form of computer programmes include pass/fail screening, graduated screening, weighted factors, penalty point assignment, composite rating, weighted composite rating and direct assignment (Anderson 1987).

2.2.5 Potential surfaces

The potential surface technique was developed in the early 1970's in Britain with the legal and administrative separation of regional level strategic, structure plans and local level district and local plans (Smith 1974: 1). There was a corresponding move away from the "blueprint", linear, survey-analysis-plan process to a systems approach which treated planning as a more cyclical continuous process (Smith 1974: 2). The potential surface method responded to a shortfall in the systems approach, which was the lack of analytical techniques to either define and relate objectives or to generate alternatives. The techniques developed thus far had assisted more on the evaluation component, such as cost-benefit analysis. Potential surface analysis has been described as a method for the location of urban growth by generating, simulating and evaluating a range of alternative strategies (Smith 1974: iv). The method relies heavily on weighting which creates a framework for relating the importance of objectives and for generating alternatives. In addition the method seeks to link alternative generation and evaluation in a more consistent manner through the weighting system (Smith 1974: 2). The technique incorporates dimensions of within and between place characteristics over time. A strength of the tool is that it can incorporate many spatial characteristic which are important in assessing potential but a weakness is that a static view of time and space is taken. The technique does not simulate interactions between these dimensions and treats them in a snapshot rather than dynamic process manner (Cowling & Steeley 1973: 74).

The concept of "potential" was first used with regard to population distribution (Stewart 1947). Stewart suggested a gravity type model which measures the influence or attraction of population for population. The equation states that the potential of a particular point near a town, for attracting population is directly proportional to the population of the town and inversely proportional to the distance from that town (Smith 1974: 5). A related concept is that of "interaction" which measures the demographic energy or interchange between two towns (Stewart 1947). The equation shows that the amount of interaction between two towns is a function of the distance between the two towns and the relative populations of the two towns. There are strong conceptual and mathematical relationships between potential and interaction models since both are derived from an analogy with gravity. Both models have been used to simulate the location of activities, particularly residential and service activities, however, in practice, the interaction model has produced better results and the actual potential model is rarely used (Smith 1974: 8).The interaction model formed the basis of the Lowry model (Batty 1972). "Potential" or "interaction" is thus related to accessibility or attraction and is a prediction of potential activity at one point as influenced by the surrounding activities and distance to them. Batty (1973) recognised that the potential surface can be used to locate several urban land uses by constructing a series of surfaces and resolving competition by the use of weights.

The theory of potential has been combined with linear equations, sieve maps, design method and evaluation techniques to eventually produce what is commonly understood as the potential surface technique. The idea of potential is implicit in both the linear residential model of Chapin and Weiss (1962) and sieve maps (Keeble 1952). In the linear residential model, residential potential of a zone is calculated according to the accessibility of a zone to other activities and to the inherent physical qualities of the zone itself. With sieve maps, although usually operated visually with maps, a linear equation similar to the linear residential model can be applied. Variable are recorded in binary notion where a score of 0 means the land is physically unsuited for development and a score of 1 indicates physical suitability for development. Only physical factors are used and accessibility is not considered (Smith 1974: 11).

The gravity model, the linear model and the sieve map can all be used to simulate and predict development potential but Smith (1974: 10) argues that these models only partially provide a potential surface technique. He maintains that the models need to be placed into some kind of planning framework before the technique is able to generate and evaluate alternatives in addition to simulating development form (Smith 1974: 12). It is submitted, however, that all the techniques described need to be used within the context of a planning framework if they are to fulfil their purpose. Smith's (1974) description of a model potential surface technique therefore refers to not only the use of potential surfaces but their use within the broader planning process.

Simpson (1977: 80) criticises the point system which has typically been used for weighting to indicate the relative importance of the various factors taken into account as influencing locational decisions. In implementing the technique, he argues that often the relative importance of the various factors has been assumed to be constant throughout the study area, which cannot be so unless applicable to a featureless plain situation. He further maintains that decreasing marginal utility is often ignored in practice by the assumption that the relative importance of the various factors is constant no matter how much development takes place.

2.2.6 Threshold analysis

The theory and technique of threshold analysis originated in Poland from the work of Malisz (1969) in the 1960's and was elaborated upon and refined by Kozlowski (1971) and the United Nations (1977) and applied in Scotland (Kozlowski & Hughes 1967; Kozlowski & Hughes 1972; Scottish Development Department 1973). According to Malisz (1969: 108), threshold theory originated in response to three physical planning problems of the day. The first problem related to the lack of inter-disciplinary understanding and co-operation between physical planners and economic planners. Threshold theory attempts to translate qualitative urban design into quantitative factors. The second problem concerns feedback between the different levels of planning. Threshold analysis at the more detailed local level serves as a feedback into regional plans as to the feasibility of regional proposals. Thirdly, threshold theory goes some way to solving the problem of time. Instead of setting artificial time horizons for plans, threshold times, or times at which various thresholds are reached, can be used to plan for (Malisz 1969: 108).

The theory of threshold analysis was based on the simple observation that towns encounter some physical limitation to their spatial growth in the form of natural limitations such as topography or in the form of man-made facility limitations such as public utility network systems (United Nations 1977: 7). These limitations have been called the thresholds of urban development. They are not irremediable but can be overcome at a high capital investment cost or threshold cost (Kozlowski & Hughes 1967: 19). Threshold analysis concerns those physical characteristics of an area which would cause significant differentiation in the unit cost of future urban development, dealing only with costs which vary with location (Lichfield, Kettle & Whitbread 1975: 57). A threshold occurs when new units of development cannot be constructed and serviced at their previous unit cost levels and significant additional outlays are required. The presence of a threshold is indicated either by a steep rise in the gradient or a discontinuity in the marginal cost curve of urban development. Changes in the unit cost of development could be caused by a variety of physical factors ranging from the topography or the physical capacity of the public facility (Lichfield, Kettle & Whitbread 1975: 57).

The methodology of threshold analysis concentrated initially on three groups of capital costs. Firstly, those costs due to physical constraints imposed by factors such as slope, liability to flooding and subsistence, were taken into account. Secondly, capacity constraints in engineering infrastructural services were considered. Thirdly, structural constraints were noted when the existing urban structure limited further development such as when increased population made the construction of a new public transport system necessary (Simpson 1977: 79). Later, in further applications of the technique, an attempt was made to include a range of social facilities (Intermet 1973). The United Nations (1977) include environmental and social considerations.

Threshold analysis assists decisions pertaining to the direction and sequence of town growth and to whether intensification of existing development or new "greenfields" developments is the more cost effective option. The analysis also provides information on the relative magnitude of changes in unit development costs for alternative locations. Costs are related to the number of new inhabitants and expressed as an average threshold cost per new inhabitant. A significant consideration in the analysis is the extent to which different categories of threshold cost tend to reinforce each other instead of occurring in different time periods. A trough in one category may coincide with a crest in another category, evening out the total cost curve (Lichfield, Kettle & Whitbread 1975: 57).

The argument against threshold analysis is that although the factors included can be accurately described in monetary terms, they do not adequately represent all the criteria for making locational decisions (Simpson 1977: 80). Advocates of threshold analysis, however, do not propose that the physical development costs are the only factors which should influence decisions around future urban growth. Threshold analysis can be used either to narrow down the original number of options or as a contributing criteria in another evaluation method such as multicriteria evaluation.

2.2.7 Multicriteria evaluation

The above-mentioned methods give a neutral, technical recommendation of the "best" alternative. With the exception of the goals-achievement matrix which allows for the relative weighting of criteria, no allowance is made for political factors to be incorporated, taking no account of special interests, bargaining and short-term results, which all play a significant role in decision making and choice. Earlier evaluation methods had a rational, comprehensive approach rather than a satisfying approach, where negotiation and arbitration between conflicting groups and interest groups can be catered for (Shefer & Kaess 1990: 103). Multicriteria evaluation responds to this need to accommodate several dimensions simultaneously (Shefer & Kaess 1990: 103).

Multicriteria evaluation methods serve to investigate a number of choice possibilities in the light of multiple criteria and conflicting priorities (Voogd 1984: 21). The choice possibilities can be alternative plans or choices between alternative geographic areas (zones, regions, suburbs). It has been recognised that multicriteria analysis is important not only in the evaluating of alternatives but also at the alternative generation phase (Bayne 1995: 303). Multicriteria evaluation methods, often in combination with GIS and decision support system technology, have been used widely in relation to land use planning. The technique has been used for regional, strategic multi-land use decision making (Van Delft & Nijkamp 1977; Nijkamp, Rietveld & Voogd 1990), in sub-regional land use planning (McDonald & Brown 1984; Xiang & Whitley 1994; Shefer, Amir, Frenkel & Law-Yone 1997), for suitability assessment of land for certain land use types (Jankowski 1988; Janssen & Rietveld 1990), for locating specific facilities (Tomlin & Johnston 1990), for route selection for engineering infrastructure (Jankowski & Richard 1994) and in stormwater planning (Cash 1994). Multicriteria analysis has been used to good effect in conjunction with GIS and decisionsupport systems in land use planning (Teghem, Delhaye & Kunsch 1989; Carver 1991; Xiang, Gross, Fabos & MacDougall

1992; Whitley, Xiang & Young 1994; Malczewski & Ogryczak 1996).

The strengths of multicriteria evaluation identified by Voogd (1984: 32), include the following:

- It does not offer a rigid set of rules but a flexible framework which may be adaptable to various circumstances without a change of the basic nature of the approach;

- It allows for the political processes of dealing with the conflicts between individual and collective interests in public policy formation, to be explicitly incorporated;

- It allows for technical research aspects, relating to complexities inherent in the spatio-socio-economic system, covering a wide range of disciplines, to be incorporated in an explicit manner;

- It facilitates communication and understanding between decision makers, planning officials and stakeholders, between politicians, technicians and communities. Scientific facts, value judgements and norms are all made very explicit and thus results can be debated on an informed basis by all parties;

- It enables the simultaneous synthesis and analysis of both quantitative and qualitative information; and

- It is relatively cheap to implement from a manpower and financial perspective.

An important component of multicriteria evaluation is the weighting of criteria and various related methods have been proposed ranging from simple ranking and rating techniques to the more complex pairwise comparison techniques such as the analytic hierarchy process (AHP) and PLUS methods. AHP was developed by Saaty (1980) but its value to site suitability analysis was recognised and expanded upon later (Banai-Kashani 1989). Instead of comparing the relative importance of all criteria present in the analysis simultaneously, AHP structures the comparison in such a way that a pairwise comparison is made within a set of reciprocal matrices. A benefit of this weighting method is that it is theoretically possible to compare any number of criteria. Psychological experiments have indicated that an individual cannot simultaneously compare more than about seven objects without being confused (Miller 1956). AHP allows many more than seven criteria to be compared. Furthermore, AHP provides a consistency check of expert judgement in the pairwise comparison process. An explicit account of the weighting process is also given which is beneficial particularly in controversial site selection (Banai-Kashani 1989: 685). An extension of AHP has been proposed in the form of a method called prioritisation for land use suitability (PLUS). It is maintained that the PLUS method provides a holistic approach in dealing systematically with preference acquisition, synthesis and inconsistency diagnosis in the determination of land suitability factor weighting (Xiang, Gross, Fabos & MacDougall 1992). The most significant addition in the PLUS method is a combined interview method to elicit expert's preferences on the relative importance of land suitability preferences.

A more sophisticated method of weighting which accounts for fuzziness in addition to multicriteria and multiparticipants has been demonstrated in a land use planing application (Xiang, Gross, Fabos & MacDougall 1992). Fuzziness implies the distinct ability of humans to make descriptions and judgements based on fuzzy logic which is an extension of conventional two-valued and multivalued logics. It also represents the imprecision stemming from this kind of fuzzy description and judgement (Xiang, Gross, Fabos & MacDougall 1992).

Criticisms of the multicriteria approach include questioning of assumptions used in various methods, the neglect of spatial diversity, the complexity of the arithmetic operations, the unmeasureability of many criteria on a metric scale and the absurdity of reducing the quality of a given alternative into a single number (Voogd 1984: 21). Buckley (1987: 55) has levelled criticism expressly at the weighting problem, calling it the "Achilles heel" of the technique. He argues that judgement underlies all evaluation approaches and that judgement can only be properly applied if the information applied conveys meaning. It is contended that the focus of multicriteria evaluation is on numerical manipulations whereas it should give attention to producing measures which convey meaning to those exercising judgement (Buckley 1987: 55). As an alternative measure, Buckley (1987) proposes natural measures which, it is understood, are familiar measures, commonly known and used in areas wider than in a specific planning study such as cost in Rand and number of deaths.

2.2.8 Geographical information systems (GIS)

2.2.8.1 GIS technology

GIS technology is not another evaluation technique but is rather a tool to utilise the available techniques more efficiently and spatially. GIS technology involves the spatial relation of data. All data is thus linked to specific locations in space and then all data can be assessed in a spatially related manner. GIS technology incorporates data manipulation and analysis processes as well as permits classification and generalisation of spatial data. A GIS has been defined as "a specialised form of database system, distinguished by its ability to handle geographic data, that is, spatially referenced data which can be displayed graphically as map images" (Bracken & Webster 1990). The four major components of a GIS are:

- A data input subsystem which collects and processes spatial data derived from sources such as maps and direct digital input;

- A data storage and retrieval subsystem which organizes spatial data in a topologically structured form which allows it to be retrieved on the basis of either spatial or non-spatial queries;

- A data manipulation and analysis subsystem which performs tasks such as transforming data or producing estimates of parameters for transfer to external analytic models; and

- A data reporting subsystem which facilitates the display of all or selected portions of the spatial database by means of reports or maps (Bracken & Webster 1988).

2.2.8.2 Advantages of using GIS in land suitability assessment

2.2.8.2.1 Data handling capabilities

Large amounts of data, relevant to the assessment of suitability, is available but needs to be transformed and integrated into decision making material. GIS allows the combining of data from different sources, level of detail and accuracy, classification system and formats which previously presented insurmountable problems to anyone attempting to analyse land in a comparable manner.

In his guidelines on land suitability assessment without GIS, Anderson (1987: 5) specifies that land units must have the same boundary for each of the factors being considered. A considerable benefit of GIS is that there is no need to reduce all criteria to a common spatial unit of measure i.e. zone, catchments etc. Each criteria can be assessed on whatever spatial basis is applicable e.g. traffic according to traffic zones, water capacity according to water reservoir supply areas and accessibility according to distance contours. GIS is able to combine all zone types and an analysis is possible on the basis of unique intercept polygons formed when all zones are overlayed.

2.2.8.2.2 Data analysis capabilities

The data collection component of these types of exercises usually entails significant costs. The location of urban activities and the links between them, forms the basis of the urban system. Spatial relationships is what cities are about. The spatial analysis capabilities of GIS enable the manipulation of fairly basic data into more complex but useful information, such as accessibility measures, reducing the amount of base data to be collected.

2.2.8.2.3 Overlay capabilities

All data relating to a particular spatial location can be aggregated and the sum of the values reflected at that specific location. Where overlays intercept in space, intercept polygons are created and receive a value equal to the sum of the overlay values. In this way, all the accuracy of the input data is maintained to the final overlay product. Only at that stage is it decided whether to present the data in a coarse manner i.e. high, medium, low categorisation or in a more detailed classification.

2.2.8.2.4 Data presentation and interactive capabilities

The data are spatially related and can therefore be displayed geographically which enhances understanding and clarifies issues. The effect of changes to the data can immediately be visually displayed and implications clearly observed.

2.2.8.3 GIS and land suitability assessment techniques

The emergence of PC based GIS during the 1980's, out of a mainframe and CAD environment, facilitated the re-emergence of overlay type techniques only this time, much more was possible in terms of analysis, the numbers of criteria included and accuracy (Whitley, Xiang & Young 1993). In addition, GIS technology has been combined with overlay techniques and incorporated with multicriteria evaluation to produce a powerful evaluation tool for land use planners. GIS has been used effectively in site selection for hazardous waste disposal sites (Jensen & Christensen 1986; Carver 1991) and for labour intensive industry in the Nanking-Gaging industrial corridor (Lin, Wan, Li, Chen & Kong 1997) and in route selection for a water supply line (Jankowski & Richard 1993). The use of GIS in strategic land use planning for regions or areas has been demonstrated in a rapid land use assessment study in the Philippines (Planning and Development Collaborative International 1994), an agricultural land use application in the Netherlands (Janssen & Rietveld 1990) and in regulating urban expansion in Cape Town (Van der Merwe 1996). The importance of GIS in large-scale urban simulation and optimisation models has been recognised and at minimum, interfaces with GIS are being developed (Batty 1992; Batty 1994; Brotchie et al 1994; Harris & Batty 1993; Klosterman 1994; Wegener 1994; Landis & Zhang 1998). It has, however, been deduced from an investigation of all operational large-scale urban models that despite their recent popularity, GIS have so far contributed little to methodological innovation in urban analysis and that the opportunity lies in linking GIS with the analytical capabilities of urban models (Wegener 1994: 26).

2.3 Comparison and assessment of techniques

2.3.1 Type of goal

All the techniques described have as an ultimate goal, to assist in determining appropriate future action in the utilising of scarce resources in such a way as to maximise the expected attainment of a set of given ends (Hill 1990). What differs between techniques is the "set of given ends", ranging from pure costs to more qualitative, softer issues or a combination of the two. Schofield (1987: 146) essentially identifies the planning balance sheet and the goals achievement matrix as subsections of cost-benefit analysis, with the only real difference being that cost-benefit analysis measures everything in monetary units whereas the others measure in a range of units.

The sieve technique has been criticised for only taking physical factors into account (Smith 1974: 1). It is not the principles of the sieve technique which are at fault but that only physical factors were used in the sieve technique. Multicriteria evaluation would be criticised if only physical factors were used in the evaluation.

2.3.2 Number of goals

The evaluation methods developed can broadly be divided into those that focus on a single objective (cost-benefit analysis), those that set one objective at a particular level as a constraint (planning balance sheet) and those that formulate a multi-objective to address trade-offs among the objectives (goals achievement matrix, potential surfaces, multicriteria evaluation) (Shefer & Kaess 1990).

2.3.3 Planning approach

Two basic planning methods can be identified: linear planning and cyclical planning. Linear planning has a comprehensive, often optimising, 'ideas" based approach, with the planner assuming the role of technician, augmenting a policy advocated by the client. Cyclical or incremental planning, on the other hand, is more implementation and monitoring based with a short term planning horizon, periodically revised, with the planner assuming a more active, negotiating role (Shefer & Kaess 1990: 105). Of all the methods described, multicriteria evaluation is the most suited to a planning environment of incremental planning processes, short term, focused studies with a participatory mode of policy adoption whereas the other methods are more suitable in the comprehensive planning environment. The planning approach currently being advocated in South Africa through the Development Facilitation Act (Republic of South Africa 1995) and the Local Government Transition Act Second Amendment Act (Republic of South Africa 1996), is typically the cyclical, incremental planning approach thus calling for multicriteria evaluation type procedures.

Sometimes the technique is criticised but in fact it is the planning method, which incorporated the technique as a tool, which was the problem and not the technique itself. Smith (1974: 1), for example, criticises the sieve technique for not generating alternatives to compare yet it is not the sieve technique which is at fault but the way in which the technique was used in the planning process.

2.3.4 Generation versus evaluation

In the systems approach to planning, certain analytical techniques have been developed for certain parts of the process. The process is described as comprising four main steps: definition of goals and objectives; generation of alternative policies with a view to optimising objectives; translation of policies into spatial patterns of development and evaluation of the effects of development patterns against objectives (Smith 1974: 2). As far as techniques to support this process is concerned, the spatial sciences have provided models of urban growth to assist with the third stage of the process (Wilson 1968). Threshold analysis, potential surface analysis and sieve analysis have all been used for generation of alternatives, whereas goals-achievement, cost-benefit, planning balance sheet and multicriteria evaluation have typically been used for plan evaluation. Evaluation techniques are more well developed than generation techniques (Simpson 1977: 79) and the literature reporting on the application of techniques to the evaluation stage far outweighs that for the generation phase.

Threshold analysis is virtually the only technique which can be used as a rigorous economic planning tool at an early stage in the planning process. Cost-benefit analysis is very much a technique for evaluation rather than generation of proposals. Sieves and potential surfaces have frequently been used as alternatives to threshold analysis in the early stages of the planning process. Sieves are useful for broad initial assessment and as such constitute the preliminary stages of both threshold analysis and potential surfaces (Simpson 1977: 80).

It is argued that typical plan evaluation techniques can be used as plan generation techniques, with some adaptation, by "evaluating" spatial locations in relation to each other instead of evaluating one plan against another. Multicriteria evaluation can be used as effectively to compare various locations for specific land uses as to compare alternative development plans or alternative sites for a particular use.

2.3.5 Spatial orientation

All evaluation techniques are spatial in nature in that they evaluate options which exist or potentially exist at a specific location in space. If the comparison is between specific sites or plans, the evaluation can be conducted effectively in tabular or matrix form. In the case of land suitability assessment where all land is relatively assessed, the analysis can still be performed in tabular format but it is in making the resulting information meaningful and understandable to decision makers that difficulties arise. A clear spatial representation of information is beneficial in clarifying results.

Probably all the techniques discussed could have their results represented geographically to a greater or lesser extent. Those techniques aimed at evaluation are probably less spatial and more tabular than generation techniques which by nature need to be spatial in that they are being used to generate a spatial plan. The best indicator of which of the techniques are more spatial in orientation is to observe which techniques have been used with GIS. Multicriteria evaluation, sieve, overlay and potential surface techniques are by far the most commonly used techniques in conjunction with GIS.

2.3.6 Intended applicability

A very important principle emerges from McHarg's approach (1969) which is applicable to the criticisms of many of the other techniques described. It is clearly stated that the technique does not produce the plan or is not responsible for the entire evaluation of the plan. It is clearly specified that the technique is a contribution towards the evaluation or the plan. The criticism of the technique centres around the fact that only natural, ecological factors are taken into account in the assessment. The point is that it was the express intention to take only these factors into account in this particular technique, while clearly stating that other factors also need to be incorporated, perhaps using other techniques, in order to undertake a complete evaluation. The problem with much of the criticism aimed at this and other techniques, is that it criticises the technique for not being what it was never intended to be. Smith (1974), in his application of potential surfaces, attempts to put the technique into a wider planning context. Probably the success of multicriteria evaluation is due to its all - encompassing, framework approach where many different types and forms of criteria can be incorporated into one assessment.

2.3.7 Mutual exclusivity

The evaluation methods which have been described are not mutually exclusive. Many of the applications described in the literature are combinations of techniques. Multicriteria evaluation is a more all-embracing technique within which there is room for threshold analysis and cost-benefit analysis for the measurement of the more quantitative criteria. Overlay and sieve techniques can be used to incorporate physical factors. Potential surfaces can be used to generate the accessibility measures. As has been mentioned earlier, sieves are useful for broad initial assessment and as such constitute the preliminary stages of both threshold analysis and potential surfaces (Simpson 1977: 80). Threshold analysis incorporates aspects of cost-benefit analysis as a certain benefit is present in the form of existing capacity until a certain time when enormous costs are again necessary to extend the infrastructure.

2.4 Method choice for current study

Consideration of the purpose for which the study is intended and the assessment of the various techniques considered, resulted in a choice of a "package of techniques" appropriate for use in the study. The purpose of the study is to improve the land suitability assessment component of the generation stage of the planning process by incorporating bulk infrastructure cost considerations. Multicriteria evaluation, incorporating the overlay technique, using GIS technology, is used as the overall land suitability assessment technique. The measurement of certain criteria incorporated into the multicriteria evaluation utilise potential surface techniques (accessibility) and sieves (geotechnical suitability). The bulk infrastructure cost model is developed against a backdrop of threshold analysis and cost-benefit analysis, utilising GIS technology.

CHAPTER 3: ENGINEERING SERVICES INFRASTRUCTURE COSTING IN PRACTICE

3.1 Introduction

A variety of sources were accessed in order to assess the utilisation of engineering services costing procedures in practice and to ensure that the intended focus area of this study had not been previously investigated. Unpublished reports, originating largely from the public sector, provided the most insight into practice, particularly in South Africa. Outside South Africa, the World Bank and the Real Estate Research Corporation offered the greatest practical insight into methods and roles of engineering services costing within the broader planning arena. Threshold analysis literature offered infrastructure costing methodologies but this detail has been included as part of a separate chapter (Chapter 5). The wider field of infrastructure provision was perused but only the applicable cost modelling and cost assessment aspects as relating to, or potentially relating to land use planning, are reported on.

The purpose of this chapter is thus to provide an overview of predominantly South African sources of infrastructure costing related exercises. The purposes of these studies, their assumptions and outcomes is reported and their relationship, if any, to the present study is identified.

3.2 Wider infrastructure provision arena

It was by no means the intention to get involved in the wider sphere of civil engineering literature but rather to focus on that small component dealing with infrastructure costing. Certain broader engineering aspects did, however, implicitly relate to the present study. Educational aspects relating to broad definitions and explanations of infrastructure assisted in defining the scope of the study (Rainer 1990). The importance of institutional arrangements in infrastructure provision and its effect on costs (Hood & Schuppert 1988; Swyngedouw 1995; Van der Hoff and Steinberg 1992), is taken into account in the bulk infrastructure potential cost model methodology in the very first step of identifying roles and responsibilities. One of the areas of integration which has been reported on significantly in the literature and has also occurred in practice is the integration of land use and transportation planning (Dimitriou 1992; Gakenheimer 1993; Headicar 1995). Lessons learnt from land use/transportation modelling exercises have been incorporated into the present study. Although operation and maintenance cost impacts have not been included in the present study, they have been identified as an important cost element and an area of future incorporation into the bulk infrastructure potential cost model (Santry 1972; Peratta 1996). The incorporation of capital facilities planning within an overall integrated planning approach (Brevard 1985) has highlighted the need to position the bulk infrastructure potential cost model within a broader land suitability assessment framework which in turn is part of a wider integrated development planning approach. The utilisation of differential cost structures as incentives for development (Nunn 1995) has pointed to the use of the bulk infrastructure potential cost model for wider application than only as an input to land suitability assessment. The output of relative cost surfaces can be used in the determination of bulk infrastructure contributions required by local authorities from developers and in this manner can be used to influence the direction of growth.

3.3 Infrastructure and sustainability

Recent government policy and legislation calls for development to proceed in an integrated manner in order to achieve sustainable development. A challenge to infrastructure planners and providers is given in the literature for sustainable infrastructure management (Wright 1996; Marrazzo 1997).

Whereas Wright (1996) proposes public-private partnerships as a means of achieving sustainable development through accelerated innovation, Marrazzo (1997) suggests seven concepts and practices which should be embraced in order to contribute towards achieving sustainable communities in the infrastructure arena. The bulk infrastructure potential cost model complies with four of Marrazzo's (1997: 38) infrastructure sustainability concepts. Firstly, it recognises the value of existing infrastructure, promoting development in areas of spare capacity or in areas which are relatively cheaper to service than others thus saving in the resources needed to extend and maintain infrastructure systems. Secondly, a broad systems approach towards problems and solutions is taken where bulk infrastructure cost considerations are incorporated with a range of other criteria in finding a solution for the identification of suitable land for low income residential development. Thirdly, the bulk infrastructure potential cost model is a start to accounting for the true costs of actions. Marrazzo (1997: 38) asks that engineers, planners and economists work together to determine the real impact of infrastructure decisions so that the most cost-effective solutions are chosen. Fourthly, Marrazzo (1977: 38) proposes collaboration with other disciplines and interests in decision making and the integration of infrastructure management into GIS, so that the efforts of one community or discipline do not interfere with or duplicate that of another, but rather enhance and inform each other. The purpose of the bulk infrastructure potential cost model is to exactly comply with this last proposal as related to the disciplines of engineering and planning in land suitability assessment.

3.4 Bulk infrastructure costs as a component of development costs

3.4.1 Development costs and urban form

Reports on infrastructure costing in the formal and more informal literature can broadly be divided into those that report on infrastructure costing as one component of a broader development costing exercise and those that deal only with engineering services costing. The studies dealing with infrastructure costs as only a component of development costs predominantly relate to the evaluation of alternative urban forms. By far the most common urban forms investigated and reported on, are the dense, compact, contained, intense urban form as opposed to the sprawled, dispersed urban form. In the United States of America, the Real Estate Research Corporation's "Cost of sprawl" (RERC 1974) still remains the most comprehensive qualitative and quantitative assessment of the impacts of urban form. More recently, Ladd (1992), investigated local government spending in relation to densities on a statistical basis, arriving at some interesting conclusions relating to increased public sector spending at higher densities. In South Africa, development cost impact studies have been undertaken in the major metropolitan areas of Johannesburg, Pretoria, Cape Town and Durban.

3.4.2 Cost of sprawl

The purpose of the "Cost of sprawl" study was to enhance decision making regarding the use of land in terms of how land should be used and how much and what type of development should be allowed (RERC 1974: 1). The study attempts to determine economic, environmental and personal or social costs as they apply to different neighbourhood types and to different community development patterns and to indicate whether the costs are incurred publicly or privately (RERC 1974: 1). Three urban form types were costed: low density sprawl, combination mix (half low density and half high density) and high density planned. The results of the study indicate that higher densities result in lower economic costs, environmental costs, natural resource consumption and some personal costs for a given number of dwellings. It is cautioned that the results should not be interpreted as recommending one type of development over another as there are too many costs and benefits which have not been included, particularly those associated with personal preference and revenues generated (RERC 1974).

Infrastructure costs are included in the assessment of economic costs as utility costs and includes capital and operating sewer, water, stormwater drainage, gas, electricity and telephone costs. The methodology used to obtain utility costs was to assume typical site conditions and an absence of any existing infrastructure at the site and then, using standard unit cost figures, to estimate the costs of building alternative types of development (RERC 1974: 1). This methodology differs significantly from the bulk infrastructure potential cost model. Firstly, existing infrastructure in terms of capacity and location is crucial in determining additional cost expenditure required and secondly, costs are influenced by non-typical conditions such as geotechnical or environmental factors.

3.4.3 Population growth, density and the costs of providing public services

Ladd's (1992) approach to determining development costs differs significantly from that of the RERC (1974). Rather than using hypothetical prototypes, Ladd uses actual statistical data of local government expenditure and relates that to two dimensions of residential development patterns, the rapidity of population growth and intensity of land use as measured by gross residential densities. The results of the study balances the engineering and planning view that greater population density lowers the cost of providing public services, by documenting a U-shaped relationship between spending and density. It is concluded that, except in sparsely populated areas, higher density typically increases public sector spending largely as a result of increased expenditure on public safety. In addition, the results suggests that rapid population growth imposes fiscal burdens on established residents in the form of lower service levels (Ladd 1992). The study does not distinguish infrastructure costs but incorporates them into capital outlays. The costs are not calculated but are actual costs from 247 large county areas.

3.4.4 Improvement of mobility as a result of land use planning

The South African Roads Board (SARB 1992) commissioned a study to investigate the question of whether it would be economically feasible to undertake residential development on relatively expensive land, close to employment concentrations (thus requiring lesser transportation subsidies), rather than on inexpensive land on the periphery, where transportation subsidy requirements are high. The study compares the costs of a location on the urban periphery of Greater Johannesburg (Orange Farm) with two locations on the mining land of Johannesburg (River Park and Crown Park).

The cost comparison was done on the basis of three cost categories: settlement costs, transportation costs and land costs. Settlement costs were divided into two categories, the initial cost of settlement and the running cost of the settlement. The initial cost of the settlement included: the cost of land, bulk services, internal services and housing. The running cost of the settlements reflects the cost to operate and maintain the services and included the annual cost of water, electricity, sewerage, waste removal and road maintenance. The cost of land was calculated as the average price for land, using market values of real transactions and considering the cost for developing on geotechnical constraints. A minimum area of 50 to 60 hectares was assessed since that is the area on which a community of 5000 people could be settled. Transportation costs were based on morning peak hour trip costs including vehicle costs, time costs and accident costs.

The study concluded that from the viewpoint of society, the costs of centralisation are less in both Crown Park and River Park than the cost of dispersion at Orange Farm. From the viewpoint of the individual a centralised locality at Crown Park is more expensive than a dispersed location at Orange Farm. This can be attributed to the high transportation subsidies being received by residents located in dispersed communities (SARB 1992).

The costs of the bulk and internal services were calculated by applying a constant average cost per stand for each service for three different level of service options. Essentially the infrastructure costs are thus to be the same for any development location. As in the case of the "Cost of sprawl" (RERC 1974), the bulk infrastructure potential cost model methodology differs significantly from that applied in the Greater Johannesburg study in that locational cost differentiation is a vital component of the methodology with existing infrastructure capacities and environmental conditions influencing the costs.

3.4.5 Integrated urban densification study for the GPMC area

The aim of this study was to prepare two residential development scenarios based on two different approaches. The "trend" scenario was prepared based on current development trends and approaches. The "densification" scenario, or "integrated urban densification strategy", was prepared on the basis of sustainability precepts. The aim was furthermore, to develop a general costing and multicriteria evaluation model to be used in evaluating the two scenarios qualitatively and quantitatively (GPMC 1997a).

Only initial costs were calculated for the purposes of this study. The scenarios were formulated with no time horizon attached which made the inclusion of costs other than initial costs, difficult if not impossible. The emphasis was also on comparative costs not necessarily actual costs and every effort was made to ensure that precisely the same factors, methodologies and calculations were used in calculating the costs associated with the "trend" and "densification" scenarios. Bulk engineering services costs, including waste water treatment work, outfall sewer, distribution reservoir, water feeder main and electricity costs, were calculated. Local reticulation costs including sewer, water, electricity, rods and stormwater costs were also included in the cost calculation. Land costs, building costs, social facilities costs and transportation costs were further included.

The difference between available bulk infrastructure capacity and required capacity yielded an estimation of required additional infrastructure units, either as number and size of infrastructure facility modules or as length of conduit. Costs were allocated to each unit of infrastructure required on the basis of average cost data determined from records and engineering experience. Total costs for each services were then expressed per additional person added per scenario so that relative comparison between scenarios was facilitated (GPMC 1997a). The per capita bulk infrastructure costs reveal that the "densification" scenario costs 17% less per person, than the "trend" scenario. Overall, all costs included, the "densification" scenario performs better than the "trend" in terms of per capita costs with a 30% saving being indicated (GPMC 1997a).

The results are unique to a particular place at a particular time under a particular scenario. The costs which were calculated arise from a unique combination of factors relating to where and how many additional people have been allocated in relation to the unique situation of existing capacity conditions in the engineering services infrastructure. The results are therefore very different from a simple factoring exercise where the number of additional people is multiplied with a cost factor for each service as was the method used in the Greater Johannesburg (SARB 1990) and the RERC (1974) examples. The methodology used in the GPMC (1997a) study was based on the present bulk infrastructure potential cost model and so it is not the intention to contrast the two methodologies but rather to highlight the fact that the effect of influencing factors on the cost such as environmental and land use factors were not included in the GPMC (1997a) study but are included in the bulk infrastructure potential cost model. The other main difference is that the methodology was applied at the plan evaluation stage in the case of the GPMC (1997a) study rather than at the plan generation stage as in the case of the present model.

3.4.6 Cost tradeoffs between mobility and accessible land: Kwandebele vs Mamelodi

A study was commissioned by the Department of Transport (DOT)to investigate the potential cost implications of resettling people from Kwandebele closer to Pretoria and to establish at what distance, the capitilised cost savings resulting from shorter commuting, would equal the increased costs associated with higher necessary urban standards and land costs (Republic of South Africa 1991).

The costs considered in the exercise were bulk infrastructure, reticulation, operation and maintenance, commuting, travel time, housing structure and land costs. Bulk infrastructure costs were calculated using average per erf costs per service, thus assuming no existing infrastructure, that proximity to exiting infrastructure has no effect on cost and that environmental and land use conditions have no differential effect on cost, unlike the case in the bulk infrastructure potential cost model.

The findings of the study were depicted in a graph indicating that the total commuting costs increase with distance while total land and housing cost decreases with distance from the Pretoria Central Business District. The study concluded that purely from a cost point of view, the implication is that no new settlement further than about 60km is likely to be economically justifiable. However, if it is assumed that most households would eventually want to upgrade to a brick dwelling and waterborne sewerage, the least cost settlement distance becomes no further than about 30km (Republic of South Africa 1991).

3.5 Engineering services costs

3.5.1 Application of engineering services costing

Other than the inclusion of infrastructure cost in the evaluation of alternative urban forms, engineering services costing is undertaken to serve a number of purposes. Engineering services costs have been determined and packaged in the form of guidelines so as to provide options and give cost and other implication of those options (National Housing Board1994; Behrens & Watson 1994). Costs have further been used in policy formulation relating to taxes, prices and subsidies (Van Ryneveld 1995; Water Research Commission 1994a; Bhattacharyya & Pant 1996). In the context of financial modelling, engineering services costing is considered in relation to income in order to assess the impact of investments in services infrastructure, and the implementation of different tariff and subsidy policies, on the long term financial viability and sustainability of service agencies (Eberhard 1995). Services costing is also undertaken as part of optimisation modelling in order to find a solution to the problem of allocating water from sources to demand through the use of heuristic modelling procedure (Birkin et al 1996). Services costing has also been utilised in the development monitoring and approval process to ensure that decision makers approve projects only when adequate infrastructure is available or is provided at the expense of the developer (Kushner 1988).

3.5.2 World Bank South African Urban Sector Reconnaissance services cost model

As part of their 1993 mission to South Africa, the World Bank developed a spreadsheet model to assist in the preparation of an investment profile for each of the main metropolitan areas. The focus areas of the investment profiles were upgrading of existing communities, development of suitably located vacant land and the expansion of bulk infrastructure systems (World Bank 1993). A number of existing and potential settlement sub-areas were identified and for each area the existing status in terms of demographics and level of service were noted. A number of cost tables were developed to indicate the cost of progressing from one level of service to the next and infrastructure costs are calculated as densities and levels of service change. Costs are expressed per person per hectare and were obtained as averages from local authorities concerned. Once densities and level of service have been proposed per settlement and costs calculated accordingly, financial aspects such as investment period, borrowing aspects and revenue sources are included to relate costs to affordability in terms of tax base.

The spreadsheet model was developed for a specific purpose in a very short period of time, relying heavily on cost inputs from local authorities. The Development Bank of Southern Africa (DBSA)has used this model as a basis for building a more refined financial model which is to be discussed later in this section. Although the bulk infrastructure potential cost model does not in itself deal with financial costs, a link to the DBSA's financial model is possible and advisable to further extend the application of the bulk infrastructure potential cost model.

3.5.3 Optimisation and simulation models

3.5.3.1 Differences in modelling approach

Modelling in urban analysis and in other sciences has typically followed two approaches described as analytical and simulation (Ayeni 1979). Analytical approaches, including optimisation, involve the development of models whose solutions would be deduced using analytical methods of mathematics. They consequently require the exact identification of the components of the system of interest as well as the unambiguous specification of relationships within and between components and the equations which describe them (Ayeni 1979). The analytical approach has limited application in the urban system arena due to the insurmountable problem of identifying the complexity of relationships between the system components. The analytical approach has been applied in urban planning in relation to location and land uses (Alonso 1964). More recently, the analytical approach has been used in a general optimisation model developed in Australia in the form of the TOPAZ (Technique for the Optimal Placement of Activities in Zones) model (Brotchie 1969; Sharpe & Brotchie 1972; Brotchie et al 1980; Sharpe et al 1984; Brotchie et al 1994). The approach has also been applied to a specific component of the urban system, water provision, using optimisation modelling (Birkin et al 1996; GPMC 1997b).

Simulation modelling, on the other hand, recognises the inability of analysts to know and specify all the relationships and hence develop a series of approximating techniques towards finding solutions (Ayeni 1979). Consequently, simulation modelling has been used extensively in urban modelling particularly in relation to the land use-transportation interaction (Stylianides & Gunning 1990; Chapin 1965; Reif 1973; Harvey 1967; Morrill 1965; Echenique et al 1969; Ingram, Cain & Ginn 1972; Senior 1973; Senior 1974).

The contrasting analytical versus simulation approaches to urban modelling have been described using alternative terminology by various authors. "Optimisation" or "normative" models have been contrasted with "predictive" models in that predictive models give the likely impacts if a particular policy is followed whereas optimisation models inform on the sort of development necessary to best meet their objectives (Webster, Bly & Paulley 1988). Sharpe (1988) distinguishes predictive or behavioural models, which assume that the planner's role is rather passive, from prescriptive or optimising models, where a more active planning role is assumed in determining future land use patterns.

Few urban optimisation or simulation models explicitly consider bulk infrastructure and these correspond to more recent development in urban modelling. Many of the models developed during the 1960's for American and European application under circumstances of stable demographics resulted in models which focussed on movement of people between existing housing stock rather than accommodating an increasing urban population. The 1960's models concentrated on housing, transportation and employment. Infrastructure in terms of engineering services is not mentioned at all but is rather a concern after the modelling is completed in that infrastructure must now be provided to support the modelling results. Recent efforts have been made to in some way incorporate infrastructure concerns into the urban modelling process and these models are described in more detail below.

3.5.3.2 WADISO S.A

WADISO S.A. is a model developed for the design and analysis of water distribution systems. It was originally developed in the USA but the South African version has been developed to suit the particular needs of South African water utilities, local authorities and consulting engineers (Wadiso S.A. 1997). The model allows the determination of pressures and flow rates in water distribution systems, the simulation of system performance over extended time periods and under various emergency conditions and for system design for minimum cost, including capital investment for pipes and tanks as well as recurring costs for pumping energy. In the steady state analysis module, an existing or proposed distribution system is analysed and flow rates and pressures in various parts of the system determined for a given point in time. The module contains an interactive graphics routine, facilitating the viewing and verification of the system, interpretation of results, plotting of pressure contours and the highlighting of pipes with high friction losses. In the extended time simulation module, the variation in pressure over time in response to changes in demand and fluctuations in water levels of tanks and the required capacity of new tanks is determined on a scenario basis. The optimisation module guides the engineer in the design of a low cost solution. In the simplest formulation, the programme selects the least cost pipe size which will guarantee certain minimum pressures under a particular demand pattern. Pipe costs are then entered by the user and can vary with local conditions. The most advanced formulation of the optimisation routine facilitates the optimal sizing of new reservoirs and tanks to be installed.

WADISO S.A. is far more complex and detailed in its handling of the water distribution network than the proposed potential cost model. The intention of the bulk infrastructure potential cost model was to provide a coarse level, strategic planning tool to assist in land suitability assessment. WADISO S.A. could very well replace the water costing component of the present model if the model is applied in local authorities where WADISO S.A. is up and running. Experience has shown, however, that to run a particular demand scenario using WADISO S.A. is particularly demanding in terms of cost and time and to run it purely for the purposes of input to land suitability assessment is not efficient. It is more suited to evaluation of a limited number of alternative development scenarios or to optimise a water solution for the final chosen development scenario. Given the level of detail for the other engineering services which form part of the potential cost model, it is not feasible that one service be modelled to a far greater level of detail and complexity than the others. As and when similarly complex models for the electricity network and sanitation system are available and operational in local authorities, they could replace those parts of the potential cost model which determine additional infrastructure requirements and the costs thereof, if time and funds are available.

3.5.3.3 TOPAZ

The Technique for the Optimum Placement of Activities in Zones (TOPAZ) is a model which allocates land uses within an urban area in a way which minimises the overall costs of establishing and servicing those land uses (Brotchie, Dickey & Sharpe 1980). TOPAZ was originally developed to evaluate alternative development patterns in Melbourne, Australia and was able to identify the development pattern which minimised total cost (Sharp et al 1974). TOPAZ is a non-linear model which simultaneously optimises land use and transport (Sharpe 1988). Both the establishment costs and the operating costs relate predominantly to transport infrastructure and transportation costs. TOPAZ has been applied in various areas of Australia to evaluate the optimum pattern and sequence of urban development in terms of development costs (Foot 1981). The model has been extended to determine the most efficient form of new development and transport movement in the city in order to minimise energy consumption (Foot 1981).

More recently, an additional module has been developed to support integrated urban water planning and management. The water sub-model provides an evaluation of water planning and management scenarios to satisfy future urban water resources, infrastructure and service needs by generating alternative future urban land use patterns and allocating appropriate water usage activities to those patterns for various time periods. Development scenarios are optimised over time periods for a cost-effective establishment and operation of the urban water system (CSIRO 1997).

The water model evaluates water, sewer and drainage needs and establishment costs of service infrastructure for a given pattern of urban development. These costs are estimated by considering demand, supply and disposal constraints of the urban water system and construction staging options over a specified time period (Brotchie et al 1994: 8). For infrastructure cost computation, the cost components considered are a reticulation network, branch and trunk network and headworks. Reticulation network costs are a function of a base cost, type of activity serviced and terrain conditions.

Branch and trunk network costs are calculated by calculating design flow, determining required diameter and length, and from that, cost. Terrain conditions other than slope do not seem to be considered in this cost component. Headworks cost seem to include waste water treatment works but not water reservoir costs. Headworks costs include capital and operating costs (Brotchie et al 1994:12). Existing capacity conditions are not taken into account in any of the cost components. Although there are some significant differences between the TOPAZ water sub-model and the bulk infrastructure potential cost model, of all the existing models considered, the TOPAZ model relates most closely to the aims and proposed method of the bulk infrastructure potential cost model and opportunity exists to enhance both models from a consideration of the other.

3.5.3.4 GRIDNET

GRIDNET is a water simulation model for a range of operational planning and management activities, including analysis and growth of demand, effect of leakage control, analysis of hydrological change, changes in reservoir operating rules and the overall impacts of land use changes or catchment management policies (Birkin et al 1996: 184). The model allows for the specification of water sources, the network and water treatment works and is run over a 40-year historical data set of weekly rainfall so that the operating costs of the network in a particular scenario can be assessed under a wide range of likely natural operating conditions. The objective is to operate the grid in a way that attempts to minimise operating costs. GRIDNET comprises a reservoir simulation module, a pumping station module, a treatment works module and a network optimisation module, which integrates the output of the other modules and attempts to find a solution to the problem of allocating water sources to demand through heuristic modelling procedures (Birkin et al 1996: 185). The calculation of operating costs is the main aim of this model and not capital costs. Once flows through the network have been determined under certain conditions, costs are determined for each link in the network, comprising pumping costs, treatment costs and electricity tariffs and represented graphically as this model is linked to a GIS (Birkin et al 1996: 185). There is thus some spatial representation of costs which allows some assessment of the relative costs in relation to location for a given scenario, although the costs included are only operational costs.

3.5.3.5 Fort Collins water system model

Founded on the method of simulation known as systems dynamics, the Fort Collins water system model is a simulation model which can link population changes with water supply levels and with the finances of the water supply utility (Grigg 1997: 28). The purpose of the model was to illustrate the use systems dynamic methodology to a common urban engineering problem. The model is described as an economic simulation model and measures the flows of water stock, money and physical plant (Grigg & Bryson 1975: 83). The model comprises a population and land subsystem, a water supply subsystem and a financial subsystem. Financial inflow comes form the sale of water services and from tap fees and outflow is for the purchase of water rights and for construction of supply systems (Grigg & Bryson 1975: 83). The water costs are calculated using simple water rates per gallon of water required. The model operates for the city as a whole and does not differentiate between various locations within the city.

3.5.3.6 What if? PSS

What if ? PSS is an interactive, GIS-based, planning support system (PSS) which supports all aspects of the land use planning process including land suitability analysis, land use demand projections, land use plan preparation, allocating projected demand to suitable locations and evaluating the likely impacts of alternative policy choices and assumptions (Planit 1997). At the moment, infrastructure cost considerations seem to be accounted for in the evaluation of outcomes rather than having an influence on land suitability. In addition, infrastructure is focussed on social infrastructure rather than engineering services infrastructure which is to be expected in a model developed for USA demographic and socio-political circumstances.

3.5.4 Infrastructure cost modelling for East St. Louis

The problems which this model addresses in St. Louis are very similar to the problems which the bulk infrastructure potential cost model addresses and yet the underlying causes of the problem are very different. The problems in St. Louis relate to underutilisation of existing infrastructure due to a declining economy and related decline in the housing stock or in the occupation of existing housing stock, resulting in growing pockets of vacant land within developed areas (Bhattacharyya & Pant 1996). The continued maintenance of this infrastructure, places an ever increasing financial burden on the decreasing numbers of citizens. In South Africa, the underutilisation of existing infrastructure is a result of racial policies which resulted in overprovision in some areas.

The St. Louis cost model attempts to quantify the cost impact of this changing pattern of development and assess its effect on the tax base. The approach used is to model the maintenance cost of infrastructure as a function of distance between land parcel units and infrastructure service centres using regression or weighted distance. Either linear network distance or radial distance was used depending on the type of service (Bhattacharyya & Pant 1996). Distance is obviously a crucial cost element particularly in calculating maintenance costs which is the main focus of the St. Louis model. In the bulk infrastructure potential cost model, where upgrading and expansion of the existing network, distance is an important determinant of cost but in relation to capacity and environmental conditions. Only those lengths of conduit requiring upgrading or installation are costed and that cost adjusted depending on environmental conditions along that length of conduit.

3.5.5 Local reticulation cost guidelines

Local level engineering services reticulation costs have been calculated to serve as guidelines to planners and engineers in layout planning (National Housing Board 1994; Behrens &Watson 1996). The methodology used to calculate these costs vary. Behrens and Watson (1994) use hypothetical layouts at varying densities as a basis for the costing. The costs were determined from a review of *de facto* development costs and engineering cost assessments of the hypothetical layouts under ideal development conditions. The costs are expressed per erf and include capital costs and operation and maintenance cost estimates. The National Housing Board's (1994) approach was to develop a level of service (LOS) cost matrix giving the cost per site for each service at each level of service within a fixed density range. Although the intention was to include operation and maintenance costs as well as capital costs, data to determine operation and maintenance costs was limited. The costs were determined from a survey of local authority service providers of actual development costs.

The use of actual average development costs as a guide to determining costs is possible with local reticulation costs although criticism can be levelled at both the quoted studies because no attempt is made to take non-ideal conditions into account. Due to the very unique characteristics of each area's bulk infrastructure capacity situation, the approach of using existing cost data to estimate future costs is not appropriate and an alternative, capacity centred approach has been used in the bulk infrastructure potential cost model.

3.5.6 Costs and affordability

Van Ryneveld (1995) investigated the interrelationship between the cost of services, the price which is affordable to pay and subsidies which have to make up the difference between cost and price. After a detailed discourse on the definitions of various types of costs, Van Ryneveld (1995) clarified that the costs given in his paper are essentially average costs (total cost divided by the total number of units of output) calculated at current replacement value and at full utilisation. It is further argued that in the case of full water-borne sanitation, the relative magnitude of marginal cost (the additional cost of producing one more unit of output) and average cost, for internal or local level infrastructure, is similar, whereas in the case of bulk infrastructure, it is not. It is contended that for bulk infrastructure, particularly in areas with significant peripheral development, marginal costs would be higher than average current replacement costs and would give a more realistic indication of future service provision costs (Van Ryneveld 1995). Van Ryneveld (1995) uses costs obtained from local authorities and expresses them per site per month.

3.5.7 Financial cost models

South Africa faces a great challenge to provide adequate municipal services to all residents in a financially viable and sustainable manner. It is against this background that the DBSA (1995) has developed a modelling tool to assists managers and planners to design an investment programme and finance policy to ensure the adequate provision of municipal services to all their residents, yet maintaining the financial viability and sustainability of the service agency. The intention of the financial model is to assist the user to calculate the capital and operating costs and borrowing requirements associated with the proposed investment programme and to assess the affordability of the programme to households and to the local authority (DBSA 1995). The services modelled are water, sanitation, electricity, stormwater drainage and refuse removal. Key model outputs are future capital investment requirements, future grant finance requirements, future borrowing requirements, tariff levels required to maintain financial viability and future net cash flow of the service provider (Eberhard 1995: 2). These outputs assist in the more qualitative assessment of affordability which needs to be assessed at the levels of household, service provider, central government and macro-economic affordability.

Infrastructure costs required to meet the demand are calculated as part of the investment programme taking into account backlog and new household formation for the entire study area as a whole. Costs are calculated by applying standard average rates per household. The main focus of the model is on financial considerations rather than on detailed costing and the model operates for the local authority as a whole rather than to calculate relative costs between areas.

A computerised model for financial planning and control in the provision of urban services has been developed with the aim of assessing the cost implications of alternative capital projects likely to be undertaken within a particular planning period with a view to drawing up and implementing a development plan (implementation plan) so that planning can be linked more effectively to budgeting (Boaden 1981). The model allows for the projection of future growth, thus demand for services, the specification of services if required in terms of capital projects to meet demand (preliminary development plan) and the costing thereof, the determination of operating income and expenditure resulting from the capital projects, the drawing up of a development schedule and calculation of cash flows and evaluation of the preliminary development plan (Boaden 1981). Services costs are calculated at the preliminary development plan stage using unit costs, either standard unit costs or costs as directly provided by the local authority.

3.5.8 Costs and national policy formulation

The Water Research Commission (WRC 1994a) conducted an institutional and financial review of water supply and sanitation services in the urban areas of South Africa, in order to address the need for unified and concerted action in the water and sanitation sector to meet the large and increasing need for adequate services. As part of the investigation, an estimation of total future demand and costs for water and sanitation services in the urban areas in South Africa is made. The capital costs of making up the backlog and meeting new demand for services are quantified based on estimates of costs per site and bulk infrastructure cost, assuming various level of service scenarios (WRC 1994a). The results are used to give an indication of the funding requirements of supply agencies over a specific time period.

As part of the institutional and financial review, an investment-tariff model for water was developed as an analysis tool for strategic planning for services provision in urban areas and to illustrate the impact and sensitivities of different investment scenarios and tariff (cost recovery) policies on the financial viability of a water utility which has overall responsibility for water supply in a unitary urban area but which purchases bulk treated water from an external bulk supply agency (WRC 1994b). New service demand is calculated on the basis of projected population growth rates for specific time periods and the capital costs (including internal services, connector costs, capital replacement costs) and operating and maintenance costs are calculated per site and would be the same wherever the development occurs in South Africa. Bulk costs are taken as an operating expense and the model uses current, future and increase in cost to determine current and future operating expenses. Current cost would normally be equivalent to the current tariff and reflects the average historical cost of the bulk supply. Future cost is reflected in the long-run marginal cost (average incremental cost) and increase in cost is the expected annual percentage increase in the long-run marginal cost WRC 1994b). Neither bulk capital costs, nor existing capacities nor cost influencing factors are incorporated into the model but the model serves the intended purpose of influencing national water and sanitation institutional and financial policy.

3.5.9 Development monitoring and approval

The Los Angeles County Development Management System (DMS) utilises computer technology to determine capital facility supply capacity and demand placed upon that system by each approved and proposed development in order to ensure that projects are only approved when adequate infrastructure capacity is available or is provided at the expense of the developer (Kushner 1988). The DMS comprises five components. Firstly, the demand for off-site capital improvement needs generated by the project proposal and the existing capacity supply to meet that need are quantified. The second component comprises access rules to avoid leap-frog type sprawl. The third component is an infrastructure supply programme designed to plan infrastructure capacity expansion. Fourthly, a development limit is set for each expansion area in terms of numbers of residential units to ensure that development does not exceed that which is required to accommodate the projected growth for a particular period. The fifth component is a growth analysis component allowing plan modification to reflect actual growth performance (Kushner 1988).

3.6 Infrastructure planning and GIS

Engineering services planning comprises three aspects, referred to by Birkin et al (1996), specifically in relation to water, as hydrology, engineering and economics. Generalising the concepts to apply to a wider range of engineering services, it firstly entails an understanding of the mechanisms of generation and modification of the engineering service commodity (water, sewerage, electricity). Engineering, refers to the control and transformation of the commodity and economics relates to the cost associated with maintaining a supply to the consumer of acceptable quality and the subsequent pricing of that supply to the consumer. Geography is an essential element of all three aspects as they all have a spatial dimension and supply, quality and demand vary across space (Birkin et al 1996). The use of GIS in engineering services planning is thus recognised. GIS has been used in network analysis, including the linking of established hydrological simulation, optimisation and regression models with GIS, water quality assessment and waste water disposal (Birkin et al 1996). Virtually all the more recently developed infrastructure models described in this chapter are GIS-based or at least GIS-linked.

3.7 Conclusion

It is clear from the practical costing processes analysed, that engineering services are included in only very few examples although there is significant evidence for the inclusion of transportation costs in costing exercises. All the instances investigated are used in the plan evaluation stage of the planning process rather than in the generation of plans. Where engineering services costs are incorporated into the cost analysis, costs are calculated by applying a constant cost per person rate with additional costs incurred by influencing factors or existing capacity not playing any role, the differential costs between various locations in the study area are thus not accounted for in most examples considered. The water systems models developed particularly for the optimum design of water networks are on the other hand too sophisticated and complex and are thus in normal circumstances too costly and time consuming to utilise for the intended use of the bulk infrastructure potential cost model in land suitability assessment. If these models are up and running in case study areas, certain modules could be utilised to replace certain more simple calculations in the bulk infrastructure potential cost model, although, the effect of influencing factors on the costs, due to locational differences, would still need to accounted for.

CHAPTER 4: LAND SUITABILITY ASSESSMENT METHODOLOGY

4.1 Introduction

From the appraisal of available methodologies presented in the literature, multicriteria evaluation was selected as the appropriate methodology to use for the overall land suitability assessment. It is not the intention of the study to undertake the most sophisticated multicriteria evaluation possible. There are many opportunities for complex mathematical applications of multicriteria evaluation, however, the process has been kept simple for the present application. The aim of the research is to demonstrate the impact of bulk infrastructure costs on land suitability assessment results and to make input and resultant engineering and planning information explicit to all relevant development decision-makers. The land suitability assessment method is the overall framework within which the bulk infrastructure cost model is tested. In addition, there are numerous opportunities for using more complicated "models" as input to the multicriteria suitability framework, for the other criteria involved. Environmental inputs, for example, could be significantly extended to include a wider range of factors in a more rigorous manner. For the purpose of this study, all the other multidisciplinary criteria included in the suitability assessment are kept constant, so that the impact of bulk infrastructure costs can be assessed.

The use of GIS in association with multicriteria evaluation to inform the planning question of where the most suitable land for low income residential development is located, can be defined as a Spatial Decision Support System (SDSS). Prior to describing multicriteria evaluation and its application using GIS in the present study, the proposed land suitability assessment methodology and its component bulk infrastructure potential cost model, are contextualised as a SDSS.

4.2 Land suitability assessment as a SDSS

4.2.1 Emergence of SDSS

SDSS have been described in various ways in the literature but essentially they:

- Are geoprocessing systems which supports a decision research process (as opposed to a more narrowly defined decision making process, enabling understanding and explanation of the system as well as exploring solutions for decision taking); and

- Provide a framework for integrating:
    - database management systems;
    - analytical models;
    - graphical displays;
    - tabular reporting capabilities; and
    - expert knowledge of decision-makers (Densham 1991: 404).

SDSS have evolved out of four different but related traditions of urban planning, urban spatial analysis and modelling, computation in general but GIS specifically and Decision Support Systems (DSS) from the field of Operations Research. Although in some of the literature, SDSS implicitly relate to the field of strategic urban planning (Harris & Batty 1993: 187), it has been proposed that when SDSS are applied in the particular domain of urban strategic planning, they should explicitly and specifically be referred to as Planning Support Systems (PSS) (Harris 1989: 85). Much has been written in the literature contrasting and relating the various systems, defining them and motivating why the one is not the other. The following discussion traces the debate in relation to the definition given above and accordingly contextualises the land suitability assessment method and the bulk infrastructure potential cost model.

4.2.2 Urban planning processes and models

A critical component of SDSS is that of focus on a particular problem or decision domain. The domain at issue here is that of urban planning. The tradition of the application of computer models to urban planning began over 30 years ago with the development of so-called large-scale urban models. In 1973, Lee assessed the application and success of these models and concluded very categorically that large-scale models, as they existed at that time, had been a failure for a number of reason. Wegener (1994) demonstrates that large scale urban models did not disappear after Lee's condemnation but continue to be applied, not widely but persistently. Batty (1994: 7) argues that while many of the arguments used by Lee have been solved by advances in computational power, technological advances and advances in data availability, it is the volatility of the problem context that planning addresses and the inability to develop tools sufficiently robust to withstand such shifting viewpoints, which has been at the root of problems with large-scale urban models. Wegener (1994: 17) identifies the most likely fundamental problem as being that these models were linked to the rational planning paradigm dominant in most western countries at that time. The models reflected the ambition to understand the complex mechanisms of urban development and based on this understanding, to predict and control the development of the city. The trend in planning since then has been a departure from the ideal of synoptic rationalism towards a more modest, incrementalist interpretation of planning (Wegener 1994: 17).

Although these trends have been identified in general as western-world trends, the recent trends in strategic planning in South Africa are not necessarily in compliance with international trends. Without becoming involved in a critique of current South African planning practice, using all the correct methodological terminology, which is beyond the scope of this study, it is noted that the move away from blueprint, physical, top-down planning where planning was often undertaken in isolation from budgeting and implementation, towards integrated, framework, enabling, community-driven planning where planning, budgeting and implementation is more integrated, is commendable. At the same time, however, it is observed that in practice, one tendency has been for more and more "integrated" plans to be developed for various segments of development, e.g. integrated transport plans, integrated development plans, integrated environmental assessments with the result that there are moves afoot to re-establish spatial planning to integrate the integrated plans and to ensure "control" and create order between integrated plans. Another tendency has been that the integration effort begins to resemble comprehensive planning in that it is attempting to incorporate all aspects into the planning process. A further tendency is in response to the attempt at community-based planning, where numerous and disparate needs and aspirations are required to be incorporated into a single plan, in a relatively short time period so that delivery can proceed. This tension between community participation and delivery has tended more recently to sway more to delivery with a concurrent move to control and top-down decision making.

The prognosis for large-scale urban models internationally and for South Africa, is that they represent theories and instruments for planning that are both natural and essential and that if they adapt to the changing trend in planning, away from large to the smaller scale, from more to less comprehensive and from idealistic and intellectually inspired theory to more routinely pragmatic and managerial in focus, there is a good chance of success (Batty 1994; Klosterman 1994; Wegener 1994). Relevant and successful SDSS would need to address specific planning problems and decisions appropriate to the specific planning process context.

4.2.3 Analytical urban modelling

SDSS need to incorporate analytical models to qualify. The urban modelling tradition has been discussed necessarily in the section before in relation to prevailing planning paradigms but is discussed here in terms of types of urban models and their application in SDSS. Batty (1992: 663) has identified a number of traditions in the broader arena of urban modelling and spatial analysis which have begun to, or can potentially, to various degrees, be linked to GIS to form the basis of SDSS. Batty (1992: 663) distinguishes between two types of models which together define the broad domain of spatial analysis: those used for conventional science and those used for applied problems of design. Conventional scientific models are primarily used for understanding and explanation with the major mode of analysis being statistics. Those models focussed on applied problems of design, deal mainly with forecasting and decision making. Such models may be based on some explanation of the system of interest but their orientation is on the prediction of impacts and the design of optimal plans (Harris 1967). Design focussed models can be either dynamic (Bertuglia et al 1990) or static (Putman 1992).

Other traditions in spatial analysis and urban modelling include spatial interaction, optimisation and microeconomic modelling. All these traditions are being influenced by the revolution in computing particularly relating to the use of graphics and user-friendly interfaces, the increase in computing power and visualisation (Batty 1992: 664). The development of GIS is part of this computing revolution and there have been significant developments in linking GIS and urban modelling. GIS are being coupled to analytic and modelling techniques in various ways and to various extents along a continuum ranging from loosely coupled to strongly coupled systems. Loose coupling is the simple linking of inputs and outputs between GIS and particular models (Brail 1990) and some clever means of achieving these links have been devised (Ferreira & Evans 1992). Strong coupling is only likely to exist for purpose-built GIS which incorporate spatial analytical and modelling techniques explicitly and some pioneering attempts have been made (Robinson & Coiner 1986; Webster et al 1988; Birkin et al 1990).

4.2.4 Geographical information systems (GIS)

The GIS tradition has evolved separately from urban modelling and although GIS technology combines the digital data required to represent maps and their features with the spatial attribute data characterising those features, such systems do not significantly offer many functions for strategic planning because the technology is broadly relevant to any spatial systems and largely operates independently of the system of interest (Batty 1994: 12). It has been argued that GIS alone cannot be termed SDSS because no particular problem domain or decision making process is supported, they are not flexible enough to accommodate variations in either the context or process of spatial decision making and in themselves lack the support of analytical modelling (Densham 1991; Batty 1992; Batty 1994; Keenan 1997). It has been proposed, however, that the overlay function, which has been termed spatial analysis by some vendors, can be likened to formal optimisation when utilised to identify map areas which meet given spatial constraints or to seek areas where the potential or utility for development is greatest (Harris & Batty 1993: 192). While GIS are not SDSS, they are nevertheless a vital component of SDSS with the roles of definition of geographic areas and the aggregation and disaggregation of these, display and overlay (Harris & Batty 1993: 196). Although GIS has been used in urban planning, it was initially used mainly for mapping purposes (French & Wiggins 1990; Huxold 1991). More recently, there have been a number of efforts to extend the functionality of GIS to embrace model-based applications (Batty 1992; Batty & Harris 1993; Webster 1993; Landis 1994; Keenan 1997; Landis & Zhang 1998).

4.2.5 Decision support systems (DSS)

DSS have been defined as computer-based systems that are used on an ongoing basis by managers as a tool to directly support managerial decision making (Liebowitz 1990: 12). SDSS have evolved in parallel with DSS developed for business applications but SDSS development has lagged behind that of DSS by about 10 - 15 years so SDSS can learn from the experiences of DSS (Densham 1991: 406). DSS was developed in response to perceived shortcomings in management information systems (MIS) in the late 1960's and early 1970's. MIS did not adequately support analytical modelling capabilities and did not facilitate the decision makers interaction with the solution process (Densham 1991: 406). Addressing these shortcomings in the form of DSS was made possible by the merging of the theoretical studies of organisational decision making undertaken at the Carnegie Institute of Technology with the technical accomplishments on interactive computer systems by the Massachusetts Institute of Technology (Liebowitz 1990: 12).

The distinguishing characteristics of DSS are:

- They deal with unstructured problems where the objectives of the decision maker and the problem itself cannot be precisely or fully defined;
- They have a user interface;
- They enable the combination of analytical models and data;
- They enable the exploration of solution or options by using models to generate

alternatives. They do not come up with solutions or recommendations; and

- They allow problem solving to be interactive and recursive, where decision making proceeds by multiple paths rather than a single linear path (Liebowitz 1990: 13; Densham 1991: 406).

The way that SDSS differ from DSS is in response to complex spatial problems where in addition to the DSS characteristics listed above, SDSS have these added characteristics:

- They provide mechanisms for the input of spatial data;
- They allow representation of complex spatial relations and structures;
- They provide output in a variety of spatial forms such as maps; and
- They include analytical techniques that are unique to spatial and geographical analysis (Densham 1991: 406).

It is clear that the first three additional characteristics, and to a lesser extent the fourth, are present in GIS which indicates the emergence of SDSS out of the combined traditions of DSS and GIS, applied in the context of the spatial planning tradition, using urban modelling and spatial analytical techniques.

Kozar (1989: 16) and Emery (1987: 105) distinguish between data-oriented DSS and model-oriented DSS . Data-oriented DSS provides the decision maker with only selected information by means of simple summary reports, ad hoc queries and graphical representations (Van Helden (1993: 60). Model-oriented DSS utilises models to predict possible outcomes of decisions to assist the decision maker to make choices. Models used, range from the more sophisticated optimisation and simulation models and expert systems to more simple spreadsheets and simple mathematical formulae (Van Helden 1993: 61). The methodologies described for land suitability assessment later in this chapter and for the bulk infrastructure potential cost model described in the following chapter, comply with the description of a model-oriented DSS and the strong spatial component means they could be referred to as model-oriented SDSS, with the multicriteria evaluation model and the cost model, being loosely-coupled with GIS.

4.2.6 Planning support systems (PSS)

GIS technology is relevant to any spatial system and is thus largely independent of the system of interest. SDSS, although incorporating a focus on a particular decision making problem, have arisen out of DSS from management science or operation research modelling rather than being focussed on large scale planning and urban systems theory (Batty 1994: 13). It has been argued that the gap between SDSS technology and its use in strategic planning and design is so wide that PSS are required to achieve an effective incorporation of planning decisions into SDSS (Harris 1989: 85).

The spatial planning arena is very different to the management arena in that the concerns of planning are far longer term than management. An important concern of planning is the avoidance of unintended consequences while pursuing intended goals. In order to assess these consequences, planning needs techniques for making conditional predictions based on alternative hypothetical "what-if" decisions (Harris & Batty 1993: 184). These techniques require extensive computation resources and simulation modelling and although GIS plays an important role, in itself it is not sufficient to be used as the main tool of analysis in planning (Harris & Batty 1993: 185). PSS require analytical and design functions which incorporate goals, objectives, costs and benefits and for GIS to be truly beneficial in the spatial planning domain, it needs to be constantly and strongly linked to problem definition and the systems models used to inform the planning process. The framework within which this linkage between computation, social and functional theories of the system being planned, the theory of planning and spatial representation takes place, is termed PSS (Harris & Batty 1993: 187). It has been concluded from an assessment of the problems and opportunities of linking GIS and PSS, that systems and models are not easily embedded within one another and that more rapid progress can be made if PSS were to be developed independently of but in parallel with and loosely coupled to, GIS (Harris & Batty 1993: 1997).

There are two essential requirements for planning and thus, in turn, for PSS. The first requirement is that, since urban system optimisation is impossible (this would equate to the automatic generation of plans), the search for good plans must be by means of an informed process of trial and error which generates plans and prepares them for testing (often referred to as sketch planning). Secondly, planning and policy making need tools for determining the consequences of alternative courses of action or decisions so that choices can be made in terms of costs and benefits or adjustments and improvements to alternatives can be made (Harris & Batty 1993: 194). Both the land suitability assessment method described later in this chapter and the bulk infrastructure potential cost model described in the following chapter, comply with the requirements of PSS. The land suitability assessment method, combines GIS and multicriteria evaluation to inform the process of plan generation. The cost model generates potential bulk infrastructure costs under different density conditions which also informs the plan generation process but can also be used to determine the engineering services cost consequences of certain development decisions.

The problem with the term "planning" in PSS is that particularly in South Africa, with recent moves to enforce an "integrated planning" approach, strategic planning is seen to be far broader than spatial and physical planning, incorporating the entire spectrum of development including the economic, social, institutional, financial, environmental and spatial realms. PSS should accordingly, theoretically support much more than only spatial decisions. It is proposed that the term spatial planning support system (SPSS) would better describe SDSS applied to the spatial component of strategic integrated planning.

4.3 Multicriteria evaluation, GIS and the land suitability assessment process

Multicriteria evaluation and GIS technology together are powerful in the process of the assessment of land suitability. Multicriteria evaluation and GIS terminology and techniques are integral to the following discussion of the land suitability assessment process. For clarification purposes, an attempt is made to highlight the role, process and terminology of each of the three participating components and to highlight some of the major interactions between them (Figure 4.1). The land suitability assessment process column indicates the broad flow of actions necessary. The multicriteria evaluation column, utilising the terminology of Voogd (1983), indicates the development of the evaluation matrix through to the appraisal matrix and illustrates the content of each matrix type. In the third column, the GIS process is shown.

4.4 Multicriteria evaluation process

4.4.1 Criteria identification

A criterion can be defined as "a measurable aspect of judgment by which a dimension of the various choice possibilities under consideration can be characterised" (Voogd 1983: 57). The generation of criteria is similar to the generation of objectives and can be approached in one of two ways, either inductively or deductively. The inductive approach starts with a detailed inventory or list of all possible factors and features which are then grouped and aggregated to form a set of evaluation criteria. With the deductive approach, detailed criteria are derived around broad "areas of interest" or categories or components relevant to the problem at hand such as "living", "working", "recreation". So the deductive approach is from a broad to a detailed level or "top down" whereas the inductive approach is more "bottom up".

Whichever approach is adopted, whether broader or more detailed criteria are used as the point of departure, some type of specification of criteria needs to be clarified. There needs to be a certain amount of hierarchy formulation and systemising so that there is a clear subdivision of a criterion into one or more lower level criteria, which clarify the intended meaning of the higher level criterion (Voogd 1983: 60).There are many different ways of categorising and grouping factors and for practical reasons it has been stressed, that the systemising process should not become an end in itself and that it is sufficient to ensure, once the final set of evaluation criteria has been selected, that no gaps or discontinuities occur in the criteria included.

In the present study, the inductive approach was used as firstly, it is the easier and less confusing approach according to Voogd (1983: 69) and secondly as the intention of the study was not primarily to investigate the generation of criteria but rather the integration of criteria, in particular, the integration of bulk infrastructure cost criteria. The generation of criteria is a crucial aspect of the suitability assessment process and factors affecting suitability can be extracted from existing policy documentation for that particular area or can be determined for each individual study according to goals and objectives set by the stakeholders of the area.

Policy, goal and objective statements need to be interpreted in the light of the availability of existing data in deriving specific criteria for short term analysis. In the longer term, when time and funds are available for new data collection, obviously criteria choice will not be limited by existing data availability. The method allows for any number of suitability criteria to be incorporated. The inclusion of criteria in the present study is limited by data availability rather than the capacity of the model. As part of the criteria generation process, a value statement needs to be attached to each criterion. This can either be a general value statement e.g. the more accessible the land is to employment opportunities, the better, or a more specific statement e.g. land further than 20 km from work opportunities is categorised as poor accessibility, land between 10 and 20 km is categorised as moderately accessible and land closer than 10 km is highly accessible land. Whether a general or specific approach is taken is dependant on the result required. The specific, categorisation approach will result in final, specific discreet suitability categories whereas the more general approach will result in a continuum of suitabilities which can be represented in any number of categories. The general approach was selected for the present study.

To illustrate the process of criteria generation, an example is used. For the present study, criteria were formulated from policy statements e.g. "Land for housing must be suitably located geologically, environmentally, and with respect to economic opportunities and social amenities" (RDP 1994: 24). A criterion extracted from that policy statement was that land for low income housing must be suitably located in relation to economic opportunities. The interpretation of criterion referred to the questions: what is "suitably located" and what are "economic opportunities"? Criteria subdivision offers a number of varied interpretations and opportunities for innovation and application under various conditions and should be influenced by data availability. In the present study, economic opportunities were defined as the number of formal, existing work opportunities per zone, for which data were available. "Suitably located" was interpreted as a least cost function in terms of travel costs to get from home to work. Output from transportation modelling was available to be utilised in the calculation of travel costs. The value statement regarding this particular criterion was that the lower the relative cost of accessing the most work opportunities, the greater the suitability.

4.4.2 Criteria quantification

Each criterion needs to have a measure or score which reflects the degree to which a choice possibility, in this case, a geographic area, meets a certain criterion. The measures can be quantitative or qualitative, reduced to some form of quantification, detailed or broad and can be based on intense scientific investigation or simple observation. Certain of the criteria used in the analysis can be detailed cost figures and others could be simple 'yes-no' measures. Multicriteria evaluation techniques allow the integration of all these types of measures. The quantification of criteria or subcriteria into raw scores enables the preparation of the evaluation matrix (Voogd 1983: 28; Figure 4.1).

To continue with the example of access to work, the question to be asked next is what could be used as an indicator or measure of accessibility to work?

- distance to existing work opportunities along the transport network or as the crow flies
- distance to potential work areas or activity corridors
- time taken to get to work
- whether public or private transportation is used
- congestion levels
- number of work opportunities in the area
- potential work opportunities
- costs of getting to those work places

There can be a number of possibilities in terms of measuring a criterion or subcriterion. The selection of a particular measure would be influenced by data, time and funds availability and by the level of accuracy required for the particular problem being addressed. Some of the measures can be combined to form some type of index. In other situations where no specific data is available to quantify a criterion, it is possible to derive data from other related data. GIS analysis capabilities are also useful in providing data by calculating from other input data. For example, distances to work can be calculated if the location of the work areas and residential areas and the road network, are known.

The parallel GIS process involves a significant amount of preparatory work in order to generate the choice possibility polygons which form one of the axes of the evaluation matrix (Figure 4.1). The measurement of criteria is undertaken for each of these spatial polygons and in the final appraisal matrix, a relative suitability index is obtained for each polygon. A cadastral base map of the study area first needs to be prepared so that all subsequent data layers can be spatially related to that base map. Spatial data, relating to the spatial unit according to which the criteria are quantified need to be either digitised or electronically transferred from some other source into the GIS. After the spatial data have been verified for each layer, individual layers are overlayed and intercept polygons are generated. These intercept polygons become the choice possibility polygons of the evaluation matrix. Layer snapping has to occur in order to ensure that when the layers are overlayed, there is spatial integrity or matching of data. Particularly when there are varied sources for each layer, spatial mismatch is common due to the use of different accuracy requirements and other standards.

A significant benefit of GIS in the criteria quantification phase is that it is not necessary to have a common spatial unit of measure for each criteria. Before, all criteria had to be measured for say, a traffic zone or planning zone so that the summation of values for all criteria into a final suitability index was possible. This meant that it took an immense effort to convert available, spatially disparate data, to a common spatial unit, with a commensurate decrease in accuracy. GIS allows for the capturing of each layer in whichever spatial unit it is available in, and through spatial overlay, to enable the calculation of a more accurate, suitability index for a theoretical intercept polygon which can in turn be related back to reality by overlaying with the cadastral base map. Furthermore, accuracy is enhanced because each and every change in measurement over space, for each criteria, is accounted for and not averaged out over some often indiscriminate, common spatial measurement unit.

In the present study, a suitability index for each polygon covering the entire study area, for developed and undeveloped land, is calculated. This was done to achieve the particular aims of this study. Suitability analysis can be undertaken in various ways together with availability analysis. If the aim of the study is to relatively assess the suitability of particular cadastral portions of land, then, only the participating land portions form part of the analysis. Even if particular cadastral land portions are the only areas being assessed for suitability, it is nevertheless suggested that the analysis is undertaken on a polygon basis. Certain cadastral portions such as farm portions can be so large that suitability can vary considerably from one end of the land portion to the other. It is crucial to be able to distinguish suitability changes within a particular land portion and not to average out suitability for that portion.

4.4.3 Score standardisation

In order to reduce all "raw" scores or measures to a directly comparable format, so that apples are not compared with pears, all scores need to be transformed into one common measurement unit. This process of transformation is called standardisation and the raw scores of the evaluation matrix are replaced by standardised scores to generate the effectiveness matrix (Voogd 1983: 28; Figure 4.1). There are a number of options regarding the standard used, depending amongst others on the statistical techniques to be used in the next stage of the evaluation. It is usual to transform the raw scores to within a range from 0 to 1. There are, however different ways of calculating the standardised score and three transformation types have been distinguished as the most important (Voogd 1983: 77):

- transformation of the raw score to within a range from 0 to 1 with an additivity constraint;
- transformation of the raw score to within a range from 0 to 1 in a manner whereby its ratio-scale properties may be further used; and
- transformation of the raw score to within a range from 0 to 1 in a manner whereby its interval-scale properties may be further used.

4.4.3.1 Additivity score

In this type of standardisation, each individual raw score (i) is divided by the sum of all raw scores and is particularly appropriate in standardising different sets of criterion weights since the implication is that all those weight sets will then add up to unity (Voogd 1983: 77).

$$\text{standardised score } i = \frac{\text{raw score } i}{\text{sum of raw scores}}$$

4.4.3.2 Ratio-scale score

The second type of standardisation expresses the individual raw score relative to the maximum raw score and is useful in standardising an evaluation matrix that will be analysed by a weighted summation technique or any other technique which utilises the magnitude of the individual scores (Voogd 1983: 78).

$$\text{standardised score } i = \frac{\text{raw score } i}{\text{maximum raw score}}$$

4.4.3.3 Interval- scale score

This type of transformation sets the lowest individual score at 0 and the highest at 1 and is particularly appropriate where a technique is used which performs a pairwise comparison of the criterion scores (Voogd 1983: 78). This type of standardisation was utilised in the present study.

$$\text{standardised score } i = \frac{\text{raw score } i - \text{minimum raw score}}{\text{maximum raw score} - \text{minimum raw score}}$$

4.4.3.4 Direction of scores

For some criteria, a higher score implies a better suitability e.g. additional capacity in the water system, whereas, for others, a lower score reflects a higher suitability e.g.

land values or costs (Voogd 1983). So all scores need to be formulated with a common direction e.g. the higher the score, the better the suitability.

directed standardised score = standardised score in the case of "benefit" criterion
directed standardised score = 1 - standardised score in the case of "cost" criterion

4.4.4 Sensitivity analysis

There will always be a degree of uncertainty related to the results obtained using techniques such as multicriteria evaluation. The uncertainty is a combination of criterion uncertainty, assessment uncertainty, priority uncertainty and method uncertainty (Voogd 1983: 190). Have the relevant criteria all been taken into account, have the correct measures been used, have the correct weights been used and have the right methods been used for the specific application? Sensitivity analysis is a well-known approach in dealing with uncertainties. It indicates how a change in one criterion score (or weighting) will influence the final result.

An important draw-back of sensitivity analysis is, however, that it assumes that the various scores are mutually independent. In addition, the uncertainty introduced in the weighting process is also difficult to deal with, particularly if the weights have to be assessed with respect to strategic planning issues, i.e. issues which are not related to one specific and concrete situation (Voogd 1983: 198). Voogd (1983: 195) suggested that the two best ways of dealing with assessment uncertainty are rescaling to a lower measurement level and "feedback to research". His conclusion is that it is sometimes better to decrease the accuracy of the information employed in an evaluation in order to increase its reliability. The feedback to research approach is based on the assumption that if there is much debate about certain criteria scores, then this should evoke questioning as to whether the various choice possibilities have been investigated thoroughly enough on that particular issue. A feedback to previous research results or additional research would then be necessary which would hopefully increase the certainty.

4.4.5 Criteria weighting

Not all criteria play an equal role in the final suitability assessment. It may be required that more importance is attached to certain criteria relative to the others. A crucial component of multicriteria evaluation is the prioritisation or weighting of criteria. A priority matrix is constructed giving the importance of each criterion, relative to the others, according to various views (Voogd 1983: 30; Figure 4.1). Communities, stakeholders or decision makers in a particular area would be able to adjust the weightings as pertaining to that specific area. For the purposes of the current study, all criteria used are equally weighted so that the impact of including bulk infrastructure criteria can be assessed.

There are different available techniques for determining the relative weightings which are basically variations of ranking and rating techniques. A priority matrix is constructed as a result of the weighting process. If seven or fewer criteria are involved, the criteria can be directly ranked and rated in comparison to each other. It has been found that respondents are able to discriminate optimally about seven items (Miller 1956; Green & Rao 1970). If more criteria are involved, techniques using pairwise comparisons are preferable, when each criterion is compared with each other criterion on a pairwise basis e.g. analytical hierarchy process (AHP)(Banai-Kashani 1989) or the PLUS method (Xiang & Whitley 1993). Three simple, commonly-used weighting techniques are described below.

Complete ranking is a method whereby criteria are simply arranged in order of importance. It is assumed that these rankings can be considered as units on a cardinal scale with the consequence that the weights can be determined by standardising the rank orders according to standardisation formula. In order to arrive at group weights, the weights of the various individuals can be added and divided by the number of group members. A disadvantage of this method is that its accuracy decreases with the increase in the number of criteria to be ranked.

Seven-points scale ranking is based on the work of Osgood, Suci and Tannenbaum (1957) who found that a distinction in seven categories was adequate to allow the expression of preferences. An expression such as "unimportant" is allocated to 1 and the opposite, "important", is given to 7, or, visa versa. Each criteria will receive a value within a range from 1 to 7.These values can then be standardised, resulting in a set of weights. The group weights are the mean weights of the various members of that group (Voogd 1983: 104).

The most well known *rating* method is the constant sum approach. Each respondent receives, say, one hundred points which must be distributed over the criteria in such a way as to reflect relative importance (Voogd 1983: 105). The rationale behind this method is that it resembles the distribution of a given budget.

4.4.6 Criteria summation

Criteria are integrated by combining, by summation, the weighted scores for each criterion, for each overlay intercept polygon created by the GIS, to obtain a total suitability index (Figure 4.1). The technique of adding the weighted values is referred to in the literature as weighted summation. In order to display the resulting suitability indexes in the form of suitability maps, suitability category cut-off values need to be decided upon and GIS thematic maps created. In the present study, because all criterion scores are standardised, the scores thus have a built in relativity, therefore cut-offs can be set at regular intervals. In the present study, there is a continuum of suitability ranging from most suitable to least suitable. There is no decision made as to what is an acceptable suitability level and what is not. Another possibility would be to decide, through stakeholder involvement, on acceptable cut-offs for each individual criteria at the criteria quantification stage of the process. This could be classified into high, medium and low suitability for each criteria. The criteria summation stage would then be a much more simple step of combining only three categories for each criteria. It depends very much on the specific purpose of the exercise as to which approach is adopted.

4.5 Incorporating bulk infrastructure costs into the land suitability assessment framework

This chapter presents the land suitability assessment methodology as the framework within which the bulk infrastructure potential cost model operates. Bulk infrastructure cost criteria are generated and measured within the bulk infrastructure potential cost model and slotted into the land suitability assessment model in order to enhance the suitability assessment, ensuring that relative infrastructure costs are taken into account in the decision making process. The infrastructure potential cost model only deals with the incorporation of one group or category of land suitability influencing factors. There is opportunity to investigate and include other influencing factors in the same manner. The incorporation of economic, environmental, transportation and social factors offers almost limitless opportunity for multidisciplinary integration at a simple or more complex level. The multicriteria evaluation technique presented in this chapter is flexible and broad-based enough to include very simple criteria or criteria which have been generated through a more complex modelling procedure, such as what is being attempted with the bulk infrastructure potential cost modelling.

CHAPTER 5: BULK INFRASTRUCTURE POTENTIAL COST MODEL

5.1 Introduction

In order to incorporate bulk infrastructure cost considerations into the land suitability assessment process, a bulk infrastructure potential cost model has been developed. The bulk engineering services infrastructure relating to water, sanitation and electricity have been included in the model. The theoretical underpinning of the model is threshold analysis which is expanded upon in the first section of this chapter. A broad overview of the cost model methodology is given followed by a description of the generic steps involved in calculating the potential bulk infrastructure costs for infrastructure services.

Although the intention with the potential cost model is to provide a tool for planners to ensure that bulk infrastructure cost consideration are incorporated into the planning process at an early stage, it was deemed essential that the formulation of the cost model methodology involve input from engineers. An interactive model development process with engineers was therefore initiated to ensure that the planning perspective and needs were balanced by an engineering perspective. A thorough understanding of and appreciation for relevant engineering issues had to be gained and in turn, a comprehension of the planning need had to be instilled in the engineers so that the solution in the form of the potential cost model could be developed from a basis of mutual understanding.

Chapter 7 provides a description of the results of applying the model to a metropolitan area, where relative potential cost comparisons between various locations are possible.

5.2 Threshold analysis theory

5.2.1 Background

It is evident from various urban planning initiatives in South Africa and also in the international literature, that decisions are often made in the urban planning arena, which indicates that economic consequences are not appreciated, resulting in the ineffective use of resources and ill-advised investment policies. Surely, whatever planning philosophy and approach is adopted, a basic goal of urban planning is to facilitate the best possible use of existing resources. Choosing the most suitable areas for development and selecting the best functional patterns for urban expansion are crucial in achieving this best use of existing resources. Land suitability evaluation becomes a basic element of any urban planning exercise. Essential to the land suitability assessment process, is the identification of opportunities and constraints of land characteristics. Land suitability assessment creates a framework upon which urban development patterns can be conceptualised, designed, adapted and evaluated (United Nations 1977). A crucial aspect to be included is the assessment of constraints that need to be overcome to open up particular areas for development and the subsequent estimations of investment cost involved in overcoming these constraints. It is critical that this information is fed into the decision making process at an early stage of the planning process. Threshold analysis is the technique which permits the identification of physical development constraints, defined as thresholds, and the calculation of the costs, termed threshold costs, of overcoming these constraints (United Nations 1977).

5.2.2 Concept of threshold and threshold costs

5.2.2.1 Constraints to growth

Discontinuity points exist in the urban development process and in most cases these discontinuities result from physical limitations (thresholds) which need to be overcome, at a cost (threshold cost), before development can proceed. The physical limitations can be natural or man-made. A natural physical limitations could be a valley, across which a bridge is needed before further development can proceed or the sea, which requires land reclamation. Man-made limitations refer to infrastructure limitations where pipes, roads, cables or facilities such as waste water treatment works or reservoirs, are no longer adequate to cope with additional demand. This occurs once the design capacity has been reached. The present study is concerned with man-made limitations and the costs of rectifying the constraint.

5.2.2.2 Normal and locality costs

There are two cost elements which comprise the total cost necessary to locate a new unit of physical development: normal and locality costs (United Nations 1977: 10). Normal costs are those costs which are constant for a given type of development regardless of location. Locality costs are those costs tied to the existing conditions and characteristics of a given site, whether they be natural or man-made. Threshold analysis is concerned with locality costs. In the present study, the concern is with relative or comparative costs between various locations rather than total development costs, therefore it is those costs which vary with location which are pertinent.

5.2.2.3 Thresholds defined

A threshold is defined as the number of development units, defined either as dwelling units, population or non-residential units, or some combination, such that the next unit cannot be constructed at the previous cost per unit (United Nations 1977: 11). Threshold cost is defined as the cost necessary to overcome the threshold so that the next units can be built. Two types of thresholds can be distinguished: stepped and grade thresholds (United Nations 1977: 12). Stepped thresholds are those that require a once-off lump sum to be spent on overstepping them. The total stepped threshold cost is thus incurred prior to the first unit being built. This stepped threshold cost is not associated with the construction cost of the unit. The present study is concerned directly with stepped threshold in that the provision of waste water treatment works, outfall sewers, electricity substations and cables, reservoirs, pump stations and water pipes are typical infrastructure requiring lump sum investments, before development can proceed.

A cost development curve can be used to illustrate the threshold concept graphically (United Nations 1977: 12; Scottish Development Department 1973: 4; Figure 5.1). The top graphs indicate the relationship between the total development cost for constructing new units (c) and the number of units (n). The cost development curve for stepped threshold initially displays an increase in total costs directly in proportion to the number of new units due to normal costs, followed by a discontinuity in the form of a significant step which results from the lump sum cost incurred by the addition or construction of a new infrastructure facility. Grade thresholds arise as a result of a change in some site condition which impacts on the subsequent construction cost of the units. As development occurs in an area, for example, an area of poor soils could be reached, necessitating special foundation treatment, thus incurring higher costs. Grade thresholds are indicated on the cost development curve by a change in slope (Figure 5.1). The lower graphs indicate the average unit cost (ac) against the number of units. In the case of stepped thresholds, the average unit cost remains constant until the point where there is a considerable increase as a result of a necessary lump sum investment to overcome a threshold. Thereafter the average unit cost decreases as the number of units utilising the investment increases. For grade thresholds, the average unit cost remains constant until a point where the threshold is reached and thereafter the average unit cost is higher as each unit now has additional expenditure to overcome the grade threshold.

Three levels of threshold are identified in the literature: first, boundary and intermediate thresholds. Each level can be indicated spatially as a line on a map but would also have some quantity attached to it e.g. population, capacity. The first threshold is the limit to which the town can expand without incurring any threshold cost. According to the literature, the developed area would be included in this first threshold. Boundary threshold lines are lines on a map which bound areas which are to be excluded from urban development due to natural or man-made environmental conditions which need protection. Intermediate thresholds are those lying between the boundary and first thresholds which require some cost expenditure in order to overcome the threshold (United Nations 1977: 14; Scottish Development Department 1973: 21).

Foot-bound and foot-loose thresholds refer to yet another classification of thresholds

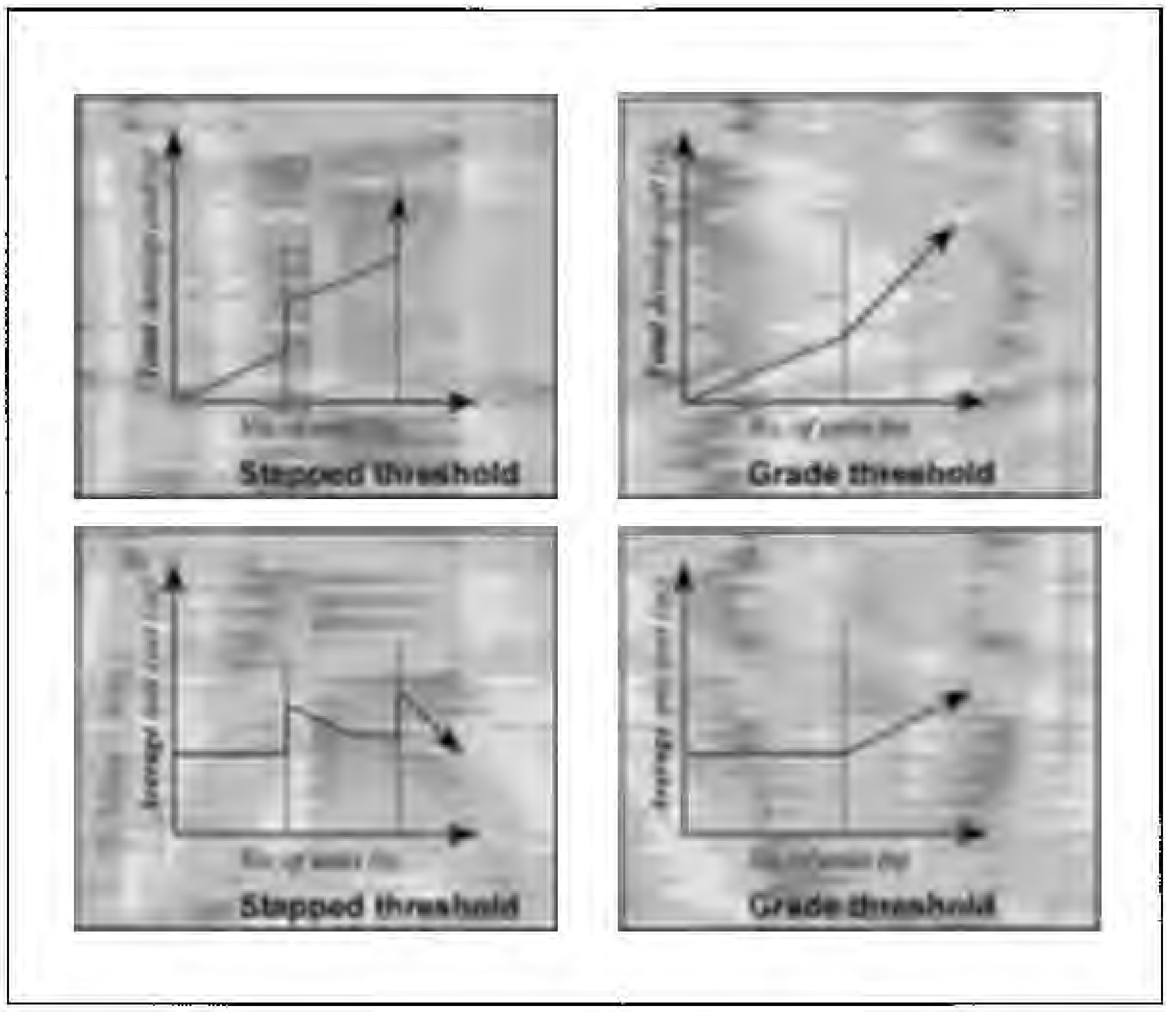


Figure 5.1: Cost development curves for stepped and grade thresholds

(Source: Scottish Development Department 1973: 4) relating particularly to infrastructure. Foot-bound thresholds refer to threshold lines which bound certain areas on a map which are served by given infrastructure systems e.g. the catchment area of a particular waste water treatment works. Foot-loose thresholds are distinguished as quantifying the existing and potential capacity of a system, best expressed as a number of new inhabitants that can be accommodated (United Nations 1977: 74). A point of disagreement with the literature is that these foot-loose thresholds can in fact be linked to a particular area, in particular to a foot-bound threshold. A foot-loose threshold thus becomes the quantity or measure relating to the foot-bound threshold, on the basis of which the threshold cost calculation is made. In the case of the United Nations (1977) guidelines, where basic threshold analysis is emphasised, foot-loose threshold cost analysis is referred to but is considered optional. The identification of only foot-bound thresholds is considered sufficient. Foot-loose threshold are, however, essential if basic threshold analysis is to be followed by threshold cost analysis as the quantification of spare capacities is critical in calculating the costs of providing additional capacity required.

5.2.2.4 Threshold costs

Threshold costs are those costs incurred in overcoming a particular threshold or limitation to further development. Any cost analysis should involve a comprehensive economic analysis including all current and future costs attributable to the proposed development. Threshold analysis, however, is concerned with the costs that change with location (United Nations 1977: 94). This focus enables a simplification of the costing process which is of significance particularly in environments of limited resources. Two categories of cost have been identified in the literature. Initial or direct development costs and exploitation or indirect costs, which included operating, recurrent or running costs and "frozen assets" costs (United Nations 1977: 94; Scottish Development Department 1973: 39). Direct costs refer to the capital investments required to overcome thresholds whereas indirect costs occur later, once the threshold has been overcome, in relation to the ongoing operation and maintenance of the development. Some running costs are directly related to the capital cost in that the capital cost may be lower due to a certain material having been used, but with higher operating costs necessary to maintain that material or vice versa. Both costs are therefore essential in obtaining a complete cost picture, however, the calculation of running costs is more complex than that of capital costs. The literature is clear that the calculation of indirect costs should only be undertaken for selected areas, which on the basis of other criteria, appear to be more suitable for development or in cases where even after direct costs have been calculated, there is no clear decision evident i.e. use indirect costs as a fine level rather than coarse level sieve. In reality, according to local authority engineering services departments, running costs are equivalent to the budget allocated for maintenance. This does not mean that is sufficient for the maintenance required, but it is what is available.

An even more difficult cost to measure is that of "frozen assets" costs. Whereas capital and running costs have to do with labour or materials, "frozen assets" costs are not connected with direct financial transactions. "Frozen assets" cost are the costs of having resources unused due to the incompletion of a capital project or the underutilisation of facilities during the time that the population increases to such an extent that the facility is operating at full capacity (Scottish Development Department 1973: 39). If these costs were included in the calculation, a different picture could emerge than if only capital costs are included. In the literature, although the importance of the costs other than capital costs are stresses, no practical guidance is given as to how these costs should be included other than to say that it is with difficulty. It is also cautioned that due to the technical difficulties and complex nature of " frozen assets", the costs involved should be calculated apart from the initial costs and not combined in a single cost index (United Nations 1977: 97).

It was decided that only initial costs would be calculated for the purposes of this study. This means that capital costs were included, excluding financial costs, and running and maintenance costs. The density levels are set with no time horizon attached which made the inclusion of costs other than initial costs, difficult if not impossible. The emphasis was also on comparative costs not necessarily actual costs. Given the strategic nature of the project on hand, its focus on costs which change with location, the emphasis on relative rather than absolute costs, the fact that material used and other such variables are kept constant for measuring the costs for different parts of the study area, all support the decision to use only initial costs for the present study.

5.2.3 Threshold analysis process

The United Nations (1977) and Scottish Development Department (1973) have both produced detailed guidelines as to the methodology to be followed in performing threshold analysis. The generic process followed by both parties is similar and those components applicable to bulk infrastructure costing have been extracted and summarised next.

5.2.3.1 Problem setting

- Defining aims: Purpose, expected results and how they should be presented, study area delimitation, how the threshold analysis links to the overall planning process.
- Formulation of assumptions: Determine main functions/land uses of study area, time span, construction types and densities, identify and categorise threshold generating factors, set accuracy level of the study, determine basic standards of service and supply to be provided.
- Identify specific difficulties: Identify political, administrative, legislative, social, aesthetic and historical constraints to urban development processes and indicate which parts of the threshold analysis will be affected.
- Defining necessary adjustments to the threshold analysis process and the need for additional parallel studies.
- Formulating a detailed list of threshold generating factors.

5.2.3.2 Basic threshold analysis

- Determining boundary thresholds: Boundary thresholds are lines on a map which bound areas which are to be excluded from urban development due to natural or man-made environmental conditions which need protection. Boundary thresholds represent absolute constraints to development which, it has been decided, must not be overcome.
- Determining normal thresholds: Normal thresholds represent constraints that can be overstepped to proceed with development. First and intermediate thresholds

are determined as imposed by the existing natural and man-made environments and by layouts and capacities of the infrastructure systems. Various threshold areas are defined, their urban development potential calculated and implications evaluated.

5.2.3.3 Threshold cost analysis

Threshold cost analysis is particularly concerned with the costs that change with location. Costs must be calculated for each intermediate threshold to determine the cost involved in overcoming these thresholds.

- Specify all the factors causing direct threshold costs.
- Determine the location and size of each investment component necessary to overcome the intermediate thresholds.
- Calculate direct/initial costs of supplying each investment component.
- Sum all threshold costs calculated and express the cost per dwelling unit.
- Calculate indirect costs in order to bring the time element into the equation by means of measuring frozen costs, developing alternative phasing and measuring exploitation costs.

5.3 Bulk infrastructure potential cost model: theoretical concept

5.3.1 Application of threshold theory to the bulk infrastructure potential cost model

The methodology developed for the bulk infrastructure potential cost model is entrenched in threshold analysis theory. Significant adaptations and additions were, however, necessary in order to apply threshold analysis methodology in the present context of enhancing land suitability assessment in the generation phase of the planning process. The major deviations of the proposed bulk infrastructure potential cost methodology from the threshold methodology as presented in the literature, relate to a range of aspects. Threshold analysis as presented in the literature is very enmeshed in a particular overall planning method with the success of the analysis being dependent on knowing or predicting such aspects as the population growth per area and having a land use plan. Threshold analysis, therefore, seems to take place after a significant amount of planning for the area has already occurred. Although it is maintained that it can assist throughout the planning process and brings costs in at an early stage, threshold analysis appears to be evaluative rather than generative in nature. The purpose of the present study is to have a stand- alone analysis which can be used as input to planning at an early stage, to inform the land use plan rather than to evaluate already existing options. There has been an attempt to introduce a type of "what if" testing capability into the methodology to assist in the generation phase of the planning process. The intention is that the bulk infrastructure potential costing can be undertaken within whichever planning process is followed rather than being part and parcel of a particular planning process. In developing the costing methodology, therefore, there was an attempt to free the analysis from as many of the assumptions inherent in the planning process as possible so that it is fairly autonomous and can be used in a wider range of applications.

Related to the aspect of threshold analysis being presented as an integral part of a planning process, a further relevant issue is that the methodology presented is too all-encompassing for the needs of bulk infrastructure potential costing. Costs such as land acquisition costs and building costs as influenced by grade thresholds i.e. changes in soil conditions, are included in threshold analysis. Furthermore, threshold analysis is applied in a fairly wide context to include natural environmental conditions. In the present study, the threshold analysis theory has been applied to infrastructural costs whereas other factors have been handled in different ways within the context of multicriteria evaluation. The literature also extends the concept of threshold to include aspects such as accessibility thresholds. So almost all the criteria included in the present multicriteria evaluation exercise could be reinterpreted into some form of threshold and analysed within the framework of threshold analysis. The problem arises in calculating threshold costs for all these criteria. The benefits of threshold analysis to the present study are in the concept of linking threshold costs to each threshold which is extremely appropriate in bulk infrastructure potential costing. With regard to integrating a number of disparate criteria, some cost criteria and others indices, multicriteria was found to be more appropriate as discussed in a previous chapter.

On the more detailed level, the issue regarding the infrastructure costs associated with upgrading, redevelopment or densification within the developed city is pertinent. In the literature, the first threshold includes all developed area and areas which entail no threshold cost. It is thus assumed that there is no cost associated with further development within the developed city area. To subscribe to this assumption in the present study would negate the very essence of the study which is to identify suitable land in terms of factors such as access, proximity, opportunity and capacity. It is within the developed city limits that these factors often reach their highest suitability value and with vacant or developable land being available in many South African cities and with the policy directives to densify and compact, the cost differentials for development within the developed city limits need to be incorporated into the overall assessment of the study area.

Although both threshold analysis guideline documents consulted were strong on the threshold analysis component, neither handled threshold costs to the same level detail. At the appropriate point in the methodology where it is time to calculate threshold costs, there is much to say about organising the costs into tabular format but little about how to actually calculate the costs (United Nations 1977: 99; Scottish Development Department 1973: 33) . The calculations for indirect costs and frozen costs are given, but surprisingly, not direct costs. The United Nations (1977) gives examples of the application of basic threshold analysis but gives no examples of the application of the threshold cost analysis. The Scottish Development Department (1973) does go further by listing all the possible infrastructure cost components but in the example of the application of the methodology, it is assumed that the water supply and drainage networks have sufficient capacity for the target population, but road costs are given, although it is unclear exactly how the costs were arrived at (Scottish Development Department 1973: 129). The road costing methodology is clear up to the point of identifying which sections of road need to be added but there is then a jump to simply stating the costs. It is assumed that a cost factor per km of road was used as listed earlier in the document (Scottish Development Department 1973: 63).

Besides clearly specifying the actual cost calculations necessary to determine direct threshold costs, the proposed methodology for a bulk infrastructure potential cost model builds further on the cost calculation in that the infrastructure unit cost, be that a length of network or a particular facility, is used only as a base cost under ideal conditions. This base cost is then adjusted depending on non-ideal conditions which influence the installation costs. No evidence of the incorporation of cost influencing factors was found in the literature except with reference to grade thresholds which influence the dwelling unit cost.

A further significant difference between threshold analysis as described in the literature and the proposed bulk infrastructure potential cost model, is the format of the output. In the literature, the cost results are displayed in tabular format whereas in the present study, GIS-based, cost contour maps are proposed which, in addition to providing a far more visual and clear means of displaying output, allows the information to be incorporated in to the GIS-based, multicriteria land suitability evaluation process.

5.3.2 Bulk infrastructure potential cost model in relation to threshold theory

The intention of the bulk infrastructure potential cost model is to enable the relative comparison of infrastructure costs between various sub areas of the study area. The cost outputs are mapped in the form of cost surfaces and are used as input in the assessment of land suitability. For purposes of clarity, the model concept is explained against the background of theoretical threshold analysis graphs, for two arbitrary sub areas: Area A and Area B (Figure 5.2). For each area, bulk infrastructure costs for a selection of infrastructure types, are plotted against number of new units. Only a few types of infrastructure have been represented for illustration purposes. Many more infrastructure types are included in the actual model.

As an initial step in the model, the proposed or potential density level needs to be assumed. The number of new units will be derived from the density assumption by subtracting the existing unit density from the proposed unit density, multiplied with the area (ha) of the sub-area. The model can either be run repeatedly for various density alternatives, where for comparative purposes the densities applied are kept constant throughout the study or, as an alternative, different densities can be applied to each sub-area according to some planning strategy. To illustrate, three different density strategies have been indicated, d1, where the fewest units have been added, d2, and then d3, where the most units have been added. If a potential density, d2, is assumed, the model will calculate the cost of each infrastructure type necessary to service that particular density in that sub area i.e. the cost of a reservoir, c2R, the cost of outfall sewers, c2O, the cost of waste water treatment works, c2W and the cost of electricity substations, c2S. For density d2, the costs will be summed to give a total infrastructure cost for that sub-area, at that particular time, at that particular density and the relative costs can be mapped using cost surfaces to indicate which sub-areas are relatively expensive to develop and which are relatively cheaper.

If the problem statement is slightly different in that different potential densities are being assumed for each sub-area, say d1 for Area A and d3 for Area B, the costs will be calculated for each at a different point along the graph but will also be compared using cost surface maps to indicate the range of costs from the least to the greatest costs for that particular density strategy. The latter type of problem statement is more suitable for application during the planning evaluation phase, once differential densities have been proposed for the whole study area. The former application where the entire area is compared at constant densities are more appropriate for the present application of the model in the planning generation phase.

The output of the model can be mapped either as total infrastructure costs or as individual infrastructure element costs, so that the planner can be better informed as to precisely which services are causing the cost increases at which stage. It is clear, even from only a visual inspection of the graphs in the example given, that at d2, Area A will be more expensive to develop than Area B and that the most expensive cost item is a reservoir.

5.3.3 Three pillars of the bulk infrastructure potential cost model

There are three essential elements of the cost model: threshold, density and cost (Figure 5.3). It is the manner in which these three pillars are incorporated into the model and relate to each other within the model, which form the basis for the model. Engineering services infrastructure, is by its very nature, a utility to people, particularly to urban people, necessary for health, access and industry. As the number of people increases within an area, so the infrastructure needs to expand to accommodate additional requirements. Due to the fact that infrastructure has physical dimensions i.e. pipe diameter, reservoir capacity, limits or thresholds, directly proportional to size of infrastructure, exist. The relationship between density and threshold dictates whether or not additional infrastructural expenditure is necessary to accommodate additional people.

The manner in which the three pillars are incorporated into the model is largely through capacity analysis (Figure 5.4). The density levels set, convert into the number of additional person units required per sub area, which in turn can be translated into infrastructure capacity demand figures. The resulting capacity demand figures are influenced by desired level of services. The lower the level of service, the less the demand for infrastructure. In the present study, levels of service are kept constant in order to calculate relative costs. Infrastructure thresholds are equivalent to the design capacities of the various components of the infrastructure system. The existing infrastructure network and facility design capacities are compared with the current utilisation of infrastructure in order to quantify the capacity supply situation. The quantitative comparison of the capacity demand situation with the capacity supply situation determines firstly, whether or not additional infrastructure is required and secondly, if infrastructure is required, how much, or how many infrastructure investment units are required. Investment units can be in the form of metres of network or number of facility modules. In the present study, the basic cost per investment unit is influenced by additional cost factors relating to local conditions. The resulting relative costs are mapped and incorporated into the wider land suitability assessment model.

5.4 Generic bulk infrastructure potential costing methodology

The various methodological steps involved in the bulk infrastructure potential cost model are explained with reference to a schematic representation of the process (Figure 5.5).

5.4.1 Conceptualise bulk infrastructure components and operation

It is important to understand the functioning of the particular infrastructure under consideration within the context of the study area, in order to enable the definition of cost components and to delimit the level of detail for the study. This step results in a schematic representation of the system which assists in clarification of the elements and interrelationships between them and highlights any aspects peculiar to the particular study area which may differ from the generic norm. For example, in testing the proposed methodology by means of a pilot study, the conceptualising phase immediately brought to light the peculiar occurrence of a sewerage works located on top of a hill instead of in a valley, as is normally the case. These quirks need to be identified and accommodated within the methodology. Institutional arrangements, administration of the systems, responsibilities and functions also need to be understood from a perspective of defining what parts of the system are to be included. It may be that the limits or cut-offs will be defined on the basis of who the provider is and to what point in the system that particular provider hands over to the next level.

5.4.2 Define "bulk" infrastructure for study area and according to particular purpose

Following on from an understanding of the functioning of the infrastructure system, it is possible to precisely define what is to be defined as bulk infrastructure and thus what level of detail the study will be involved in. It seems that "bulk" cannot categorically be defined, say in terms of size of pipe, but rather needs to be defined for a particular study area, depending on the requirements of the particular study and on the basis of physical and institutional factors.

5.4.3 Subdivide study area according to intermediate thresholds

The entire study area needs to be delimited in terms of supply or catchment areas. Each section of network and each facility has some geographic area which it serves in terms of either supplying water or electricity or taking away waste. A major distinction needs to be made between those areas with existing networks and facilities and those areas with no infrastructure. For those areas with no existing infrastructure, two situations need to be identified. Firstly, for areas where there is planned infrastructure, the supply and catchment areas and networks need to be included. Secondly, for those areas where no planning has yet been undertaken, coarse level assumptions regarding possible future infrastructure provision in these areas need to be made in consultation with engineers familiar with the area and from an assessment of natural drainage in the area. Assumptions must be made as to whether or not the areas will be served by existing infrastructure i.e. if the area falls within the same drainage basin as an existing facility or if the possibility exists for pumping over a watershed, or, if an entirely new system is more likely. If absolutely no development is envisaged in those areas, they can be excluded from the cost model.

5.4.4 Undertake existing capacity supply analysis

For each threshold area defined in the step above, the current capacity situation needs to be quantified in order to determine, firstly, whether or not any spare capacity exists in the existing infrastructure and, secondly, if spare capacity is available, to determine the amount of capacity available for use. The spare capacity is calculated by comparing the existing utilisation of the network and facilities to the design capacities for the system. Existing utilisation of the system can be ascertained from either direct measures of current flow or indirectly, by derivation from existing land use types or population figures and using engineering services demand or supply factors.

New areas, currently not supplied with infrastructure, which can feed into or be supplied by an existing facility are assigned the capacity of that existing facility. New areas with no possibility of linking into an existing facility, will be assigned a value of zero existing capacity. The calculated capacity needs to be expressed in the same unit measure as the potential capacity demand so that the two figures can directly be compared. Capacities can either be expressed as a volume measure or as the number of additional people that can be accommodated or that need to be accommodated. Volume measures can be converted to population number which can be accommodated using services supply and demand factors. These factors are determined from average daily utilisation figures, usually expressed per person and often vary between income levels and intensity of land use.

5.4.5 Generate comparative density scenario/s

Potential infrastructure costs are directly proportional to the number of units that need to be served and therefore potential or proposed density is crucial in the determination of cost. Due to the intended use of this model in the early phases of the planning process, to inform the decision on proposed densities, rather than to evaluate proposed densities, almost arbitrary potential densities need to be set in the form of density scenarios in order to enable the determination of relative advantage of one area as opposed to another in terms of infrastructure costs. The interpretation of results will always be conditional on the set density assumptions. Various density scenarios can be generated and the model run a number of times to ascertain the effect of different density consideration on the cost surfaces.

Time is almost implicitly taken into account by virtue of the inherent relationship between increasing densities, population or units, with time. If time goes by and no units are built, no costs, other than operational and maintenance costs will be required. The model therefore revolves directly around density rather than time. A time element could, however, be incorporated by deliberately setting the various density scenarios to coincide with specific forecast years.

5.4.6 Calculate potential capacity demand

The density scenarios are converted into additional population which will require services in each threshold area. If the output of the existing capacity analysis was in volume measures, then the potential demand output also needs to be converted from population figures to volume figures using the per capita services demand and supply factors.

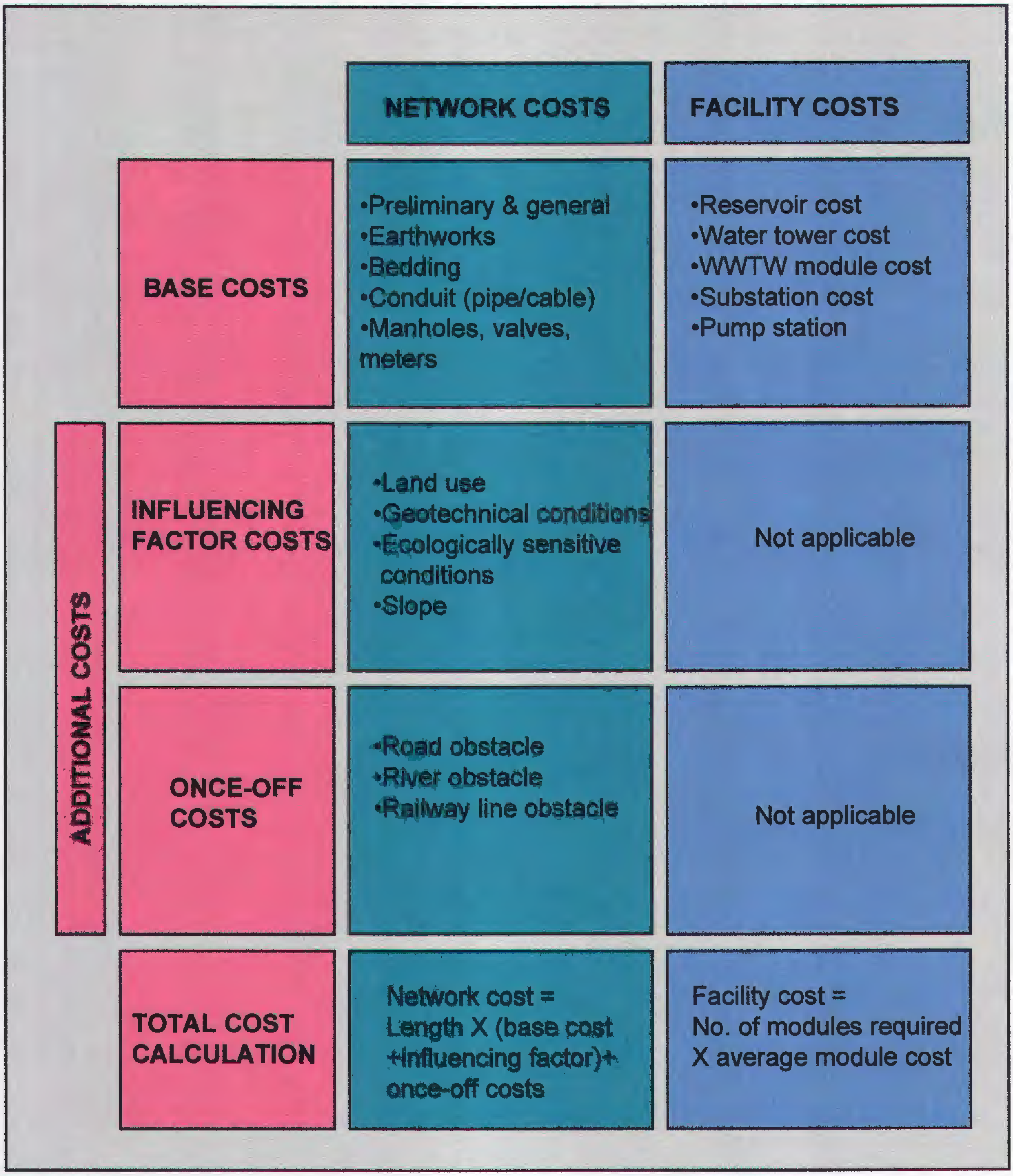
5.4.7 Determine required additional infrastructure

A comparison of the output of the existing supply analysis with that of the potential capacity demand analysis, allows the determination of what additional infrastructure is required to meet the potential demand. The additional requirements specified would relate to both networks and facilities. Required network infrastructure specification would involve the stipulation of location, length and diameter or related characteristic, of additional pipes or cables needed. For the purposes of this model, where additional capacity is required in sections of the existing network, the assumption is that a new section of conduit will be laid alongside the existing section so that the locational position and length of the new conduit is the same as the old. For totally new conduits in the form of links to the current network or new networks, the route is assumed after a consideration of topography, current development and existing infrastructure. Size of the conduit, as measured by diameter for water and sewer pipes or resistance for electricity cables, is determined according to tables prepared by engineers for the specific purposes of this model, which relate density, slope (where applicable) and diameter in accordance with required flow, pressure or electricity output requirements.

Required facility specification involves the determination of the location and number of new or additional facility modules which need to be constructed to serve the additional potential population. Tables and graphs, relating numbers of persons to amount of storage required and size of facilities have been prepared for this purpose, using engineering design principles.

5.4.8 Calculate threshold cost

For each additional section of network or facility required, as specified in the step above, the cost of overcoming those thresholds of limits in the physical infrastructure needs to be calculated. There are two broad cost components to be considered: base costs and additional costs (Figure 5.6). Base cost for the network refer to the per metre cost of conduit under ideal conditions. Infrastructure facility base costs are defined as the average cost per facility module related to size of module. Additional costs take account of costs involved due to non-ideal conditions and include what have been termed, influencing factor costs and once-off costs. Influencing factor costs take into account the impact of locality on the per metre network base cost, in terms of natural and built environmental conditions. Once-off costs refer to the additional network cost



		NETWORK COSTS	FACILITY COSTS
	BASE COSTS	•Preliminary & general •Earthworks •Bedding •Conduit (pipe/cable) •Manholes, valves, meters	•Reservoir cost •Water tower cost •WWTW module cost •Substation cost •Pump station
ADDITIONAL COSTS	INFLUENCING FACTOR COSTS	•Land use •Geotechnical conditions •Ecologically sensitive conditions •Slope	Not applicable
	ONCE-OFF COSTS	•Road obstacle •River obstacle •Railway line obstacle	Not applicable
	TOTAL COST CALCULATION	Network cost = Length X (base cost +influencing factor)+ once-off costs	Facility cost = No. of modules required X average module cost

Figure 5.6: Cost components of the bulk infrastructure potential cost model

of traversing a particular physical, man-made obstacle such as a railway line or road. Once-off costs do not affect the per metre cost but are included as a single additional cost value.

5.4.8.1 Determine base costs

For network costs, all cost component relating to laying an infrastructure conduit need to be identified. The components can be broadly categorised as preliminary and general costs (insurance, tools site office etc), labour costs (project management, earthworks, bedding) and materials costs (conduit, valves, metres, manholes). The contribution of each component to the per metre cost needs to be ascertained and a total base cost calculated. The reason for breaking the base cost down into components parts is that different influencing factors influence different components of the cost and only that specific portion of the cost is factored up to take account of influencing factors.

The facility module average costs need to be determined and can be ascertained from an assessment of contract documentation for the construction of such facilities. For water infrastructure, facilities include reservoirs and water towers, for sanitation, waste water treatment works and pump stations and for electricity, electrical substations.

5.4.8.2 Determine influencing factor costs

Those factors which cause an increase in the per metre base cost of conduit need to be determined and the cost implications calculated. The manner in which it has been conceptualised that the influencing factors be included for the purposes of this study, is that each influencing factor is categorised into one of three categories. Category 1 conditions are ideal conditions and only the per metre base cost applies. Category 2 conditions are such that some additional cost is necessary. Category 3 conditions are least favourable and significant additional cost needs to be added to the per metre base cost. Additional costs are included by means of percentage increases which need to be applied to specific cost components of the base cost e.g. to the excavation or materials components.

Influencing factors identified for the purposes of the present study include aspects of land use, geotechnical conditions, natural environmental factors and topography. The influence of land use is in terms of intensity of development. Ideal conditions refer to undeveloped land where there is no impediment to installing infrastructure. Generally, costs increase as intensity of development increases with the increasing possibility of obstacles and digging up existing constructions. The highest cost is associated with central business district type development. Geotechnical conditions influence the per metre base cost largely according to hardness of rock and amount of clay in the soil, requiring blasting or special protection of pipes.

5.4.8.3 Determine once-off costs

Once-off costs account for additional expenditure as a result of traversing an obstacle which can be man-made such as a road or railway line or natural, such as a river. The per metre cost is not affected, rather a once-off cost is involved. As in the case of influencing factors, once-off costs are categorised in terms of size of obstacle. Single carriageways and railway lines would cost less to traverse than highways, multiple railway lines and large rivers.

5.4.8.4 Calculate total relative potential cost

All costs need to be increased to present day costs or at least all compared at the costs of a particular year. For each particular density scenario, for each defined, threshold area, the network and facilities cost need to be calculated. Network costs are calculated by multiplying the distance to be traversed with the appropriate per metre cost (base costs and influencing factor costs included), adding any additional once-off costs required. Facility costs are simply the number of modules necessary to service the additional population multiplied with the module cost.

5.4.9 Calculate per capita cost

In order to relatively compare costs between locations, the infrastructure costs need to be distributed amongst the people who use that infrastructure. Some costs, i.e. the link costs would only be distributed amongst the people in the particular threshold area whereas the costs of say, a major outfall sewer, would need to be distributed amongst all the threshold areas which utilise that particular section of pipe. There thus needs to be an equitable per capita assignment of costs across the entire study area to facilitate the relative comparison of costs between locations.

5.4.10 Prepare thematic maps for incorporation into multicriteria evaluation model

For each density scenario, thematic maps, displaying cost surfaces or relative cost categories, need to be prepared in order to make the results explicit and visual to decision makers and planners. In addition, the spatial mapping of the results is necessary to incorporate the bulk infrastructure cost results with other multicriteria layers, into the overall land suitability assessment model. Depending on specific requirements, each different infrastructure service layer can be incorporated individually into the multicriteria evaluation or the costs of each service can be further amalgamated into a single bulk infrastructure layer which is incorporated into the multicriteria evaluation.

CHAPTER 6: BULK INFRASTRUCTURE POTENTIAL COSTS

6.1 Introduction

The generic bulk infrastructure potential cost methodology described in the previous chapter is applied in the GPMC area and the results presented in this chapter. Water, sanitation and electricity capital costs, at 1995 prices, are determined and represented spatially, for various population density scenarios. Bulk water costs comprise link costs (cost of linking the development with the distribution reservoir), distribution reservoir costs (including pressure towers), feeder main costs (pipes linking distribution reservoirs with system mains or Rand Water mains), system main costs (pipes linking distribution reservoir feeder mains to receiving reservoirs) and receiving reservoir costs. Waste water treatment works costs, bulk outfall sewer network costs and sewer link costs (linking the development with the outfall sewer network) are included in sanitation cost. Electricity costs incorporate 132/11kV substation, cabling and transformer costs.

All individual costs are ultimately integrated into a single cost for each of water, sanitation and electricity which are the cost layers incorporated into the overall land suitability assessment, presented in the following chapter.

Infrastructure costs vary with location according to local density, infrastructure capacity, land use, geotechnical, environmental and built conditions, making the role of GIS in the model appropriate and important. GIS is loosely coupled with the spreadsheet-based bulk infrastructure potential cost model.

This chapter has been organised so as to firstly elaborate on the results for certain key elements of the methodology presented in the previous chapter. These key elements of bulk infrastructure system components, density and cost inputs are described in terms of approach, data sources and assumption used. The second part of this chapter deals more specifically with each individual cost, indicating the specific method used in each cost calculation and describing the resultant cost tables and maps. Finally, the role and benefits of GIS in the model, as applied to the study area, are discussed in relation to the cost model process as presented in the previous chapter.

Due to the length of some of the tables presenting results, tables which are longer than one page have been included in Appendix A rather than being incorporated as part of the text.

6.2 Elaboration of results of key methodological elements

6.2.1 Arrangement of section 6.2

In order to reduce complexity in the descriptions of individual cost calculations and results, presented in section 6.3, results regarding certain key elements of the methodology requiring elaboration are discussed in section 6.2, but referred to again in section 6.3 without further explanation. Key elements are discussed in relation to the methodology presented in chapter 5 (Figure 6.1). Relevant aspects of the methodology are highlighted and the applicable paragraph numbers indicated in parenthesis (Figure 6.1). Bulk infrastructure system components, density issues and base and additional factor cost inputs and derivations are the key elements reported on in this section (Figure 6.1).

6.2.2 Components of the bulk infrastructure system

6.2.2.1 Water system components

The GPMC area is supplied primarily with water from the bulk supplier, Rand Water, and to a limited extent, from secondary, internal supply sources including boreholes and springs (Figure 6.2). These sources supply water to both receiving and distribution reservoirs and sometimes directly to certain areas. There are seven receiving reservoirs in the study area which mainly supply water to distribution reservoirs but also supply some areas directly. Receiving reservoirs supply distribution reservoirs via system mains. Feeder mains supply water directly to certain areas or to distribution reservoirs, from

Rand Water pipes and also connect distribution reservoirs to system mains. Each distribution reservoir serves a distinct reservoir supply zone and each receiving reservoir serves a number of distribution reservoirs. Water towers serve to maintain pressure in a network and are not intended to provide capacity for balancing peaks and for emergency supply. For the purpose of this study, the areas which towers serve are included in the relevant distribution reservoir zone and the negligible tower capacity added to that of the reservoir. Developments within distribution reservoir supply zones are served from the reservoir by means of a supply link network which supplies water to the edge of a development. Thereafter, water is distributed via internal services.

Bulk supply of water in the study area is defined, for the purpose of this study, as all pipe network and water storage facilities, excluding internal service, but including links to distribution reservoirs (link network), distribution reservoirs and their towers (including pumps), connections between distribution reservoirs and receiving reservoirs or Rand Water pipes via feeder mains and system mains and direct feeds between Rand Water mains and certain areas (Figure 6.2). This definition is in accordance with the extent of responsibility of the metropolitan authority of the GPMC area.

The water system, particularly the pipe component, is more difficult than the gravity-driven sewer system to model accurately. The water system operates under pressure in networks, supplying water through the network in any direction depending on draw-offs. It is thus difficult to predict direction of flow and to assign certain discrete areas to certain discrete pipes as is possible in the sewer system. Adjustments to the modelling approach have been made accordingly. In the case of feeder mains, and to a lesser extent system mains, it is possible to predict the water supply path and a specific method has been developed to do that. In the case of water link cost, where it is virtually impossible to simply determine a supply path, a much more theoretical estimation approach to determining costs has been developed.

From an understanding of the operation of the water supply system in the study area, and according to the definition of bulk water supply for the study, five bulk water components, to be costed in the model, have been distinguished:

- water link network costs;
- water distribution reservoir costs (including towers and pumps);
- water feeder main costs;
- water system main costs; and
- water receiving reservoir costs.

6.2.2.2 Sanitation system components

Waste water treatment for the study area currently takes place at eight waste water treatment works (WWTW) within or near the study area. WWTW are generally located in lower lying areas and are fed, usually by gravity, although pumping is sometimes necessary, via outfall sewer branch networks from areas within the predominantly natural catchment boundary of the particular works (Figure 6.3). Each outfall sewer also has its own definable catchment area. Particular developments are served by internal services within the development but the link to the outfall sewer system is included as bulk infrastructure. Generally, pipes with a diameter of greater than 250mm were included as part of the bulk analysis. In cases where sewers lie alongside each other with interconnections, serving the same area, the model adds the capacities and treats the pipes as one. Planned WWTW additional modules or new works and outfalls, which have been budgeted for, are assumed to be paid for and included in the model as existing available capacity. Modules and WWTW "under investigation" are included in terms of potential service areas but are assigned zero current capacity with the effect that all costs associated with providing this new infrastructure is included in the model.

On the basis of an understanding of the functioning of the sanitation system in the study area, three sanitation system components have been identified as potential cost items in the model:

- WWTW costs;
- outfall sewer network costs; and
- sewer link costs.

6.2.2.3 Electricity

Electricity is supplied to the study area primarily from Eskom but also directly from two power stations at Rooiwal and Pretoria West. Electrical power is transformed to a lower voltage at a number of 132/11kV substations located throughout the study area (Figure 6.4). These substations and the transmission lines that interconnect them, comprise the bulk or primary power distribution system for the study area. Each substation has a definable supply area associated with it. The lower voltage secondary distribution system, which is supplied by the primary system, distributes electricity within particular developments and are not included in the model.

As in the case of the water system, electricity is supplied by means of a network, through which current "runs" in any direction, which is difficult to predict. Accordingly, in the model, electricity is handled on the basis of 132kV substation costs and the associated transmission line costs, including transformer costs, are simply determined in proportion to the cost of the substation.

6.2.3 Density considerations

6.2.3.1 Purpose of density scenarios

Establishing population density scenarios is critical in the model process. It is necessary to keep density constant throughout the study area in order to relatively compare potential infrastructure costs spatially across the area. The bulk infrastructure potential cost model is intended for use in the early, informative stages of the planning process when proposals regarding land use and densities have not yet been made. In fact, the intention of the model is to inform precisely the question of where it would be most suitable to develop, for what type of land use at what type of densities. The density scenarios set for the model are thus theoretical in nature for the purpose of locational comparison of costs across the study area. Different density scenarios are set to enable the assessment of the effect of changes in density on bulk infrastructure costs.

6.2.3.2 Density scenarios adopted

The existing gross population density for the GPMC area is 14 persons per hectare. This existing density figure was calculated on the basis of a 1995 total population of 1570 000 and a gross area of 116 200 hectares (as calculated by GIS) for the study area. The population figures used excludes "single people" resident in hostels, old age homes, military bases and as domestic servants. The total 1995 population including "single people" is 1 760 000 (GPMC 1996). The reason for excluding "single people" in the bulk infrastructure potential cost model is twofold. The first reason has to do with data availability. In order to determine the existing population per infrastructure catchment or supply zone, existing population figures were required on as detailed a geographic level as possible. The most detailed available population data was at the traffic zones level, used for transportation modelling. Due to the fact that transportation modelling deals with trip-making in the morning peak hour, most of the population included as "single people", are excluded from transportation modelling figures as they do not make a morning trip. Secondly, most infrastructure usage figures relate to household consumption, with shared household utilities contributing to calculated per person usage factors. The cost analysis is thus restricted to population forming part of households which is in any case by far the greatest population in the study area.

Three realistic, but arbitrary density scenarios are set for this study: a low density scenario corresponding with 20 persons per hectare, a medium density scenario of 40 persons per hectare and a high density scenario of 60 units per hectare. The intention was to show the impact of increasing densities on cost, within reasonable density limits. It was not the intention to set a density scenario corresponding to high-rise, Sunnyside-type development (98 persons per hectare) throughout the entire area. Rather, without being location specific, the selected average gross density scenarios are intended to represent a range of housing types and densities which vary with location e.g. high densities along major public transport routes and lower densities further away and to accommodate other land uses, roads and open areas.

The approach in adopting density scenarios is to calculate relative bulk infrastructure costs if all land in the study area is developed to a gross density of 20, 40 or 60 persons per hectare. In instances where current population exceeds the scenario population, the current population is taken as the scenario population. This occurs predominantly in the low income areas of Soshanguve, Atteridgeville and Mamelodi where current densities are between 60 and 100 persons per hectare (GPMC 1997a). In reality, all land in the study area will not be developed. Nature reserves, for example, have been designated for preservation, conservation and recreation activities. The model does not exclude any area from analysis due to current land use, even if it is currently nature reserve. The model includes all land, developed and undeveloped, and asks the question: if this land should be developed or redeveloped to a certain density, what would the relative bulk infrastructure potential cost be? It would be the role of the broader land delivery process to include or exclude land for development on the basis of a much wider range of issues, including the results of this model.

6.2.3.3 Density and infrastructure demand

Potential population numbers determine potential infrastructure usage which is utilised in the demand-side analysis of the infrastructure cost model. Residential population are not the only users of bulk infrastructure - industry, agriculture, social and commercial uses also have infrastructure requirements. In the urban context, industrial and commercial activities are most pertinent. For the purposes of this model, usage of infrastructure by social facilities, such as schools and libraries, and by business areas, is not taken into account since the usage is relatively minor and does not peak at the same time as the main residential peak (National Housing Board 1994). It is assumed that for large water and electricity dependant, high effluent producing industrial uses, separate infrastructure provision arrangements are made and are thus not included in the model.

6.2.3.4 Density and infrastructure supply

The relationship between infrastructure capacity (supply) and density (infrastructure demand) is crucial in the model. There are two available options for comparing infrastructure supply and demand, necessary for the determination of additional infrastructure required and thus cost. The first option entails a comparison between spare capacity (the difference between design capacity and current usage) and additional capacity required (based on potential additional population). In the second option, design capacity is compared with total capacity required (based on total population including existing and potential additional population). The resulting costs are exactly the same whichever option is used. In both cases, costs are eventually expressed per additional population with the argument being that the costs incurred by new development are the responsibility of the additional people and not the responsibility of the people already resident in the area. The latter option was applied in the case of the present study on the basis that less computation is required in relation to data availability.

6.2.3.5 Density and over-capacity

A further consideration relating to density and capacity is that of infrastructure already operating theoretically at over-capacity. This occurs when existing calculated demand exceeds design capacity. In reality, such circumstances are possible due to the fact that infrastructure is designed to cater for peak usage whether that peak occurs daily, seasonally or in the case of emergency. Under periods of non-peak usage, therefore, more users can be accommodated in practice. Operating at over-capacity does not mean the infrastructure ceases functioning totally, but rather that certain users, depending on their location in relation to the infrastructure system, will not have, or will have limited service, for certain periods, be that daily or seasonally.

The problem created by this phenomenon in the model is that in situations where theoretical over-capacity occurs, as soon as the scenario population exceeds the existing population, the cost of rectifying the current over-capacity problems accrue to the new development. The problem has been solved in the model, in areas where the problem exists, by proportioning the incurred cost to the additional population defined as the difference between scenario population and infrastructure design population, rather than the difference between scenario population and existing population. An element of the "theoretical" still remains, however, in that the "new" or additional population figures includes some of the existing population, but this is preferable to assigning all the cost to the truly "new" population with the result that the per capita costs for those areas are relatively higher than for others, where no over-capacity conditions exist.

6.2.4 Base cost determination

6.2.4.1 Network base costs

The determination of generic per metre pipe costs under ideal conditions was based on an assessment of sewer contract documents and standards from the South African Bureau of Standards (SABS). Total base costs were derived by aggregating five cost elements: preliminary and general, earthworks, bedding, mains and manholes/valves and metres. Preliminary and general cost are those associated with organising and supervising the construction, setting up the site office, equipment and plant hire and standing time, under assumed ideal conditions of labour intensive constructions methods, where the construction site is less than 50km away from the contractor's site camp. Earthworks costs include clearing and preparing the site, excavation and backfill under ideal conditions of soft excavation. Bedding costs relate to embedding the pipe in granular and fill material. Main costs are the actual pipe costs including materials and labour cost of laying, fitting and junctions. For sewer main base costs, asbestos cement material and a 150 mm diameter pipe are assumed. Water main costs assume uPVC pipes and a diameter of 100 mm. Sewer manhole costs include material, excavation, supply and installation and covers and steps. Water valve and metre costs includes the material costs of valves, valve chambers, anchor blocks and water metres. Base cost components and their specific contribution to the total base costs are detailed for water and sewers in Appendix B.

The resulting sewer base cost is R206.76 per metre whereas the water base cost is less than half of the sewer base cost, at R92.63 per metre (1995 prices). The reason for this significant cost difference is predominantly due to the difference in preliminary and general, main and manhole/valves and metres costs (Figure 6.5). Preliminary and general costs for water are less than half that of sewers largely attributable to the determination of these costs on a percentage basis of total cost, which in the case of water pipes, is significantly less. For both water and sewers, preliminary and general costs are calculated as about 20 percent of total costs Sewer main costs, are more than double the cost of water mains and manhole costs are five times more than water valve and metre costs (Figure 6.5).

6.2.4.2 Adjusting network base costs for diameter requirements

The population density scenario directly impacts on pipe cost in relation to pipe diameter. The greater the number of people who use the pipe, the larger the diameter needs to be, the greater the cost. The relationship between pipe diameter and population is very different for water pipes and sewers. Whereas slope plays an important role in the relationship between sewer diameter and population, the network nature of water supply and pressure considerations, complicate the relationship between population and water pipe diameter.

6.2.4.2.1 Water network base cost adjustments for diameter

The base cost for water feeder mains and system mains was calculated for a pipe diameter of 110 mm which ideally supplies a certain number of people with water at an ideal pressure. As the number of people requiring water supply increases, so the required pipe diameter increases in relation to level of service. For a high level of service, where more water is used per household, a larger pipe diameter is required in order to achieve optimum pressure and flow conditions (Figure 6.6). For the same population, a lower level of service, with associated reduced water usage, a smaller pipe diameter is required. In the model, the cost implications of diameter on the base cost are broadly treated in terms of percentage increase of the base cost for various pipe diameter categories (Table 6.1).

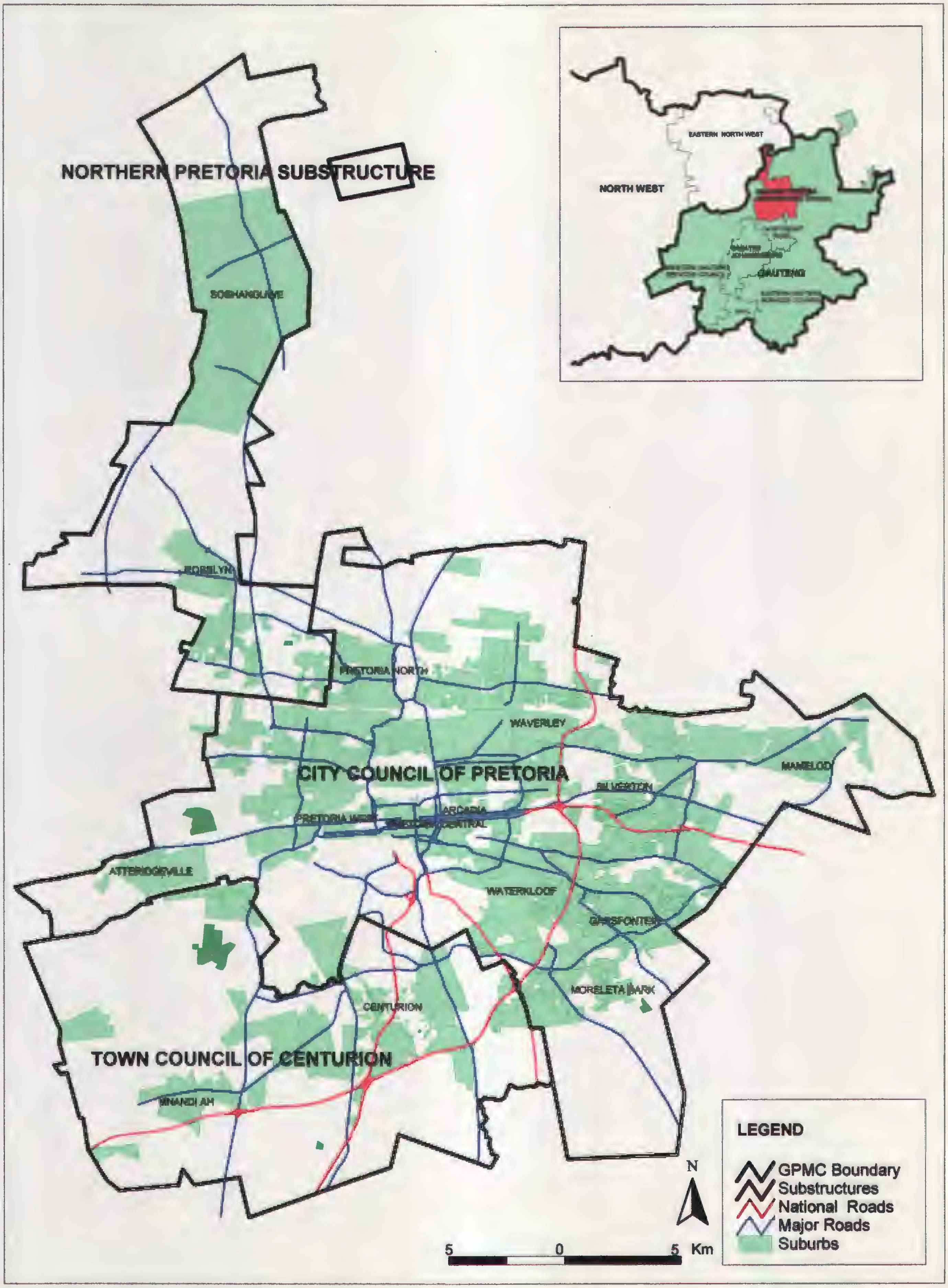


Figure 1.3: Locality map of the Greater Pretoria Metropolitan Council study area

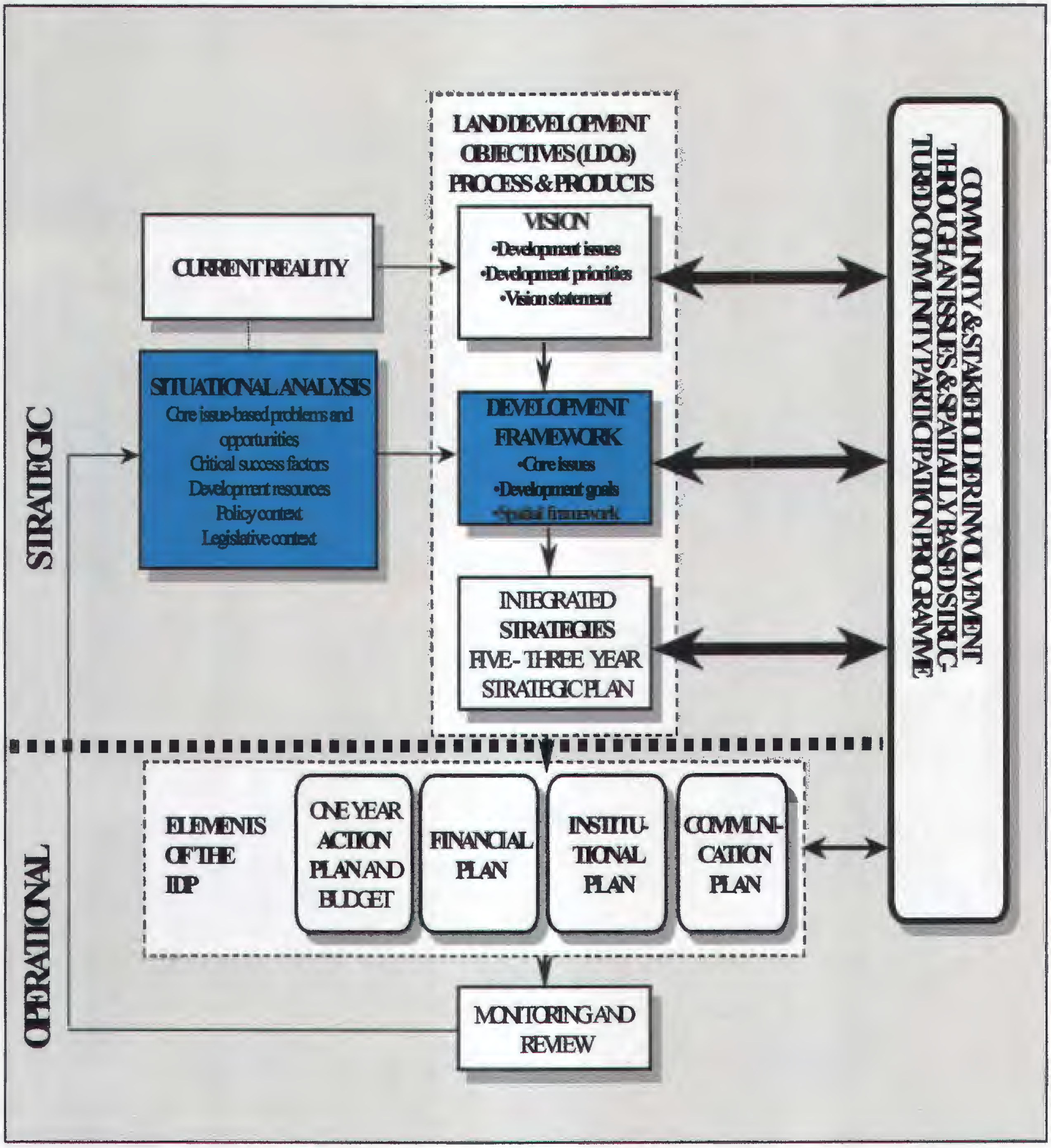


Figure 1.1: Integrated Development Plan (IDP) methodology

(Source: Republic of South Africa, Department of Constitutional Development 1997)

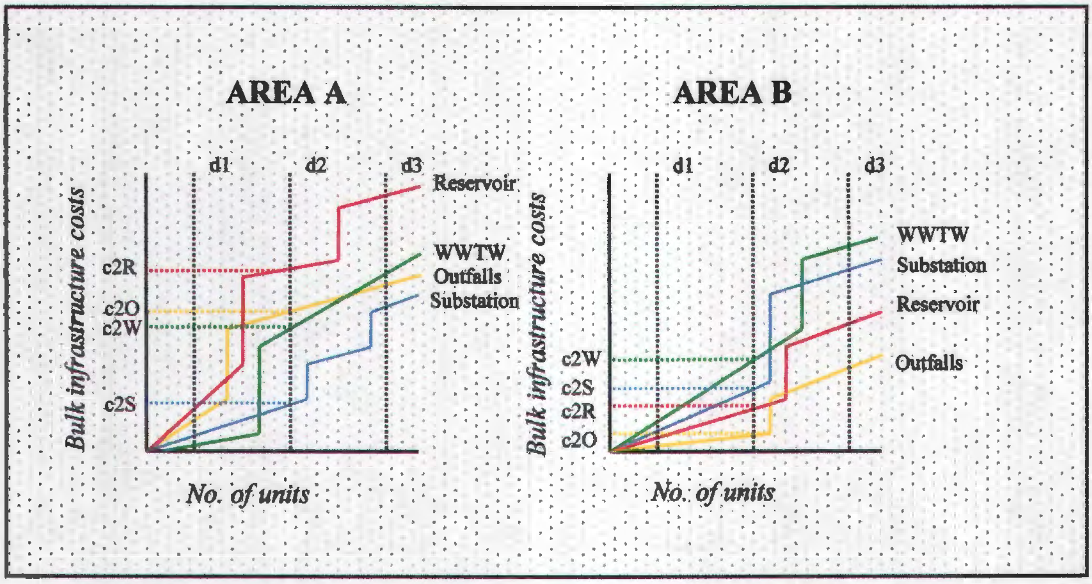


Figure 5.2: Graphical representation of the bulk infrastructure potential cost model in relation to threshold theory

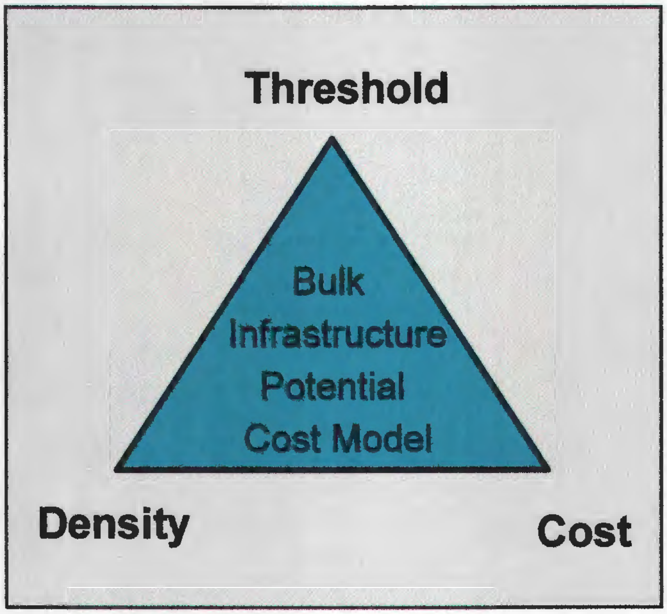


Figure 5.3: Three pillars of the bulk infrastructure potential cost model

Table 6.1: Percentage water pipe base cost increase adjustments per pipe diameter category

Pipe diameter category	% increase in base cost	Adjusted base cost (Rand per metre)
<150mm	0	92.63
150 - 300mm	8	100.04
>300mm	16	107.45

6.2.4.2.2 Sewer base cost adjustment for diameter

The relationship between population number and sewer diameter is complicated by slope considerations. To simplify the model, differences in level of service were not considered in compiling the table which relates population numbers to diameter under different slope conditions (Table 6.2). The population which can be accommodated by a specific diameter pipes is assumed to be proportional to the area of the pipe. In calculating the relationship between population and sewer diameter, a peak flow rate of 0.0039 litres/second/day was used, based on a usage factor of 600litres/household/day, with a household size of 5 persons. A minimum slope of 1:300 and a maximum flow rate of 1.5 metres/second were assumed. In order to maintain optimum flow, if the slope is such so as to cause the calculated flow to exceed the maximum flow rate of 1.5 metres/second, a smaller pipe diameter must be used. Also taken into account in the calculation is the fact that the larger the pipe, the less sensitive the pipe is to slope. The Manning formula and continuity principle were used as the basis for the calculation (Appendix C).

Table 6.2: Maximum population accommodated according to pipe size and slope

Pipe diameter (mm)	Slope					
	0.3%	0.5%	1%	3%	5%	7.5%
< 100	860	1100	1590	2720	3000	3000
101 - 150	2540	3280	4615	6780 @slope 2.2%	6780 @slope 2.2%	6780 @slope 2.2%
151 - 200	5385	6925	10000	12050 @slope 1.5%	12050 @slope 1.5%	12050 @slope 1.5%
201 - 250	9745	12565	17820	18975 @slope 1.15%	18975 @slope 1.15%	18975 @slope 1.15%
251 - 300	18205	20512	27180 @slope 0.9%	27180 @slope 0.9%	27180 @slope 0.9%	27180 @slope 0.9%
301 - 400	33335	42820	48205 @slope 0.63%	48205 @slope 0.63%	48205 @slope 0.63%	48205 @slope 0.63%
401 - 500	58974	73075 @slope 0.48%	73075 @slope 0.48%	73075 @slope 0.48%	73075 @slope 0.48%	73075 @slope 0.48%
501 - 600	100000	107690 @slope 0.37%	107690 @slope 0.37%	107690 @slope 0.37%	107690 @slope 0.37%	107690 @slope 0.37%
601 - 900	242302 @slope 0.3%	242302 @slope 0.3%	242302 @slope 0.3%	242302 @slope 0.3%	242302 @slope 0.3%	242302 @slope 0.3%
901 - 1200	431183 @slope 0.3%	431183 @slope 0.3%	431183 @slope 0.3%	431183 @slope 0.3%	431183 @slope 0.3%	431183 @slope 0.3%
>1200	>431183 @slope 0.3%	>431183 @slope 0.3%	>431183 @slope 0.3%	>431183 @slope 0.3%	>431183 @slope 0.3%	>431183 @slope 0.3%

In the model, the cost implications of diameter on the base cost are broadly treated in terms of percentage increase of the base cost for various pipe diameter categories (Table 6.3).

Table 6.3: Percentage sewer base cost increase adjustments per pipe diameter category

Pipe diameter category	% increase in base cost	Adjusted base cost R per metre)
<150mm	0	206.76
150 - 300mm	8	223.3
301 - 600mm	16	239.84
601 - 900mm	30	268.78
901 - 1200mm	40	289.46
>1200mm	50	310.14

6.2.4.3 Facility base costs

6.2.4.3.1 Reservoir costs

Reservoir construction costs were obtained from contract documentation and a graph prepared which relates reservoir capacity to 1995 cost (Figure 6.7). The graph was smoothed using regression. Tower and associated pumps costs are included in the reservoir cost. The graph applies to construction costs of both new reservoirs (distribution and receiving) and additional modules.

6.2.4.3.2 Waste water treatment works costs

WWTW unit costs were obtained from an assessment of contract documentation (Table 6.4). Economies of scale come into effect with large units costing less per person than smaller units.

Table 6.4: Waste water treatment works unit costs

Size of WWTW unit	Persons per unit	Unit construction cost (R)	Per capita cost (R)
Small	5 000	250 000	50
Medium	20 000	800 000	40
Large	50 000	1 500 000	30

6.2.4.3.3 132 kV substation costs

Generalised electricity unit costs for various substation sizes (MVA) were obtained from Pretoria City Council's Primary Power Distribution Department (Table 6.5). Costs differ according to whether or not the substation stages required are new or additional to an existing substation. If the substation is new, the first or initial stage costs more than the additional stages of the new substation.

Table 6.5: Electricity 132 kV substation costs

Size of substation unit (MVA)	Initial stage cost (Rand million)	Additional stage cost (Rand million)
20	14.4	5.0
35	-	7.5
40	19.4	7.5

6.2.5 Additional cost determination

Additional costs account for those costs incurred as a results of non-ideal conditions, either man-made or natural, whereas base costs are the per metre costs which apply under ideal conditions. Additional costs are either in the form of continuous land and ground conditions which the pipe needs to pass through, which have been termed influencing factors, or, discrete, once-off obstacles which the pipe needs to pass over or under, which have been termed once-off factors. In the model, influencing factor costs are expressed as a percentage by which the base cost should be increase to account for non-ideal conditions whereas once-off costs are expressed as a Rand cost, to be added to the base cost at the point of contact.

Additional costs apply only to water and sewer network costs and not to facility costs as it is assumed that exact site choice for specific facilities will take into account and minimise non-ideal conditions. It was decide not to apply additional costs to water and sewer link costs as precise pipe positions are not known. For sewer outfall network and water feeder main and system main pipe costs, it is assumed that additional pipe sections required will be layed adjacent to existing pipes and therefore pipe position is known and the effect of the pipe's path through non-ideal conditions can be accounted for by means of additional cost factors. Due to predominantly above-ground routes of electricity conduit, and due to the more coarse level in which electricity costs are handled in the model, additional costs are excluded in electricity cost determination.

In determining the additional cost factors to be used in the model, engineering experience and contract documents were used to approximate percentage and once-off cost increases applicable for each condition. Additional factors are included in the model in a coarse and non-detailed manner because the effect of additional factor costs on the per metre cost of pipes is relatively insignificant in relation to the base cost. It would be inappropriate and disproportionate, in terms of costs and data acquisition, to undertake a detailed analysis and costing of what eventually contributes relatively little to the final cost. It is the intention to reflect on the importance of including additional costs in the model, in the conclusion, once results have been assessed.

6.2.5.1 Influencing factor costs

Influencing factors can be categorised broadly into land use and geotechnical factors (Table 6.6 - Appendix A). Land uses are further classified into categories which reflect intensity of development, which in turn is proportional to difficulty of excavation and thus to cost. The available land use classification of the study area was used to categorise land into undeveloped, developed, CBD/high density and environmentally sensitive areas. Undeveloped areas correspond to ideal conditions and thus only the base cost is applied, while the influencing factor is zero for both water and sewer costs. Developed and CBD/high density areas exert a cost penalty on pipe costs, more so for sewers than for water pipes due to the relatively larger diameters of sewers and the fact that a certain slope has to be maintained in order to facilitate flow in the sewers. CBD/high density areas exact the highest cost penalty due to the intensity of development and the related amount of impermeable surfaces, such as pavement and road surface which need to be excavated and also the difficult surrounding conditions of traffic and pedestrian movement which slows down excavation works.

Local street crossings are included in the land use cost penalties with more street crossings probable in more highly developed areas. Sensitive environmental areas in the form of nature reserves and large metropolitan open spaces may require careful excavation and construction methods or additional length to circumvent certain ecologically sensitive spots, increasing costs.

Geotechnical influencing factors comprise engineering geological and slope conditions (Table 6.6 - Appendix A). The geological classification is in terms of a broad qualitative assessment of the geotechnical constraints associated with particular rock types. This generalisation of geotechnical properties is based on literature and experience of problems relating to rock formations. The numeric part of the class, refers to the severity of the condition. Classes beginning with 1, are the least problematic, thus least costly, in terms of infrastructure provision, whereas classes beginning with 3, are problematic from an excavation and stability perspective and will have higher associated costs. The alphabetical component of the classification, refers to the type of constraint (Table 6.7 - Appendix A). The source which was utilised to relate costs implications to each class, did not distinguish between water and sewer provision and thus cost impact is the same for both (Williams 1994).

Slope has a significant impact on sewer cost. Too much slope can be a problem and

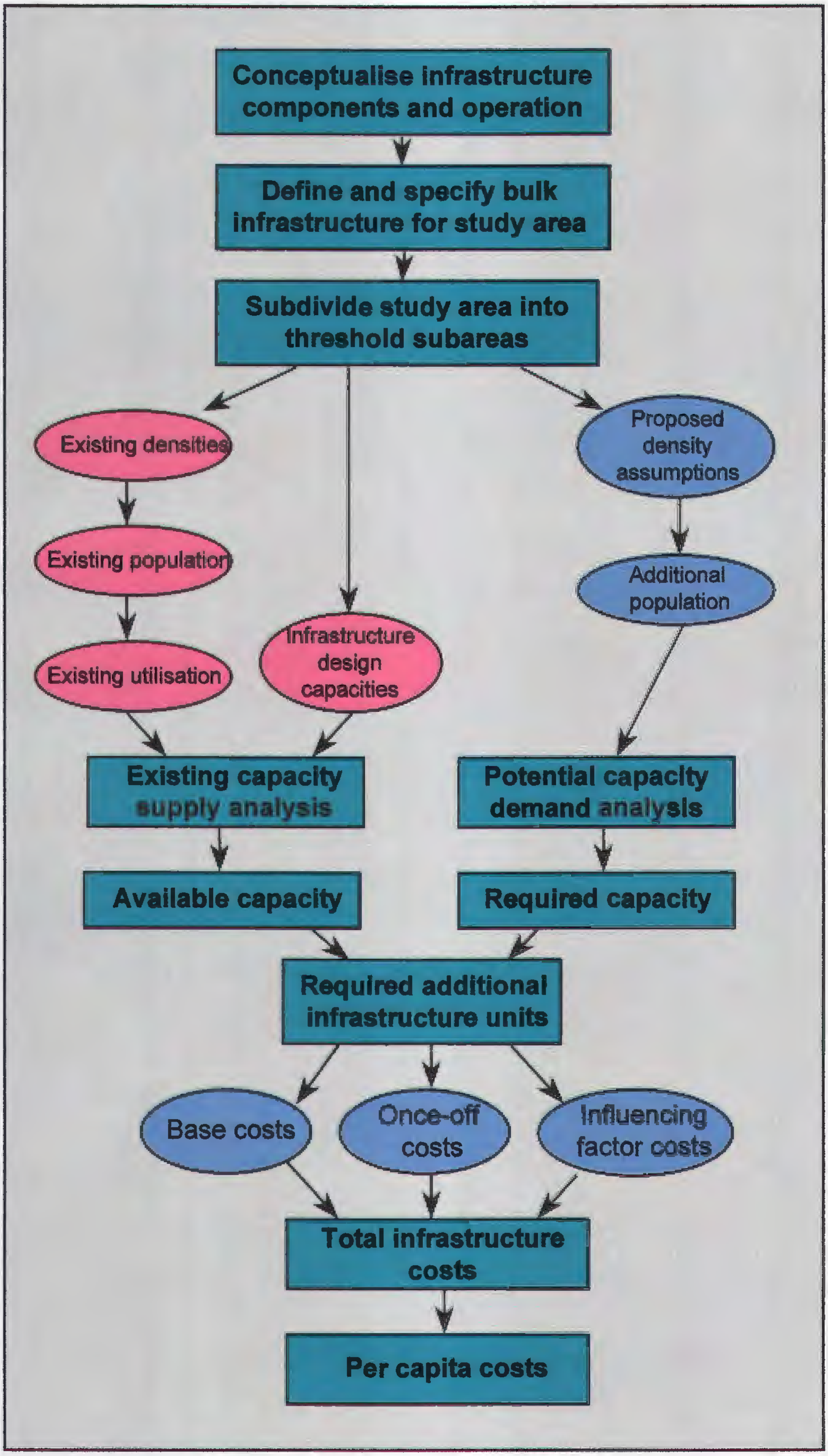


Figure 5.5: Overall bulk infrastructure potential cost model methodology

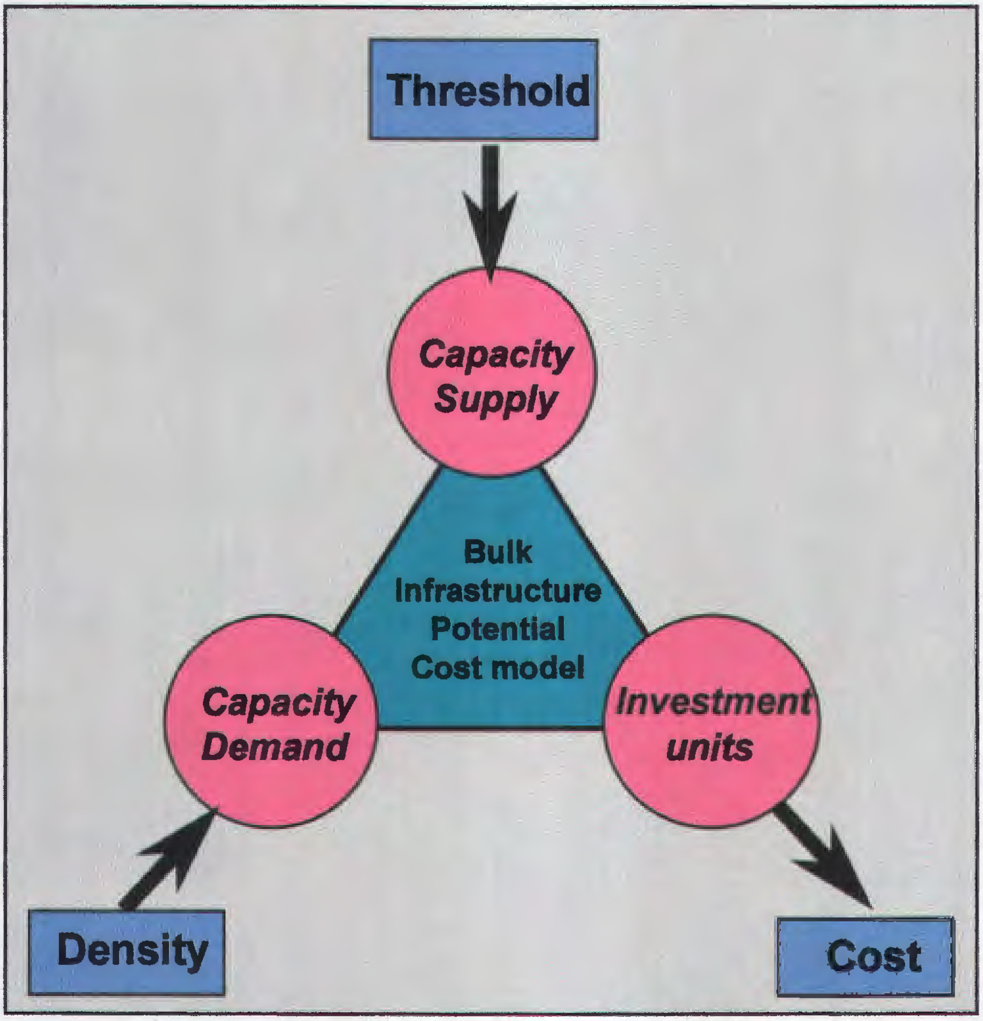


Figure 5.4: Mechanisms of interaction between the three pillars of the bulk infrastructure potential cost model

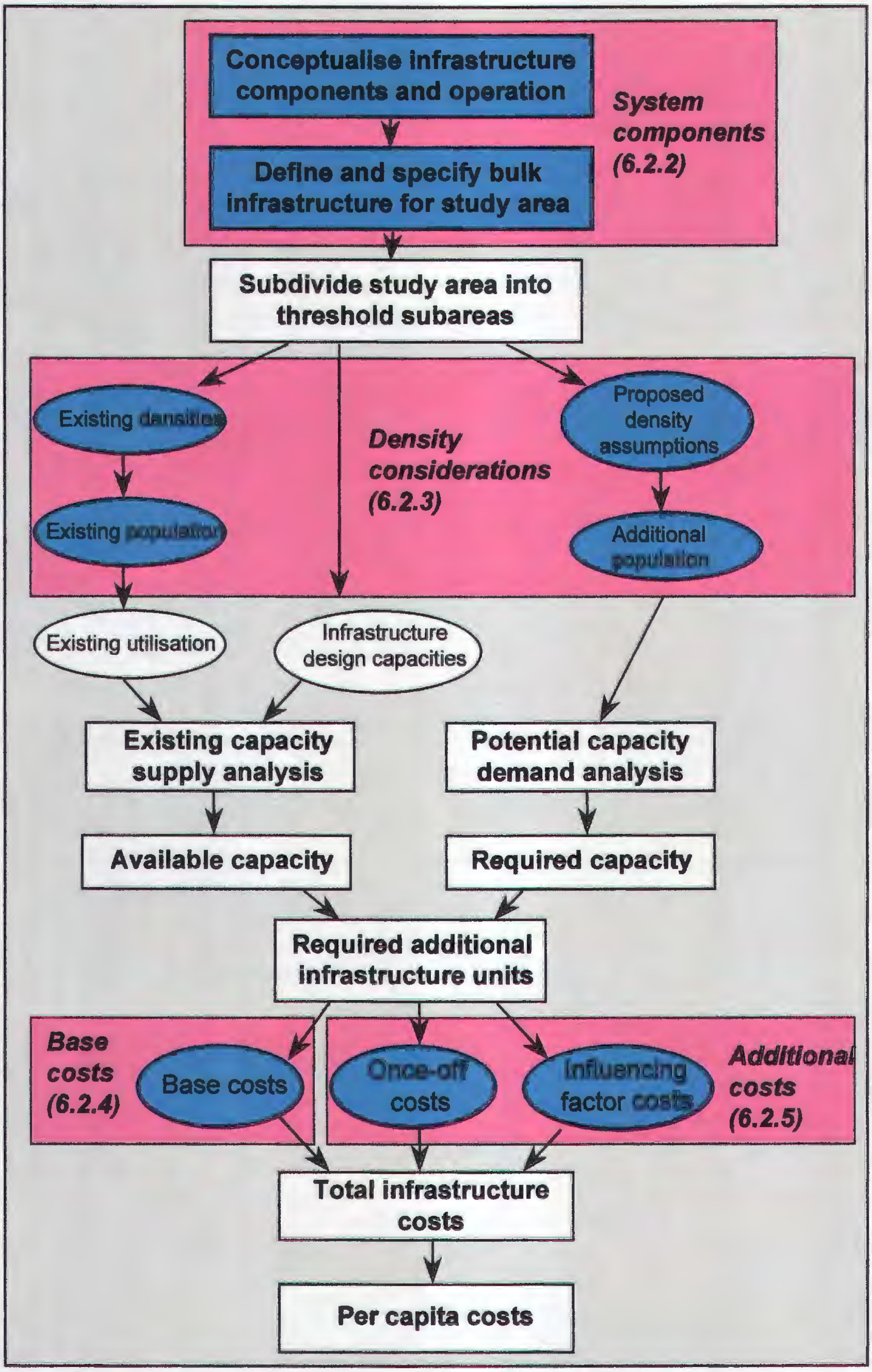


Figure 6.1: Critical components of the overall bulk infrastructure potential cost model methodology elaborated on in Section 6.2 (numbering in parenthesis indicates relevant text paragraph number)

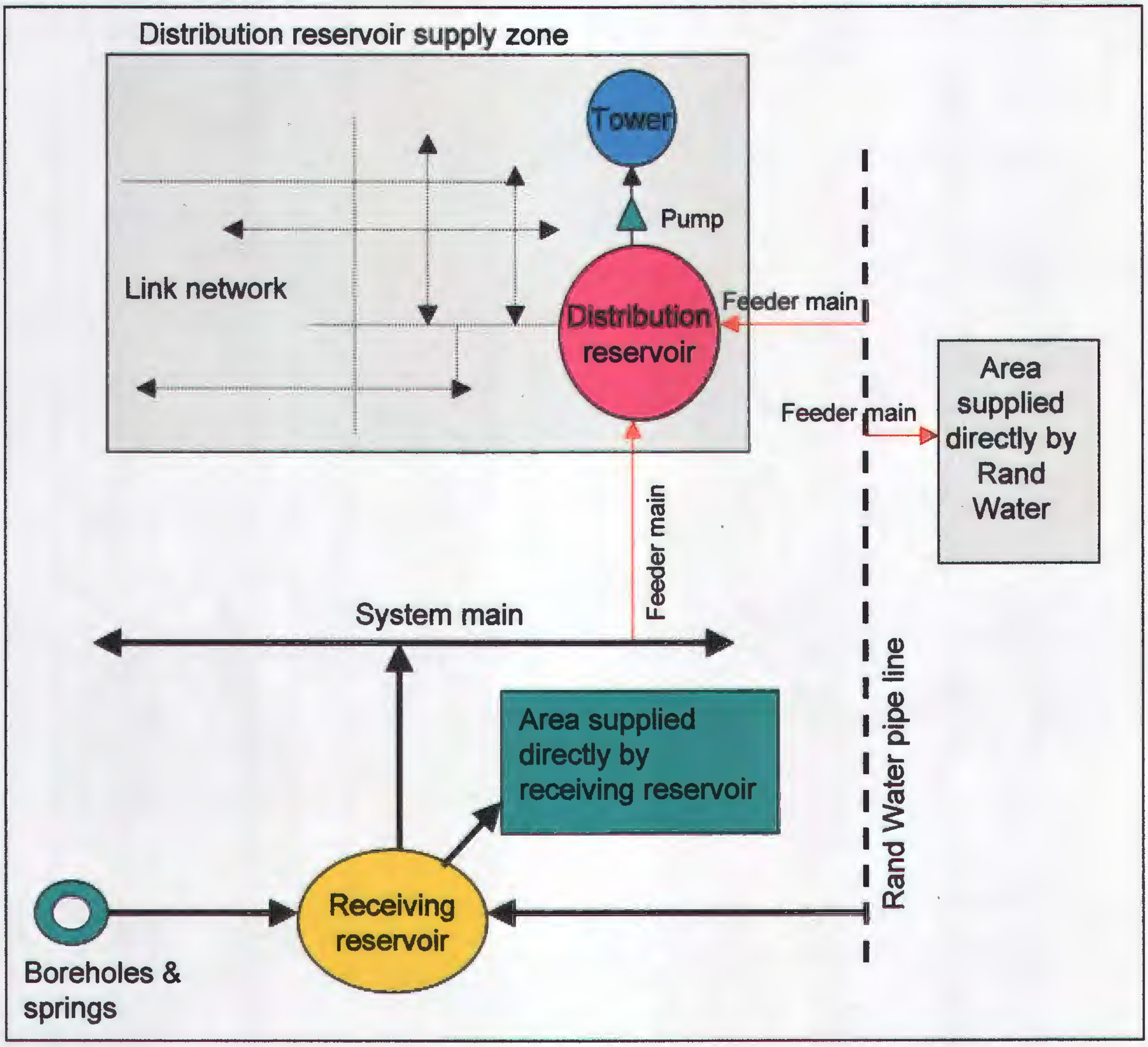


Figure 6.2: Schematic representation of the water supply system in the study area

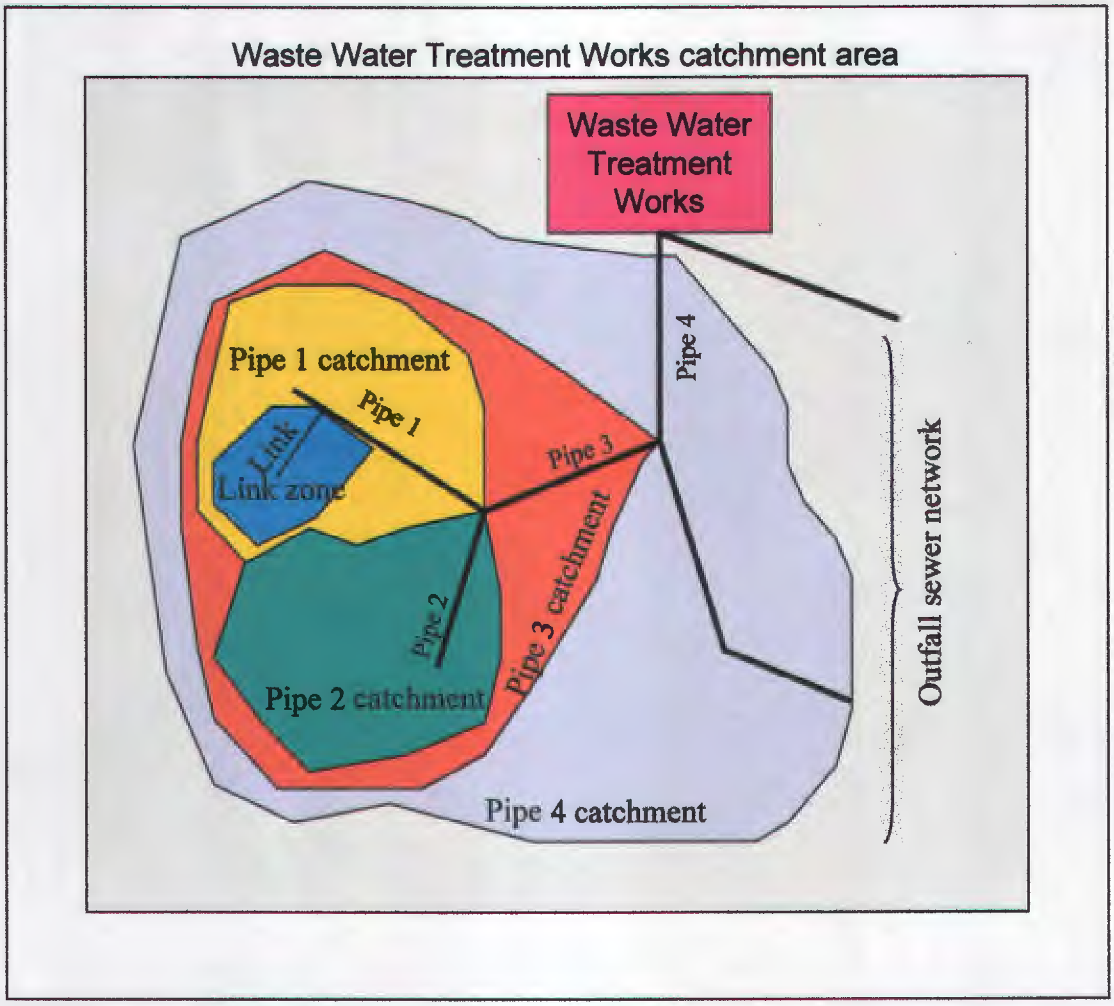


Figure 6.3: Schematic representation of the sanitation system in the study area

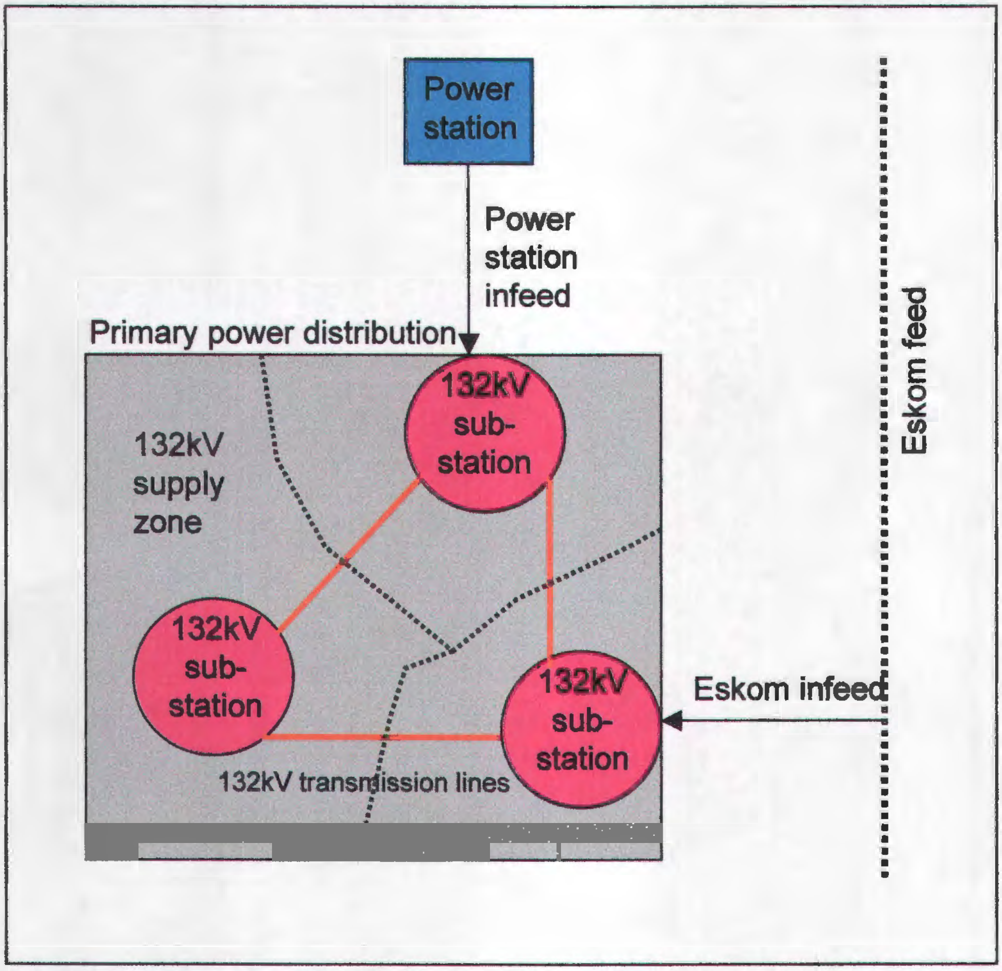


Figure 6.4: Schematic representation of the electricity supply system in the study area

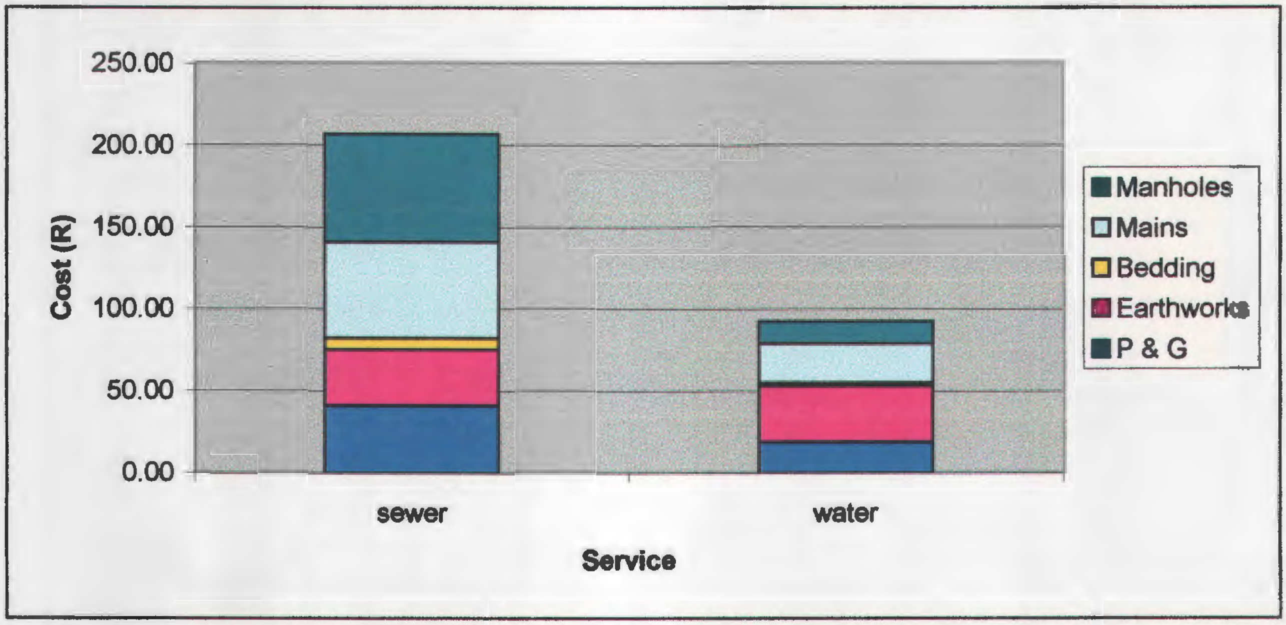


Figure 6.5: Breakdown of sewer and water pipe per metre base costs into cost components

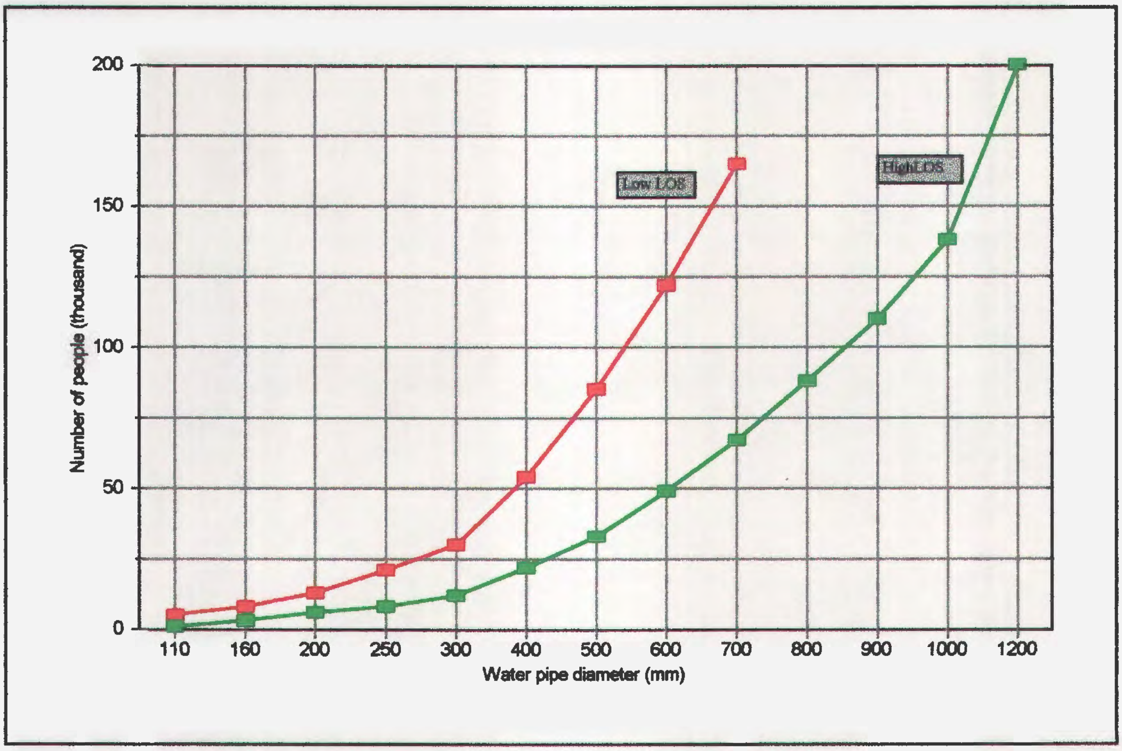


Figure 6.6: Relationship between pipe diameter and number of persons according to level of service

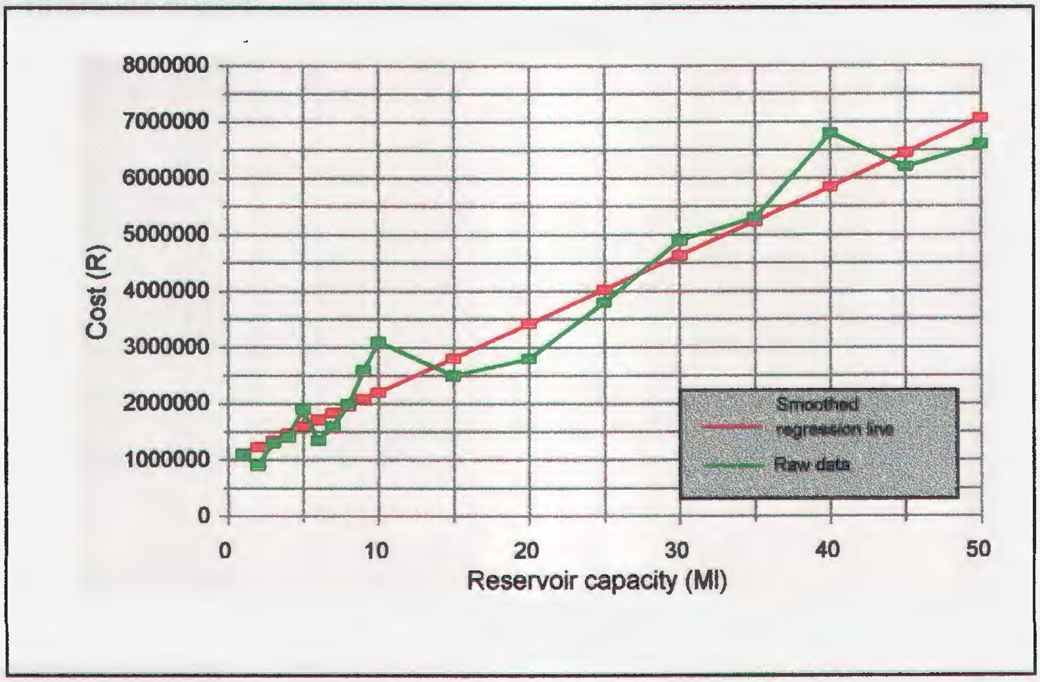


Figure 6.7: Relationship between distribution reservoir capacity and cost

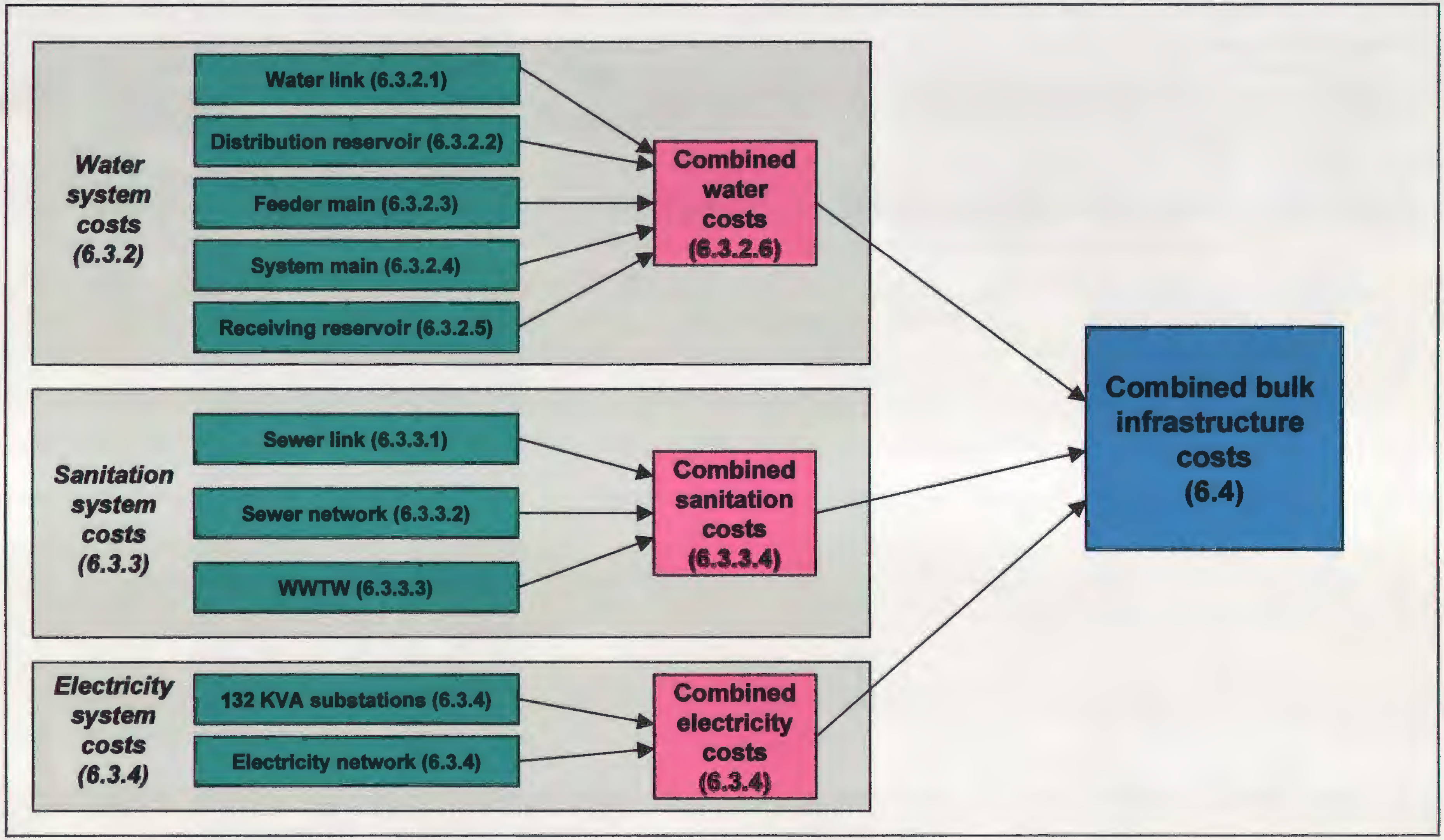


Figure 6.9: Schematic representation of the organisation of paragraphs in Section 6.3 indicating individual costs and their subsequent combination (relevant paragraph numbers are indicated in parenthesis)

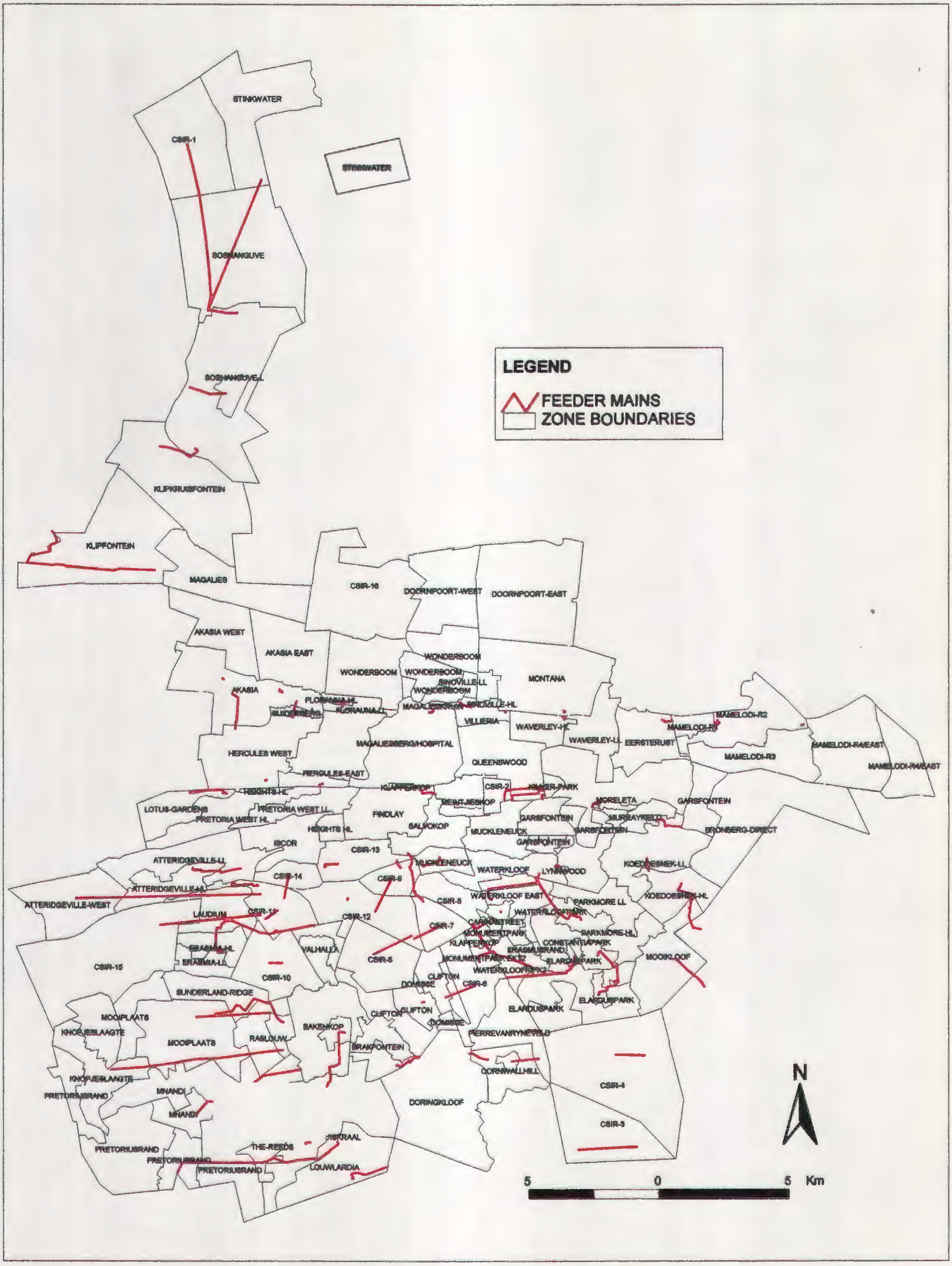


Figure 6.10: Water supply zones and feeder mains

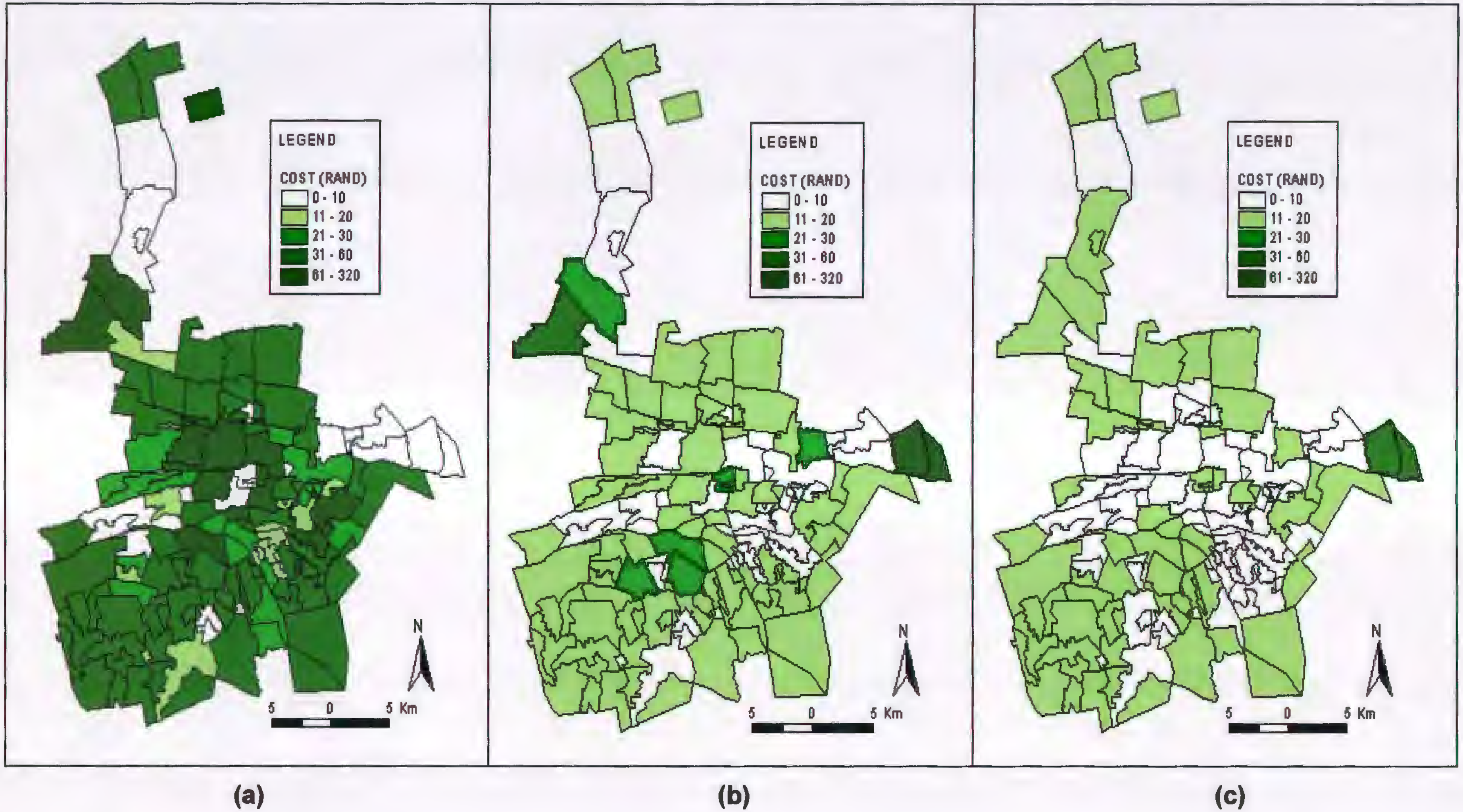
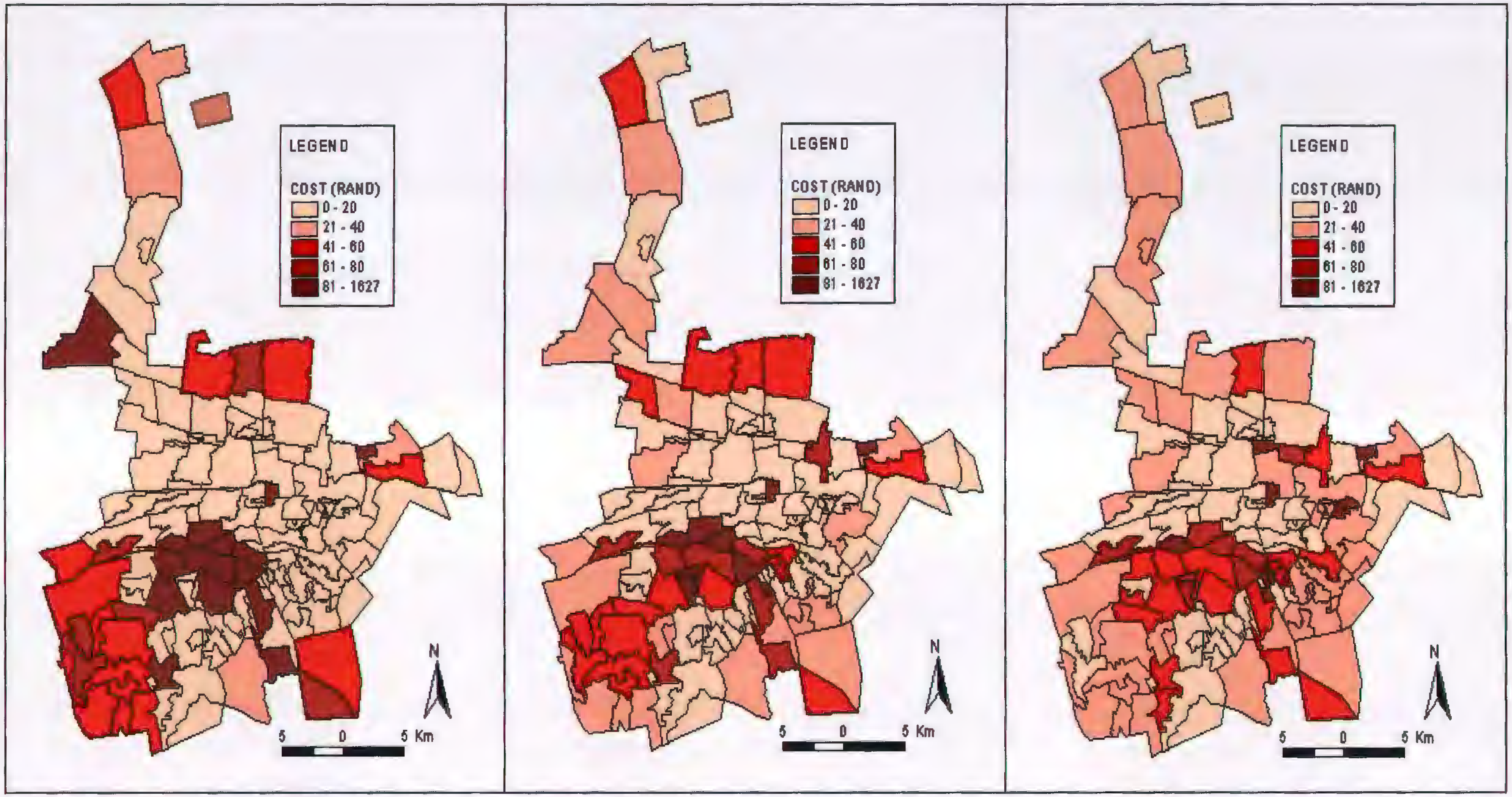
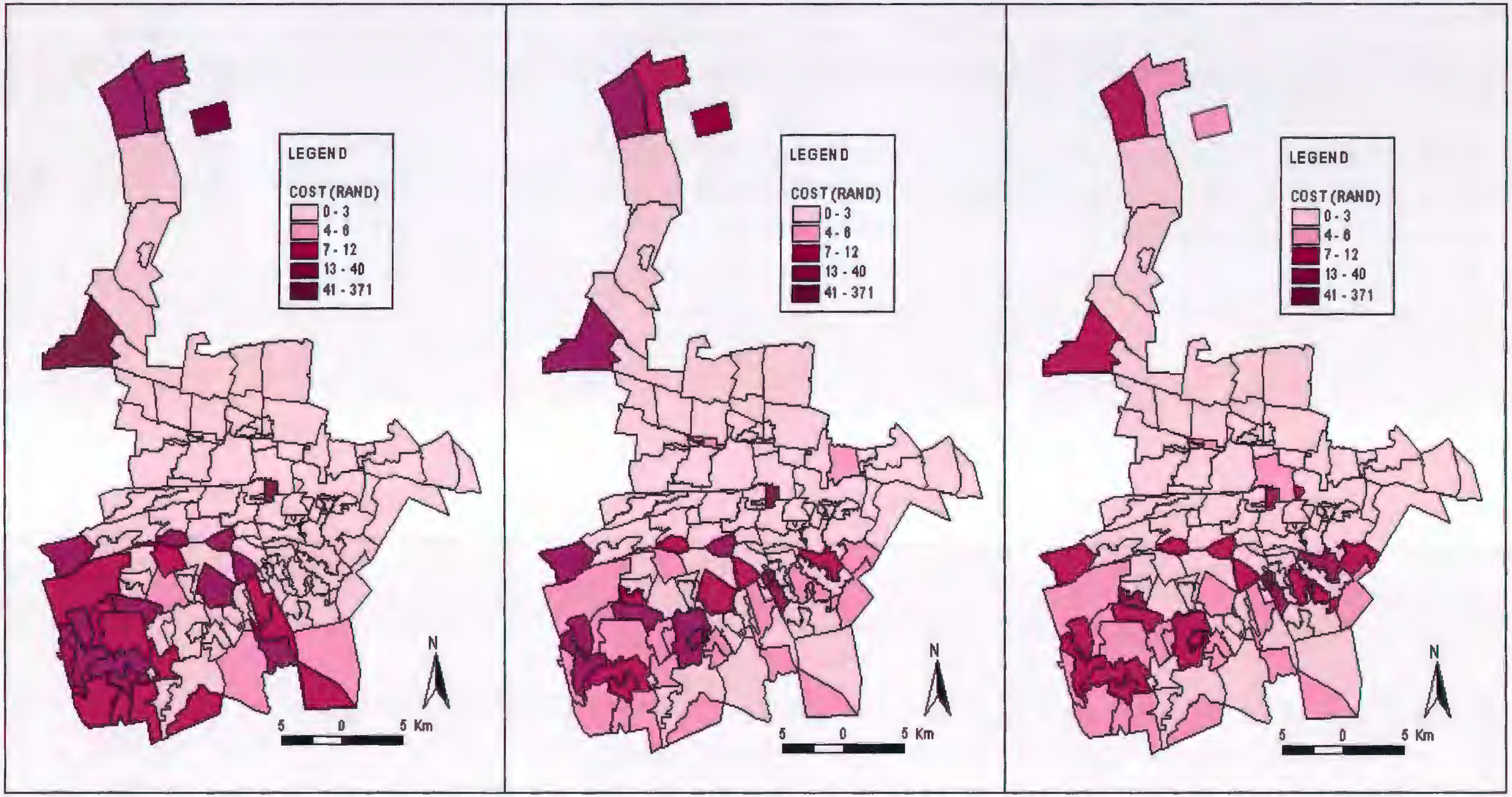


Figure 6.11: Water link costs for the low (a), medium (b) and high (c) density scenarios



(a) **(b)** **(c)**

Figure 6.12: Water distribution reservoir costs for the low (a), medium (b) and high (c) density scenarios



(a) (b) (c)

Figure 6.13: Water feeder main costs for the low (a), medium (b) and high (c) density scenarios

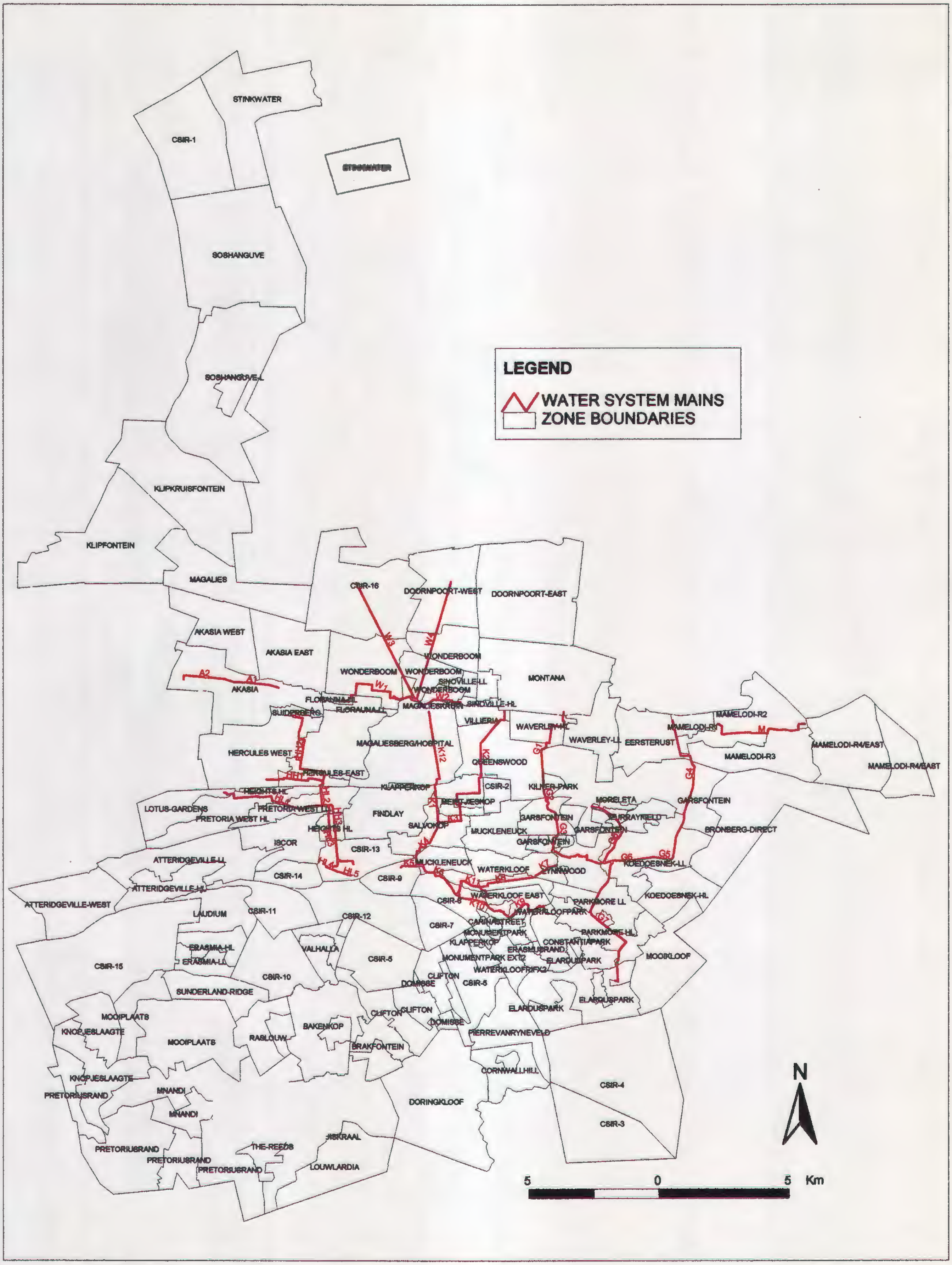
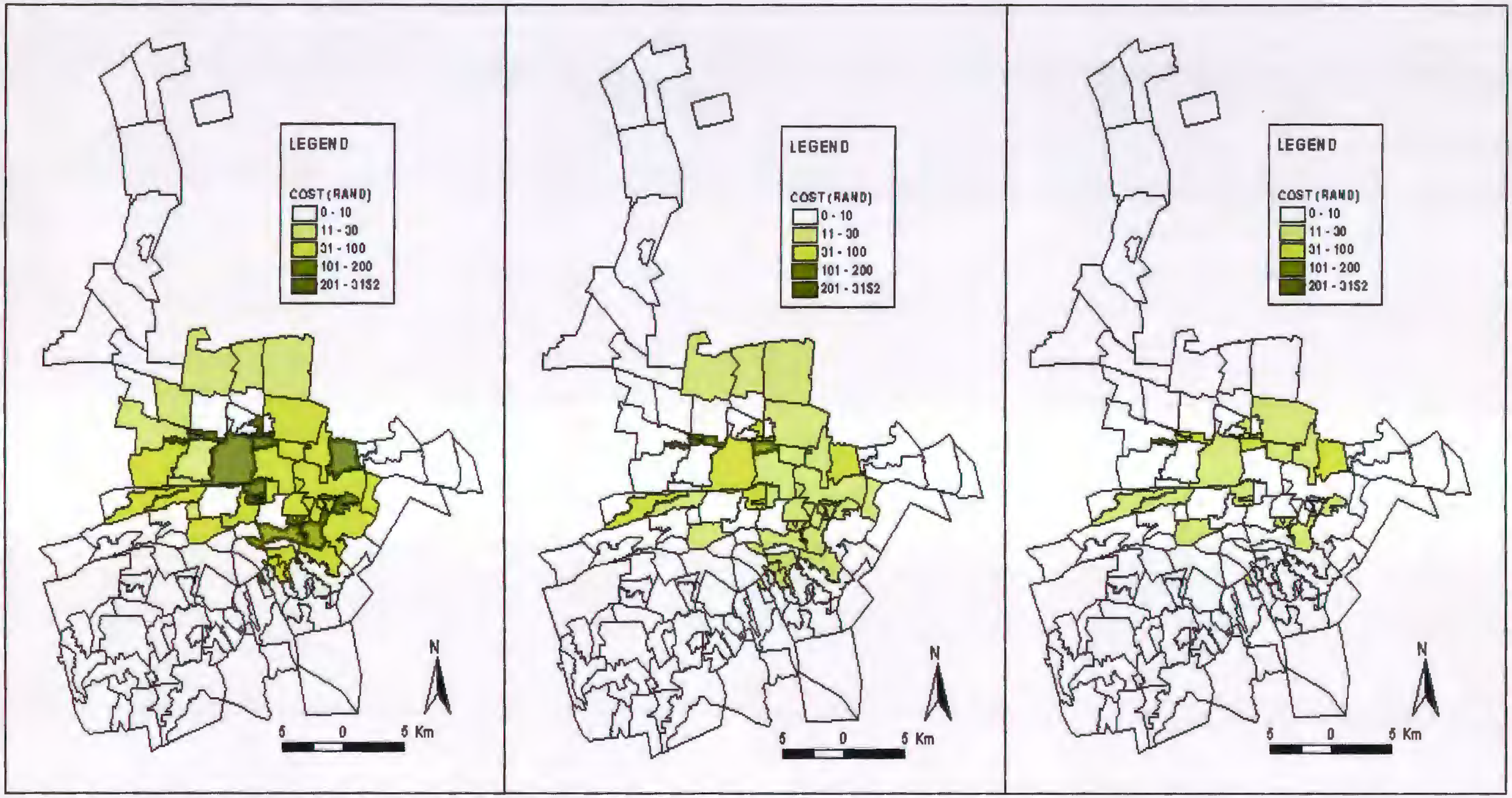


Figure 6.14: Water supply zones and system mains



(a) (b) (c)

Figure 6.15: Water system main costs for the low (a), medium (b) and high (c) density scenarios

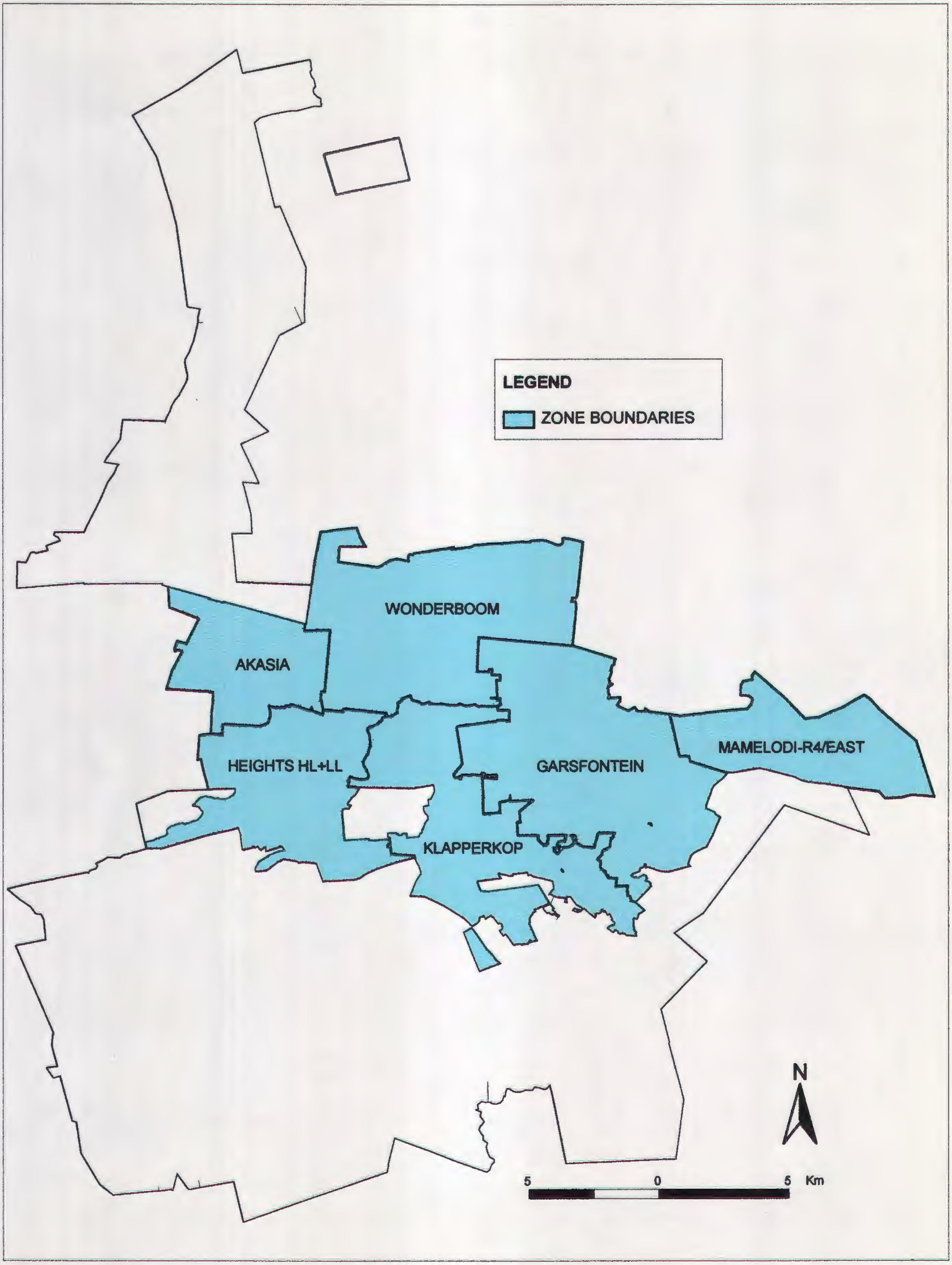
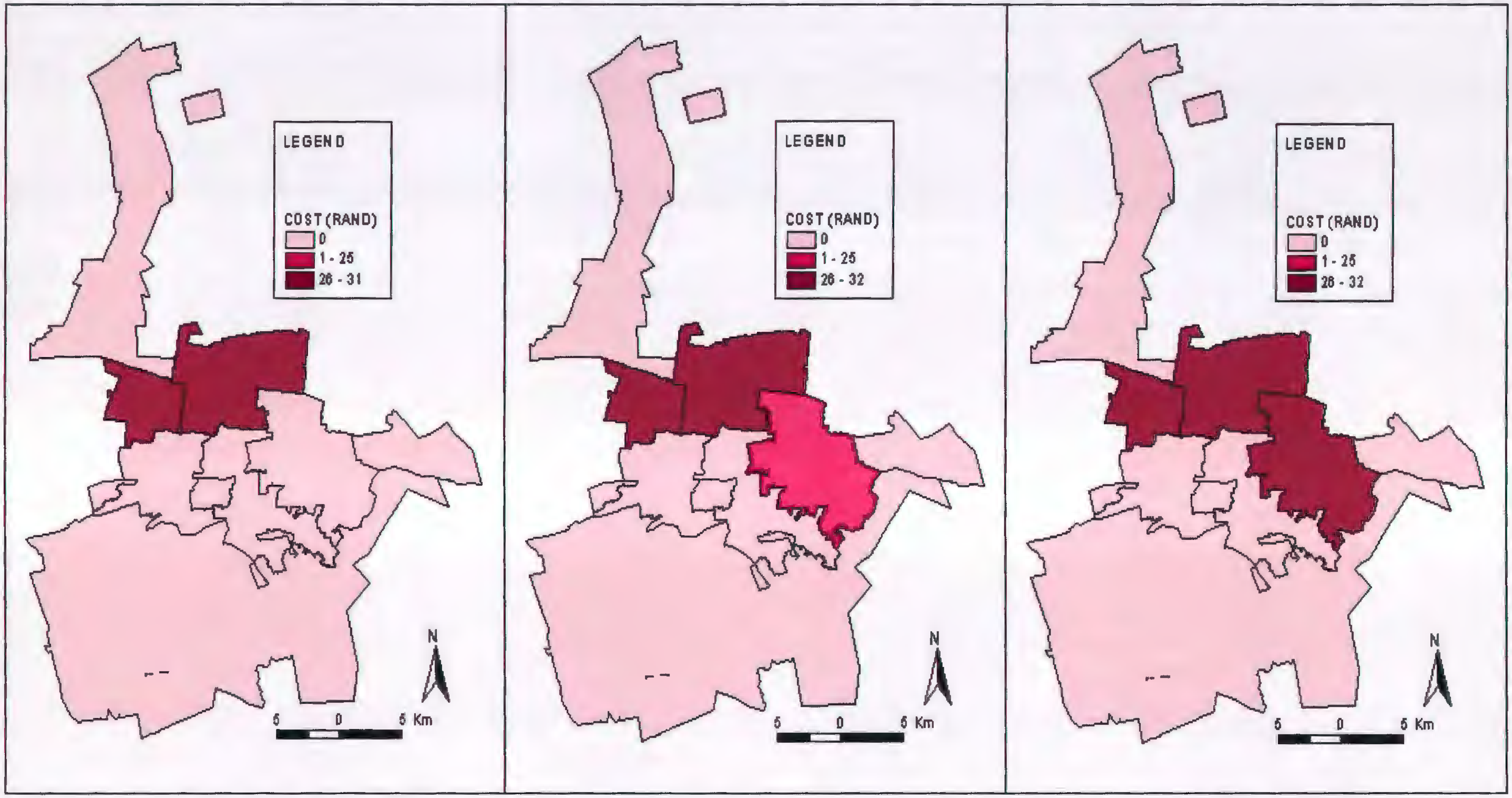


Figure 6.16: Water receiving reservoir zones



(a) (b) (c)

Figure 6.17: Water receiving reservoir costs for the low (a), medium (b) and high (c) density scenarios

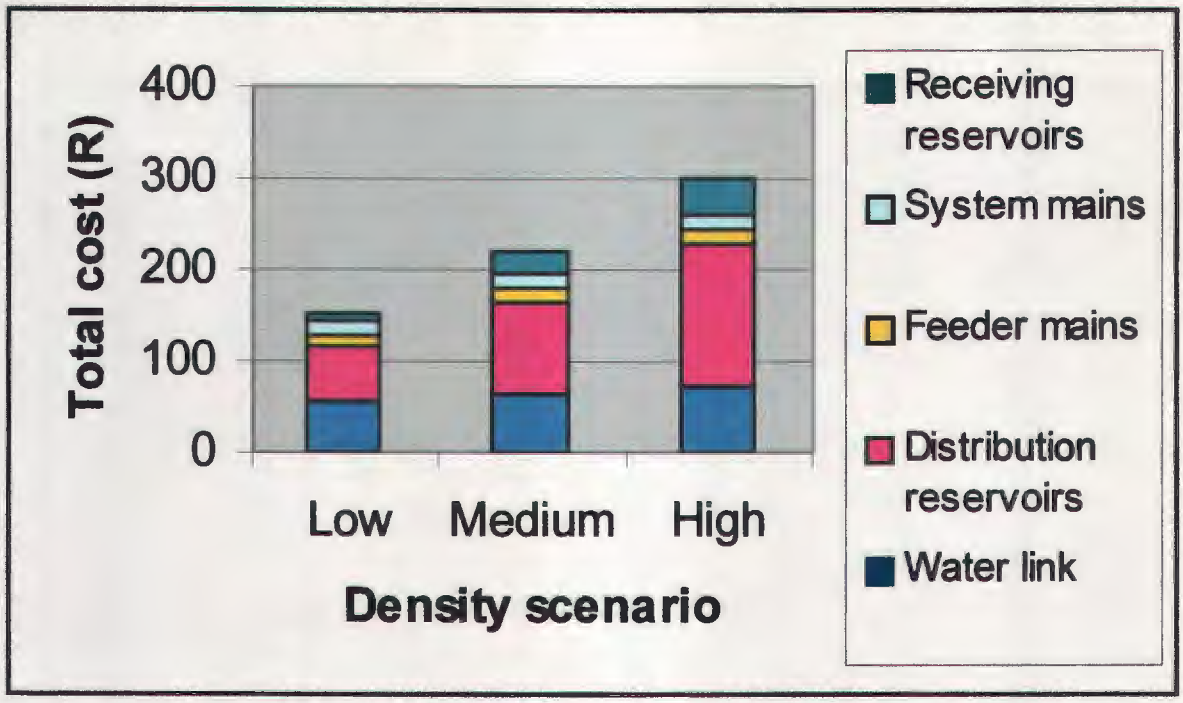


Figure 6.18 (a): Total water costs for each density scenario

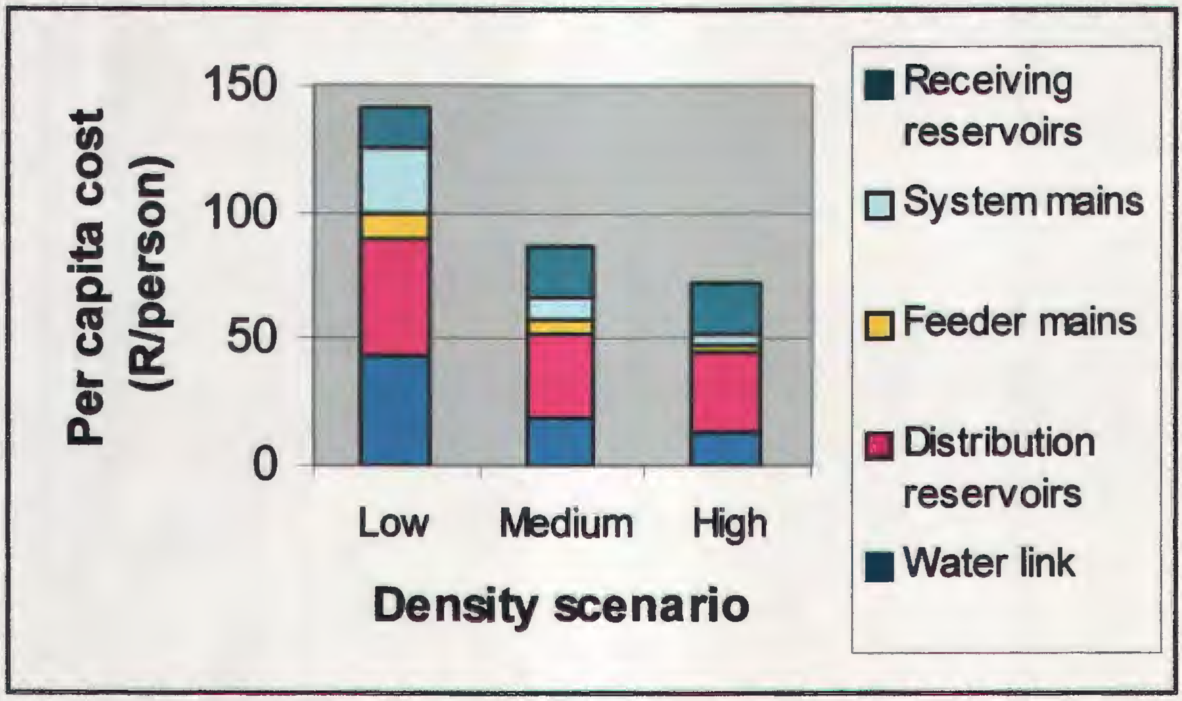


Figure 6.18 (b): Per capita water costs for each density scenario

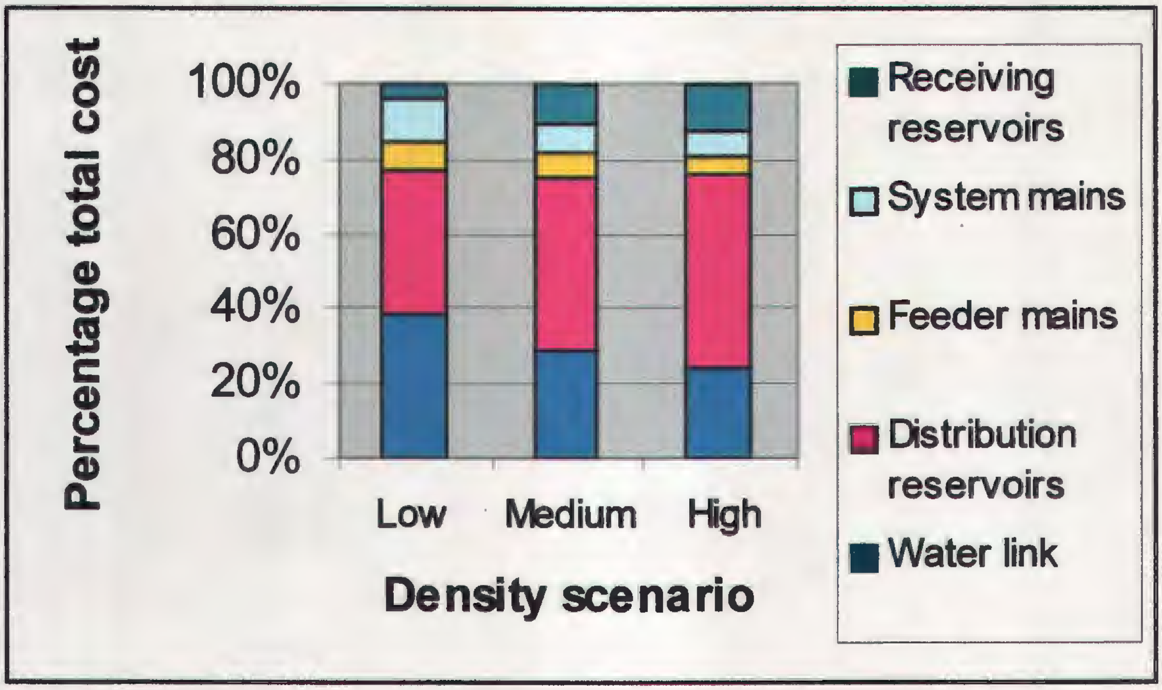


Figure 6.19 (a): Percentage total water costs for each density scenario

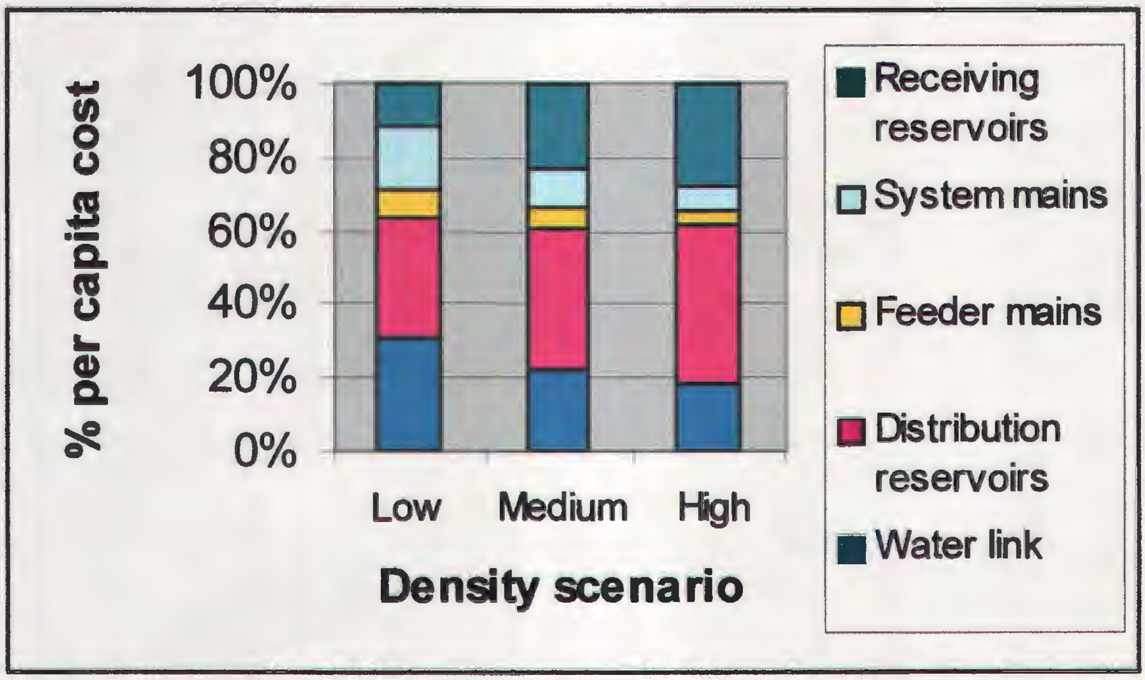
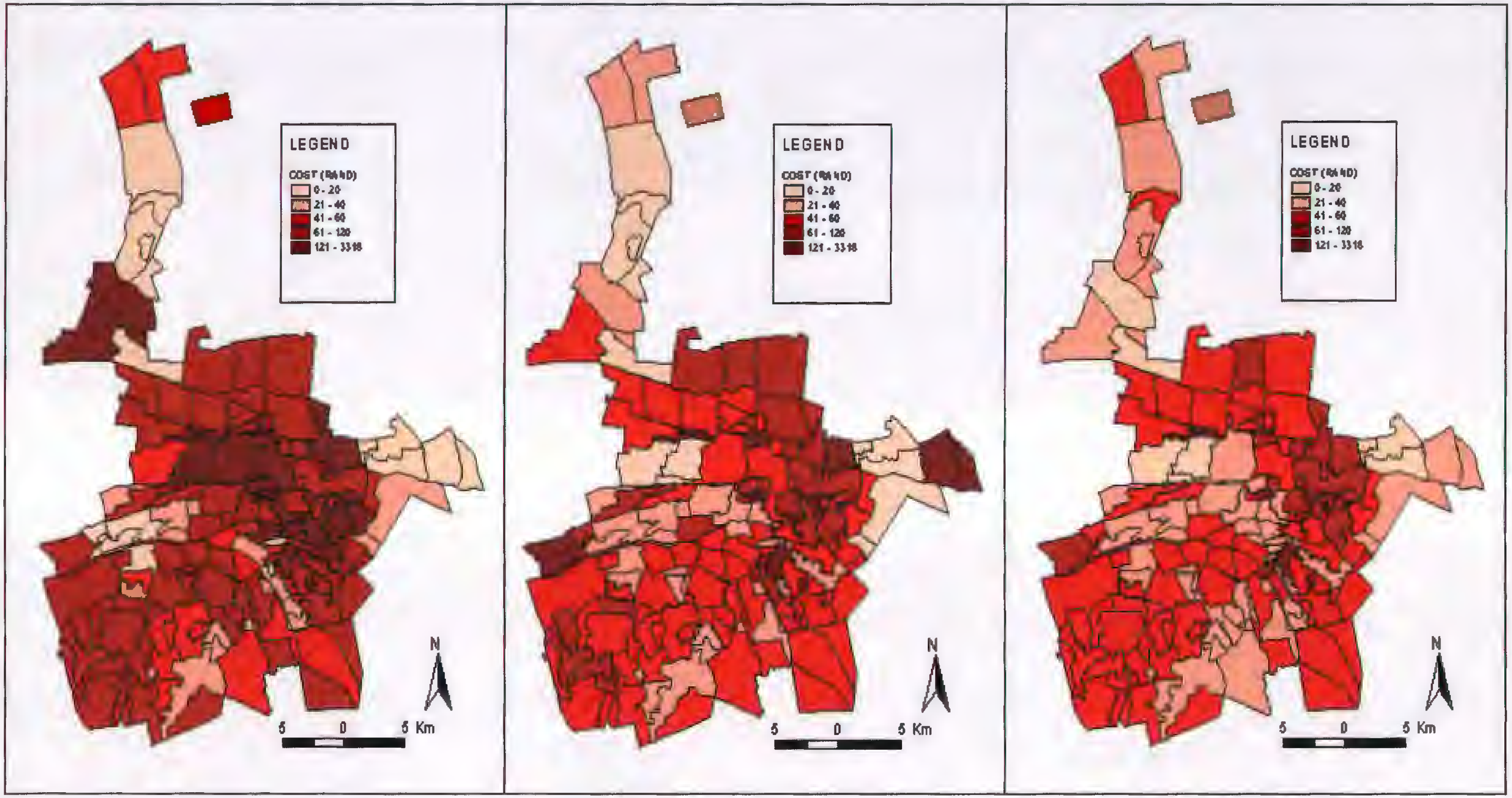
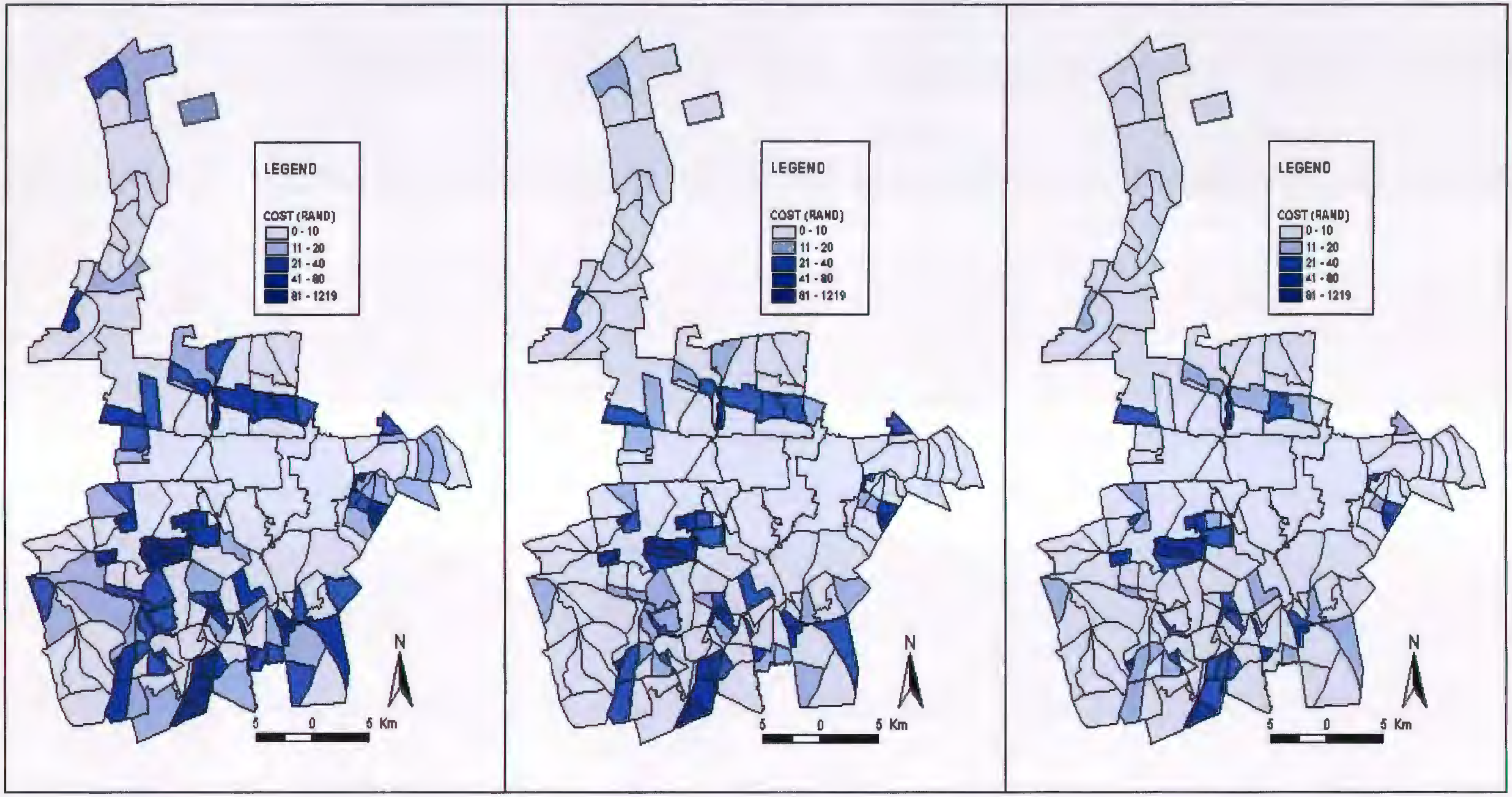


Figure 6.19 (b): Percentage per capita water costs for each density scenario



(a) **(b)** **(c)**

Figure 6.20: Combined water cost overlay for the low (a), medium (b) and high (c) density scenarios



(a) **(b)** **(c)**

Figure 6.22: Sewer link costs for the low (a), medium (b) and high (c) density scenarios

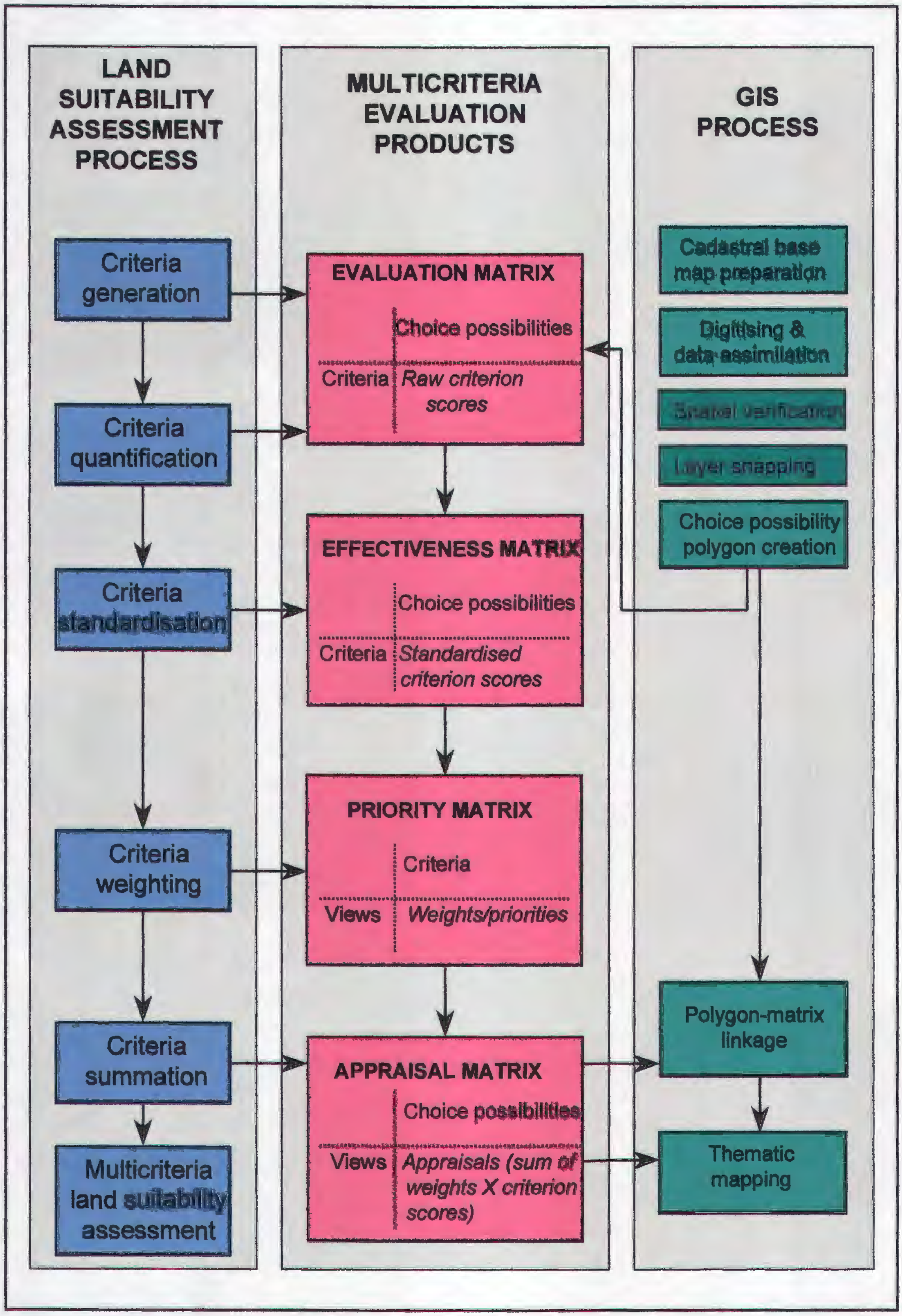


Figure 4.1: The relationship between the land suitability assessment process, multicriteria evaluation and GIS

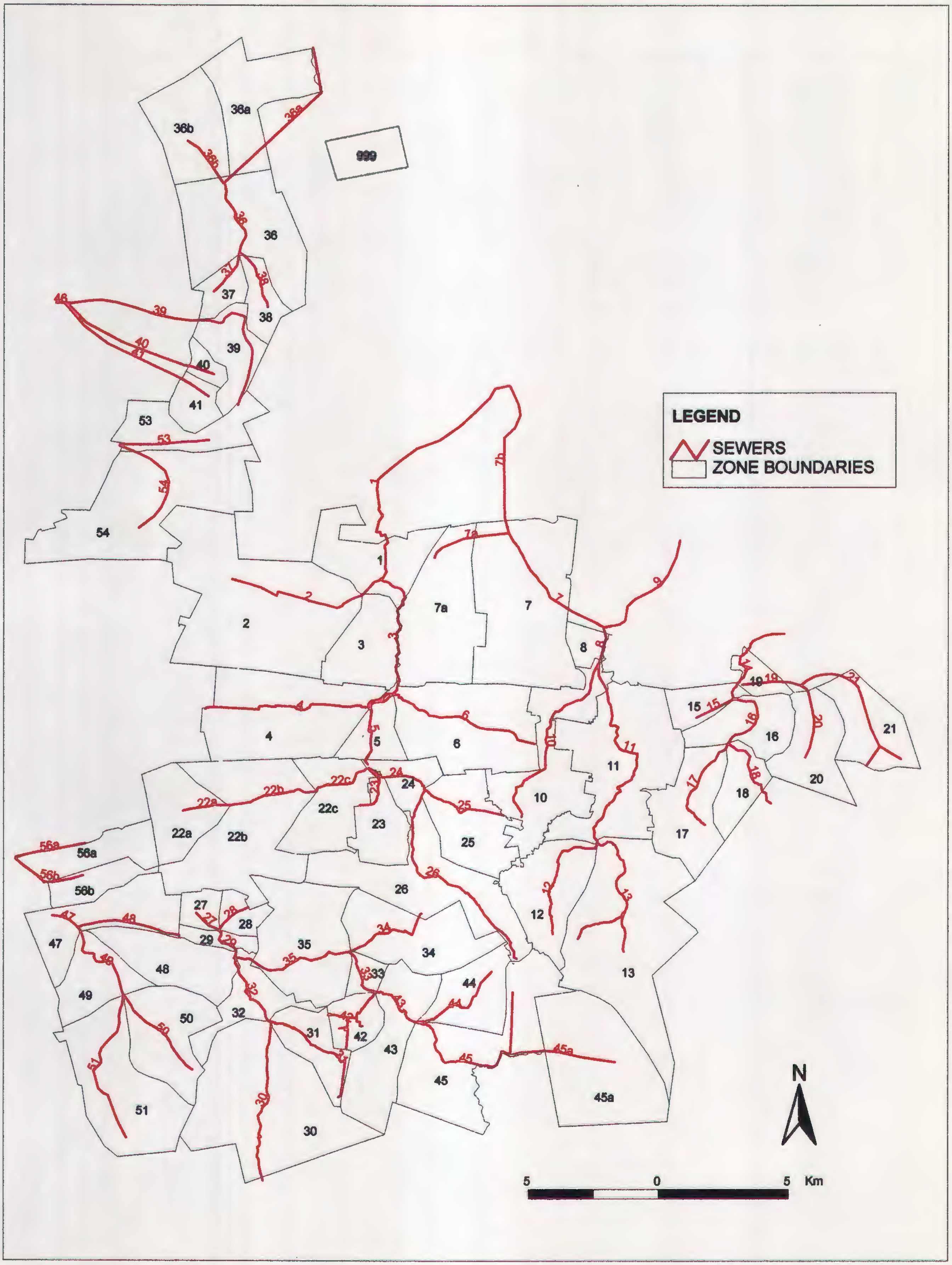


Figure 6.23: Sewer outfall zones and pipes

too little slope can also be a problem. A less than 2 degree slope is too little to facilitate optimum flow and adequate slope will need to be provided through additional excavation measures. A slope of between 2 and 6 degrees is ideal and no additional costs over and above the base costs are required. A slope of between 6 and 12 degrees requires a certain amount of slope creation through excavation whereas over 12 degrees, requires considerable raising and lowering of pipes to achieve the optimum flow. Slope has an insignificant effect on water pipes and these operate under conditions of pressure, not slope.

As expected, the water and sewer influencing factor cost layers strongly indicates the impact of geotechnical conditions on cost (Figure 6.8(a) and (b)). The dolomite area in the south west and the steep slope ridges stretching east-west along the northern central part of the study area, have the greatest cost impact for both water pipes and sewers. The land use impact in terms of intensity of use is greatest in the city centre areas while the influence of nature reserves is noticeable in the far north western and south-eastern corners of the study area. The relatively greater cost impact of influencing factors on sewer as opposed to water pipes, as is evident in Table 6.6, is visible on the maps from the cost categories and shading (Figure 6.8 (a) and (b).

6.2.5.2 Once-off costs

National and major roads and single and multi-track railway lines have been identified as classes of man-made obstacles (Table 6.7). Perennial and non-perennial rivers have been identified as natural obstacle classes. Once-off costs relating to man-made and natural obstacles are far more difficult to determine as a generic cost due to the range of costs possible depending on specific local conditions. There is, for example, a wide range of road and stream widths possible in reality. For the current purpose, however, where comparative costs are important, it is proposed that as long as the same costs are used consistently, the model operates as intended.

A particular problem encountered in applying once-off costs, was that in reality, infrastructure pipes often run alongside streets or streams. Due to the raster structure of the data, where a grid size of 50 square metres was utilised, the pipe often "touched" the street or stream, adding a cost as though the pipe was crossing the stream or road. The problem was handled by visually observing where it occurred and subtracting the cost, by hand. The problem would not occur if the analysis was undertaken using vector structure.

The once-off cost layer, applicable to both water pipes and sewers, indicates unique cost values for each once-off factor line feature (Figure 6.8 (c)). At each point where features cross or overlap, the individual feature costs are added. The routes of roads and multiple track railway lines exert the strongest cost influence while non-perennial rivers have the least cost impact.

6.3 Detailed individual cost calculations and results

6.3.1 Arrangement of sections

Each individual water, sanitation and electricity cost calculation with tabular and graphical results, for each density scenario, is presented in this section. All individual water costs are subsequently combined into a total water cost and likewise for sanitation and electricity (Figure 6.9). Finally, the total water, sanitation and electricity costs are combined into a single combined bulk infrastructure cost for each density scenario (Figure 6.9). The applicable paragraph number is indicated in parenthesis in Figure 6.9.

6.3.2 Water system costs

6.3.2.1 Water link costs

6.3.2.1.1 Water link cost calculation

Water link costs were calculated for each distribution reservoir supply zone (Table 6.8 - Appendix A; Figure 6.10). Traffic zone population totals were proportioned to reservoir zones, the area of each zone determined and the existing percentage developed area per zone calculated from the land use coverage, using GIS. Zone area (ha) was multiplied with the selected scenario population densities of 20, 40 and 60 persons per hectare to determine potential population numbers for each scenario. The greater of the calculated potential population or existing population was taken as the final scenario population.

The required pipe length, necessary to supply the scenario population with water, was determined next. Due to the nature of the network operating under pressure, pipe length is estimated on a very theoretical basis for determining link costs. A number of existing link water networks for various densities were analysed to determine the average length of different diameter pipes in a network to support a range of population sizes (Table 6.9 - Appendix A). It is obvious from the table that lower densities require longer pipe lengths due to larger land areas to be traversed. The lengths for all the various pipe sizes are subsequently converted into a single length of an equivalent pipe size of 250 mm (Table 6.9 - Appendix A) using conversion factors obtained from Greater Johannesburg Metropolitan Council (Table 6.10 - Appendix A). The exact length required for the exact scenario population is calculated using Table 6.9 - Appendix A, but proportioning the length according to the exact population figure. Seeing as the base cost of R92.63 was calculated for a pipe diameter of 110 mm, the base cost was adjusted to account for a 250 mm pipe diameter by adding and additional 8 percent to produce an adjusted base cost of R100.04. Total required length of pipe is then multiplied with the base cost of R100.04 to obtain a total expected cost as if the entire area was developed as a greenfields development i.e. as if the area is currently undeveloped. Existing development is then accounted for by reducing the cost in relation to percentage of existing development (Table 6.11). Costs are expressed as cost per additional person i.e. the difference between the scenario population and the existing population.

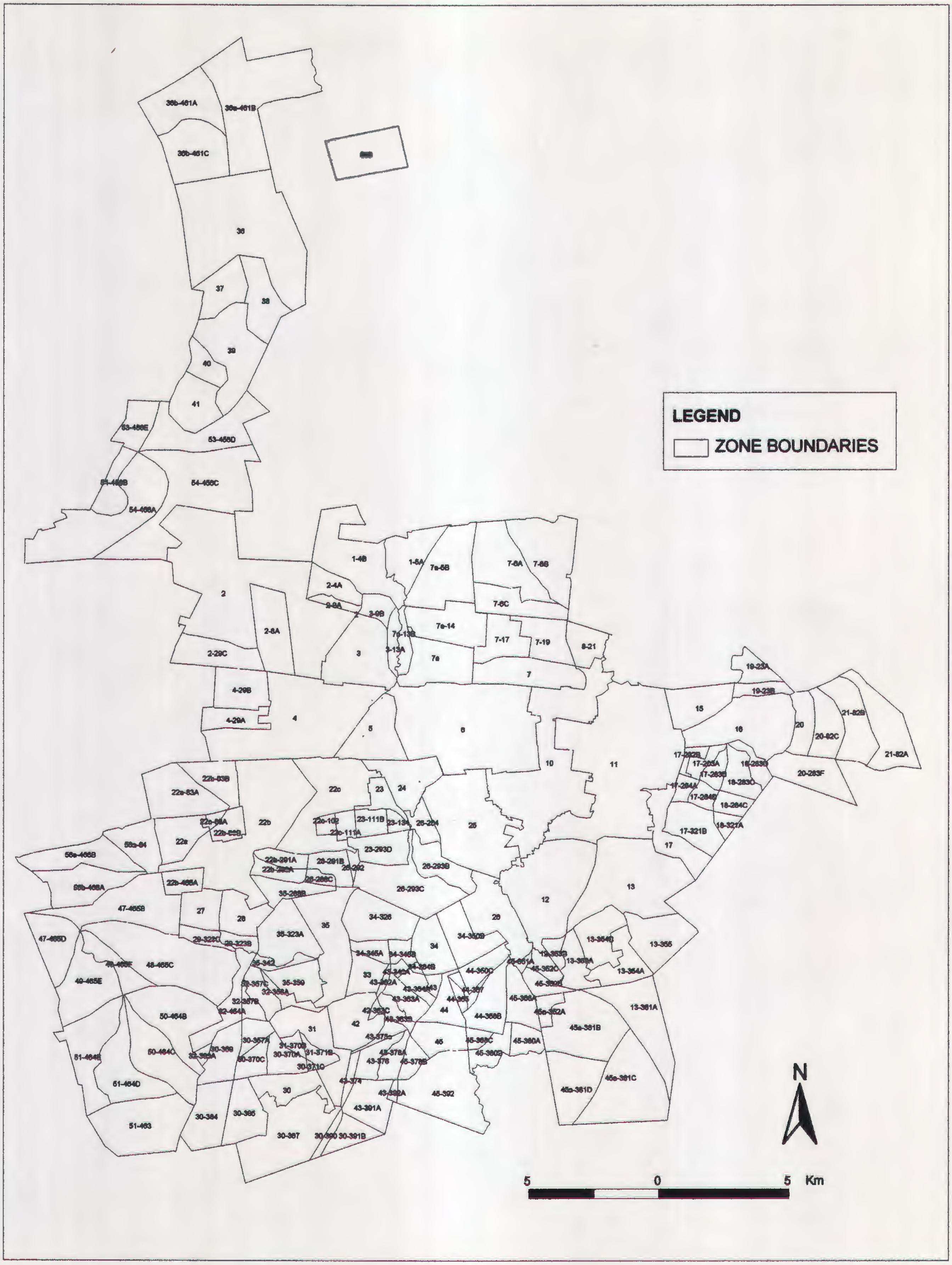


Figure 6.21: Sewer link zones

Table 6.10: Conversion factors to translate length of various pipe diameters to equivalent 250 mm pipe length

Pipe diameter (mm)	Conversion factor
110	1.00
160	1.33
200	1.71
250	1.90
300	2.19
400	2.57
500	3.57
600	4.43
700	4.81
800	5.48
900	6.05
1000	7.29
1200	9.52

Table 6.11: Percentage of total greenfields cost applicable according to current percentage development

% development	% of total cost
0 - 20	100
21 - 40	80
41 - 60	60
61 - 80	40
81 - 100	20

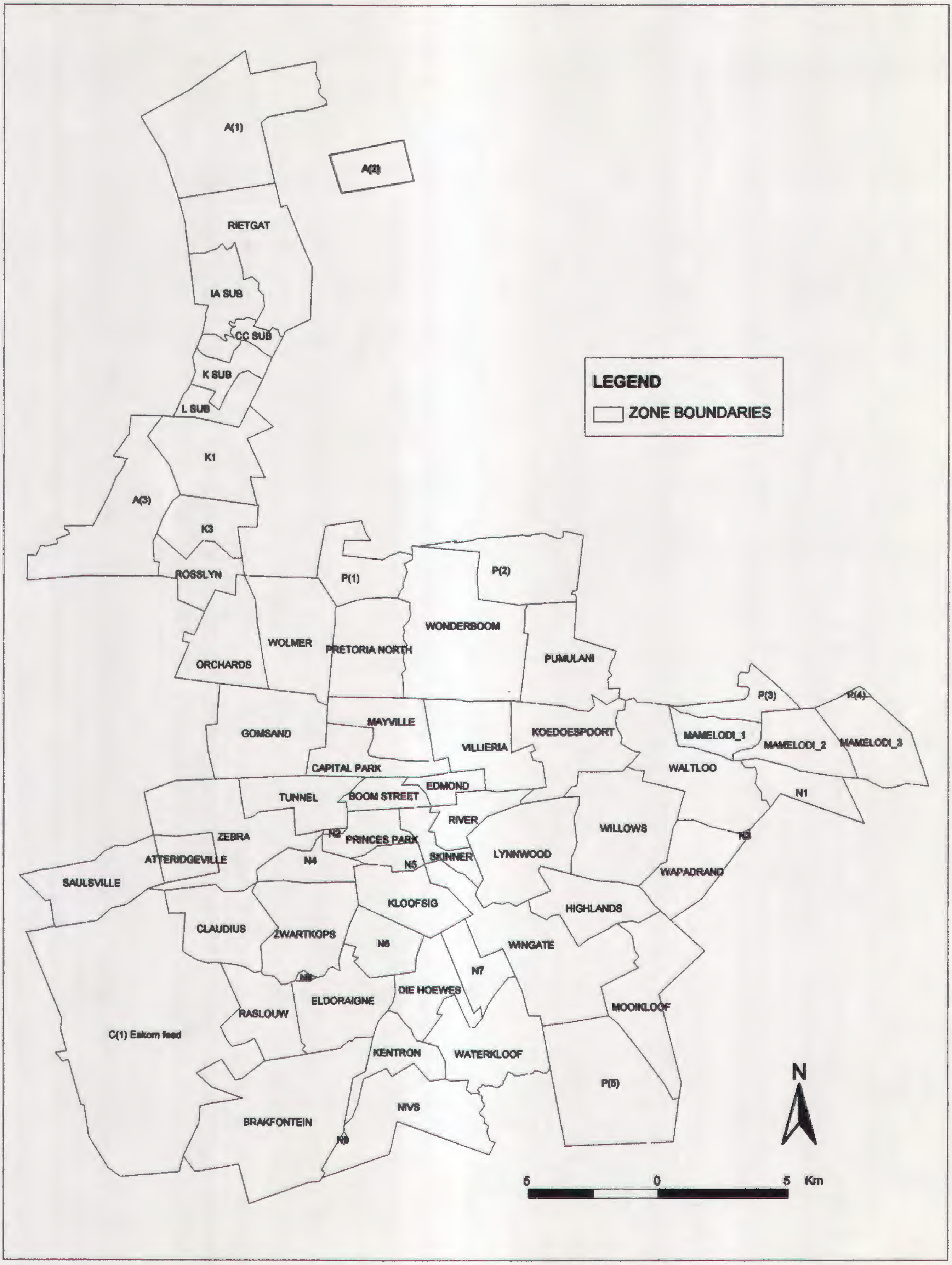


Figure 6.29: Electricity supply zones

6.3.2.1.2 Water link cost results

The total cost increases from R58 million with a low density scenario to R71 million for the high density scenario with the greatest cost incurred in the Pretoriusrand and Stinkwater reservoir zones for all density scenarios (Table 6.8 - Appendix A). The per capita cost, on the other hand, reduces significantly with increased density from R43 to R13 per person due to the fact that higher densities require less pipe length due to relatively smaller areas to be traversed (Table 6.9 - Appendix A). The highest per capita cost areas differ for each density scenario with Hercules East having the greatest cost under low density conditions and Mamelodi-R4/East exhibiting the greatest cost under the high and medium density scenarios. Due to the fact that the low density scenario population for Mamelodi-R4/East was less than the existing population meant that no cost was assumed. But if the scenario population had exceeded the existing population by even a small margin, the per capita cost would probably have been high due to the small additional population number denominator. So it is all a matter of marginal cost which also applies in the case of Hercules East. The low density scenario per capita cost is significantly higher than that of the medium and high density scenarios as a result of the cost increasing marginally with density, in relation to the significant increase in the number of additional people.

The spatial pattern of water link costs is significantly different for each density scenario (Figure 6.11). While the low density scenario yields cost of greater than R20 per person, except for a small area in the east, costs are less than R20 per person over the entire study area for the high density scenario. Link costs are higher in the currently undeveloped outer parts of the study area for the high density scenario whereas costs of greater than R60 per person occur around the currently developed central areas, for the low density scenario. The reason for this pattern can be attributed to the size of the "additional" population. In currently developed areas, particularly in the central parts of the study area, the difference between the existing population and the scenario population is small, which means that the incurred cost is shared amongst a small number of people and the lower the density scenario, the smaller the difference, thus the greater the per person cost.

In some areas, significantly the Soshanguve, Klipkruisfontein and Mamelodi East areas, the per person cost increases with increasing density (Figure 6.11). This is due to the fact that existing population exceeds the lower density scenario population figures and therefore costs are zero but as soon as scenario population exceeds existing population, a cost is incurred and shared amongst relatively small numbers of people therefore resulting in a sudden high per person cost.

6.3.2.2 Water distribution reservoir costs

6.3.2.2.1 Water distribution reservoir cost calculation

Distribution reservoir costs were calculated per distribution reservoir zone (Figure 6.10). Each existing and potential distribution reservoir relates to a particular distribution reservoir supply zone. Areas fed directly by Rand Water and from receiving reservoirs are not costed as part of this cost calculation. Population figures for 1995 were translated from traffic zones to distribution reservoir zones and the area (ha) for each zone determined (Table 6.12 - Appendix A). Scenario population figures were determined in the same manner as for link costs. The design capacity (cubic metres) of each reservoir was converted to design capacity expressed in numbers of persons which can be accommodated, taking into account level of service factors and required emergency storage factors. Usage factors of 150 litres/person/day and 50 litres/person/day were used respectively for high/medium level of service areas and low level of service areas (National Housing Board 1994). Required storage of 42 hours was assumed on the basis of 24 hour required plus 18 hours additional requirements for emergency storage (GPMC 1997). The design capacity in cubic metres was divided by 1000 to obtain capacity in mega litres. The mega litre value was multiplied with 1 million to obtain a capacity in litres. The litre value was divided by the usage factor to obtain a capacity expressed in persons per 24 hour day figure. The person per 24 hour day figure was reduced to accommodate for emergency storage requirements, by multiplying with a factor of 0.57 (24 hours divided by 42) to obtain a capacity expressed as persons per 42 hour day.

The scenario population was then subtracted from the design capacity population to determine whether or not additional capacity was required and if so, the amount of capacity required. The required person capacity was converted back to mega litre capacity and the total cost of adding the required capacity reservoir module, determined (Figure 6.7). Total cost was finally expressed per additional person.

6.3.2.2.2 Water distribution reservoir cost results

A much more significant difference exists between the various density scenario total distribution reservoir costs for the study area (Table 6.12 - Appendix A) than was the case for water link costs (Table 6.8 - Appendix A). Whereas the cost increase between the low and medium scenario and the medium and high scenario for link costs was respectively 9 percent and 11 percent, the cost increase for distribution reservoirs was respectively 71 percent and 53 percent. For the low density scenario, both total costs are around R58 million but for the high density scenario, reservoir costs are nearly two and a half times greater at R16 million whereas link costs increase to only R7 million.

The new reservoir area of Pretoriusrand, followed by another new reservoir area, CSIR-4, exhibited the greatest distribution reservoir cost for all three scenarios (Table 6.12 - Appendix A). Unlike link costs, there is more uniformity between scenario costs in that although the per capita costs decrease with increasing density, the rank order of reservoir zones in terms of per capita cost remains similar no matter what scenario is followed.

Highest costs, particularly noticeable for the low density scenario, relate strongly to the new development areas with new reservoirs located in the south west (currently agricultural land), south central (currently military land), south east (currently nature reserve), north and far north of the study area (Figure 6.12). These high cost areas for the low density scenario, generally decrease in cost with increasing density. Some areas, however, around the Akasia, Hercules West, Waverley, Koedoesnek LL, Elarduspark and Klipkruisfontein vicinities, exhibit costs of less than R20 per person under the low density scenario but move into higher cost categories under the medium density scenario. Similarly, additional areas in the south east of the study area, including Queenswood, Kilner Park, Moraleta and Soshanguwe, while costing less than R20 per person under medium density conditions, move into the cost category R21 - R40 per person under high density conditions (Figure 6.12).

There are two reasons for this cost increase with increasing density. Firstly, in the case of Soshanguve and Klipkruisfontein, existing population exceeds scenario population for some scenarios and costs increase from zero to something as soon as the scenario population exceeds current population. In the remaining instances of increasing costs with increasing densities, existing spare capacity plays a significant role. There is adequate existing capacity to service a low density scenario or even a medium density scenario population in some cases, therefore, no costs are incurred until the scenario population exceeds the design capacity, at which point, costs are incurred and shared between additional population.

6.3.2.3 Water feeder main costs

6.3.2..3.1 Water feeder main cost calculation

Feeder mains link distribution reservoirs to system mains or Rand Water pipes and each has a water supply zone linked to it (Figure 6.10). The calculation proceeds in accordance with the calculation for distribution reservoirs except that pipe design capacity is relevant rather than reservoir capacity and was expressed in litres per second (Table 6.13 - Appendix A). The conversion from litres per second to design population takes place by multiplying with 12 and again with 3600 to get to a litres per day figure which is then divided by the product of the usage factor and a peak factor of 2.0. The usage factors utilised are the same as those used in the water link cost calculation. Once required capacity has been determined by subtracting scenario population from design population, the appropriate diameter pipe is selected using the graph in Figure 6.6. Base cost implications are determined from Table 6.1 and the adjusted base cost used in further calculations.

GIS is then utilised to overlay the influencing factor and once-off cost layers with the pipe layer and, using the adjusted base cost, to determine the total cost of each pipe based on length and additional cost conditions. Total pipe costs were then expressed as per capita costs for each area supplied by each feeder main.

6.3.2.3.2 Water feeder main cost results

Even though feeder main costs include additional costs associated with environmental conditions, the costs are small in relation to distribution reservoir costs ranging from total feeder main costs for the low density scenario of R10.7 to R15.8 for the high density scenario (Table 6.13 - Appendix A). Per capita cost decreases from R10 per person for the low scenario, to R5 per person for the medium density scenario and to only R3 per person for the high density scenario. In addition to the decrease being caused in general by a greater number of people amongst whom cost can be shared, a further reason why per capita costs decrease with increasing density is because the curve relating population size to pipe size, is such that even as density increases, size of pipe required increases more slowly leading to lower costs (Figure 6.6). Highest cost occur for all three scenarios for the new Klipfontein and Knopjeslaagte feeder mains and the areas they serve (Table 6.13 - Appendix A). It is evident from an assessment of total pipe costs and per capita costs, that frequently, pipe cost is identical for each scenario and it is the number of additional people who use the pipe that leads to the significant difference in per capita cost between scenarios. That the pipe costs are often the same is not surprising as adjusted base cost can be the same for different numbers of people due to the broad categories which are used (Table 6.1) and length and additional factors are identical for all densities.

The spatial pattern of feeder main costs indicates higher costs in the southern portion, particularly the south western portion, the far northern and the Klipfontein parts of the study area (Figure 6.13). Although the intensity of costs decreases with increasing density, the spatial pattern remains consistent for each density scenario. Higher costs in the southern area can be attributed to generally longer pipes involved in supplying water directly from Rand Water pipes to distribution reservoirs. Many of the southern zones are served directly by Rand Water. Feeder main pipes which link distribution reservoirs with system mains tend to be much shorter in general. The Klipfontein and far northern area costs are high because the mains are new and long.

6.3.2.4 Water system main costs

6.3.2.4.1 Water system main cost calculation

System mains were identified by tracing the pipe paths from the receiving reservoirs to the point at which the system main intersects with a feeder main (leading to existing distribution reservoirs) or, in the case of new distribution reservoirs, right up to the new reservoir. A new main was defined whenever the pipe system split to serve another supply area (Figure 6.14). Reservoir zones which are supplied by each system main are identified and existing population and scenario populations determined for each supply area (Table 6.14 - Appendix A). Data regarding water system main design capacities were not available and therefore, for the purpose of this study, it was assumed that system mains are currently operating at their design capacities i.e. no spare capacity exists. As a results, the costs obtained are most likely higher than would be the case in reality as it is probable that at least some system mains have spare capacity. Existing population figures were subtracted from scenario population figures to obtain the additional number of persons requiring water supply. Required pipe diameter was determined from Figure 6.6 and the base cost of R92.63 adjusted to account for required diameter using Table 6.1.

It is again assumed that required additional capacity would be provided in pipes laid alongside existing pipes. System mains were overlayed with the influencing factor and once-off cost layers to calculate the total cost of each system main, taking into account adjusted base cost and length. Per capita costs for the additional population residing in each system main supply area were calculated (Table 6.14 - Appendix A). System main costs were subsequently attributed to individual reservoir supply zones (Figure 6.10) accounting for the fact that the cost of each system main needs to be proportioned amongst the individual zones which utilise that particular section of the system (Table 6.15 - Appendix A).

6.3.2.4.2 Water system main cost results

For the whole study area, system main costs are higher than feeder main costs, influenced by the assumption of no spare capacity. There is very little difference in total cost between the three density scenarios which indicated that diameter considerations, which, in the absence of capacity differences, is the only factor which can differ between scenarios, do not have a significant impact on final total cost (Table 6.14 - Appendix A). This can be attributed to the fairly small cost difference between water base cost and adjusted base costs and to the broad categories used to associate diameter changes with cost implications (Table 6.1). Length of pipe has a significant influence on total pipe cost with longer pipes being relatively more costly than shorter pipes (Table 6.14 - Appendix A; Figure 6.14). Per person costs differ significantly between scenarios and are particularly high for the low density scenario where a per capita cost of R20 has been calculated as opposed to R8 and R5 for the medium and high scenarios respectively (Table 6.14 - Appendix A). The highest per capita cost is evident for pipe W2, which serves the Sinoville and Magalieskruin reservoir areas, under the low density scenario. The reason for this is that the difference between the scenario and the existing population is very small resulting in a small additional population which has to share the cost.

The spatial pattern of costs clearly reveals cost implications for only that part of the study area for which system main costs apply i.e. those areas ultimately dependant on receiving reservoirs for storage and supply. Areas which obtain water directly from Rand Water are not affected by this cost. The central and northern central areas are served by system mains (Figure 6.15). The central areas of Suiderberg, Florauna, Magaliesberg, Sinoville, Meintjieskop, Eerstrust, Murrayfield and Waterkloofpark all exhibit costs of greater than R200 per person under the low density scenario (Figure 6.15 (a)). Only two small zones of Suiderberg and Waterkloofpark have costs of greater than R200 under the medium density scenario and only Waterkloofpark remains in the greater than R200 category under the high density scenario (Figure 6.15 (b) and (c)).

6.3.2.5 Water receiving reservoir costs

6.3.2.5.1 Water receiving reservoir cost calculation

Distribution reservoir zones which are supplied by the same receiving reservoir were aggregated into six receiving reservoir zones (Figure 6.16). Heights HL and Heights LL were included in a single receiving reservoir zone due to non-continuous distribution reservoir polygons which would have complicated the GIS analysis. Existing and scenario populations were calculated for each zone and the required capacity determined in numbers of people to be served, converted to megaliters (Table 6.16 - Appendix A). The design capacity of each reservoir was then compared with the required capacity and the difference calculated in order to determine additional infrastructure necessary. The total cost of additional reservoir modules required was determined using an extrapolation of Figure 6.7 and expressed per additional person (Table 6.16 - Appendix A).

6.3.2.5.2 Water receiving reservoir cost results

Receiving reservoir costs are by far the lowest total cost component discussed thus far for the low density scenario (R6.1 million) but as soon as densities increase, costs become significant in the vicinity of R22 million for the medium scenario and R38 million for the high density scenario (Table 6.16 - Appendix A). Receiving reservoir costs are lower than distribution reservoir costs for all scenarios. This is also a reflection of a relatively smaller number of people involved in that only a portion of the study area is served by receiving reservoirs.

Per capita costs actually increase marginally with increasing density unlike any of the other per capita costs considered thus far. In all other per capita costs considered thus far, an increase in density results in a decrease in capita costs due to the fact that the total cost increase is overwhelmed by the increase in the number of additional people amongst whom the costs are shared. In the case of receiving reservoir costs, the total costs increase as a result of additional capacity requirements is significant in relation to the population increase resulting in increasing per capita costs with increasing density.

This cost increase is most significant between the low density scenario and the medium scenario where the per capita cost increases from R16.9 to R19.8. This is as a results of the Garsfontein existing capacity threshold being exceeded under the medium density scenario. The increase from the medium density scenario to the high density scenario is a mere 24 cents per person.

A spatial assessment of receiving reservoir costs indicates the greatest costs in the northern central areas of Akasia, Wonderboom and Garsfontein (Figure 6.17). Akasia and Wonderboom costs are greater than R26 per person for all density scenarios whereas Garsfontein has no cost under the low density scenarios as the design capacity can accommodate the required additional supply. The per capita costs increase for Garsfontein under a medium and high density scenario as design capacity is exceeded.

6.3.2.6 Water cost overlay

Total water costs for the study area increase from R151.4 million under the low density scenario to almost double that (R300 million) under the high density scenario (Table 6.17; Figure 6.18). Per capita costs, however, decrease with increasing density from R141 per person under low density conditions to slightly more than half that at R72 per person in high density conditions. The most costly item in terms of total and per capita costs, under all density scenarios is distribution reservoir costs (Table 6.17; Figure 6.18). Distribution reservoir costs comprise the largest percentage of all costs (Figure 6.18). The next most costly item in terms of total cost is water link costs, but in terms of per capita costs, the next most costly item is mainly receiving reservoirs except in the case of the low density scenario, where link per capita costs are higher than receiving reservoir costs. The lowest water costs are generally those of pipe costs, namely feeder mains and system mains, except for the low density scenario total cost, where the receiving reservoir cost is the lowest. The pipe costs together, never exceed 25 percent of either total or per capita costs (Figure 6.19).

Table 6.17: Water cost summary of total (Rand million) and per capita (Rand/person) costs

Cost elements	Tot. (L)	%	Tot. (M)	%	Tot. (H)	%	Per cap (L)	%	Per cap (M)	%	Per cap (H)	%
Water link	58	38	64	29	71	24	43	31	19	22	13	18
Distribution reservoirs	59	39	101	46	156	52	47	33	33	38	31	43
Feeder mains	11	7	14	6	16	5	10	7	5	6	3	4
System mains	18	12	18	9	18	6	25	18	9	11	5	7
Receiving reservoirs	6	4	22	10	38	13	16	11	20	23	20	28
TOTAL	152	100	219	100	299	100	141	100	86	100	72	100

The spatial pattern of water costs clearly indicates decreasing costs in terms of extent, with increasing density (Figure 6.18). The water overlay for the low density scenario reveals per capita costs of greater than R60 per person applicable in about two thirds of the study area. A perusal of all water component maps for the low density scenario, reveals that distribution reservoir and feeder main costs are largely responsible for the high costs in the south western, south central, south eastern and the north western, Klipkruisfontein portions of the study area (Figure 6.20 (a)). The central areas exhibit costs of greater than R120 per person in response to mainly high link, receiving reservoir and system main costs. High costs in the central northern area are as a result of predominantly high distribution reservoir, system main and receiving reservoir costs.

The water overlay for the medium density scenario displays a much reduced area of costs of greater than R60 per person, covering approximately a quarter of the study area, predominantly in the central northern and eastern parts but with some isolated pockets of high cost in the central and south western portions (Figure 6.20 (b)). Costs in the central northern and eastern areas are high due to mainly high distribution and receiving reservoir costs. Isolated costs of greater than R120 per person in the central area relate to high system main costs. Costs of greater than R120 per person also occur in the far east in the Mamelodi area as a result of high link costs and in the far western, Atteridgeville area, attributable to high feeder main costs.

The high density scenario results in a pattern of diminished costs, with only small areas of high costs remaining (Figure 6.20 (c)). The largest area of cost greater than R60 per person remains in the eastern and northern parts of the central area, attributable to predominantly receiving reservoir costs. The remaining isolated zones of high cost are caused by high feeder and system main costs.

The importance of a spatial analysis of the data in addition to tabular analysis is demonstrated in that it would be tempting to conclude from the table that due to the relatively low cost impact of certain infrastructure types, that in the future application of the model, it is not necessary to include those items which contribute little to the final cost. The more detailed spatial analysis reveals that in certain locations, these more "minor" costs have a significant cost impact. All water costs considered therefore are necessary for a location specific indication of cost implications.

6.3.3 Sanitation system costs

6.3.3.1 Sewer link costs

6.3.3.1.1 Sewer link cost calculation

Sewer link cost zones were delineated for the purpose of calculating sewer link costs (Figure 6.21). Delineation was influence by outfall sewer position and catchment boundaries, traffic zone boundaries, natural drainage and whether the area was developed or undeveloped. Developed areas were assumed to have a well established system of link pipes to which any additional development could link at no additional cost. It was in the undeveloped areas that attention was given to subdividing outfall sewer catchment zones further into sewer link zones on the basis of the smaller traffic zone boundaries, ensuring that the outfall sewer to which the sub-area should link was in a such a position in relation to the centroid of the sewer link zone so that the link from centroid to outfall sewer would be a good reflection of the average link cost for that link zone.

The area (ha) of each link zone was determined using GIS and the scenario population determined for each density scenario (Table 6.18 - Appendix A). Required pipe diameter to accommodate the potential demand was ascertained, taking slope into account, using Table 6.2 and the necessary cost adjustments to the base cost of R206.76 determined (Table 6.3). Adjusted base cost was multiplied with the length of pipe from centroid to outfall sewer to obtain total pipe cost. Influencing factor and once-off costs were not incorporated into sewer link costs due to the fact that the link cost is a theoretical cost, reflective of the average cost for development within that link zone to link with the major outfall system. The exact path which the pipe would follow is unknown and it was thought to be unrealistic to apply influencing and once-off cost factors to this theoretical pipe.

Total pipe link cost for each link zone was divided by the additional population, which in this case was the scenario population, because only undeveloped zones were included in the cost calculation, to obtain per capita sewer link costs (Table 6.18 - Appendix A).

6.3.3.1.2 Sewer link cost results

There is not a significant difference in total link cost between scenarios (Table 6.18 - Appendix A). Total cost varies from R40 million in the case of the low density scenario to R42 million in the case of the high density scenario. This is to be expected as the only cost factor which differs between scenarios is pipe diameter, according to population number, which in itself does not have a huge impact on base cost (Table 6.3). Per capita costs vary significantly according to density scenario, decreasing from R31 per person under the low density scenario to almost half that at R16 for the medium and to R11 per person in the case of the high density scenario (Table 6.18 - Appendix A).

Highest total costs are evident in link zones 13-381A, 22b-465 and 43-391A, in response mainly to longer pipe lengths (Table 6.18 - Appendix A). Highest per capita costs occur in zones 30-371C, 32-369A and 43-392A attributable to small zones, thus small population numbers, amongst whom the cost is shared (Table 6.18 - Appendix A; Figure 6.21).

Besides the patterns of zero cost associated with the currently developed areas, there is some indication of a larger concentration of higher cost zones in the south and northern central parts of the study area in relation to the undeveloped area (Figure 6.22). Within the undeveloped areas, no obviously consistent spatial cost pattern is evident as each link zone's cost is independent from any another larger system, but dependent on internal conditions of length from centroid to outfall sewer and size of zone. Costs reduce significantly with increasing density and only a small percentage of the study area exhibits costs of greater than R10 per person in the case of the high density scenario (Figure 6.22 (c)).

6.3.3.2 Sewer network costs

6.3.3.2.1 Sewer network cost calculation

Sewer outfall zones were delineated on the basis of catchment areas for each outfall sewer section of the network (Figure 6.23). Zone areas were calculated and scenario population numbers established for each. The load on each pipe section was calculated by adding all upstream populations (Table 6.19 - Appendix A). Design capacities for section of pipe where converted from litres/second to population numbers which could be accommodated, by multiplying the litres/second figure by 12 and again by 3600 to convert to litres per day. The litres per day figure was divided by the quotient of the usage factor (litres/household per day) and the household size (persons per household) to obtain a design capacity expressed in numbers of persons which can be accommodated (Table 6.19 - Appendix A). Design capacity was compared with required load and where load exceeded design capacity, required additional capacity was determined. Required pipe diameter was obtained using Table 6.2 and the cost implications for base cost determined (Table 6.3). It was assumed that additional capacity would be provided in new pipes laid alongside existing pipes and required pipe lengths were overlayed with influencing factor and once-off costs, which together with adjusted base costs are used to calculate total pipe costs using the GIS. Total pipe costs are attributed to the additional population which is served by each pipe section and costs expressed per person (Table 6.19 - Appendix A). Per person pipe costs are ultimately calculated for each sewer outfall zone by adding the per capita costs for each pipe which the zone utilises (Table 6.19 - Appendix A).

6.3.3.2.2 Sewer network cost results

Unlike the case with sewer link costs, total sewer outfall costs differ significantly between density scenarios, increasing from R28 million under the low density scenario to R70 million in the case of the high density scenario (Table 6.19 - Appendix A). This can be largely attributed to capacity conditions where, in the low density scenario, there is available capacity to accommodate some of the additional population whereas in subsequent higher density scenarios, more existing pipe capacity thresholds are exceeded and costs incurred in providing additional capacity to accommodate the additional demand. Although a general decrease in per capita cost with increase in density is observed, there is very little difference in per capita cost between the medium and high density scenarios (Table 6.19 - Appendix A). In addition to capacity considerations, this is probably also indicative of the nature of the table used to determine pipe diameter where large categories of population can be accommodated by a single pipe diameter (Table 6.2). So even though there is a significant increase in population, if original and increased populations fall into one category, pipe diameter requirements are the same thus costs will be the same if capacity conditions are constant.

Length plays a role in differences between scenarios, in so far as new pipe lengths are added or not (if existing capacities are adequate). Length plays a more significant role in accounting for differences within scenarios. The highest per capita cost for each scenario is that of pipe 41 which has a long length to reach the WWTW situated well outside the study area, but a relatively small area (only the area within the study area served by this pipe is included) (Table 6.19 - Appendix A; Figure 6.23).

Although average per capita costs over the entire study area decrease as density increases, an interesting anomaly emerges from a consideration of the spatial pattern of costs (Figure 6.24). The portion of the study area corresponding to costs of greater than R11 per person, increases with increasing density. Under the low density scenario, smaller pockets of higher cost (greater than R31 per person) areas occur whereas in the case of the higher density scenario, fewer high cost areas are evident but more of the study area has some cost associated with it (Figure 6.24). This is attributable to increasing infrastructure capacity thresholds being reached with increasing density, but at the same time, more population being added amongst which the costs can be shared.

The highest costs in all three scenarios are associated with areas where new pipes have been added i.e. there is no possibility of any available capacity in any existing pipe to accommodate at least some of the additional population. These high cost, new pipe areas include the far northern areas of Soshanguve, the northern central pipe 7a area, the new Atteridgeville West pipes of 56a and b, the new Centurion West outfalls 50 and 51 in the south western corner of the study area and the new zone 45a in the far south west (Figure 6.23; Figure 6.24).

6.3.3.3 Waste water treatment works costs

6.3.3.3.1 Waste water treatment works cost calculation

Catchment areas for each of the ten existing and proposed waste water treatment works (WWTW) were delineated within the study area, areas (ha) calculated and existing population and scenario population determined (Table 6.20 - Appendix A). The design capacity of each WWTW was converted from mega litres/day to population which can be accommodated by multiplying with 1 million to achieve a litres/day figure and then dividing by the quotient of the usage factor and the household size factor applicable according to the level of service of an area. A usage factor of 500 litres/household/day with a household size of 7 persons/household was used in the case of low service level areas whereas a usage factor of 1000 litres/household per day, with a household size of 5 persons/household, was used for medium and high level of service areas (National Housing Board 1994). Design capacity (in persons) was then compared with required capacity and additional required capacity calculated. Cost of providing the required additional capacity were calculated using Table 6.4 and expressed per additional person for each catchment area (Figure 6.23).

6.3.3.3.2 Waste water treatment works cost results

Total cost for WWTW increases significantly with increase in density, clearly as a result of WWTW thresholds being reached as population is added. In the case of the low density scenario, the new WWTW costs come into effect (West of Atteridgeville and West of Centurion) and the thresholds of the existing Centurion and Zeekoeigat WWTW are exceeded. Under the medium density scenario, the threshold of the Daspoort WWTW is exceeded and threshold costs incurred (Table 6.20 - Appendix A). For the high density scenario, the existing WWTW thresholds of Baviaanspoort, Rooiwal and Soshanguve are exceeded resulting in a cost increase of 91 percent over the medium density scenario cost. Per capita costs increase with increasing density, unlike in the case of link and outfall network costs, from R18 per person for both the low and medium density scenarios to R20 per person for the high density scenario (Table 6.20 - Appendix A). Threshold costs increase in relation to additional numbers of people to maintain a constant per person cost for the medium and low density scenarios but for the high density scenario, the exceeding of the threshold for three large WWTW, means the balance between cost and persons amongst whom to distribute the cost, is slightly in favour of cost resulting in a higher per capita cost.

Although WWTW total and per capita costs are the lowest sanitation costs in the case of the low density scenario, for both the medium and high density scenario, WWTW costs are the highest (Table 6.21).

A spatial assessment of costs reveals that for all scenarios, WWTW costs are evident for almost the entire southern portion of the study area with the far northern, northern central and far eastern portions being added for the high density scenario (Figure 6.25). Highest costs of greater than R41 per person are evident under the low density scenario for the Zeekoeigat catchment and for the medium and high density scenarios, the West of Atteridgeville catchment (Figure 6.25).

6.3.3.4 Overlay of sanitation costs

Combining all sanitation costs results in total costs ranging from R87 million (low density) to R220 million (high density) and per capita costs of R71 (low density) to R44 per person (high density)(Table 6.21; Figure 6.26). In the case of the low density scenario, sewer link costs are the greatest cost component comprising 46 percent of the total cost and 44 percent of the per capita costs (Table 6.21; Figure 6.26). WWTW costs are consistently the greatest cost component for both total cost and per capita cost for the medium and high density scenarios. In the case of the high density scenario, WWTW costs comprise 49 percent and 45 percent of the total and per capita costs respectively (Figure 6.27). Outfall sewer costs consistently comprise 32 percent of the total cost and close to 30 percent of per capita costs (Table 6.21; Figure 6.27).

Table 6.21: Summary of sanitation total (Rand million) and per capita (Rand/person costs for each density scenario

Cost	Tot (L)	%	Tot (M)	%	Tot (H)	%	Per cap (L)	%	Per cap (M)	%	Per cap (H)	%
Link	40	46	41	29	42	19	31	44	16	33	11	25
Outfall	28	32	46	32	70	32	22	31	14	29	13	30
WWTW	19	22	57	39	108	49	18	25	18	38	20	45
TOTAL	87	100	144	100	220	100	71	100	48	100	44	100

The spatial overlay of costs reveals a pattern of higher costs extending over a large portion of the southern half of the study area, in the far northern area and in the northern central area (Figure 6.28). The cost pattern is similar for all density scenarios, but particularly so between the medium and high density scenario. The low density scenario reveals a greater coverage for the less than R20 cost category (Figure 6.28 (a)). The predominating cost factor in the entire southern portion of the study area, for all density scenarios, is WWTW costs, with additional link costs and outfall costs responsible for some of the relatively higher costs in specific zones within the southern area. The costs of greater than R40 per person in the northern central area are attributable to outfall and link costs while the far northern area costs are a result of high outfall, link and WWTW costs (Figure 6.28).

6.3.4 Electricity system costs

6.3.4.1 Electricity cost calculation

Electricity supply zones were delineated on the basis of the supply areas of 132kV substations (Figure 6.29). Areas supplied directly from Eskom feeds were treated as separate zones. Once scenario population had been determined on the basis of supply zone areas, required demand expressed in population figures were converted to MVA (Mega Volt Amperes) figures (Table 6.22 - Appendix A). The design capacity in persons was converted to MVA by dividing by household size, multiplying with the usage factor and dividing the product by 1000. The usage factor used was 2 kVA/household with a household size of 6 persons per household for areas with a low level of service and a factor of 4 kVA/household with a household size of 4 persons/household was used for areas with a medium or high level of service. Design capacity (MVA) was compared with required capacity (MVA), and additional required capacity to meet the demand, determined. The cost of additional substations to meet the demand was determined for each density scenario using Table 6.5. Finally, substation costs were multiplied with 1.5 to account for associated transmission line and transformer costs (Table 6.22 - Appendix A).

6.3.4.2 Electricity cost results

Electricity costs are significant in comparison to water and sanitation costs ranging from a total of R396 million in the case of the low density scenario to R1.4 billion under the high density scenario (Table 6.22 - Appendix A). Per capita costs increase with increasing density from R159 per person to R237 per person for the high density scenario. This is indicative of high threshold costs for substations in relation to increase in numbers of additional persons amongst whom the cost is shared. The highest total cost for all three scenarios is for zone C(1) in the south western part of the study area, which is a zone currently supplied directly from Eskom (Figure 6.29). The assumption was that as soon as significant development start to occur in this area, substations would need to be constructed. There is thus theoretical no substation capacity at present and therefore costs are great as soon as development occurs. In general, higher costs, both total and per capita, relate to zones where there are currently no substations i.e. newly developing areas. This can be explained by the fact that, as is evident from the electricity substation cost table (Table 6.5), initial costs for electrical substations are significantly higher than additional costs for the same amount of capacity.

The spatial pattern of electricity costs for the low density scenario, reveals excessively high costs of greater than R600 per person for the newly developing zones of A(3), P(1) and P(2) in the north of the study area and N4, N6 and N7 in the central area, also currently "undeveloped", with no existing substations (Figure 6.30 (a)). The number of zones costing greater than R600 per person reduces with increasing density until only zones N4 and N7 remain in this category for the high density scenario (Figure 6.30 (c)).Whereas in the case of the low density scenario, a large proportion of the study area has zero substation cost associated with it, the proportion of land with some costs, increases with increasing density. The areas where costs progress from nothing to something, are currently developed areas, with existing substations with existing spare capacity. As population increases, existing threshold are exceeded and additional infrastructure cost expenditure required. The cheapest areas from an electricity cost perspective seems to be a strip through the central area, extending from west to east and, except for the low density scenario, the far northern area (Figure 6.30).

6.4 Combination and comparative assessment of bulk costs

Total bulk engineering services costs almost double from the low density scenario to the medium density scenario from R634 to R1250 for the entire study area (Table 6.23). There is a smaller percentage increase of 56 percent from the medium density scenario to the high density scenario total cost of R1951 (Figure 6.31). Overall, the cost implication for a 200 percent increase in density (from 20 to 60 persons per hectare), is a similar 207 percent increase in cost.

The combined per capita costs are significant in that an almost consistent cost of between R350 and R370 per person is obtained for all density scenarios, although a slight decrease in cost with increase in density is observed (Table 6.23; Figure 6.31). The increase in electricity cost with density is almost balanced by the decrease in water and sanitation costs with increasing density.

Table 6.23: Summary of all bulk engineering services total (Rand million)and per capita (Rand per person)costs for each density scenario

Cost element	Total (L)	%	Total (M)	%	Total (H)	%	Per cap (L)	%	Per cap (M)	%	Per cap (H)	%
Water	151	24	220	18	299	15	141	38	86	24	72	20
Sanitation	87	14	144	12	220	11	71	19	48	14	44	13
Electricity	396	62	886	70	1432	74	159	43	222	62	237	67
TOTAL	634	100	1250	100	1951	100	371	100	356	100	353	100

Electricity costs dominate all costs with the exception of per capita costs under the low density scenario where water costs come close to electricity costs (Table 6.23). Electricity costs consistently comprise more than 60 percent of total and per capita costs except in the case of per capita costs for the low density scenario where electricity costs comprise 43 percent of the total, while water cost comprises a close 38 percent (Table 6.23; Figure 6.32). Sanitation costs are consistently the lowest cost for every scenario, for both total and per capita costs.

It is argued that the reason for these fairly consistent cost differences is twofold: differences in threshold costs and existing capacity conditions. Due to the fact that facility costs contribute the most to total services costs, and due to the difficulty in comparing pipe costs other than per metre costs, facility costs were considered in the explanation. Using infrastructure cost tables and figures (Table 6.4; Table 6.5; Figure 6.5), a comparison of infrastructure facility costs was undertaken, assuming a new development of 20 000 and 40 000 people, under ideal conditions for medium/high level of service conditions (Table 6.24). It is clear that electricity substation costs far exceed that of both WWTW and reservoir costs in terms of total and per capita costs.

Economies of scale play a mitigating role in the cost difference between facilities. Whereas reservoir per capita costs decrease by 22 percent between a 20 000 and a 40 000 person development and WWTW per capita costs decrease by 18 percent, electricity substation costs decrease by 32 percent (Table 6.24). Economies of scale would, however, generally contribute to making higher densities cheaper than lower densities.

Spare capacity considerations contribute further to the dominance of electricity costs. Spare capacity, expressed as number of people who can still be accommodated by the facility, once existing usage has been taken into account, was calculated for the study area as a whole for each facility (Table 6.25). While there is significant existing spare capacity available for all facilities in the study area, substation capacity is the least at 49 percent, whereas water and sanitation facilities have more than 60 percent spare capacity available (Table 6.25). In terms of numbers of people who can still be accommodated by existing facilities, without the total threshold being exceeded, 1.5 million people can be accommodated by existing electricity infrastructure, whereas 2.2 and 2.7 persons can be accommodated by distribution reservoirs and WWTW respectively. The number of additional people who can be accommodated by the existing receiving reservoir capacity, is less at 1.5 million but only a certain portion of the study area is served by receiving reservoirs.

Table 6.24: Infrastructure cost comparison under ideal conditions for a new development at a medium/high level of service

Cost element	20 000 people			40 000 people		
	Capacity	Total (Rmillion)	Per cap (R)	Capacity	Total (Rmillion)	Per cap (R)
Reservoir	5 Ml	1.1	55	10 Ml	1.7	43
WWTW	4 Ml	0.8	40	8 Ml	1.3	33
Substation	20 MVA	14.5	72	40 MVA	19.4	49

Table 6.25: Comparison of infrastructure spare capacity conditions

Infrastructure item	Spare capacity (persons) (Design capacity less existing use)	% utilised (Existing pop./ design pop. *100)	% spare capacity (Spare capacity/ design capacity * 100)
Receiving reservoirs	1 177 353	37	63
Distribution reservoirs	2 205 845	40	60
WWTW	2 685 609	37	63
Substation	1 531 213	51	49

As expected, from the dominance of electricity in the combined per capita cost for all three density scenarios (Table 6.23), the spatial pattern of combined costs is strongly influenced by the electricity cost patterns for the three scenarios considered (Figure 6.33). Electricity contributes increasingly 43 percent, 62 percent and 67 percent of the per capita cost respectively for the low, medium and high density scenarios (Table 6.23). The spatial implication of this dominating increase in cost with increasing density is that an increasing proportion of the study area has costs of greater than R300 per person associated with it as density increases (Figure 6.33). For the low density scenario, about one third of the study area costs more than R300 per person whereas for the high density scenario, almost the entire study area costs more than R300 per person. So with increasing population numbers, more and more threshold are exceeded throughout the study area resulting in higher costs. The area greater than R500 per person, however, decreases with increasing density which indicates the effect of cost sharing amongst more people in the higher density scenarios.

In addition to the overwhelming impact of electricity costs, the effect of water costs is evident particularly in the low density scenario where water costs contribute 38 percent to per capita cost (Table 6.23). High water costs strongly influence costs in the south west, south east and Klipkruisfontein area, due to distribution reservoir and feeder main costs and in the central and northern central area, due to a combination of system main, receiving reservoir and distribution reservoir costs (Figure 6.33 (a)).

Although sanitation costs contribute only 19 percent to the low density scenario per capita cost, the high cost areas coincide with some of the electricity and water high costs areas, contributing to a higher total cost in these areas. This occurs particularly in the south west, south east, Klipkruisfontein and far north of the study area attributable to high outfall sewer and link costs(Figure 6.33(a)).

The spatial pattern of the medium density scenario remains dominated by electricity costs which now begin to affect cost in the more central areas (Figure 6.30 (b)). At the same time, WWTW thresholds in the central areas have been exceeded, contributing to increased costs in the central regions (Figure 6.28). Costs in the south west, south east and northern central area decline from the greater than R500 per person category to the greater than R400 per person category due to reduced water costs (Figure 6.20). Costs in the far east rise due to high water link costs. In the far north, costs decrease due to a decrease in electricity and water costs (Figure 6.33 (b)).

In the case of the high density scenario, surface area covered by the R400 to R500 per person category increases significantly in the central areas due largely to electricity cost increases and higher water system main and receiving reservoir costs (Figure 6.33 (c)). Costs in the Klipkruisfontein area decline due to a decrease in water distribution reservoir and feeder main costs and lower electricity costs. The far northern area exhibits cost increases due mainly to WWTW, outfall sewer and water cost increases.

Some general observations are that higher costs in new peripheral areas are usually due to a combination of all services, whereas in the developed area, there is usually only one or two cost factors, predominantly water factors, responsible for the higher cost (Figure 6.33). This can be attributed to the fact that in developed area, not all engineering service thresholds are reached at once, whereas in newly developing areas, all services need to be provided from scratch at the start of development - there is no condition of existing spare capacity.

Relatively low combined costs in the far northern Soshanguve area and far eastern Mamelodi area can be attributed to low usage factors and the way in which the model deals with situations where existing density exceeds scenario density (Figure

6.33). Lower service levels exists in these low income areas thus per person service usage is low. Available spare capacity can therefore go much further in meeting the demand than the same available capacity in areas of higher usage. In situations where existing population exceeds scenario population, the model takes the existing population as the scenario population and as long as existing population equals scenario population, no additional costs are incurred. Due to the fact that these are areas of existing high density, the model generally allocates no additional people to these areas and thus costs are zero. Due to the currently undeveloped nature of the very furthest northern zones, some costs occur in these zones but not sufficient to exceed R400 per person (Figure 6.33).

Although costs in general seem to increase with increasing density due to the dominating influence of electricity, it is clear from the more detailed spatial assessment of combined infrastructure costs, that all services play a role in influencing costs, but that the degree of influence is very different for different services in different locations and for different density situations. These differences are caused by different thresholds being exceeded for different areas at different population numbers which makes potential cost determination extremely difficult, probably impossible without using the bulk infrastructure potential cost model. The conclusions drawn in terms of locational cost difference are also dependent on the exact conditions of the study area at that particular point and therefore conclusions cannot be generalised to apply to all areas, but are rather area and density specific.

6.5 Role of GIS in the model

GIS is an important tool in the model and is essential for three major functions: geographic proportionment, overlay and display. As opposed to GIS being embedded within or embedding the bulk infrastructure potential cost model, GIS is loosely coupled with the spreadsheet-based bulk infrastructure potential cost model. Data are transferred between the spreadsheet and GIS at appropriate points throughout the process for particular actions. The functions of GIS in the model, as applied to the study area, are discussed in relation to the cost model process as presented in the previous chapter (Figure 6.34), according to well-established GIS functionality categories

(Maguire & Dangermond 1991).

The software package ArcView3 was used for the GIS component of the model. The reasons for using ArcView3, together with its raster grid modelling extension, Spatial Analyst, were purely pragmatic based on software and expertise availability in addition to this software having the technical capability to handle what was required.

6.5.1 Capture, transfer, validate and edit

The purpose of these functions are to acquire and load error-free digital data into GIS (Maguire & Dangermond 1991: 324). No primary geographic data capture was necessary, as all source data was available in electronic format. Most data were available as ReGIS ASCII FEATURE files which were exported into ArcView SHAPE files using an interchange convertor programme. The data were validated in accordance with original source material and edited if necessary.

The spatial and attribute data transferred, validated and edited during the initial model stages (Figure 6.34) included:

- study area base information regarding metropolitan, metropolitan substructure and suburb boundaries and major roads;
- bulk infrastructure engineering services existing and potential catchment and supply areas with areas (ha);
- bulk infrastructure networks and facilities, location and design capacities;
- existing population figures, income group per traffic zone and traffic zone boundaries;
- cost influencing factor information regarding land use and geotechnical conditions; and
- once-off cost factor information regarding man-made and natural obstacles.

6.5.2 Store and structure

Data structuring is undertaken to facilitate more efficient data storage (Maguire &

Dangermond 1991: 325). The type of data structure employed should be determined by the functions required for manipulation and analysis (Maguire & Raper 1990). Both raster and vector structures were utilised in the model. Raster, rather than vector, structure was necessitated in overlay analysis primarily due to limitation of the software but also due to less complex thus faster and easier calculations (Berry 1987; Tomlin 1991). Vector was used predominantly for individual cost layers.

6.5.3 Restructure, generalise and transform

Data manipulation or data integration, allows disparate sources to be converted to a common format for analysis, through the operations of restructuring, generalising and transforming (Maguire & Dangermond 1991: 328). As a combination of vector and raster structures were used in the model, restructuring, involving conversion between vector and raster structures, was necessary. Generalising includes smoothing and aggregating features (Muller 1991). Generalising, in the form of dissolving boundaries between two adjoining polygons to create a single larger polygon, or unioning features, was performed frequently in the model, necessitated in the generation of higher order catchment or supply areas. A number of distribution reservoir supply areas, for example, comprise the supply area of a receiving reservoir. Furthermore, areas supplied by water towers were incorporated into the area which the relevant reservoir supplies.

Transformation of geographical data includes curvilinear transformations of the type used to convert between map projections (Maguire & Dangermond 1991: 329). In the study area, half the area falls into Lo29 and the other half into Lo27, causing problems in integrating data from disparate sources, using one or the other projection and necessitating transformation. In the model, transformation from Lo27 and Lo29 to Geographic Decimal Degrees and subsequently to Albers Equal Area Conic, took place using Clarke 1880 (spheroid). Albers Equal Area Conic was used particularly on the strength of its area calculation accuracies, although the coarse level, strategic nature of the model does not require fine-level accuracy.

6.5.4 Query and analyse

Spatial query and analysis necessitates distance and direction operations on spatial data (Maguire & Dangermond 1991: 329). Query involves the retrieval of attribute data about spatial features and was used continuously throughout the model process to spatially check, understand and inquire of the attribute data. The query function was used to determine the area in hectares of each different supply or catchment area in order to calculate potential population and thus potential usage of engineering services. Existing percentage development was required for certain of the cost calculations and was determined from a query of the land use coverage of the study area. Slope analysis was a further essential component of the model to determine outfall sewer diameters and as an influencing factor in determining difficulty of excavation.

Spatial analysis was more explicitly used in the model through the functions of spatial searching (buffering or proximity analysis) and overlay (Figure 6.34). Spatial searching was put to greater use in the overall land suitability assessment, in determining access to the open space network through a buffering process. It was used in the bulk infrastructure potential cost model to create centroids for sewer link zones and to generate a new line feature linking the centroid to the nearest point in the outfall sewer network, which was subsequently costed in terms of length and diameter. It was not necessary to take topography into account in generating this link as the definition of sewer link catchments ensured that the entire catchment would drain naturally into the relevant outfall pipe.

Spatial overlay was a critical function utilised in the model (Figure 6.34). Overlay is the process of comparing spatial features in two or more layers (Maguire & Dangermond 1991: 329). Overlay calculations are more easily carried out using grid or raster data structures and for this reason, vector data was restructured to raster in the model, for the purposes of overlay analysis (Berry 1987; Tomlin 1991). In his guidelines on land suitability assessment without GIS, Anderson (1987) specifies that land units must have the same boundary for each of the factors being considered. A considerable benefit of GIS is that there is no need to reduce all criteria to a common spatial unit of measure i.e. zone, catchments etc. Each criteria can be assessed on whatever spatial basis is applicable e.g. water reservoir supply areas, outfall sewer catchment area. GIS is able to combine all zone types and an analysis is possible on the basis of unique intercept polygons formed when all zones are overlayed, in the case of vector overlay, or on the basis of grid summation, in the case of raster overlay.

Overlay was used in the model to translate information from one zone type to another (Figure 6.34). In the current exercise, it was necessary to translate population information from traffic zones, to water and electricity supply zones and outfall sewer and waste water treatment works catchment areas. This was achieved by means of equal area geographic proportionment where traffic zone population is allocated to other geographic zones in proportion to the percentage area overlap.

Overlay was utilised in incorporating all cost influencing factors and once-off cost factors into single cost overlays which were then overlayed with pipes in order to calculate the total cost of specific pipes by combining base costs with influencing factor costs and once-off costs across a particular pipe length (Figure 6.34).

Overlay was essential in determining total costs as they vary over space in the study area. All cost data relating to a particular spatial location is aggregated and the sum of the values reflected for that specific location so that relative costs can be compared spatially. Where overlays intercept in space, intercept areas, either polygons or grids, are created and receive a value equal to the sum of the overlay values. In this way, all the accuracy of the input data is maintained to the final overlay product. Only at that stage is it decided whether to present the data in a coarse manner i.e. high, medium, low categorisation or in a more detailed classification. The GIS overlay capabilities also facilitate the combining of bulk infrastructure cost layers with other multi-disciplinary factors in overall land suitability assessment.

6.5.5 Present

Data are spatially related and can therefore be displayed geographically in map form, which enhances understanding and clarifies issues. The effect of changes to the data can immediately be visually displayed and implications clearly observed. Visualisation of costs differences as relating to specific spatial areas is beneficial in the decision-making process relating to development as cost implications of developing in certain areas at certain densities can easily be determined in relation to other areas. Presentation is technically probably the least sophisticated of GIS functions but could be the most important function due to the interface with decision makers and other non-technical users. The value of the technical effort which has gone before will be determined by the success of the presentation. The success of presentation lies in the capability the presenter rather than the capability of the GIS. The emphasis is on formatting output and flexibility of display using categories, colours, symbols, fonts and shading in order to impart, in the most effective way, the results of the technical analysis.

The following presentation techniques were used to ensure optimum disclosure of cost results:

- as far as possible, the number of categories for display was limited to five;
- where maps need to be compared, categories are kept constant and maps are presented on the same page;
- cost categories are tailor-made to ensure that cost differences, particularly for the numerous lower cost areas are visible, by having smaller cost ranges for the lower cost categories with increasing ranges as the costs increase and the number of associated areas decreases;
- colour shading was utilised so that least suitable, least capacity or highest cost areas are represented in light colours while more suitable, lower cost areas are represented in darker shades; and
- a base map is provided so that the user can spatially relate to the maps.

CHAPTER 7: INCLUDING BULK INFRASTRUCTURE COSTS IN LAND SUITABILITY ASSESSMENT

7.1 Introduction

The purpose of this study is to demonstrate the importance of incorporating bulk infrastructure cost considerations at an early stage in the planning process as an integral component of land suitability assessment. In the previous chapter, the application of the bulk infrastructure potential cost model in the GPMC area was discussed, demonstrating the calculation of relative potential costs and the resulting locational differences in capital costs for water, sanitation and electricity for three alternative density scenarios.

On order to establish the significance of including bulk infrastructure cost considerations in land suitability assessment, this chapter compares and contrasts the results of a land suitability assessment for low income residential development, conducted for the GPMC area (Figure 7.1). Three situations are considered:

- a land suitability assessment where no bulk infrastructure issues are considered at all;
- a land suitability assessment where existing spare capacity in the bulk infrastructure system is taken into account; and
- a land suitability assessment where bulk infrastructure potential costs (incorporating spare capacity considerations) are included.

The purpose of land suitability assessment is to identify and prioritise vacant, infill and redevelopable land for low income residential development as part of a land delivery strategy, which in turn forms part of a housing strategy, which is an integral component of integrated development planning. The land suitability assessment is multi-disciplinary in nature, combining a range of criteria to influence development decisions.

7.2 Criteria selection

7.2.1 Criteria sources

Criteria which influence the suitability of land for low income residential development were extracted from current national policy documentation. The RDP (ANC 1994: 24) is clear that land for housing must be suitably located geologically, environmentally, and with respect to economic opportunities and social amenities. The White Paper on Housing (Republic of South Africa 1994: 52) calls for effective and integrated development by, amongst others, optimising the use of existing physical and social infrastructure. In the section regarding general principles relating to land development, the Development Facilitation Act (Republic of South Africa 1995: 10) reiterates the promotion of efficient and integrated land development by promoting the location of residential and employment opportunities in close proximity to, or integrated with each other and by optimising the use of existing resources including such resources relating to land, bulk infrastructure, roads, transportation and social facilities.

7.2.1.1 RDP

- Break down apartheid geography through...more compact cities (ANC 1994: 83).

- Sustainable economic expansion must redress the imbalances in infrastructure, transportation and basic services in our cities. Housing, transport, electrification and other infrastructure and services programmes should promote access to employment opportunities and urban resources, and the consequent densification and unification of the urban fabric. In particular, industries and services that will not harm the environment should be located near existing townships. New low income housing should be situated near employment opportunities wherever possible (ANC 1994: 86).

- Land for housing must be suitably located geologically, environmentally, and with respect to economic opportunities and social amenities (ANC 1994: 24).

- The environmental impact of urban reconstruction and development must form an integral part of an urban development strategy. This includes the encroachment of urban development on viable agricultural land, air pollution, water pollution and waste management (ANC 1994: 87).

7.2.1.2 White Paper on Housing

- Redress spatial inequalities and distortions that have resulted from planning according to apartheid and segregation policies of the past (Republic of South Africa 1994: 53).

- Ensure that housing is developed on well located land which promotes physical social economic and institutional integration of South African society (Republic of South Africa 1994: 53).

- Strive for viable, socially and economically integrated communities, situated in areas allowing convenient access to economic opportunities as well as health, educational and social amenities, within which...access on a progressive basis to...potable water, adequate sanitary facilities including waste disposal and domestic electricity (Republic of South Africa 1994: 21).

- Promote effective and integrated development by:

    - promoting the location of residential and employment opportunities in close proximity to or integrated with each other;

    - optimising the use of existing physical and social infrastructure;

    - providing for a diverse range of land uses at all levels;

    - discouraging urban sprawl;

    - contribute to the development of more compact settlements, towns and cities;

- contribute to the correction of the historically distorted racial and spatial patterns; and
- facilitate and encourage environmentally sustainable development (Republic of South Africa 1994: 52).

7.2.1.3 Development Facilitation Act

- Promote efficient and integrated land development by:
    - promoting the location of residential and employment areas in close proximity to or integrated with each other;
    - optimising the use of existing resources including such resources relating to land, bulk infrastructure, roads, transportation and social facilities;
    - discouraging the phenomenon of urban sprawl in the urban context;
    - contributing to the land development of more compact cities; and
    - contributing to the correction of the historically distorted spatial patterns of settlement in the country and contribute to the optimum use of existing infrastructure in excess of current needs (Republic of South Africa 1995: 10).

7.2.2 Criteria defined

Once the issues pertinent to land suitability for low income residential development had been extracted from relevant national policy documents, criteria were finally selected in relation to data availability. Most selected criteria are indicators of suitability, based on various combinations of data, derived using GIS analysis techniques or imported from other models (Table 7.1).

Table 7.1: Selected low income residential development suitability criteria indicating data sources

CRITERIA	DESCRIPTION	DATA SOURCE
Access to employment	Index based on average trip cost for all modes from each zone to the major employment zones, weighted by the number of employment places in each zone.	• Origin-destination transport modelling cost outputs (public and private networks combined) - Greater Pretoria Metropolitan Council (GPMC) • Work opportunities per traffic zone - GPMC
Access to health facilities	Index based on average trip cost for all modes from each zone to public hospital zones, weighted by the bed occupancy rate of each hospital.	• Origin-destination transport modelling cost outputs (public and private networks combined) - GPMC • National Health Facilities Audit - CSIR/Dept of Health • Hospital and Nursing Yearbook of Southern Africa (1994) for bed occupancy rates
Access to education facilities	Index based on average trip cost for all modes from each zone to every secondary school zone and to the nearest primary school zone, weighted by the number of classrooms in each school.	• Origin-destination transport modelling cost outputs (public and private networks combined) - GPMC • School sizes - Human Sciences Research Council (HSRC) • Location and type of schools - GPMC
Access to metropolitan, public open space	Distance from nearest publically accessible metropolitan open space	• GIS buffering analysis • GPMC open space network
Agricultural potential	Index based on soil type and conditions	• Agricultural Research Institute
Geotechnical suitability	Index based on geological maps, soil conditions and slope	• Council for GeoScience • CSIR
Land values	Average land values per suburb and derived values for areas not covered by valuation roles	• Valuation roles from metropolitan sub-structures • Extrapolation using GIS
Bulk water capacity	Existing spare capacity in distribution reservoirs is calculated by comparing design capacity with existing usage	• Water Systems Master Plan - GPMC
Bulk sanitation capacity	Existing spare capacity in waste water treatment works and in major outfall sewers is calculated by comparing design capacity with existing usage	• Strategic Metropolitan Development Framework (1996) - GPMC • Metropolitan substructures
Bulk electricity capacity	Existing spare capacity of 132KVA stations is calculated by comparing design capacity with existing usage. Account is taken of corresponding cabling and transformer costs.	• Strategic Metropolitan Development Framework (1996) - GPMC • Pretoria City Council Electricity Department

7.3 Criteria measurement

7.3.1 Access to employment opportunities

An accessibility index was derived for each traffic zone in the study area, based on the transportation cost of accessing all major formal employment areas, weighted by the number of employment opportunities at each employment area.

$$ae_i = \sum_{j=1}^{n} \frac{c_j}{e_j}$$

where ae_i = employment accessibility cost index

c_j = interzonal transportation cost

e_j = number of formal employment opportunities

The lower the cost index, the better the accessibility. Interzonal transportation costs were obtained from 1995 transportation modelling, origin-destination generalised cost matrices, for public and private networks combined, for the morning peak. The total number of employment opportunities per zone (1995) was used firstly to identify the major employment zones. All zones with more than 2000 work opportunities were identified as major employment zones and access from all zones to all major employment zones were measures. So access was not measured only to the nearest employment area. Total number of employment opportunities per major employment zone was used, secondly, to weight the interzonal cost. The greater the number of employment opportunities, the greater the accessibility, the lower the accessibility cost index.

The high concentration of employment opportunities in and around the central Pretoria area (Figure 7.2) results in a pattern of decreasing accessibility from the central area outwards (Figure 7.3). The physical barrier of the northern ridge limits accessibility to the north although the areas of Rosslyn and Klerksoord to the north west, provides significant work opportunities. Accessibility to the south is improved by the highway network and employment opportunities of Centurion and Midrand. Areas of employment outside of the study area were also incorporated into the analysis. A strong ridge of high accessibility extends from the central area to the south west, influenced by the location of Iscor and the two industrial townships of Pretoria and Pretoria West. Fairly high levels of accessibility are evident to the east. In the north east, Waltloo, Silverton, Koedoespoort and Hermanstad are areas of high employment generation. A high intensity office and retail corridor extends almost continuously eastwards from the Pretoria CBD through Arcadia and Hatfield, significantly increasing accessibility to employment areas to the east.

7.3.2 Access to public health facilities

It was decided that for the metropolitan scale of this study and according to data availability, access to secondary health care was the appropriate factor. Primary health care should be considered on the more local level of detail where radii of about 2 km, or walking distances, determine accessibility. Tertiary health care facilities, on the other hand, often serve much wider areas than metropolitan areas and in the case of some of the tertiary care hospitals in the study area, the entire Southern Africa is served, depending on the specialist attention required. Private hospitals were not included because it was assumed that these would not be widely accessible to low income people. The same origin-destination cost matrices used to determine access to work opportunities, were used to determine access to public hospitals. This cost figure was weighted by the capacity of each hospital, measured according to annual bed occupancy rates.

$$ah_i = \sum_{j=1}^{n} \frac{c_j}{b_j}$$

where ah_i = hospital accessibility cost index

c_j = interzonal transportation cost

b_j = annual bed occupancy factor

A strong pattern of high accessibility to secondary health care emerges for the north western sector of the study area (Figure 7.4). All six hospitals considered are located in the north western segment of the study area, with five occurring in the central and cental west area and the Garankuwa hospital exerting a significant influence in the north west.

7.3.3 Access to education facilities

Access to both primary and secondary schools was considered. Access to primary education was determined on the basis of cost of travelling from each traffic zone to the nearest primary school.

$$aps_i = \sum_{j=1}^{n} \frac{C}{r}$$

where aps_i = primary school accessibility cost index

C = transportation cost to nearest primary school

r = number of classrooms in nearest primary school

In the case of access to secondary education, the index was based on access to all secondary facilities in the study area, with the assumption being that there is more choice and flexibility involved in secondary education facilities. For both primary and secondary education facilities, the accessibility cost index is weighted by the size of the school which was estimated from the number of classrooms.

$$ass_i = \sum_{j=1}^{n} \frac{C_j}{r_j}$$

where ass_i = secondary school accessibility cost index

C_j = interzonal transportation cost

r_j = number of classrooms

Throughout the developed areas, there seems to be a reasonable level of accessibility to both primary and secondary education (Figure 7.5 (a) and (b)). Lower levels of accessibility correspond to undeveloped areas on the periphery of the study area or government owned land currently utilised for nonresidential purposes. The density pattern of schools is directly proportional to population densities with high densities occurring in the areas of Soshanguve, Atteridgeville and Mamelodi.

For the purpose of this study, the two layers relating to access to education facilities, are combined using raster GIS, to create a single education accessibility layer (Figure 7.5 (c)).

7.3.4 Access to metropolitan public open space

Distance to the publicly accessible open space network, comprising mainly the rivers and ridges network, was used as the measure of access to recreation facilities. The assumption is that the greater the accessibility to open space, the greater the suitability for residential development. An initial buffer was placed at a half kilometre interval around each open space area to correspond with acceptable walking distance to the recreation area. Subsequent buffers were placed at one kilometre intervals. The accessibility pattern strongly reflects the open space network (Figure 7.6).

Accessibility to open space is a highly debatable criterion. Firstly, with current high crime rates, proximity to open space is deemed to be a disadvantage. Secondly, in low income areas with small stand sizes and where people depend on walking to public transport for earning a living, it is probably more feasible to measure accessibility to sport fields and parks rather than the open space network which is mostly associated with hiking and walking for pleasure. As with access to primary health care, access to local parks and sport field, need to be included in the more detailed, local level suitability analyses.

7.3.5 Agricultural potential

It is assumed that areas with high agricultural potential are unsuitable for low income residential development as they would be more appropriate to maintain or develop as farmland. The Agricultural Research Institute has categorised agricultural potential for the non-built-up areas of the study area based predominantly on soil type and characteristics and hydrological factors.

Although there are pockets of higher potential interspersed with areas of lower potential throughout the study area, generally, the eastern areas have lower agricultural potential whereas significant areas of high and medium-high potential occur in the north and south west of the study area (Figure 7.7). The analysis did not include the far northern portion of the study area and to complete the picture, it is assumed that this area has low agricultural potential as it is already largely developed with low income residential development and nature reserve. Agricultural potential will thus not be an inhibiting factor in the determination of overall suitability in this area.

7.3.6 Geotechnical suitability

Ten categories of engineering geotechnical development potential were initially identified from an analysis of dolomite stability, presence of economically valuable construction materials and geotechnical properties, derived from an assessment of slope, geology and landform. These were aggregated into three categories, indicating high, moderate or low development potential in terms of primarily excavation costs.

Broadly, the study area exhibits almost horizontal layers of alternating low and medium geotechnical suitability with an area of high suitability forming a layer across the central area, dipping to the south in the eastern part of the study area (Figure 7.8). This highly suitable layer corresponds with shale areas while the southern layer of low suitability corresponds with dolomite areas. The northern layer of low suitability relates to black clay areas with high heave potential.

7.3.7 Land values

The assumption is that the lower the land value, the more suitable the land is for low income residential purposes in terms of cost of acquiring land. Property values were obtained from the three metropolitan substructures comprising the study area. Average land values were calculated for each suburb. Areas which do not currently form part of a formal township were assigned values obtained from an average of all formal suburbs occurring within each wider planning zone.

The highest land values, expressed in Rand per square metre, occur in a wedge stretching from the central area of Pretoria to include the developed south eastern sector of the study area (Figure 7.9). The remaining area, except for some isolated high value areas such as around the Centurion lake area, is suitable for low income development from a land cost perspective.

7.3.8 Bulk water capacity

Areas with spare capacity in their water storage infrastructure are more suitable for low income residential development than areas without due to cost implications of providing additional capacity. Existing capacity in the water storage facilities, i.e. distribution reservoirs and towers, was calculated by comparing design capacities with actual usage. Capacity conditions were expressed as unit volume of spare capacity. Significant capacity exists in the northern part of the study area in the reservoir zones of Soshanguve, Klipkruisfontein and Magalies (Figure 7.10). On the northern side of the northern ridge, significant spare capacity exists in zones such as Montana. In the more central area, Pretoria West and Waterkloof reservoir areas have spare capacity as does the Mamelodi area in the east of the study area. Clifton, Rooihuiskraal and Louwlardia reservoir areas in the south of the study area also have considerable spare capacity.

7.3.9 Bulk sewer capacity

Areas with spare capacity in WWTW and major outfall sewers are deemed to be more suitable for development from a capital expenditure point of view. The results of the analysis undertaken for the Strategic Metropolitan Development Framework (GPMC 1997c) were used directly. Spare capacity in WWTW was determined by comparing design capacity with current flow and the results expressed in Ml/d. Spare capacity for each main outfall sewer was not measured quantitatively but described qualitatively in terms of theoretical flow, age of pipe and stormwater and vegetation root intrusions. For the purpose of this study, the three qualitative categories of inadequate capacity, adequate capacity and spare capacity were simply quantified with values of 1, 2 and 3 respectively and standardised in the same manner as all the other criteria. Areas with no infrastructure were included in the same category as areas with infrastructure but with no spare capacity.

The Rooiwal WWTW has the most spare capacity meaning that the Rooiwal catchment area, in the northern central part of the study area, is assigned a high suitability (Figure 7.11(a)). The Klipgat WWTW serving a small area in the north of the study area, also has some spare capacity. Centurion, Daspoort and Baviaanspoort WWTW all have limited spare capacity but Zeekoeigat is fully utilised and has no spare capacity resulting in its catchment area being assigned a low suitability rating. The remaining areas are currently not served with infrastructure although for some of these areas, e.g. Klipkruisfontein, new WWTW have been planned. Planned WWTW are not included in the capacity analysis.

Outfall sewer spare capacity exists in a large part of the northern, central and developed Centurion regions of the study area, except for the northern portion of Soshanguve (Figure 7.11 (b)). Inadequate capacity for future development occurs in the southern half of the study area, in the eastern, western and far southern areas.

For the purpose of this study, the two layers relating to bulk water capacity are combined using raster GIS, to create a single water capacity layer (Figure 7.11 (c)).

7.3.10 Bulk electricity capacity

An indicator of bulk electricity capacity is the winter load peak reading for the 132/11kV substations, expressed as a percentage of the design capacity. This figure represents the maximum required load on the system during a period of maximum use - usually the coldest winter day. Areas with low percentage winter peak loads are deemed to have greater spare electrical capacity than those areas with higher readings. Areas supplied directly from Eskom feeds are assumed to have unlimited capacity.

Electricity 132/11kV substation supply areas currently operating, theoretically, at close to or over-capacity include Atteridgeville, Cladius, Villeria, Pretoria North, Eldoraigne and Mamelodi (Figure 7.12). Areas with significant spare capacity include, besides the areas supplied directly by Eskom, Kloofzicht, Mooikloof, Wolmer, Piet Geers and Raslow. Almost half of the supply areas have a peak load reading of less than 50 percent, correlating with more than 50 percent of the study area, indicating that there is significant spare capacity currently within the study area.

7.4 Criteria standardisation and weighting

Each criterion raw score was standardised to a figure between 0 and 1 where the lowest score was standardised to 0 and the highest score standardised to 1 and all other scores standardised relative to that (interval-scale score type standardisation). The standardised score was then expressed as a percentage. The highest scoring value would be 100 percent suitable, the lowest score, zero percent suitable and all other scores would be arranged somewhere inbetween.

For some criteria, a higher score implies a better suitability e.g. geotechnical suitability, whereas for others, typically those concerning costs, a lower score reflects a higher suitability e.g. land values or accessibility indexes based on cost (Voogd 1983). All standardised scores, therefore, need to be formulated with a common direction e.g. the higher the score, the better the suitability. For the purpose of this study, it was decided that low scores would indicate lesser suitability and high scores would reflect greater suitability. In order to redirect cost-related scores accordingly, the standardised score was subtracted from 1 and the percentage suitability calculated.

Multicriteria evaluation accommodates the relative weighting of criteria to account for value judgements concerning priorities between criteria. Weighting is particularly important when comparing a wide range of factors, including quantitative and more qualitatively derived measures. If all criteria are costs, measured in the same hard currency, it is not necessary to weight the various cost criteria as the cost values are in and of themselves directly comparable and can be added or subtracted. In the present study, in the derivation of cost layers for water, sanitation and electricity, the three costs layers could be overlaid and costs summed to obtain a combined cost layer, without any weighting of criteria. In combining these bulk infrastructure cost layers with the other suitability criteria which range from accessibility criteria to geotechnical suitability, weighting is necessary to reflect relative levels of importance attached to each criteria. For the purpose of this study, where the aim is to compare suitability assessment with and without the inclusion of bulk infrastructure capacity and cost considerations, the weighting was kept constant for all comparisons and each criteria was weighted equally for simplicity.

7.5 Criteria summation and overlay without bulk infrastructure costs

7.5.1 Suitability assessment excluding any bulk infrastructure considerations

Using raster GIS, each data layer was overlayed, new intercept polygons formed and the total standardised criterion score or suitability index expressed as percentage suitability, for each polygon calculated using weighted summation. Weighted summation is when the standardised criterion score for each individual criterion is multiplied by the weighting given to that particular criterion in relation to the others (in the case of this study, the weighting is 1) and summed for all criterion scores, for each particular polygon, to obtain a total suitability index. The maximum value of the suitability index possible is 100 percent. Any number of categories can be used to display the total suitability index graphically and even a simple three categories indicating high, medium and low suitability would be effective. Five suitability categories were selected to spatially display the suitability results.

For equally weighted criteria, the resulting suitability map indicates that the most suitable land for low income residential development, with greater than 70 percent suitability, is located in the western portion of the central area (Figure 7.13). Accessibility to employment is excellent with the Pretoria CBD immediately to the east of the areas and industrial opportunities of Pretoria West nearby. There are no adverse geotechnical conditions and access to hospitals is good. Land values are not the lowest but the other criteria perform well enough to outweigh high land costs. The spatial pattern of high suitability conditions with percentage suitability of greater than 64 percent, is strongly influenced by geotechnical and work accessibility conditions. The high suitability percentage in the central areas and a band dipping southwards in the south east of the study area, indicates the high and medium suitability scores of the geotechnical layer in these areas. High levels of access to work opportunities are also evident in these central areas. School accessibility is also high for these central areas.

Some high suitability areas of greater than 64 percent suitability are also evident in the northern parts of the study area in the vicinity of Klipkruisfontein and the southern Soshanguve areas (Figure 7.13). These areas correspond to areas of low agricultural potential, high levels of accessibility to the social facilities of hospitals and schools and lower land values. Although geotechnical suitability is low for these areas, the high performance of the other criteria is more than sufficient to compensate for poor geotechnical conditions.

The south western sector of the study area displays low percentage suitability relating to poor school, hospital and open space accessibility, poor geotechnical conditions as a result of the presence of dolomite, high agricultural potential and poor levels of accessibility to work opportunities. The only factor which performs reasonable well in terms of suitability for low income housing is fairly low land values. Other areas which display pockets of low suitability percentages occur in the far east of the study area and in the northern portion of the central area correlating with poor accessibility to work, hospitals and schools (Figure 7.13).

7.5.2 Suitability assessment including bulk infrastructure capacity considerations

Although historically, bulk infrastucture considerations were not included at all in strategic planning initiatives until the late planning stages, once land use decisions had already been made, there have been some recent attempts to included at least bulk infrastructure capacity considerations in initial existing situation assessments as part of Integrated Development Plans (IDP) (GPMC 1997c).

For the study area, bulk infrastructure data, as presented in the Status Quo document of the IDP process (GPMC 1997c), was utilised virtually unaltered in order to demonstrate the effect on land suitability of including capacity considerations, albeit in sometimes a fairly qualitative form i.e. adequate and inadequate capacity. As part of conducting the bulk infrastructure potential cost model in the study area, improved and more quantitative capacity data did become available, but it was decided to conduct the land suitability assessment results comparison, using the data as presented in the IDP documentation in order to be able to draw some conclusions as to the impact of this more coarse, generalised, qualitative data on land suitability assessment in comparison to excluding it all together and in relation to the inclusion of more detailed costs.

The resulting spatial pattern of suitability for low income residential development displays some significant differences to the situation when all bulk infrastructure cost considerations are excluded (Figure 7.14). The effect of geotechnical conditions is not as obvious. Surface area of higher suitability of greater than 60 percent is considerably reduced in the southern half of the study but increases significantly in the northern half of the study area, particularly in the north west. Areas of greater than 70 percent suitability previously evident in the southern parts of the central western area are now only between 47 and 70 percent suitable. The area of high suitability previously obvious in the northern part of the central western area has been extended eastwards while northwards from it, an area of greater than 60 percent suitability extends to as far north as lower Soshanguve. The reasons for this excellent suitability performance in the north western part of the study area when bulk infrastructure capacity considerations are included in the suitability assessment, are obvious from a consideration of the individual infrastructure capacity layers (Figures 7.10, 7.11 and 7.12). WWTW spare capacity availability, expressed in volume measure, is greatest in the entire northern and north western parts of the study area. There is qualitatively expressed "spare" outfall sewer capacity in these areas. Water reservoir capacity conditions, in particular in the north western portion, have also been identified as conditions of "spare" capacity and electricity conditions are highly suitable for a portion of the area, from the perspective of low winter load readings for the Klipkruisfontein area. These advantageous bulk infrastructure capacity conditions together exert a strong influence on making the north western area highly suitable for low income development, or in fact for any type of development. The reason for the eastwards extension of the upper western central area of high suitability is due to good water capacity conditions and the reduced suitability of the lower western central, previously high suitability area, is due to lower water and sanitation capacity conditions.

7.6 Criteria overlay including bulk infrastructure potential costs

7.6.1 Importance of considering cost

A consideration of existing bulk infrastructure spare capacity at least gives some indication of areas which would theoretically be more suitable to develop in terms of cost on the basis of existing infrastructure still having some potential to accommodate additional demand. It is argued that the inclusion of only existing capacity consideration is a tenuous indicator of infrastructure costs. No attention is given to the size, current development characteristics or future potential demand of the area, supplied by particular infrastructure facilities. There may be a significant volume of spare capacity in a particular WWTW but the catchment area is large with a significant proportion of undeveloped land, which means that theoretically the available spare capacity has to go a long way. On the other hand, a more fully developed, small catchment area, with less spare capacity, may be able to cope with far greater densities and may thus be more suitable for development. In addition, areas currently not served by any infrastructure, i.e. usually currently undeveloped part of the area, are more or less excluded from the capacity analysis whereas a consideration of potential costs would differentiate suitability between currently unserved areas. Furthermore, although outfall sewer costs are theoretically included in the sanitation capacity overlay, in fact, only the capacity of the pipe as it enters the WWTW is considered. Other than that no consideration is given to any infrastructure pipe costs.

7.6.2 Comparison of suitability assessment including costs for various density scenarios

The spatial pattern of suitability is visually very similar for the low, medium and high density scenarios (Figure 7. 15). As was explained in chapter 6, distinctive differences in infrastructure cost do occur between scenarios but when these costs are standardised, combined with 7 other suitability criteria, weighted equally with the other criteria and the suitability results displayed in five categories, the differences are not that apparent.

In order to highlight the differences more clearly, a GIS subtraction process was undertaken. Due to the fact that the other criteria are identical for all three scenarios, any differences are entirely a result of changes in infrastructure costs and are evident from a comparison between the combined cost overlays (Figure 6.33). The subtraction was therefore undertaken for the cost layers rather than for the suitability assessment including the cost layers (Figure 7.16). The only difference is that in the suitability assessment the costs have been standardised whereas in the cost subtraction overlay, costs are shown, but this has no impact on the resulting spatial pattern. The higher density scenario was always subtracted from the lower density scenario which means that positive differences indicate a decrease in cost, thus increase in suitability, with increasing density while negative differences indicate increasing cost, thus decreasing suitability, with increasing density (Figure 7.16).

The following differences in the spatial pattern of suitability between the low and medium density scenarios are noticeable:

- in the far north west, Klipkruisfontein area where there is an improvement in suitability with increasing density (Figure 7.15 (a) and (b)) as cost decreases (Figure 7.16(a)); and
- in isolated pockets in the southern half of the study areas, where negative cost differences indicate increasing cost with increasing density (Figure 7.16(a)), thus declining suitability (Figure 7.15 (a) and (b)).

Suitability differences between the medium and high density scenarios are much less noticeable than between the low and medium density scenarios (Figure 7.15 (b) and (c)). Cost differences are generally less throughout the study area under the high density scenario as evidenced by greater portions of the study area being included in the smaller cost difference categories (Figure 7.16 (a) and (b)). There are only two small areas of obvious cost difference:

- in the far north, Soshanguve area, suitability declines (Figure 7.15 (b) and (c)) due to increased cost (Figure 7.16 (b)); and
- in the central south western are, suitability increases with increasing density (Figure 7.15 (b) and (c)), due to declining cost (Figure 7.16 (b).

The pattern of differences obtained between the low and high density scenarios is very similar between the low and medium density scenarios, as expected (Figure 7.16 (c)). Although not always evident, all the actual cost differences reflected in the difference maps are included in the suitability assessment and would be available for consideration when detailed assessment of certain sites is undertaken. It can be concluded from the visual analysis, however, that differences in cost between scenarios do not significantly alter the pattern of suitability when displayed according to a limited number of categories. Even when more categories are used, suitability differences are not clearly visible. Density, therefore, although definitely influencing the spatial pattern and amount of bulk infrastructure costs, as presented in chapter 6, does not play a significant role in changing the spatial pattern of suitability in the study area. In fact, as density increases, the impact of cost on the spatial suitability pattern seems to decline further which is understandable because as population numbers increase, current, existing system spare capacity has less and less benefit as more infrastructure thresholds are reached. Eventually, a stage is reached when there is no spare capacity left anywhere in the system and the per person cost for additional infrastructure becomes more similar for however many additional persons are added. This situation would not occur in reality, however, because infrastructure is continuously added, in modules or pipes which can accommodate more than simply the current demand. There is thus continuously a changing state of spare capacity which strongly influences per capita costs differentially for different areas.

7.6.3 Comparison of suitability assessment with and without costs and capacity

Due to the similarity in pattern of suitability for all three density scenarios, only the suitability assessment using the medium density scenario cost results is discussed in relation to the suitability overlay excluding all infrastructure and the overlay including only infrastructure capacity (Figure 7.17). Including infrastructure capacity in the suitability assessment has the effect of shifting the pattern of high suitability from that of high suitability in the more central and central southern areas towards high suitability in the central and north western areas (Figure 7.17 (a) and (b)). Existing capacity conditions in relation to water, sanitation and electricity play a role in influencing the suitability pattern in this central and more north western area (Figure 6.12; Figure 6.13; Figure 6.14).

The overall spatial pattern of suitability obtained by including bulk infrastructure potential costs is similar to that when infrastructure costs are excluded with higher suitability still dominating the more central, developed areas, the highest suitabilities occurring in the western central areas and lower suitability in the peripheral areas (Figure 7.17). Areas of lowest suitability, generally correlate with areas of greatest infrastructure cost i.e. in the far south east and south west, the far east, the far north east and the northern, Klipkruisfontein area (Figure 6.33 (b); Figure 7.17 (c)). Including infrastructure costs in the land suitability assessment, seems to reinforce the pattern of suitability obtained when costs are excluded in that areas of high cost occur generally in the same areas as areas of low suitability (Figure 7.17 (a); Figure 6.33 (b)).

Although standardisation allows for the comparison of suitability between areas on the same map, it is not strictly correct to rigorously make comparisons between maps which have been prepared with different criteria i.e. between the suitability map excluding bulk infrastructure costs and the map including costs. It can be observed, however, that there seems to be a general increase in level of suitability, consistently throughout the study area, when costs are included in the assessment. This can be explained in terms of the nature of the standardisation technique and the data range rather than being indicative of relative or absolute changes in suitability level. It can be observed in some of the cost result tables in chapter 6, that a few outlier or extreme cost values occur. These values have been checked and have been found to be accurate in terms of the model calculations. The reasons for the extremely high costs for these few cases have been found to be a result of very high costs, due to long pipes or no existing spare capacity, in relation to few additional persons amongst whom the cost can be shared. It was decided that these cost are significant in terms of the model and should remain as part of the analysis. The consequence of keeping these cost in the analysis, however, is that when it comes to the standardisation process, these high costs are standardised at zero suitability, the lowest cost, usually zero cost, is standardised at one, and all other costs standardised to somewhere inbetween zero and one. It can be seen from Figure 6.33 (b), that most areas in the study area exhibit costs of less than R500 per person but that single area has a cost of R2503 per person. In relation to that single extreme cost, all other standardised costs are relatively low in comparison and end up with suitability values of greater than 0.8, even though there are infrastructure costs of up to about R500 per person involved in developing those areas. As soon as these standardised costs are incorporated with the other standardised suitability criteria, it has the effect of generally raising the final suitability indices.

The conclusion that can be made from these observations is that although multicriteria evaluation as utilised in the suitability assessment is useful in integrating disparate criteria, particularly when indices of suitability, rather than actual direct quantitative measures of suitability are used, when actual cost measures are incorporated, some of the value of the direct measures are lost. It is recommended that in subsequent suitability assessment of particular study areas, that the cost analysis be undertaken separately from the analysis of the "softer" issues so that actual development costs are explicit for the decision maker to consider in conjunction with the results of the multicriteria evaluation of the softer issues. Bulk infrastructure costs, land costs and transportation costs, all measurable in Rand value should all be integrated into a single development costs value for each location of the study area. Furthermore, for the purpose of this study, weights were kept equal for all criteria. If costs are included in the multicriteria evaluation, as should occur in practice, and differential weighting is applied, the benefit of actual cost values will be further eroded.

CHAPTER 8: CONCLUSION

8.1 Reflection on purpose

A bulk infrastructure potential cost model has been developed in order to ensure that bulk engineering services cost considerations are included in the early stages of the urban strategic planning process. Potential costs are calculated on the basis of demand for services in terms of density scenarios, capacity in the existing system and includes additional cost factors such as geotechnical, land use and environmental conditions to further enhance cost accuracy. In an environment of limited financial resources, it is crucial that cost considerations play an important role throughout the planning process. It is not feasible, as has been the case in past strategic planning practice, to only be concerned with costs during the implementation phase, once plans have been finalised.

Land suitability assessment is a critical component of the initial planning phases to ascertain the appropriateness of various locations for various land uses within the overall vision, goals and objectives established for the planning process in the particular study area. Land suitabilityassessment is neccessary for land delivery which is necessary before residential and non-residential development can proceed. It has been shown that although bulk infrastructure potential costs can be incorporated into the land suitability assessment process to enhance the spatial development decision making process, it is preferable to keep the cost analysis separate from the analysis of the more "softer" issues, measured in indices rather than hard currency values.

Conclusions which can be drawn from the development and application of the bulk infrastructure potential cost model and the incorporation of resultant infrastructure costs into an overall land suitability assessment, have an impact on a number of key developmental issues in general terms and also for the study area directly. Concluding remarks, way forward and implications for a number of key issues are presented.

8.2 Bulk infrastructure potential cost modelling

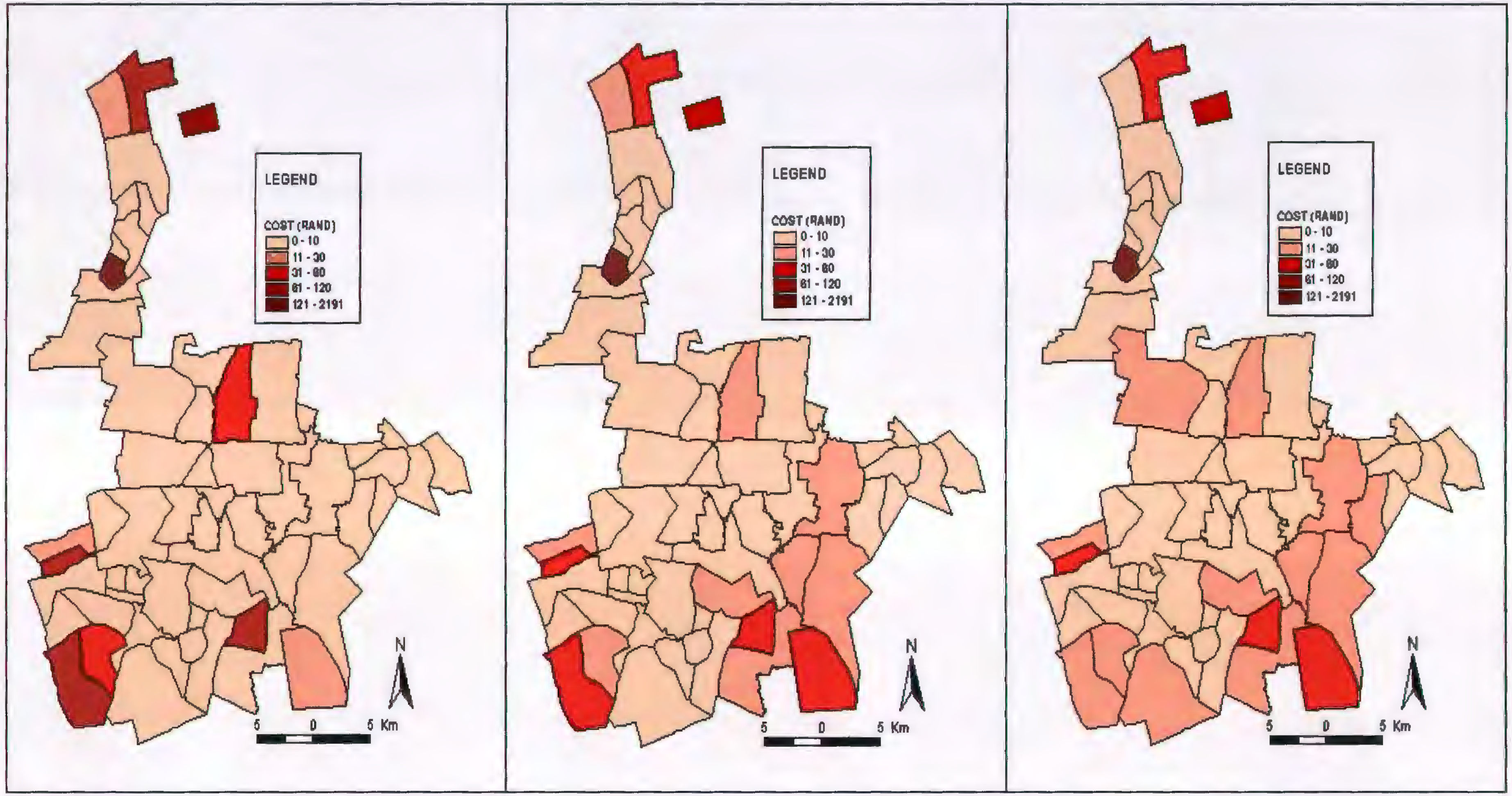
8.2.1 Strategic tool

The bulk infrastructure potential cost model is useful at the strategic scale of planning where coarse level, relative cost information is necessary to compare the suitability of various locations for particular land uses. The model by no means replaces the need for more detailed, precise infrastructure optimisation models and costing required for the implementation plan once a specific spatial development pattern has been agreed upon. The model can be conducted faster, with less data and more cheaply than the more complex system optimisation models.

It is obviously more expensive and time consuming to apply the model than not including infrastructure cost considerations at all during the early stages of the planning process. It is argued that spending the required additional time and cost on incorporating potential infrastructure costs in the early phases is actually cost effective in the longer term firstly because no time will be wasted considering areas for development which should not be developed from bulk services provision and cost perspective, which would otherwise only be discovered during later phases of the planning process, necessitating rethinking and replanning involving further costly additional public participation and technical evaluation. Secondly, with land invasion on the increase, authorities can steer development more timeously in the right direction, particularly low income development, without waiting for plans and infrastructure master plans to be completed.

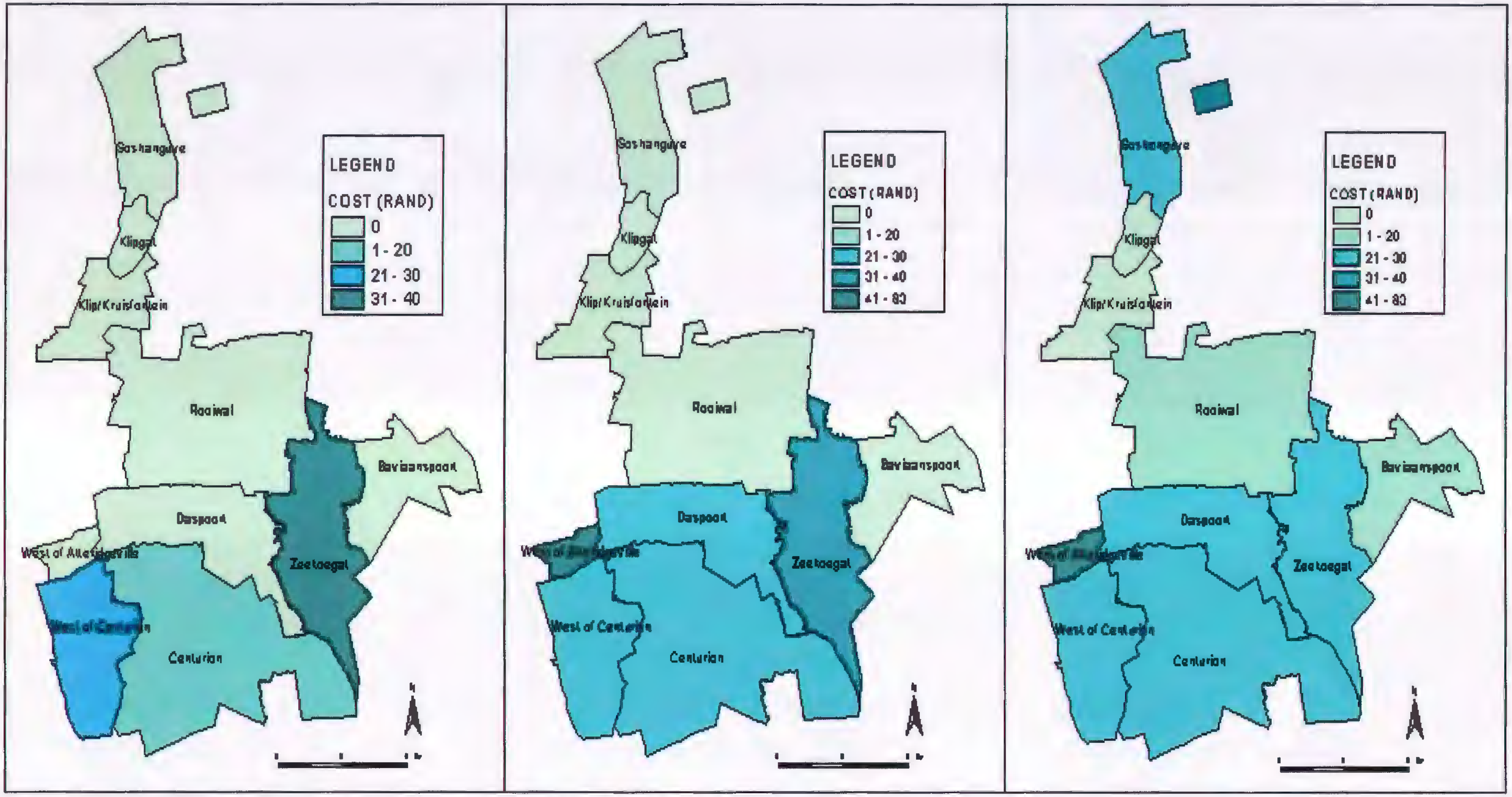
8.2.2 Variable per person costs

It is common engineering practice to estimate bulk costs in terms of "rule of thumb" per person bulk costs for each service. Previous studies investigated, which do at least consider bulk infrastructure costs in the assessment of development suitability, all included costs by means of standards per person costs, uniformly applicable throughout the study area. It has been shown during the course of the present study



(a) (b) (c)

Figure 6.24: Sewer network costs for the low (a), medium (b) and high (c) density scenarios



(a) (b) (c)

Figure 6.25: Waste Water Treatment Works cost for the low (a), medium (b) and high (c) density scenarios

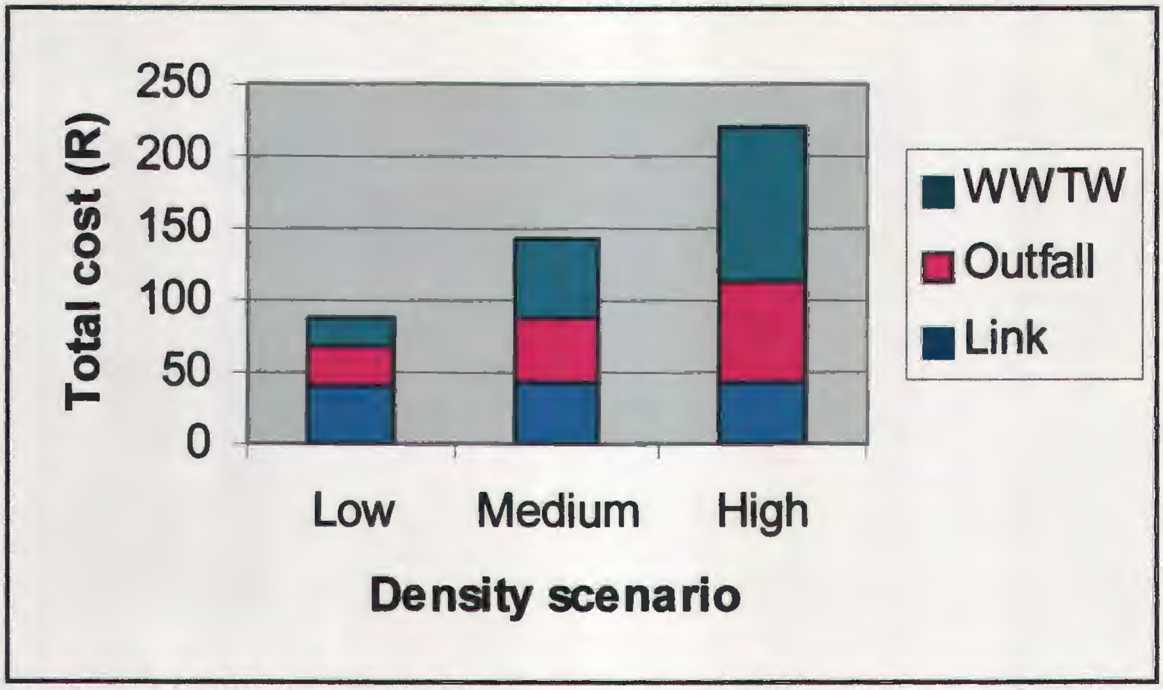


Figure 6.26 (a): Total sanitation costs for each density scenario

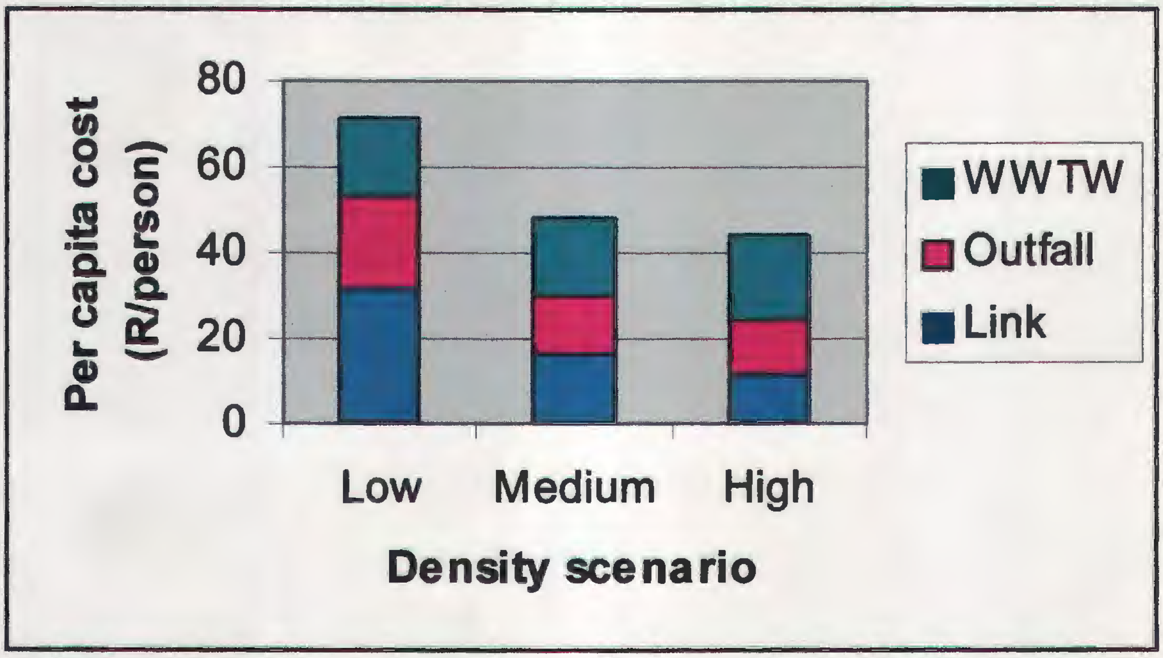


Figure 6.26 (b): Per capita sanitation costs for each density scenario

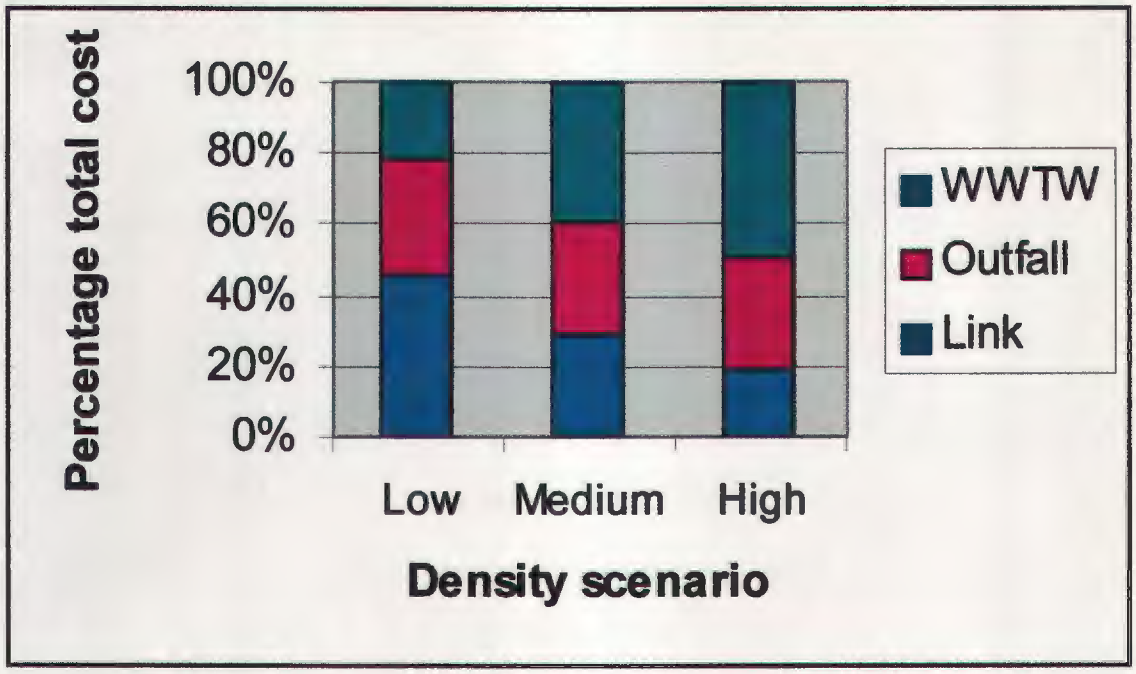


Figure 6.27 (a): Percentage total sanitation costs for each density scenario

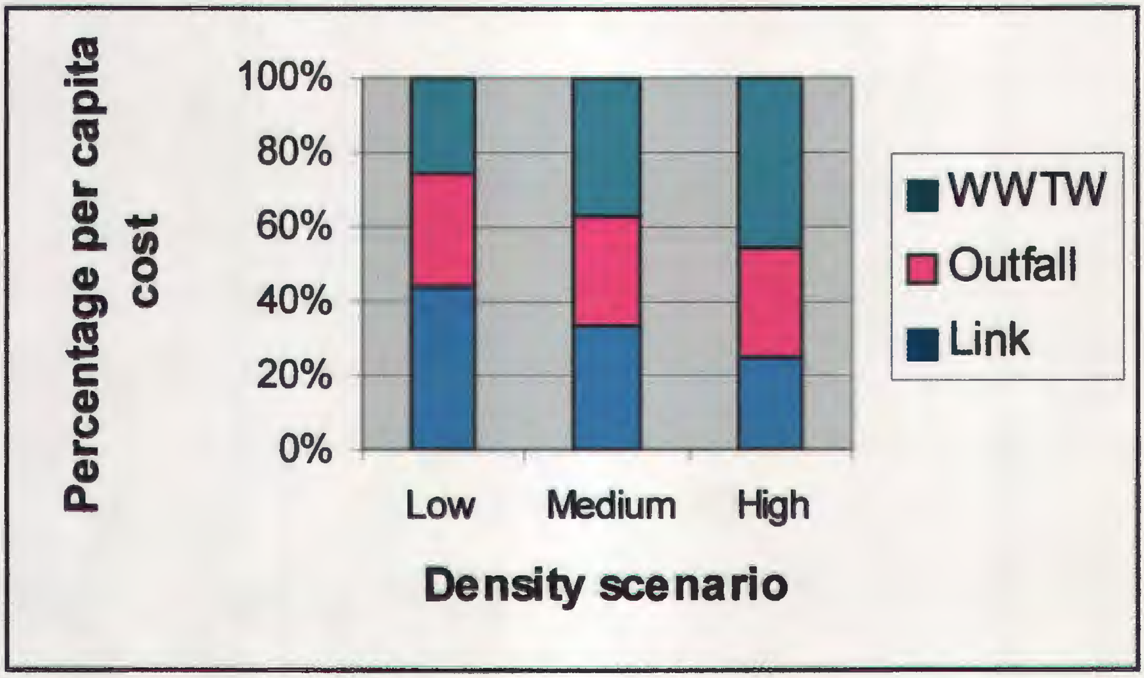
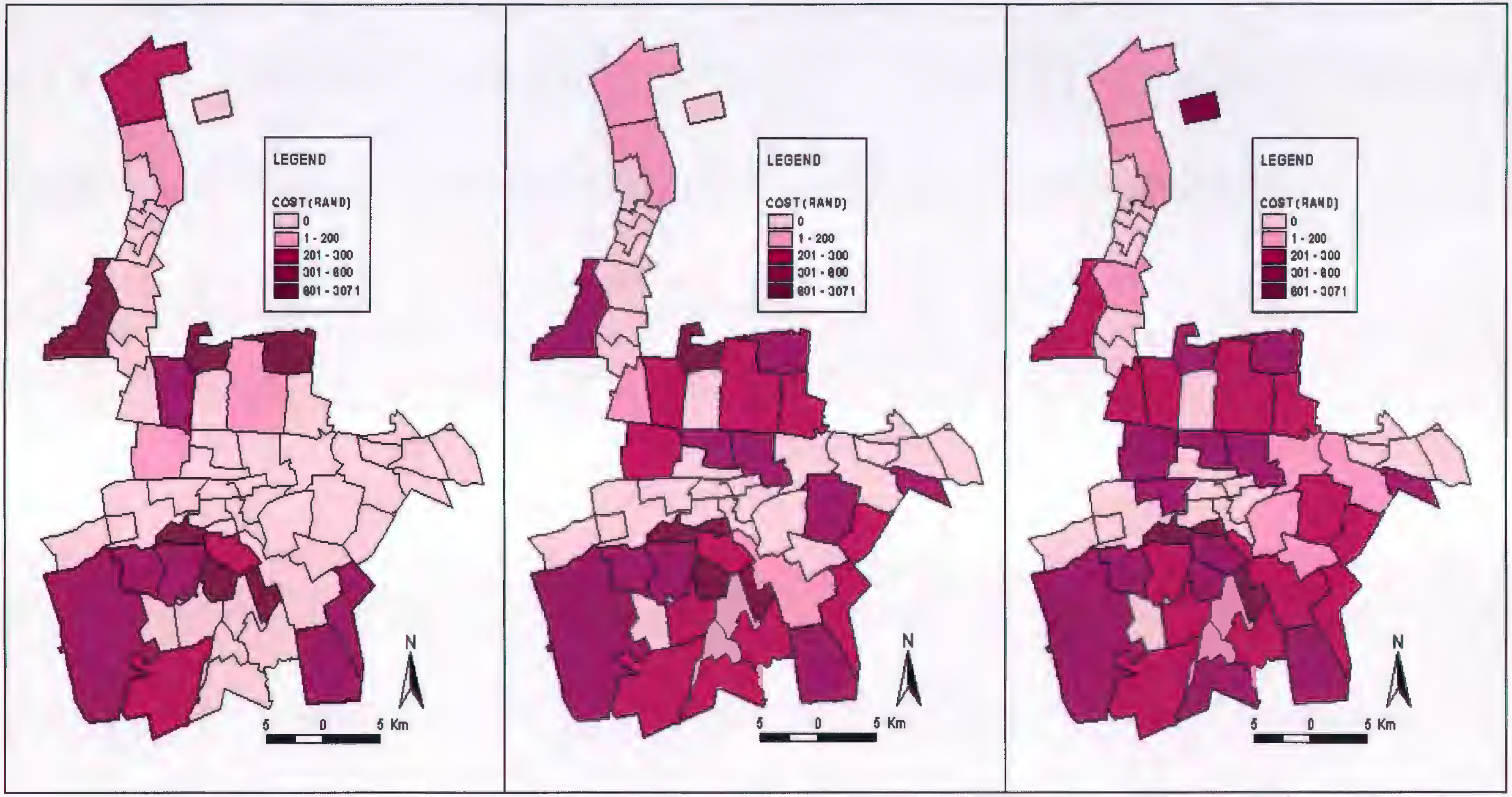


Figure 6.27 (b): Percentage per capita sanitation costs for each density scenario

(a) (b) (c)

Figure 6.28: Combined sanitation cost overlay for the low (a), medium (b) and high (c) density scenarios



(a) (b) (c)

Figure 6.30: Electricity costs for the low (a), medium (b) and high (c) density scenarios

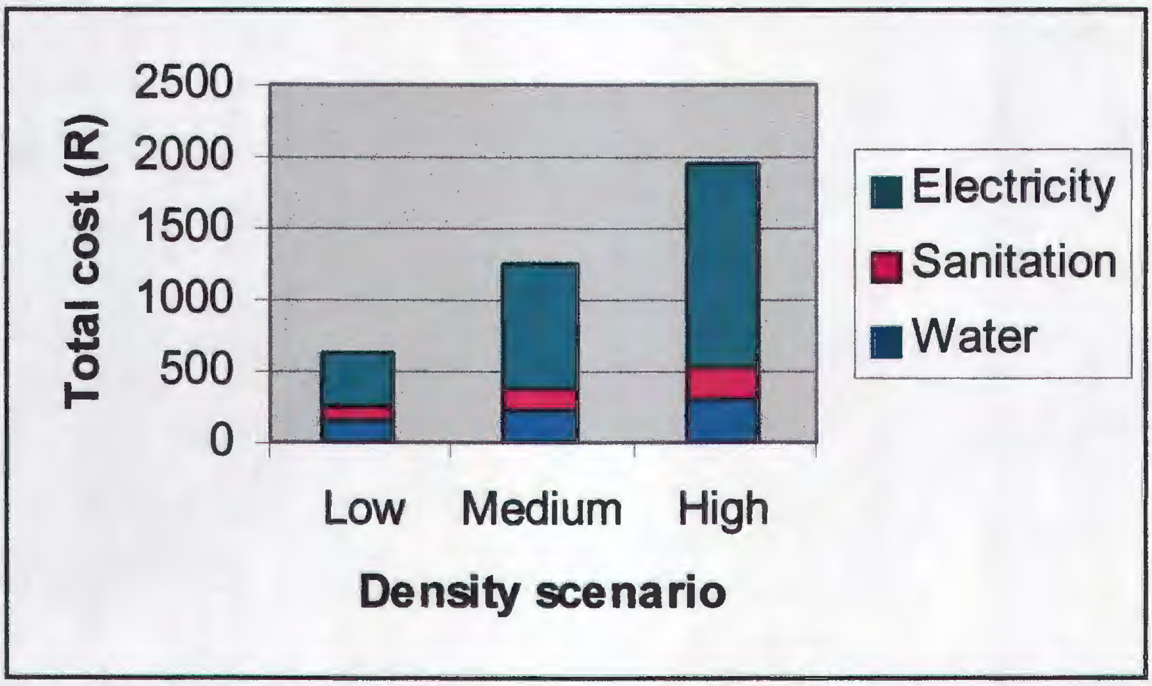


Figure 6.31 (a): Total costs (Rand) for each service for each density scenario

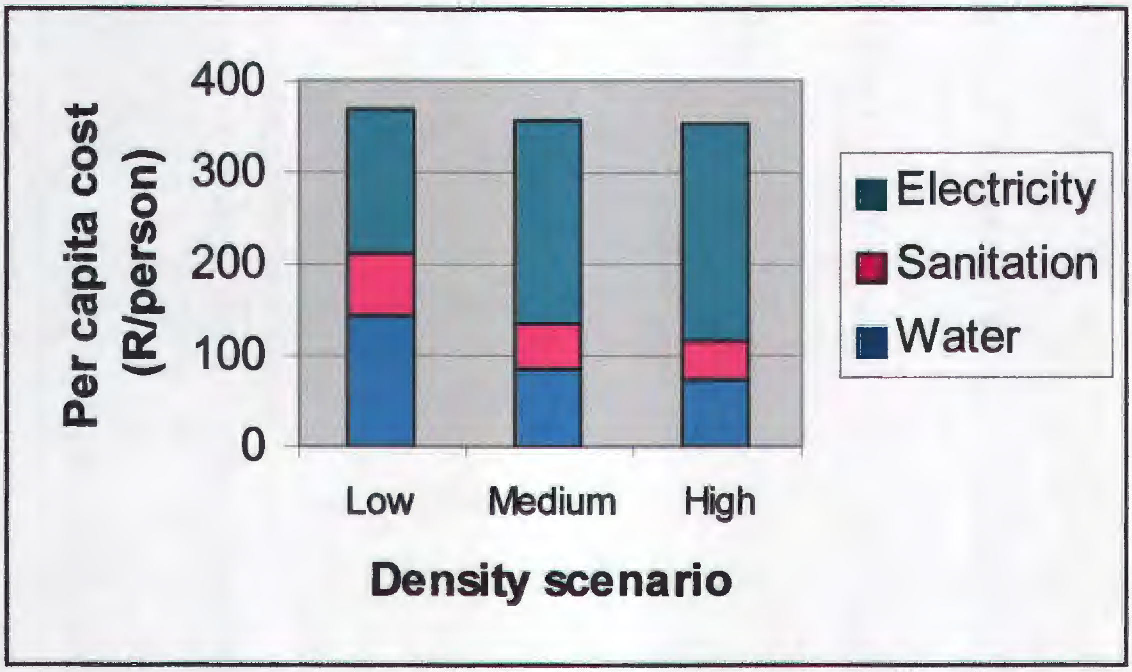


Figure 6.31 (b): Per capita costs (Rand per person) for each service for each density scenario

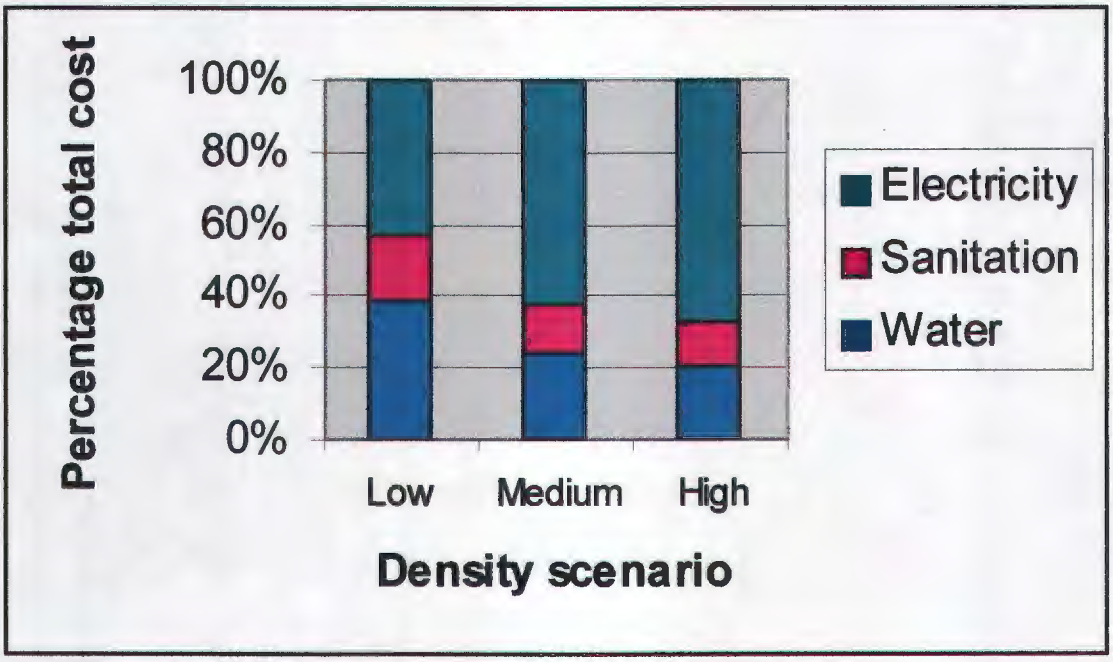


Figure 6.32 (a): Total cost of each service as a percentage of total bulk infrastructure cost

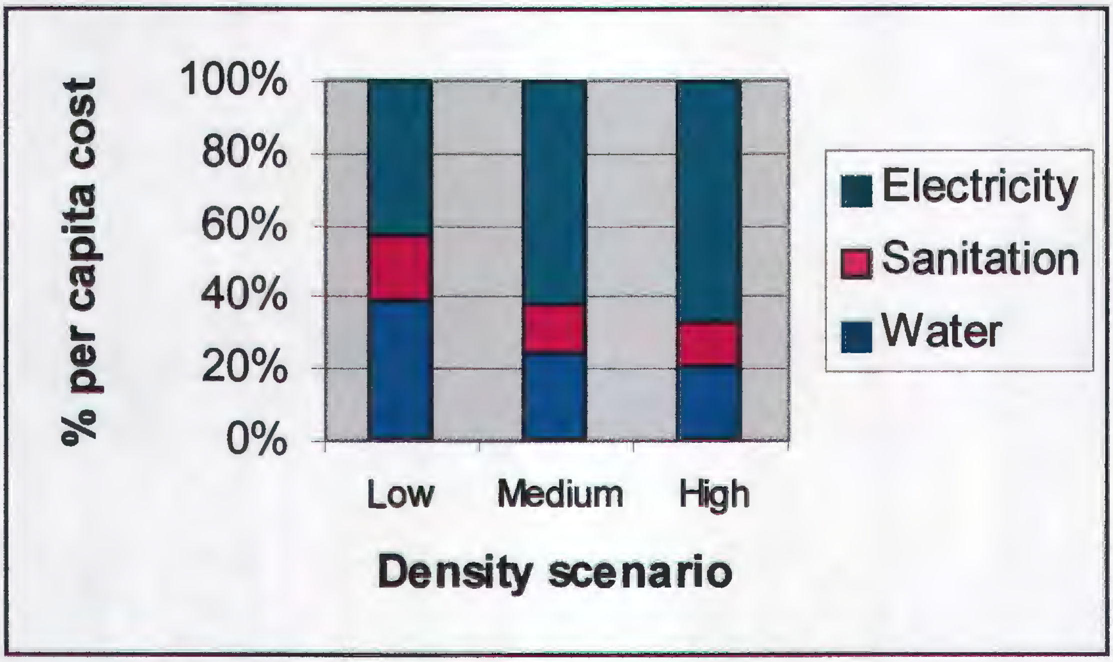


Figure 6.32 (b): Per capita cost of each service as a percentage of bulk infrastructure per capita cost

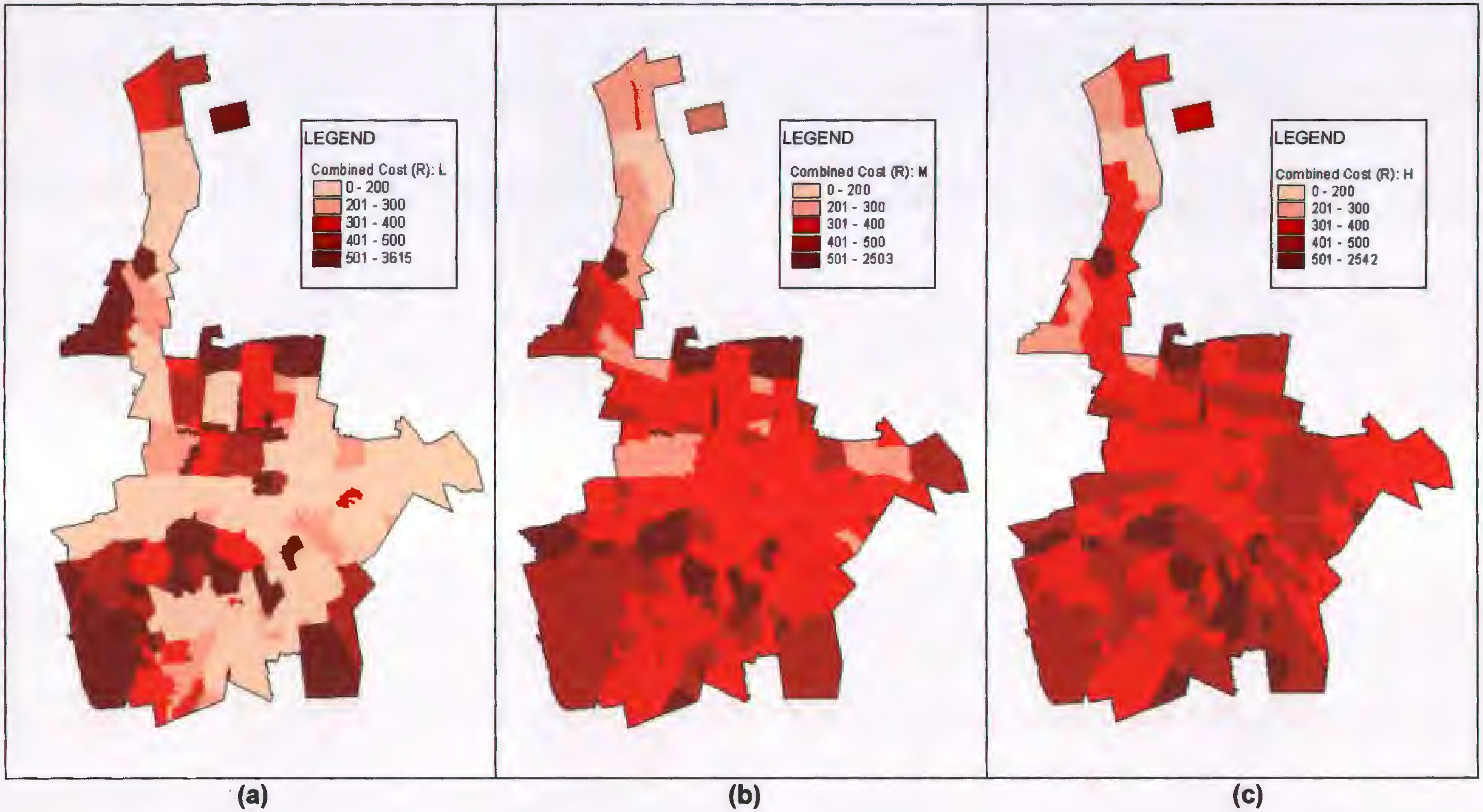


Figure 6.33: Combined water, sanitation and electricity costs for the low (a), medium (b) and high (c) density scenarios

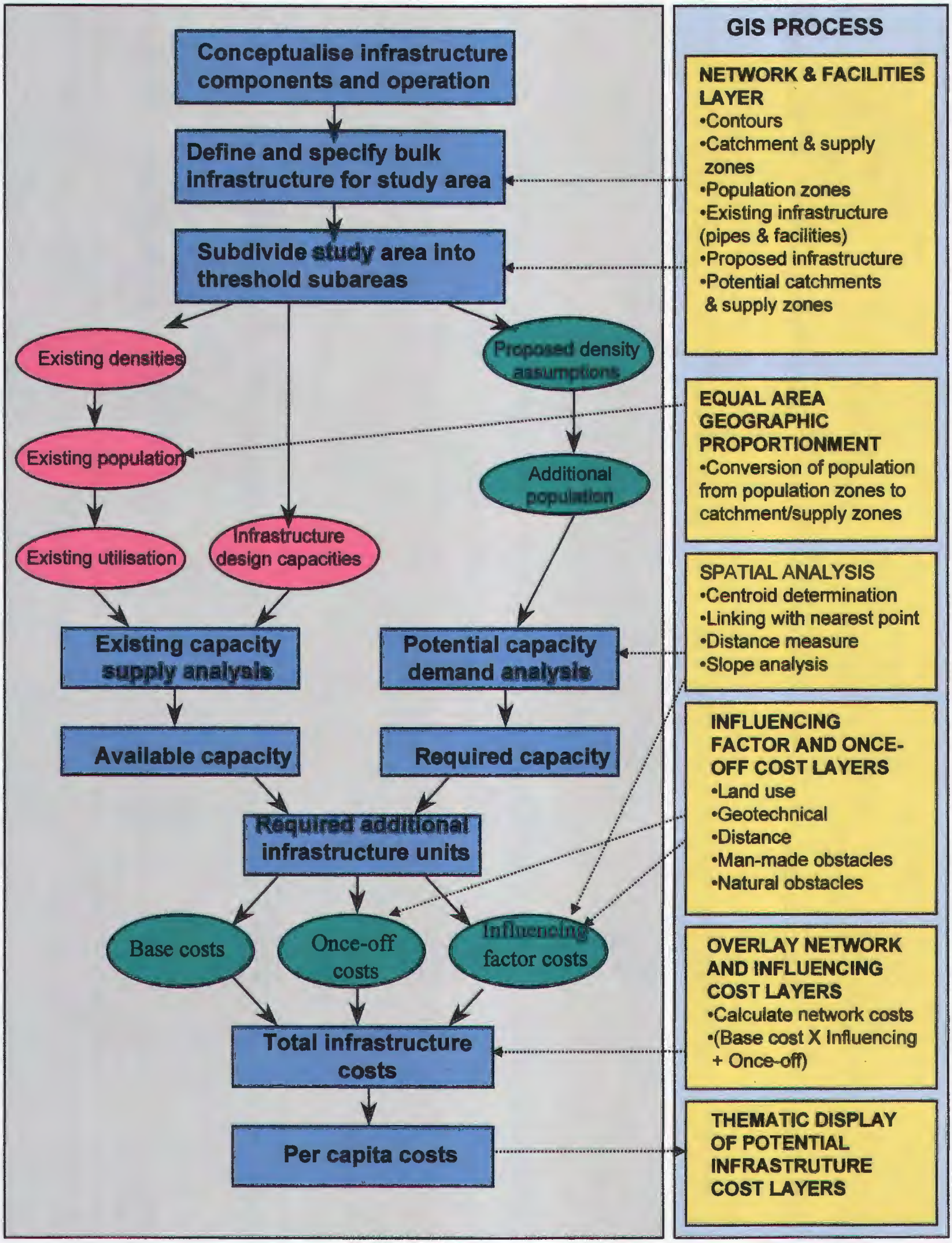


Figure 6.34: Overall bulk infrastructure potential cost model methodology with associated GIS process

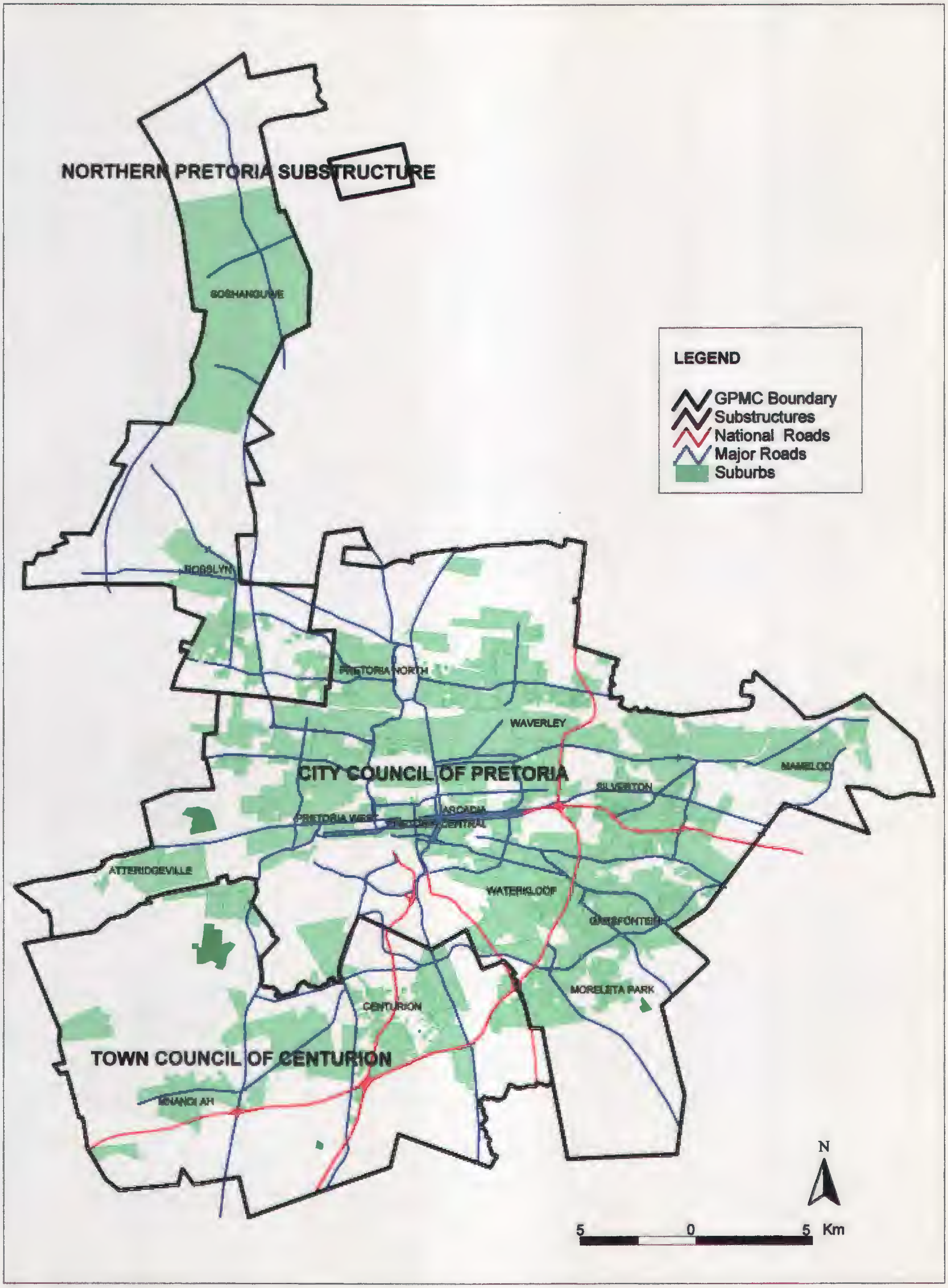


Figure 7.1: Orientation map of the Greater Pretoria Metropolitan Council area

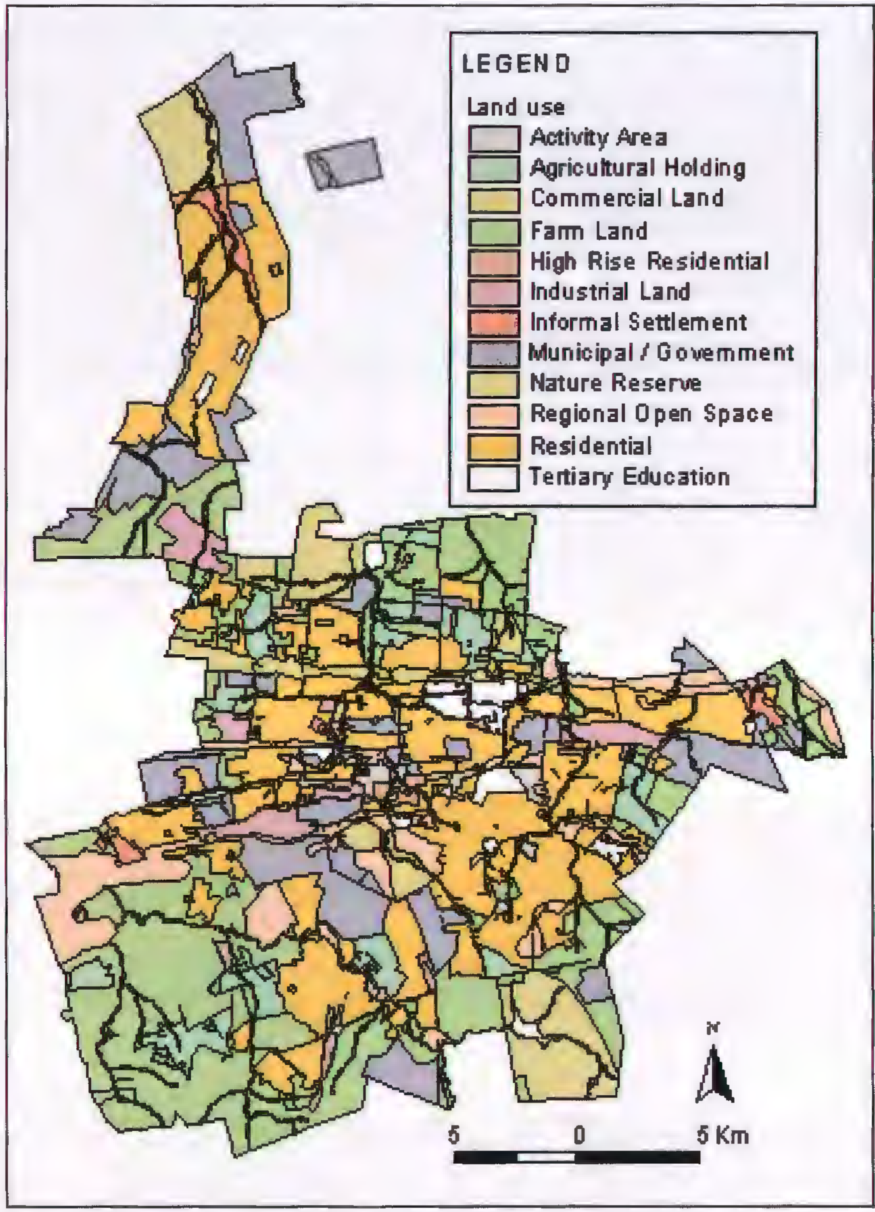


Figure 7.2: Land uses in the Greater Pretoria Metropolitan Council area

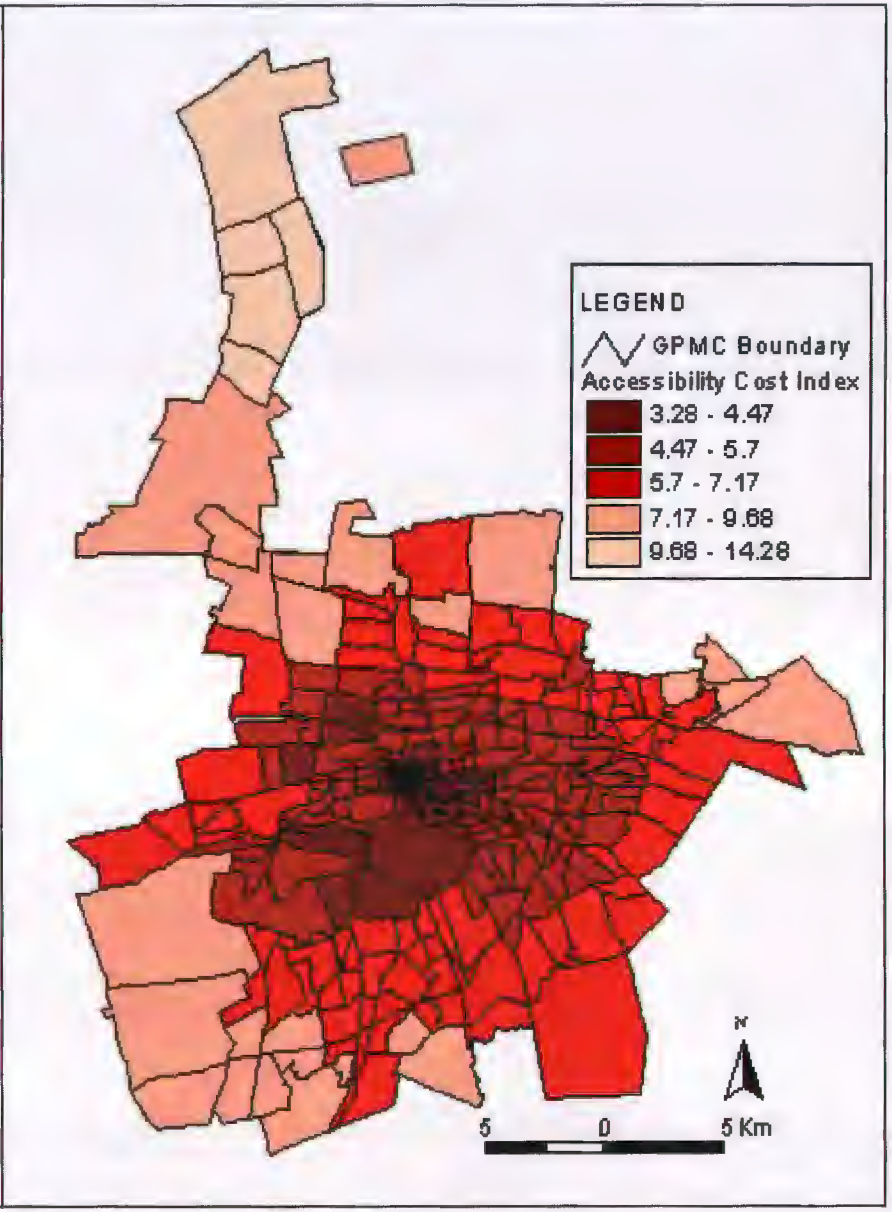


Figure 7.3: Access to employment

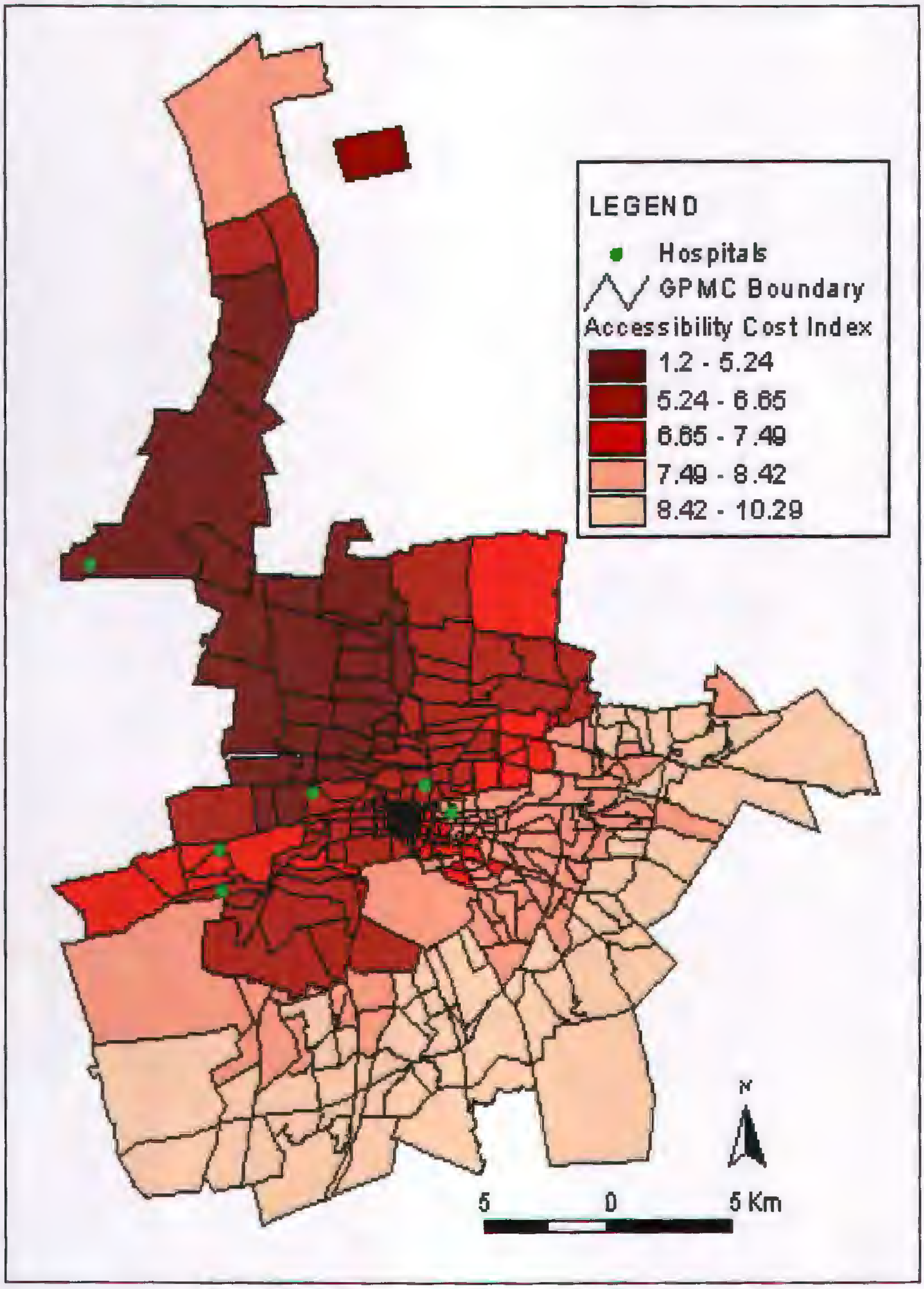
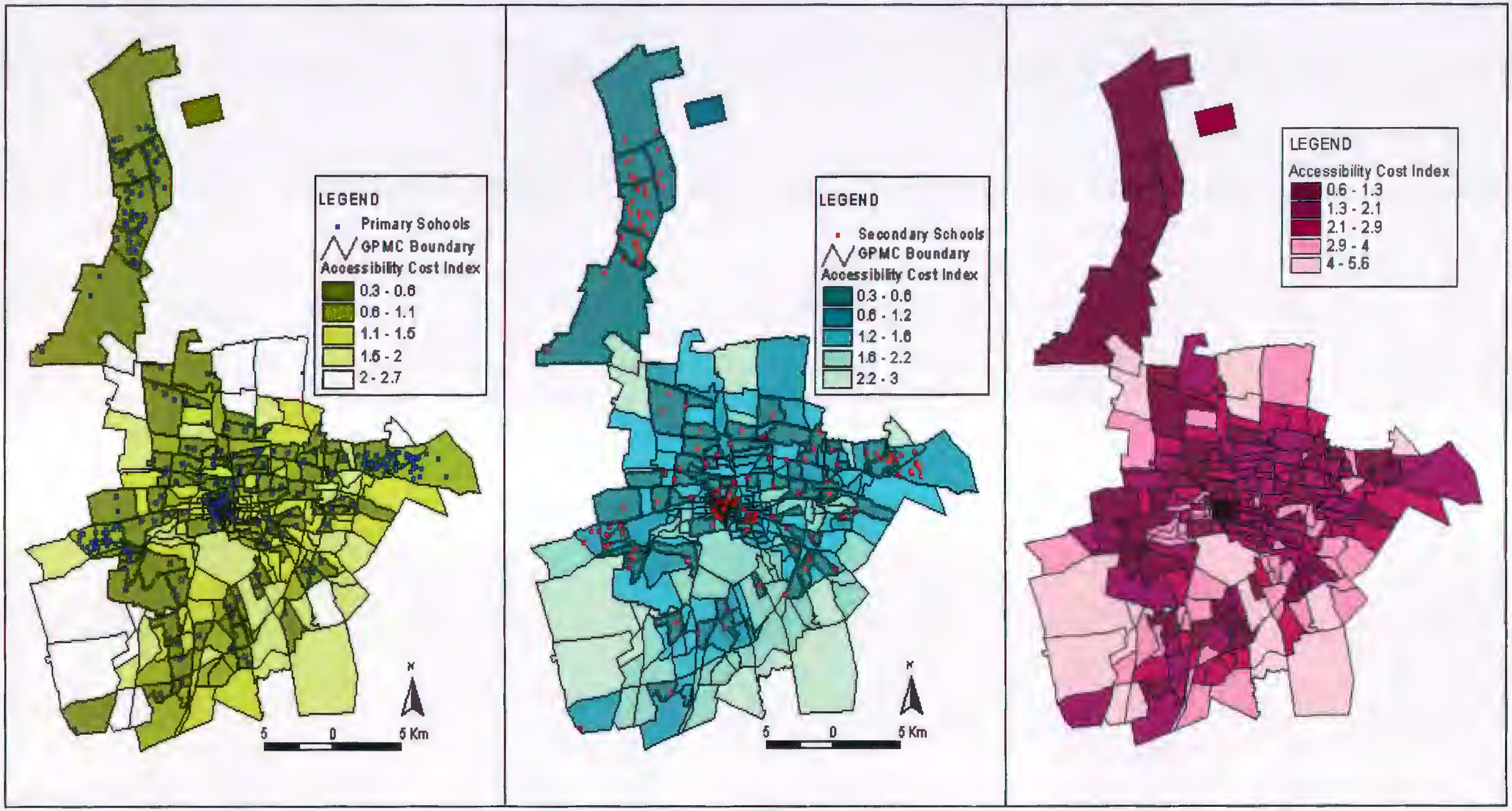


Figure 7.4: Access to hospitals



(a) (b) (c)

Figure 7.5: Access to public primary schools (a), secondary schools (b) and both combined as access to education (c)

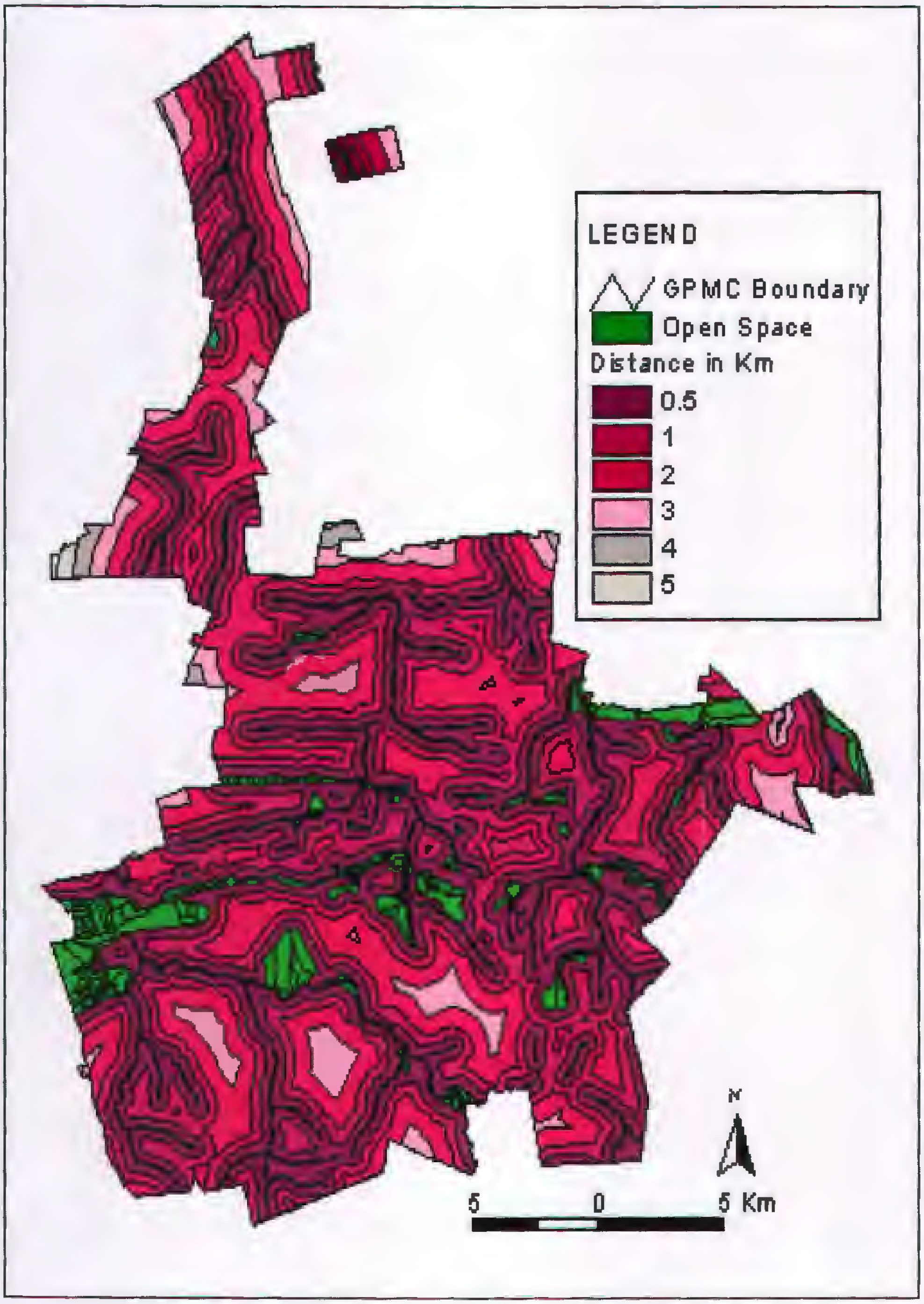


Figure 7.6: Distance to publicly accessible metropolitan open space

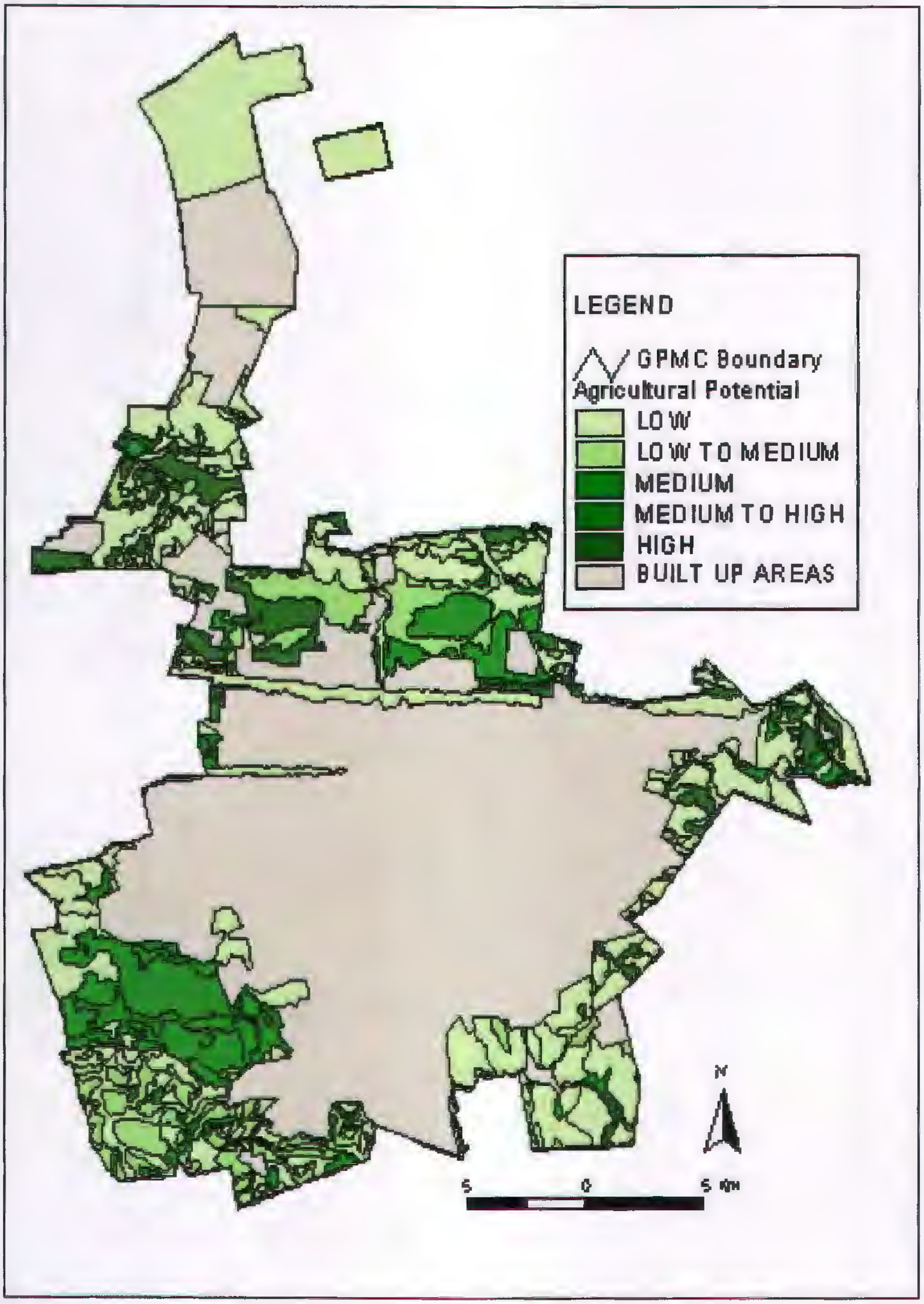


Figure 7.7: Agricultural potential

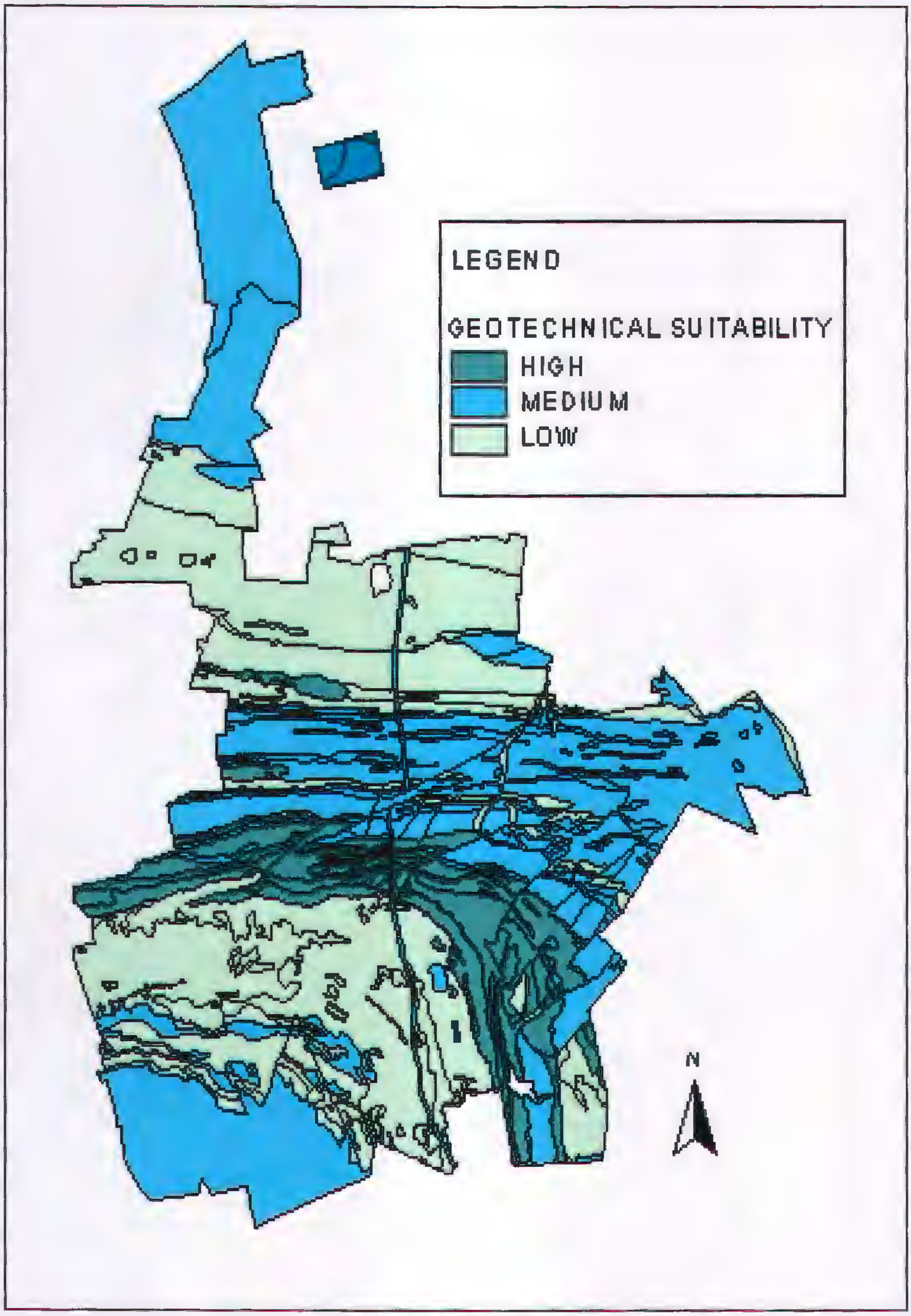


Figure 7.8: Geotechnical suitability

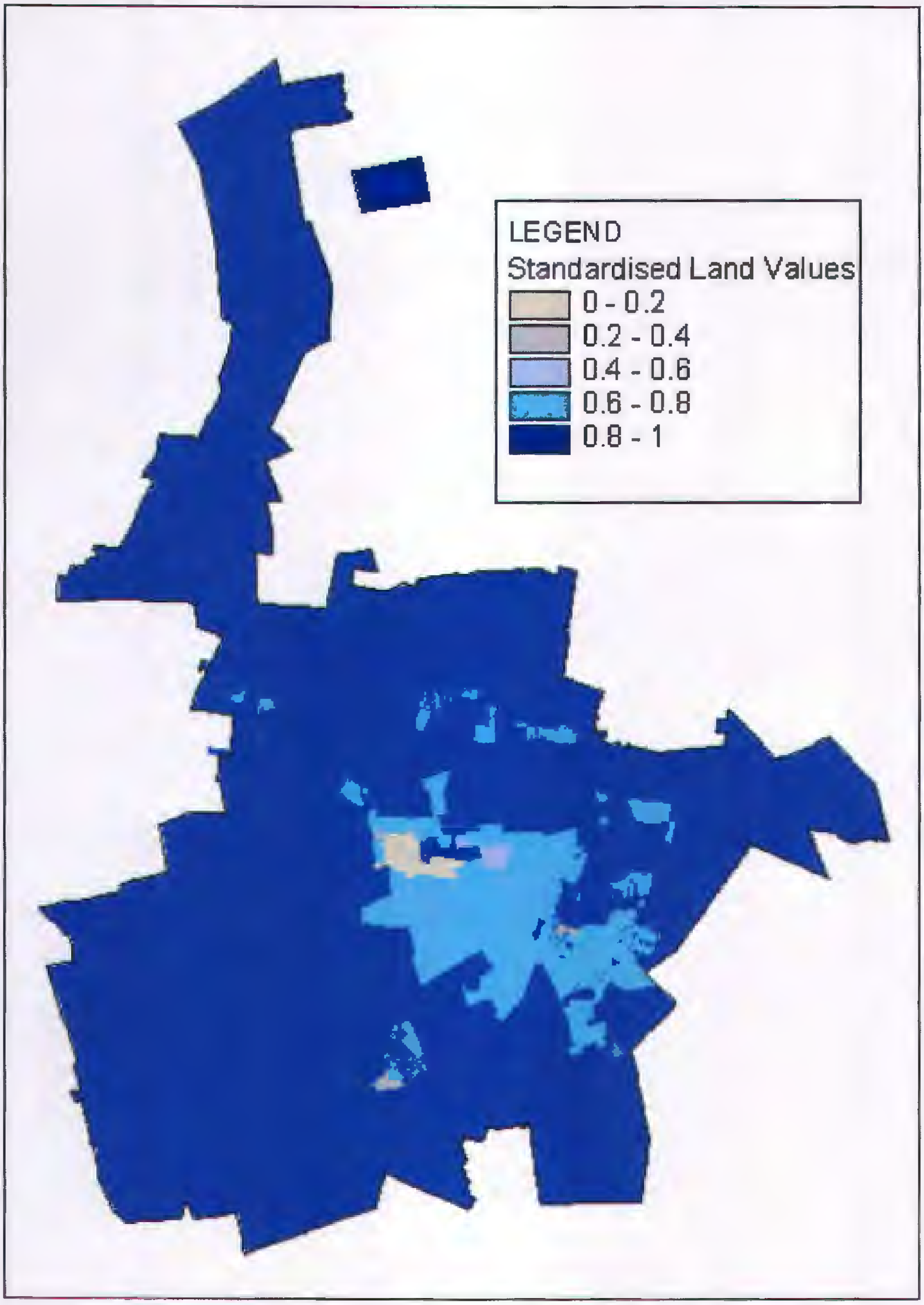


Figure 7.9: Average land values according to municipal valuation roles

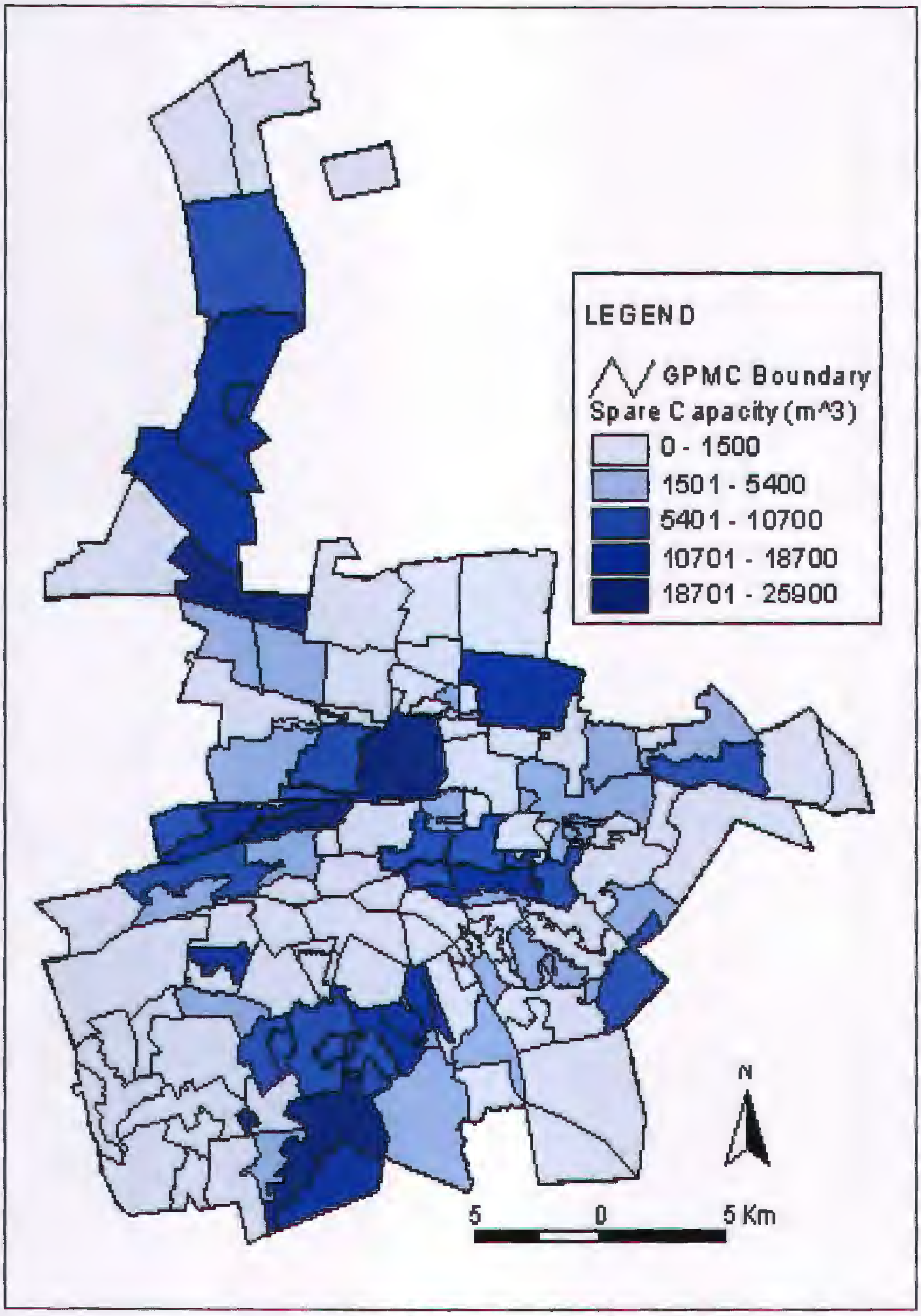
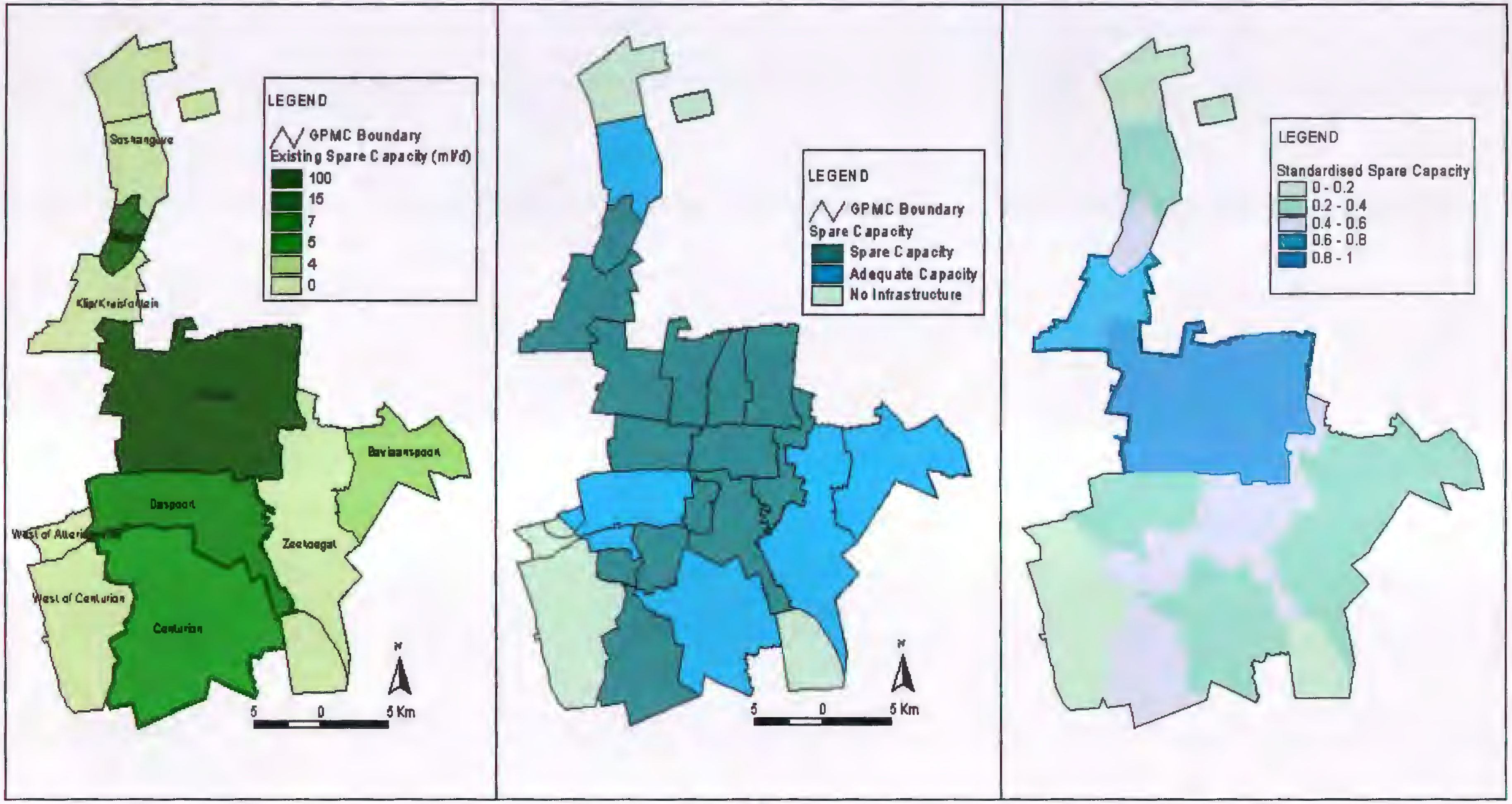


Figure 7.10: Water distribution reservoir spare capacity conditions



(a) (b) (c)

Figure 7.11: Spare capacity situation for waste water treatment works (a), main outfall sewers (b) and combined for sanitation (c)

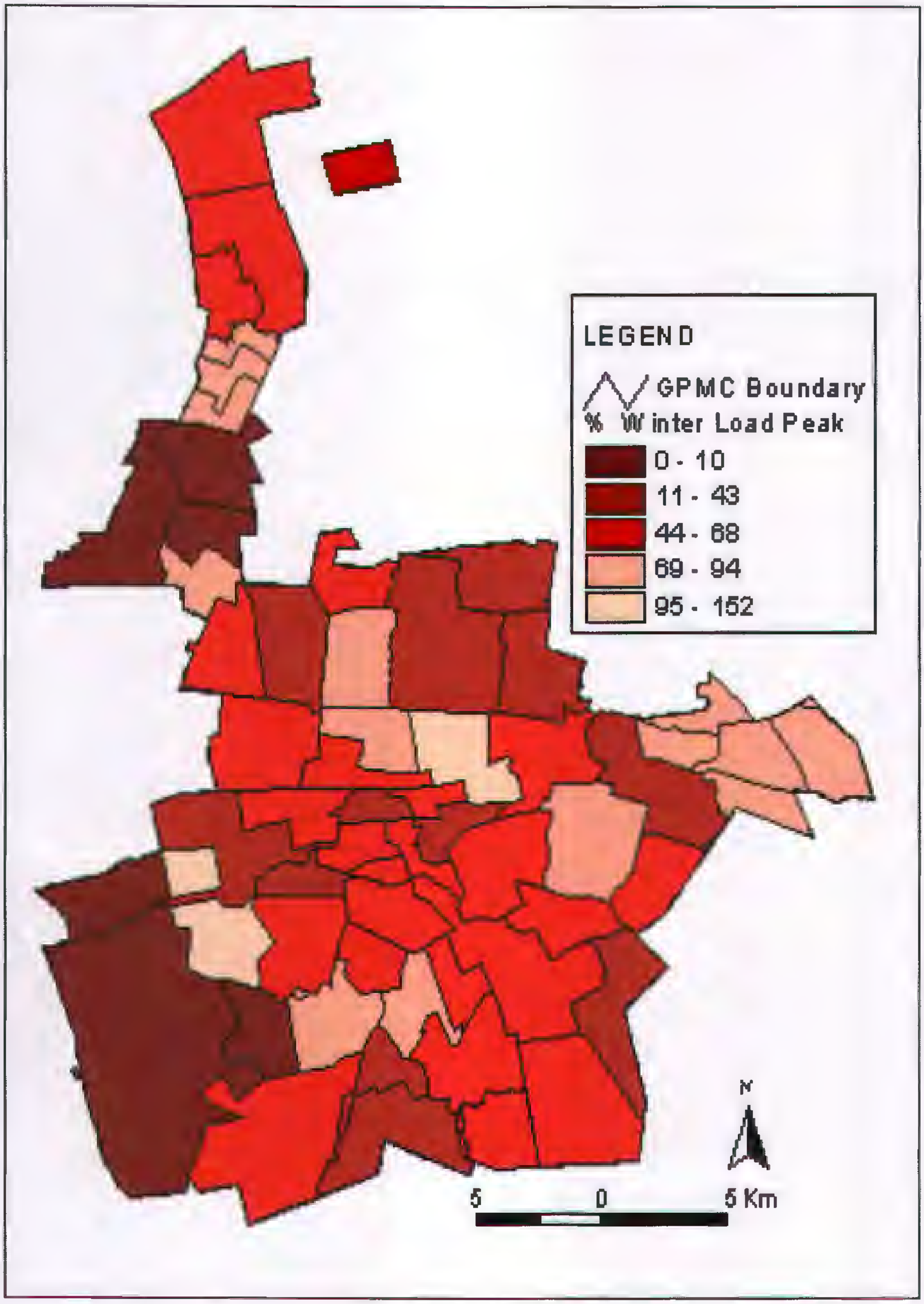


Figure 7.12: Electricity capacity conditions in terms of percentage peak winter load reading

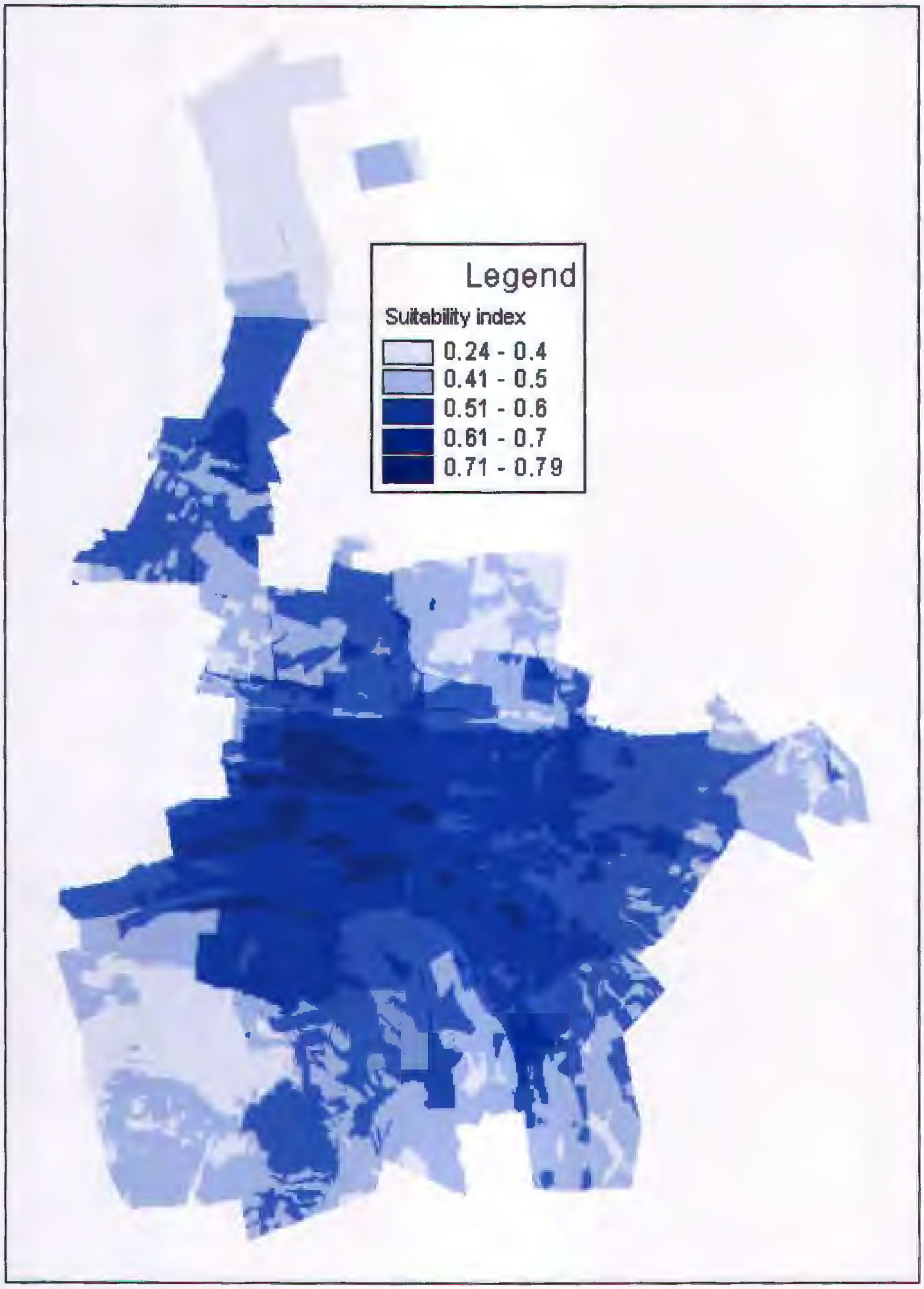


Figure 7.13: Suitability assessment excluding all bulk infrastructure considerations

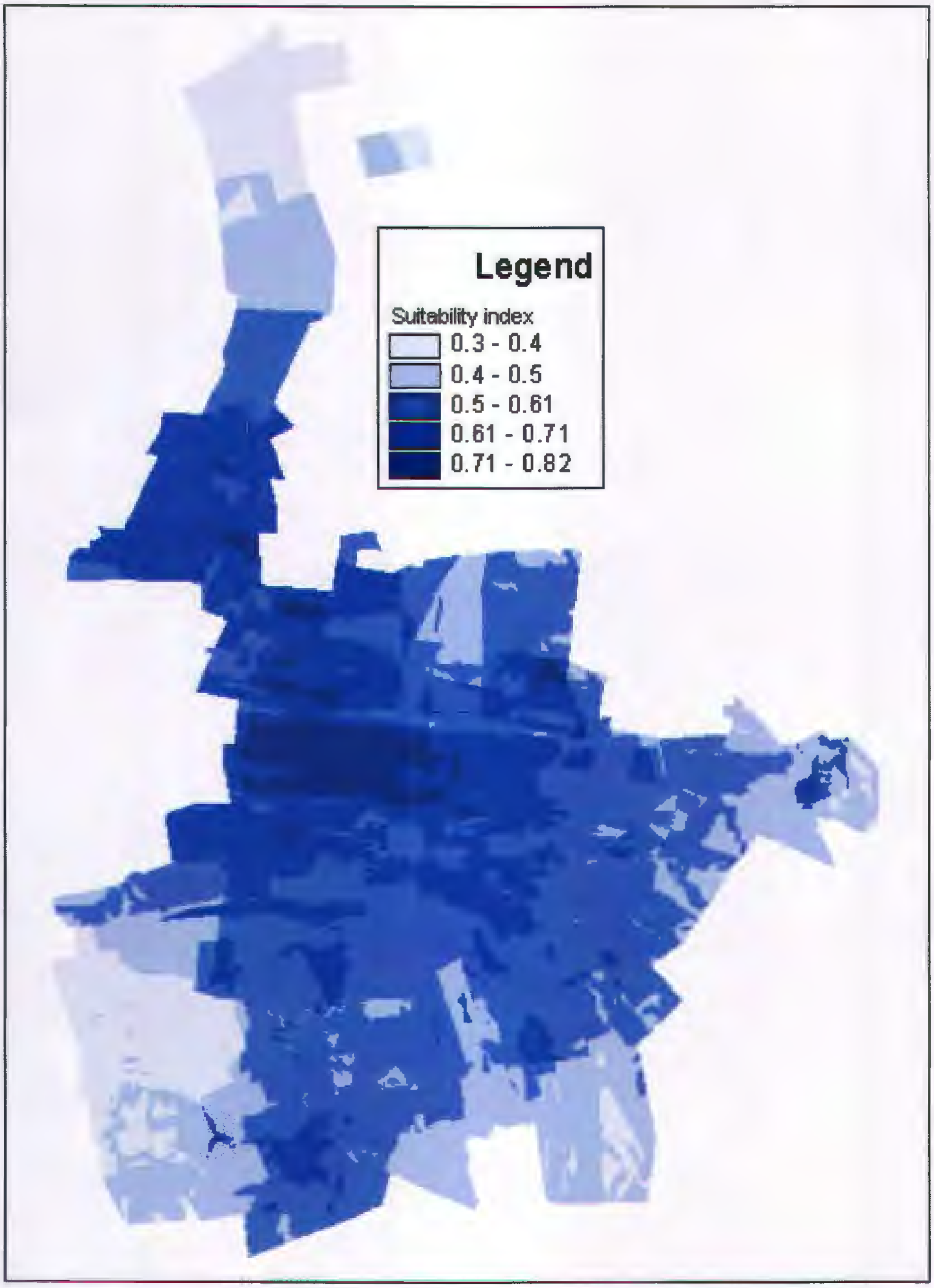


Figure 7.14: Suitability assessment including bulk infrastructure spare capacity considerations

that the inclusion of existing spare capacity or threshold conditions and variable diameter requirements in terms of population numbers, significantly influence the per person costs variably throughout the study area. The inclusion of such consideration considerably increases the accuracy of predicting bulk infrastructure costs.

8.2.3 Range of bulk services costs included

The question is posed whether or not it was worth all the effort and cost of including all the costs which were included and whether it would not suffice to only include the most costly infrastructure elements in future costing exercises. Results of the cost calculations clearly demonstrated that although in total for the entire study area, certain costs are much higher than others, it is important to include all the costs, network and facility, for water, sanitation and electricity, because of the variation in all the costs with location. In some areas, the particular cost which may be the least, in terms of total cost for the study area, may be extremely high for that particular area and significantly influence the development potential of that particular location. If that cost was left out of the equation, an incomplete thus incorrect cost pattern would emerge for particular locations in the study area.

The inclusion of additional costs in total pipe costs by means of cost factors to increase the base cost, accounting for particular locational conditions, certainly influenced base costs relatively for different areas. If the model was being applied under conditions of time, data and financial constraints, excluding some of the additional factors would be the least detrimental mitigating action. The minimum influencing factors to be included should be high intensity development and dolomitic conditions as these have the most significant impact on increasing the base cost for both water pipes and sewers. Slopes of greater than 12 degrees are significant for sewer costs and all once-off factor costs should be included. While land use and geotechnical investigations are costly, the location of roads, railway lines and streams are easily obtained from 1:50000 topo-cadastral maps, available country-wide, and thus once-off costs should always be fairly easy to include.

8.2.4 Development costs

The present study has shown how cost considerations of the bulk engineering services of water, sanitation and electricity can be incorporated into the early stages of the planning process. There are other significant cost factors which also need to be included in the development cost equation throughout the planning process. In the engineering services arena, costs of bulk roads, stormwater and solid waste removal need to be included. Potential demand for roads is more difficult to determine than is the case for water and sanitation due to less predictable behaviour in terms of road usage and policy interventions as far as transport mode is concerned. If public transport use increased significantly, there may be a smaller demand for road infrastructure but there would be a commensurate greater need, thus cost, for public transport related infrastructure such as buses, trains and rail lines and associated operational costs.

It is submitted that as soon as road costs are included, all other transportation related costs need to be incorporated so that all possible permutations can be part of the analysis. Traditional four-step transportation models and the more recent public transport focussed models can be used to assist in incorporating transportation considerations into the development costing process. Due to the greater complexity of the transportation system, with more variables and assumptions, time, cost and financial needs are significant to incorporate these costs.

Development costing could also be extended to include operation and maintenance costs. The purpose of the present study was simply to determine relative capital or threshold costs of developing in one area as opposed to another and a full water-borne system was assumed. When alternative systems are introduced, they may have higher initial, capital costs but have far lower operation and maintenance costs or vice versa. In addition, when transportation costs are incorporated, operation and maintenance costs are more significant than initial costs in many instances and should be accounted for.

The focus of the present study has been on bulk engineering services costs but local or internal reticulation costs are a significant development cost component and can also differ according to local circumstances. Local reticulation costs and building costs are particularly relevant in relation to housing subsidies and the whole densification debate. Different land subdivision layouts, erf size and shape and housing type, whether single dwellings, attached dwellings, high rise or low rise, all have an impact on cost of internal services and eventually on total development costs.

Although land costs have been included in the overall suitability assessment presented in this study, it is proposed that land costs be excluded from the "softer" issue analysis and included in the development cost analysis where real Rand values are included rather than standardised values.

8.2.5 Cost input data

Due to the focus of the present study on relative or comparative costs the most important consideration was consistency throughout the study area. 1995 costs were used as a basis for the present study but as soon as actual costs are required for more accurate budgeting purposes, input costs need updating. The spreadsheet basis of the model is such that more accurate input costs can be included as and when they are available or required.

8.2.6 Technology and affordability

The assumption in the present study has been that of a full water-borne system to accommodate future development. These systems are relatively expensive to implement and in an environment of limited financial resources, alternative technologies are being developed and implemented to, for example, treat sewage on-site by means of new technology septic tanks, small-bore systems and urinary diversion technology.

A necessity in terms of development costing specifically and integrated development planning in general, is to link costs with affordability and local authority budgets. Demand for services results in certain cost implications for the local authority and individuals which need to be considered in relation to local authority and individual incomes before decisions can be made regarding expenditure. The Combined Services Cost model of the Development Bank of Southern Africa, referred to in chapter 3, does this for engineering services for the local authority areas as a whole and there is opportunity to extend this model to include other development costs and to even refine the level of detail to account for sub-regional locational differences.

8.2.7 Application in smaller areas

The model was developed for application at the city-wide or metropolitan-wide planning scale but it is possible to adapt the model for use at a smaller scale during initial investigation phases of planing a particular area. The model was initially tested over a relatively small development area, producing valuable comparative cost results. Local reticulation costs also become very important at the lower level of planning and the model will not assist in determining internal costs.

8.2.8 Evaluation of alternative spatial development patterns

Although the original purpose of the model was to inform the early stages, or plan generation stages of the planning process, prior to any proposals being made, the model can be adapted and applied in the plan evaluation stage, at a strategic level in situations where time, technical capacity, optimisation models and funds are limited or lacking. The model can be used in evaluating alternative spatial development proposals in terms of engineering services cost implications. Rather than a particular density scenario being set artificially, as is the case in applying the model in the early, generation phase of the planning process, actual proposed densities, which may vary with location, are used as model input to determine demand.

8.2.9 Determination of bulk service contributions

Infrastructure cost considerations, as all the other suitability criteria considered, only serve to better prioritise land for development. No land is excluded from development due to infrastructure cost factors, but rather, land which is cheaper to service is considered and promoted for development first. Cost is of significance both when the State is providing the housing or in cases of private development. In the case of public provision, the lower the development costs, the more housing can be provided for the same amount of money. For private development, local authorities can recover the real bulk infrastructure cost of development by charging real cost of services. If private developers want to develop in certain areas which are not cost effective from a services provision point of view, they can proceed with development as long as they pay the local authority the total costs for the service provision. The way that services contributions are levied in many local authorities locally and internationally at present, is often on an averaged basis and it is argued that this encourages sprawl because on the periphery, where infrastructure costs are usually the highest, as the present study has shown, the development cost to the developer and eventually to the consumer, is the same as infill development. If real costs were levied, this would contribute to development occurring where it is economically sensible to do so, thus reducing the negative impacts of sprawl. The model can assist in determining a differential levy for various locations, more reflective of real costs for that particular location.

8.3 Implications for densification and the cost of sprawl debate

8.3.1 Densification and compaction as a policy directive

National housing, transport and development policy all promote densification and compaction of urban areas and discourage sprawl in the interest of efficient and integrated development. As far as the wider sprawl debate is concerned, ascertained from the international and local published realm, it is argued that it is not prudent to make generalised categorical statements for densification or against sprawl as a policy directive for the following reasons:

- definitions vary;
- there are very few quantitative studies with proven results to back up statement and position taken;
- differences in the range and type of costs included; and
- local circumstances.

It is submitted that there is not enough evidence in the literature to conclude that densification is the cost-effective alternative in all situations and under all conditions. The implication for policy making is that such words as "compact" and "densify" should be avoided as imperatives. Rather, emphasis should be placed on reducing the negative aspects attributed to both "sprawl" and "densification" and promoting the positive aspects of both. This is in fact done in existing housing and development policy where directive to "promote the location of residential and employment opportunities in close proximity to ... each other" and "optimise the use of existing physical and social infrastructure" (Republic of South Africa 1994: 52; Republic of South Africa 1995: 10). It unnecessarily complicates an interpretation of policy to included statement like "discourage sprawl" and "contribute to the development of more compact settlements" (Republic of South Africa 1994: 52; Republic of South Africa 1995: 10). The result of applying policy which emphasises the positive and mitigates the negative aspects of sprawl and densification, will be a sprawled or compact physical form or some combination of both as applicable and appropriate to the specific conditions.

Findings of the present study support and add credence to the argument presented above, although the intention of the present study was not to explicitly inform the debate. Particular conclusions from the results of the bulk infrastructure potential cost model are applied to the sprawl debate and policy implication with regard to development and infrastructure costs given.

8.3.2 Results in relation to sprawl and densification

The general planning and engineering view is that greater population densities lowers the cost of providing public services on the basis that smaller land areas need to be traversed and due to economies of scale savings. This view has been challenged on the basis of other social and environmental cost factors which increase public sector spending with increased densities such as policing (Ladd 1991). This highlights the importance of not isolating a single cost and drawing conclusions from only that cost but considering development costs in their widest sense before making any decisions. With regard to bulk infrastructure costs as considered for the present study, some conclusions regarding the wider sprawl debate can be made.

The results have indicated that bulk infrastructure costs do not simply decrease with increasing density. In all cases, total infrastructure costs increase as density increases due to the additional demand placed on the system as a whole. Per capita costs, however, do decrease with increasing densities for some cost items but not for all. Electricity per capita costs, for example, increase with increasing density. The model assumes increasing densities over a constant area. Infrastructure costs are determined for a particular geographic area for increasing densities of 20, 40 and 60 persons per hectare. A different effect on cost would be obtained if the density was increased by keeping the total population constant but confining it to a smaller and smaller area by means of increasing building density. Building costs would need to be incorporated into the equation to obtain a true cost picture. So the conclusions for the present study are only valid for its present purpose, definitions of density and for the specific cost types included.

It is important that all engineering services infrastructure costs are considered although in total, for the study area as a whole, one particular cost may dominate due to the differential effect of different costs at different location throughout the study area. A particular cost which is low for the study area as a whole may be very significant in the development cost of a particular area.

It is obvious from the results that local existing infrastructure capacity and other locational conditions significantly affect the cost at a particular place within the study area. This concept could be broadened to conclude that other study areas themselves have very different local circumstances and that the results from the application of the model in this particular study area cannot be generalised or transferred to any other study area.

The only general conclusion which can be made in relation to general policy directives concerning sprawl and densification is that development should be promoted in areas of existing spare infrastructure capacity and in areas where infrastructure would be relatively cheaper to provide. For private development, the real costs of development should be recovered from the developer who will in turn recover it from the consumer. Areas of dolomite, slopes of greater than 12 degrees and highly intensive land use should be avoided in the case of greenfields or infill development, unless affordability levels are high enough to afford the mitigating costs.

8.4 Implication for sustainability and integration

The development and application of the model has demonstrated how the disciplines of planning and civil engineering can be integrated around the specific problem statement of incorporating bulk infrastructure potential costs into the early phases of the planning process, in land suitability assessment. The model itself is the means by which planning issues such as density, growth and suitability are integrated with aspects of infrastructure systems, capacity, thresholds and infrastructure costs. The model is the mechanism to understand, identify, define and extract appropriate information from one discipline and convert, adapt, apply and make relevant and explicit to another discipline thus facilitating integration between not only disciplines but also of information which results in enhanced decision making.

The model contributes towards sustainable development in that it complies with four of Marrazzo's (1997) sustainability concepts and practices which were developed to contribute to ensuring that engineering services provision occurred in a sustainable manner. Development is promoted in relation to areas of existing spare capacity or cheaper infrastructure provision costs. Bulk infrastructure costs are considered as part of a broader systems approach where it is recognised that many other cost consideration as well as "softer" issues play an important role and should be considered in the development decision. It promotes the payment of real costs for bulk infrastructure services to avoid the occurrence of development in costly areas unless there is commensurate affordability levels. The model encourages collaboration between disciplines and the use of common data sets, particularly in relation to GIS, so that costly duplication is avoided.

8.5 Land suitability assessment process implications

The results of applying the model in the study area have indicated that valuable quantitative costs data are diluted when standardised and combined with other standardised, often more qualitatively measured, "softer" suitability factors. If only infrastructure capacity conditions are known, it is reasonable to include these in a standardised manner with all the other criteria using multicriteria evaluation. If the cost model is used to determine relative potential costs, these cost should be combined with other costs, such as transportation , land and building costs, measured in currency value, without any standardisation so that true development costs can be compared for different areas as a separate decision making input.

8.6 Land and housing policy implications for the GPMC area

Areas of highly suitable land correlate with existing developed areas. Land and housing policy for the GPMC area will need to focus on infill and redevelopment strategies to facilitate low income residential development within the developed city boundaries in these suitable areas. The directive from the suitability map would be to further investigate these areas for redevelopment and infill opportunities using more detailed micro-suitability assessment of surrounding land uses, ownership, zoning and other legal factors such as title deed restrictions. The current Integrated Development Plan for the GPMC area (GPMC 1997c) proposes six strategic development areas for low income development. Three of these, Kirkney, Lotus Gardens and Pretoria CBD west, occur in the western central parts of the study area on land which the suitability assessment indicates in the higher suitability ranges. The bulk infrastructure cost implications for these proposed developments, under conditions of medium density, indicate costs of between R200 and R300 per person in the Kirkney area and costs of between R300 and R400 per person in the case of Lotus Gardens and west of Pretoria CBD.

The least suitable land is situated predominantly in the south western, far eastern and far northern parts of the study area, correlating well with areas of high infrastructure costs. Three strategic development areas have been proposed in these peripheral areas: Klipkruisfontein which is already under development in the north, Nellmapius, south of Mamelodi in the east, also currently undergoing development and a large potential development area in the south, related to the proposed PWV 9 route and Mabopane-Centurion development corridor. Of these three peripheral developments, Klipkruisfontein is the most suitable largely as a result of nearby existing Rosslyn, providing some work opportunities. Cost considerations, however, somewhat alter the suitability picture. Bulk infrastructure provision costs in Klipkruisfontein and in parts of the proposed southern developments exceed R400 per person whereas the Nellmapius area is most suitable in terms of costs of between R300 and R400 per person.

For those areas of existing low income residential development, located on unsuitable land, namely, Mamelodi and the far northern areas inside and outside the current GPMC boundary, efforts will need to be made in increasing the suitability of those locations where possible by increasing accessibility to employment and social facilities either by providing those activities physically closer to the low income residential areas or by providing improved transportation links. In practice, both these options are being addressed in current integrated planning initiatives in most urban centres in South Africa. In particular, the strategy of public transport corridors in association with higher density residential development and employment opportunities is receiving significant attention.

8.7 GIS implications

GIS technology has been found to be an essential tool, together with spreadsheet technology, in the bulk infrastructure potential cost model. Equal area geographic proportionment, cost and suitability overlay, slope analysis, standard query functions, difference analysis and presentation, were all invaluable functions of GIS in the model. Variations in cost factors over space made GIS indispensable in incorporating the cost effect of factors such as geology and land use intensity.

Problems were encountered and areas of improvement identified for the future application of the model. ArcView3 was adequate but not optimum in terms of many functions which would have been more efficiently performed in ArcInfo. Raster overlays caused some problems when once-off costs in terms of road, rail and stream grids intersected with pipe grids incorrectly, when pipes run alongside streams or roads as is often the case in practice. The model could also be made more interactive so that the cost database is on-line at all times for query of costs and other suitability indices for specific land areas. For further enhancements of network costs, the networking features of Spatial Analyst or any other raster-based analysis package could be utilised more fully.

8.8 Development of a SDSS

SDSS emerged out of the combined traditions of DSS and GIS, applied in the context of the spatial planning tradition, using urban modelling and spatial analytical techniques. The methodologies described for land suitability assessment and for the bulk infrastructure potential cost model, comply with the requirements of a model-oriented DSS, and the strong spatial component, with the multicriteria evaluation and cost model, being loosely-coupled with GIS, means they could be referred to as model-oriented SDSS.

In addition, with the focus of the models on a specific planning problem, both the land suitability assessment method and the bulk infrastructure potential cost model , comply with the requirements of a PSS. There are two essential requirements for planning and thus, in turn, for PSS. The first requirement is that, since urban system optimisation is impossible (this would equate to the automatic generation of plans), the search for good plans must be by means of an informed process of trial and error which generates plans and prepares them for testing (often referred to as sketch planning). Secondly, planning and policy making need tools for determining the consequences of alternative courses of action or decisions so that choices can be made in terms of costs and benefits or adjustments and improvements to alternatives can be made (Harris & Batty 1993: 194). The land suitability assessment method, combines GIS and multicriteria evaluation to inform the process of plan generation. The cost model generates potential bulk infrastructure costs under different density conditions which also informs the plan generation process but can also be used to determine the engineering services cost consequences of certain development decisions.

The problem with the term "planning" in PSS is that particularly in South Africa, with recent moves to promote an "integrated planning" approach, strategic planning is seen to be far broader than spatial and physical planning, incorporating the entire spectrum of development including the economic, social, institutional, financial, environmental and spatial realms. PSS should accordingly, theoretically support much more than only spatial decisions. It is proposed that the term spatial planning support system (SPSS) would better describe SDSS applied to the spatial component of strategic integrated planning.

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APPENDIX A

Table 6.6: Sewer and water pipe influencing and once-off factor costs affecting base costs

Sewer base cost (1995 R/m): 206.76 **Water base cost (1995 R/m):** 92.83

INFLUENCING FACTORS						
Factor	**Category**	**Classification**	**Sewer** % cost inc	**Sewer** R/m	**Water** % cost inc	**Water** R/m
Land use	Undeveloped	Agricultural	0	206.76	0	92.83
		Farmland	0	206.76	0	92.83
		Government	0	206.76	0	92.83
	Developed	Commercial	8	223.30	1.5	94.22
		Industrial	8	223.30	1.5	94.22
		Informal	8	223.30	1.5	94.22
		Residential	8	223.30	1.5	94.22
		Education	8	223.30	1.5	94.22
	CBD/High density	Activity area	40	289.46	3	95.61
		High rise res	40	289.46	3	95.61
	Environmental	Nature reserves	10	227.44	12.5	104.43
		Open spaces	5	217.10	6.5	98.86
Geotechnical	Geology	1 AC	0	206.76	0	92.83
		1 BEG	0	206.76	0	92.83
		2 ADE	12.5	232.61	12.5	104.43
		2 ADE	12.5	232.61	12.5	104.43
		2 B	10	227.44	10	102.11
		2 E	12.5	232.61	12.5	104.43
		2 EG	12.5	232.61	12.5	104.43
		3 B	20	248.11	20	111.40
		3 BCI	20	248.11	20	111.40
		3 EGH	12.5	232.61	12.5	104.43
		3 F	40	289.46	40	129.96
	Slope	2 - 6 degrees	0	206.76	n/a	n/a
		6 - 12 degrees	25	258.45	n/a	n/a
		< 2 degrees	25	258.45	n/a	n/a
		> 12 degrees	50	310.14	n/a	n/a
ONCE-OFF FACTORS				R		R
Man-made obstacles	Roads	National		20000.00		20000.00
		Major		20000.00		20000.00
	Railway lines	Single track		10000.00		10000.00
		Multiple track		30000.00		30000.00
Natural obstacles	Rivers	Perennial		15000.00		15000.00
		Non-perennial		5000.00		5000.00

Table 6.7: Geotechnical classification for urban development

	CONSTRAINT	Most favourable (1)	Intermediate (2)	Least favourable (3)
A	Collapsible soil	Any horizon or consecutive horizons totalling a maximum depth of less than 750mm in thickness	Any horizon or consecutive horizons totalling a maximum depth of more than 750mm in thickness	n/a
B	Active soil	Low soil heave potential predicted	Moderate soil heave potential predicted	High soil heave potential predicted
C	Highly compressible soil	Low soil compressibility expected	Moderate soil compressibility expected	High soil compressibility expected
D	Erodability of soil	Low	Intermediate	High
E	Difficulty of excavation to 1.5 m depth	Scattered or occasional boulders less than 10% of volume	Rock or hardpan pedocretes between 10 and 40% of total volume	Rock or hardpan pedocretes more than 40 % of total volume
F	Instability in areas of soluble rock	Possibly unstable	Probably unstable	Active sinkholes and dolines
G	Steep slopes	Between 2 and 6 degrees	Slopes between 6 and 18 degrees and less than 2 degrees (Natal and W. Cape) Slopes between 6 and 12 degrees and less than 2 degrees for all other regions	> 18 degrees (Natal and W. Cape) > 12 degrees for all other areas
H	Areas of unstable natural slopes	Low risk	Intermediate risk	High risk (especially in areas subject to seismic activity)
I	Areas subject to flooding	Absence of favourable conditions for this situation	Areas adjacent to a known channel or floodplain with a slope < 1%	Areas within a known drainage channel or floodplain

Table 6.8: Water link costs

		Area		>existing	>existing	>existing	250mm Pipe length(m)			% of gfld	Total	Total	Total	Per cap	Per cap	Per cap
Water reservoir zone	POP95	(Ha)	%dev.	or potpopL	or potpopM	or potpopH	L	M	H	cost	cost(R):L	cost(R):M	cost(R):H	cost(R):L	cost(R):M	cost(R):H
AKASIA	5345	1693	19	33862	67724	101586	11802	12736	14043	1.0	1180235	1273589	1404284	41	20	15
AKASIA EAST	9244	1282	28	25635	51269	76904	9282	10224	11543	0.8	742557	817941	923478	45	19	14
AKASIA WEST	12540	1112	53	22232	44464	66696	8312	9363	10834	0.6	498718	561761	650021	51	18	12
ATTERIDGEVILLE-HL	72831	674	53	72831	72831	72831	11325	11325	11325	0.6	679494	679494	679494	0	0	0
ATTERIDGEVILLE-LL	100559	1308	66	100559	100559	100559	13901	13901	13901	0.4	556037	556037	556037	0	0	0
ATTERIDGEVILLE-WEST	0	1275	0	25502	51004	76507	9234	10171	11484	1.0	923399	1017142	1148381	36	20	15
BAKENKOP	18436	1559	74	31176	62352	93527	11160	12191	13635	0.4	446388	487643	545400	35	11	7
BRAKFONTEIN	6258	675	89	13507	27013	40520	3462	3976	4696	0.2	69236	79523	93926	10	4	3
BRONBERG-DIRECT	788	2351	6	47023	94046	141068	16389	17686	19501	1.0	1638947	1768584	1950075	35	19	14
CARINASTREET	7423	688	82	13754	27509	41263	3525	4049	4782	0.2	70506	80982	95648	11	4	3
CLIFTON	14842	1481	50	29624	59248	88872	10604	11584	12956	0.6	636256	695059	777383	43	16	11
CONSTANTIAPARK	7847	873	57	17458	34916	52373	5373	6110	7142	0.6	322376	366598	428509	34	14	10
CORNWALLHILL	2089	818	0	16370	32740	49110	4196	4819	5692	1.0	419562	481903	569180	29	16	12
CSIR-1	0	2051	0	41029	82059	123088	14301	15432	17015	1.0	1430054	1543168	1701527	35	19	14
CSIR-10	2476	1109	3	22180	44360	66540	8293	9341	10808	1.0	829251	934076	1080831	42	22	17
CSIR-11	4185	768	3	15359	30718	46078	3937	4522	5340	1.0	393658	452151	534040	35	17	13
CSIR-12	10433	1228	0	24561	49122	73684	9020	10036	11458	1.0	901990	1003559	1145755	64	26	18
CSIR-13	8201	741	16	14811	29622	44434	3796	4360	5150	1.0	379613	436018	514986	57	20	14
CSIR-14	3805	378	82	7556	15113	22669	1568	1934	2447	0.2	31364	38687	48939	8	3	3
CSIR-15	63	3134	0	62676	125353	188029	21845	23573	25992	1.0	2184542	2357334	2599243	35	19	14
CSIR-16	453	2357	0	47147	94293	141440	16433	17732	19552	1.0	1643260	1773238	1955207	35	19	14
CSIR-2	3686	218	23	4362	8725	13087	799	1267	1711	0.8	63882	101385	136899	94	20	15
CSIR-3	47	1482	0	29647	59294	88941	10612	11593	12966	1.0	1061250	1159331	1296643	36	20	15
CSIR-4	1361	3173	0	63465	126930	190394	22120	23870	26319	1.0	2212021	2386987	2631938	36	19	14
CSIR-5	1650	1077	1	21544	43088	64632	8055	9073	10498	1.0	805469	907288	1049834	40	22	17
CSIR-6	77	865	14	17297	34594	51891	5323	6054	7076	1.0	532340	605364	707597	31	18	14
CSIR-7	29	491	0	9810	19620	29431	2036	2511	3177	1.0	203592	251129	317680	21	13	11
CSIR-8	334	539	8	10785	21570	32355	2779	3293	4012	1.0	277947	329287	401162	27	16	13
CSIR-9	34	411	0	8229	16457	24686	1708	2106	2665	1.0	170768	210641	266463	21	13	11
DOMISSE	2079	103	100	2079	4135	6203	381	601	811	0.2	7612	12013	16221	0	6	4
DOORNPOORT-EAST	3520	2709	10	54174	108347	162521	18882	20375	22466	1.0	1888183	2037534	2246625	37	19	14
DOORNPOORT-WEST	527	1349	4	26983	53965	80948	9770	10762	12150	1.0	977005	1076190	1215048	37	20	15
DORINGKLOOF	8269	2657	24	53147	106293	159440	18524	19989	22040	0.8	1481909	1599124	1763226	33	16	12
EERSTERUST	22391	879	60	22391	35169	52754	8371	6154	7194	0.6	502276	369262	431623	0	29	14
ELARDUSPARK	14943	1723	56	34455	68911	103366	12009	12959	14289	0.6	720551	777545	857336	37	14	10

Table 6.8: Water link costs

		Area		>existing	>existing	>existing	250mm Pipe length(m)			% of gfld	Total	Total	Total	Per cap	Per cap	Per cap
Water reservoir zone	POP95	(Ha)	%dev.	or potpopL	or potpopM	or potpopH	L	M	H	cost	cost(R):L	cost(R):M	cost(R):H	cost(R):L	cost(R):M	cost(R):H
ERASMIA-HL	2090	422	34	8431	16862	25293	1750	2158	2730	0.8	139974	172657	218413	22	12	9
ERASMIA-LL	806	336	31	6725	13450	20176	1119	1954	2638	0.8	89514	156296	211044	15	12	11
ERASMUSRAND	1748	161	98	3229	6458	9687	591	938	1267	0.2	11821	18761	25333	8	4	3
FINDLAY	17988	1048	66	20966	41931	62897	7838	8829	10216	0.4	313538	353172	408660	105	15	9
FLORAUNA-HL	332	22	0	440	880	1320	81	128	173	1.0	8057	12787	17266	75	23	17
FLORAUNA-LL	3962	251	34	5011	10022	15032	834	1456	1966	0.8	66695	116453	157244	64	19	14
GARSFONTEIN	3519	1153	37	23069	46138	69207	8472	9426	10762	0.8	677755	754074	860920	35	18	13
HEIGHTS HL	2221	239	91	4790	9580	14369	797	1391	1879	0.2	15938	27829	37577	6	4	3
HERCULES WEST	6083	1669	49	33376	66752	100128	11633	12553	13841	0.6	697975	753184	830475	26	12	9
HERCULES-EAST	27722	1418	91	28364	56727	85091	10270	11313	12772	0.2	205401	226254	255447	320	8	4
HEUWELOORD	2258	676	15	13517	27034	40551	3464	3979	4700	1.0	346447	397924	469992	31	16	12
ISCOR	5931	860	80	17192	34383	51575	5291	6017	7033	0.4	211639	240671	281315	19	8	6
KILNER-PARK	483	93	90	1867	3734	5601	342	542	732	0.2	6835	10847	14646	5	3	3
KLAPPERKOP	1863	106	100	2114	4227	6341	387	614	829	0.2	7738	12280	16582	31	5	4
KLIPFONTEIN	49419	2777	0	55546	111093	166639	19360	20892	23036	1.0	1936031	2089167	2303556	316	34	20
KLIPFRUISFONTEIN	47238	2656	27	53114	106228	159341	18512	19977	22027	0.8	1480996	1598140	1762140	252	27	16
KNOPJESLAAGTE	0	1634	0	32684	65368	98053	11700	12781	14295	1.0	1169966	1278094	1429473	36	20	15
KOEDOESNEK-HL	6989	756	44	15130	30259	45389	3878	4454	5261	0.6	232666	267237	315636	29	11	8
KOEDOESNEK-LL	19840	1330	59	26597	53194	79791	9630	10608	11977	0.6	577820	636480	718604	86	19	12
LAUDIUM	16238	705	61	16238	28189	42284	4162	4149	4901	0.4	166474	165971	196030	0	14	8
LOTUS-GARDENS	218	640	9	12792	25584	38376	3297	3906	4758	1.0	329675	390569	475822	26	15	12
LOUWLARDIA	490	1297	11	25945	51890	77836	9394	10348	11683	1.0	939439	1034810	1168329	37	20	15
LYNNWOOD	9504	684	83	13688	27376	41064	3508	4030	4759	0.2	70165	80591	95187	17	5	3
MAGALIES	2550	1537	80	30742	61485	92227	11005	12022	13445	0.4	440181	480863	537817	16	8	6
MAGALIESBERG/HOSPITA	33704	1909	72	38180	76361	114541	13308	14360	15834	0.4	532301	574404	633350	119	13	8
MAGALIESKRUIN	1275	67	68	1349	2698	4046	247	392	529	0.4	9876	15673	21164	135	11	8
MAMELODI-R1	16203	218	48	16203	16203	16203	2119	2119	2119	0.6	127117	127117	127117	0	0	0
MAMELODI-R2	69655	1128	25	69655	69655	69655	10831	10831	10831	0.8	866485	866485	866485	0	0	0
MAMELODI-R3	118812	1122	98	118812	118812	118812	16424	16424	16424	0.2	328484	328484	328484	0	0	0
MAMELODI-R4/EAST	80843	2310	10	80843	92397	138595	10715	17376	19159	1.0	1071501	1737578	1915888	0	150	33
MEINTJIESKOP	11318	476	23	11318	19029	28543	2917	2436	3081	0.8	233343	194844	246480	0	25	14
MNANDI	439	1629	0	32580	65161	97741	11663	12740	14249	1.0	1166252	1274037	1424936	36	20	15
MONTANA	6994	2126	15	42522	85044	127566	14821	15993	17634	1.0	1482075	1599303	1763423	42	20	15
MONUMENTPARK	1606	155	92	3098	6197	9295	567	900	1215	0.2	11342	18001	24307	8	4	3
MONUMENTPARK EXT2	1724	123	51	2454	4909	7363	449	713	963	0.6	26956	42780	57766	37	13	10

Table 6.8: Water link costs

Water reservoir zone	POP95	Area (Ha)	%dev	>existing or potpopL	>existing or potpopM	>existing or potpopH	250mm Pipe length(m)			% of gfld cost	Total cost(R):L	Total cost(R):M	Total cost(R):H	Per cap cost(R):L	Per cap cost(R):M	Per cap cost(R):H
							L	M	H							
MOOIKLOOF	6113	1182	25	23633	47265	70898	8679	9656	11024	0.8	694315	772498	881955	40	19	14
MOOIPLAATS	92	2365	0	47297	94594	141891	16485	17789	19614	1.0	1648502	1778895	1961444	35	19	14
MORELETA	20806	2051	74	38388	76775	115163	13380	14438	15920	0.4	535191	577523	636788	30	10	7
MUCKLENEUCK	17541	1037	72	20735	41469	62204	7752	8732	10104	0.4	310082	349279	404156	97	15	9
MURRAYFIELD	3630	265	97	5305	10609	15914	883	1541	2081	0.2	17651	30820	41616	11	4	3
PARKMORE HL	13897	773	96	15468	30936	46404	3964	4554	5378	0.2	79289	91071	107565	50	5	3
PARKMORE LL	12291	653	96	13059	26117	39176	3365	3987	4857	0.2	67309	79742	97148	88	6	4
PIERREVANRYNEVELD	4883	893	42	17860	35720	53579	5497	6251	7306	0.6	329799	375039	438376	25	12	9
PRETORIA WEST HL	4199	916	41	18329	36659	54988	5641	6415	7498	0.6	338469	384899	449900	24	12	9
PRETORIA WEST LL	5384	600	50	12009	24018	36027	3095	3667	4467	0.6	185698	219998	268019	28	12	9
PRETORIUSRAND	2	3679	0	73573	147146	220719	25643	27672	30511	1.0	2564340	2767173	3051139	35	19	14
QUEENSWOOD	22983	1255	97	25105	50210	75315	9220	10258	11711	0.2	184393	205157	234226	87	8	4
RASLOUW	1896	835	0	16707	33415	50122	5142	5847	6835	1.0	514197	584732	683481	35	19	14
ROOIHUISKRAAL	9536	2233	39	44653	89307	133960	15564	16795	18518	0.4	622546	671787	740726	18	8	6
SALVOKOP	49427	624	83	49427	49427	49427	5729	5729	5729	0.2	114572	114572	114572	0	0	0
SINOVILLE-HL	866	35	86	866	1409	2113	158	205	276	0.2	3169	4092	5526	0	8	4
SINOVILLE-LL	2761	129	100	2761	5152	7729	505	748	1011	0.2	10107	14968	20211	0	6	4
SOSHANGUVE	236131	3620	69	236131	236131	236131	32642	32642	32642	0.4	1305673	1305673	1305673	0	0	0
SOSHANGUVE-L	157008	3753	76	157008	157008	225172	31127	31127	31127	0.4	1245078	1245078	1245078	0	0	18
STINKWATER	0	2920	0	58402	116804	175207	20356	21966	24220	1.0	2035569	2196578	2421990	35	19	14
SUIDERBERG	294	99	36	1986	3973	5959	364	577	779	0.6	21815	34622	46749	13	9	8
SUNDERLAND-RIDGE	172	718	13	14365	28731	43096	3682	4229	4995	1.0	368189	422896	499487	26	15	12
THE-REEDS	3720	569	28	11388	22775	34163	2935	3477	4236	0.8	234787	278155	338870	31	15	11
VALHALLA	9444	528	99	10566	21133	31699	2723	3226	3930	0.2	54463	64523	78607	49	6	4
VILLIERIA	4019	241	35	4817	9634	14450	801	1399	1889	0.6	48084	83957	113366	60	15	11
WATERKLOOF	12527	733	97	14655	29310	43965	3756	4314	5095	0.2	75121	86283	101910	35	5	3
WATERKLOOF EAST	3850	232	96	4641	9281	13922	772	1348	1820	0.2	15442	26962	36407	20	5	4
WATERKLOOFPARK	135	27	95	549	1097	1646	100	159	215	0.2	2008	3188	4304	5	3	3
WATERKLOOFRIFX2	3777	301	57	6020	12040	18060	1002	1749	2361	0.6	60097	104932	141688	27	13	10
WAVERLEY-HL	7440	458	83	9154	18307	27461	1900	2343	2964	0.2	37994	46865	59284	22	4	3
WAVERLEY-LL	9665	786	42	15724	31448	47172	4030	4629	5467	0.6	241803	277731	328031	40	13	9
WONDERBOOM	32266	2735	51	54701	109403	164104	19066	20574	22685	0.6	1143945	1234428	1361105	51	16	10
TOTAL	1575586			2937080	4966026	7106891					57990418	63715494	71176940			
PER CAPITA											43	19	13			

Table 6.9:Water link network required length of pipe per population category

LOW DENSITY

Population category	Length required of various pipe diameters								250 mm equivalent pipe length								
	110	160	200	250	300	400	500	600	110	160	200	250	300	400	500	600	Total
0-4500	500	150	90						263	105	81	100	0	0	0	0	549
4500-7500	1000	300	180	100					526	210	162	100	0	0	0	0	998
7500-10500	1500	450	270	150	300				789	315	243	150	370	0	0	0	1868
10500-13500	2000	600	360	200	450	400			1053	420	324	200	556	541	0	0	3093
13500-16500	2500	750	450	250	600	450			1316	524	405	250	741	608	0	0	3845
16500-19500	3000	900	540	300	750	500	500		1579	629	486	300	926	676	943	0	5640
19500-22500	3500	1150	630	350	900	550	550	600	1842	804	568	350	1111	743	1038	1395	7851
22500-25500	4000	1300	720	400	1050	600	600	650	2105	909	649	400	1296	811	1132	1512	8814
25500-28500	4500	1450	810	450	1200	650	650	700	2368	1014	730	450	1481	878	1226	1628	9776
28500-33000	5000	1600	900	500	1350	700	700	750	2632	1119	811	500	1667	946	1321	1744	10739
>33000	6000	1900	1080	600	1650	800	800	800	3158	1329	973	600	2037	1081	1509	1860	12548

MEDIUM DENSITY

Population category	Length required of various pipe diameters								250 mm equivalent pipe length								
	110	160	200	250	300	400	500	600	110	160	200	250	300	400	500	600	Total
0-15000	1100	400	280	200	350				579	280	252	200	432	0	0	0	1743
15000-21000	1600	550	370	250	400				842	385	333	250	494	0	0	0	2304
21000-27000	2100	700	460	300	550	500			1105	490	414	300	679	676	0	0	3664
27000-33000	2600	850	550	350	700	550			1368	594	495	350	864	743	0	0	4416
33000-39000	3100	1000	640	400	850	600	600		1632	699	577	400	1049	811	1132	0	6300
39000-45000	3600	1250	730	450	1000	650	650	700	1895	874	658	450	1235	878	1226	1628	8844
45000-51000	4100	1400	820	500	1150	700	700	750	2158	979	739	500	1420	946	1321	1744	9806
51000-57000	4600	1550	910	550	1300	750	750	800	2421	1084	820	550	1605	1014	1415	1860	10769
57000-66000	5100	1700	1000	600	1450	800	800	850	2684	1189	901	600	1790	1081	1509	1977	11731
>66000	6100	2000	1180	700	1750	900	900	900	3211	1399	1063	700	2160	1216	1698	2093	13540

HIGH DENSITY

Population category	Length required of various pipe diameters								250 mm equivalent pipe length								
	110	160	200	250	300	400	500	600	110	160	200	250	300	400	500	600	Total
<22500	1240	540	420	340	490				653	378	378	340	605	0	0	0	2354
22500-31500	1740	690	510	390	540				916	483	459	390	667	0	0	0	2914
31500-40500	2240	840	600	440	690	640			1179	587	541	440	852	865	0	0	4464
40500-49500	2740	990	690	490	840	690			1442	692	622	490	1037	932	0	0	5216
49500-58500	3240	1140	780	540	990	740	740		1705	797	703	540	1222	1000	1396	0	7364
58500-67500	3740	1390	870	590	1140	790	790	840	1968	972	784	590	1407	1068	1491	1953	10233
67500-76500	4240	1540	960	640	1290	840	840	890	2232	1077	865	640	1593	1135	1585	2070	11196
76500-85500	4740	1690	1050	690	1440	890	890	940	2495	1182	946	690	1778	1203	1679	2186	12158
85500-99000	5240	1840	1140	740	1590	940	940	990	2758	1287	1027	740	1963	1270	1774	2302	13121
>99000	6240	2140	1320	840	1890	1040	1040	1040	3284	1497	1189	840	2333	1405	1962	2419	14930

Table 6.12: Water distribution reservoir costs

Water reservoir name	POP95	Area (Ha)	Design cap(m^3)	Design cap persons	>existing or potpopL	>existing or potpopM	>existing or potpopH	Req cap (Ml):L	Req cap (Ml):M	Req cap (Ml):H	Total cost (R):L	Total cost (R):M	Total cost (R):H	Per cap cost:L	Per cap cost:M	Per cap cost:H
AKASIA EAST	9244	1282	9000	34286	25635	51269	76904	0	4	11		1500000	2300000	0	36	34
AKASIA WEST	12540	1112	9000	34286	22232	44464	66696	0	3	9		1300000	2100000	0	41	39
ATTERIDGEVILLE-HL	72831	674	15000	57143	72831	72831	72831	1	1	1	1100000	1100000	1100000	70	70	70
ATTERIDGEVILLE-LL	100559	1308	29475	112286	100559	100559	100559	0	0	0				0	0	0
ATTERIDGEVILLE-WEST	0	1275	0	0	25502	51004	76507	2	4	7	1200000	1500000	1800000	47	29	24
BAKENKOP	18436	1559	26186	99756	31176	62352	93527	0	0	0				0	0	0
BRAKFONTEIN	6258	675	15066	57394	13507	27013	40520	0	0	0				0	0	0
CARINASTREET	7423	688	5000	19048	13754	27509	41263	0	2	6		1200000	1700000	0	60	50
CLIFTON	14842	1481	29066	110728	29624	59248	88872	0	0	0				0	0	0
CONSTANTIAPARK	7847	873	9450	36000	17458	34916	52373	0	0	4			1500000	0	0	34
CORNWALLHILL	2089	818	0	0	16370	32740	49110	4	9	13	1500000	2100000	2600000	105	69	55
CSIR-1	0	2051	0	0	41029	82059	123088	11	22	32	2300000	3600000	4800000	56	44	39
CSIR-10	2476	1109	0	0	22180	44360	66540	6	12	18	1700000	2400000	3200000	86	57	50
CSIR-11	4185	768	0	0	15359	30718	46078	4	8	12	1500000	1900000	2400000	134	72	57
CSIR-12	10433	1228	0	0	24561	49122	73684	6	13	19	1700000	2600000	3300000	120	67	52
CSIR-13	8201	741	0	0	14811	29622	44434	4	8	12	1500000	1900000	2400000	227	89	66
CSIR-14	3805	378	0	0	7556	15113	22669	2	4	6	1200000	1500000	1700000	320	133	90
CSIR-15	63	3134	0	0	62676	125353	188029	16	33	49	2900000	5000000	7000000	46	40	37
CSIR-16	453	2357	0	0	47147	94293	141440	12	25	37	2400000	4000000	5500000	51	43	39
CSIR-2	3686	218	0	0	4362	8725	13087	1	2	3	1100000	1200000	1300000	1627	238	138
CSIR-3	47	1482	0	0	29647	59294	88941	8	16	23	1900000	2900000	3700000	64	49	42
CSIR-4	1361	3173	0	0	63465	126930	190394	17	33	50	3100000	5000000	7100000	50	40	38
CSIR-5	1650	1077	0	0	21544	43088	64632	6	11	17	1700000	2300000	3100000	85	56	49
CSIR-6	77	865	0	0	17297	34594	51891	5	9	14	1600000	2100000	2700000	93	61	52
CSIR-7	29	491	0	0	9810	19620	29431	3	5	8	1300000	1600000	1900000	133	82	65
CSIR-8	334	539	0	0	10785	21570	32355	3	6	9	1300000	1700000	2100000	124	80	66
CSIR-9	34	411	0	0	8229	16457	24686	2	4	6	1200000	1500000	1700000	146	91	69
DOMISSE	2079	103	3181	12118	2079	4135	6203	0	0	0				0	0	0
DOORNPOORT-EAST	3520	2709	0	0	54174	108347	162521	14	29	43	2700000	4500000	6300000	53	43	40
DOORNPOORT-WEST	527	1349	0	0	26983	53965	80948	7	14	21	1800000	2700000	3500000	68	51	44
DORINGKLOOF	8269	2657	9985	38038	53147	106293	159440	4	18	32	1500000	3200000	4800000	33	33	32
EERSTERUST	22391	879	15000	57143	22391	35169	52754	0	0	0				0	0	0
ELARDUSPARK	14943	1723	11350	43238	34455	68911	103366	0	7	16		1800000	2900000	0	33	33
ERASMIA-HL	2090	422	15000	57143	8431	16862	25293	0	0	0				0	0	0
ERASMIA-LL	806	336	4000	15238	6725	13450	20176	0	0	1			1100000	0	0	57

Table 6.12: Water distribution reservoir costs

Water reservoir name	POP95	Area (Ha)	Design cap(m^3)	Design cap persons	>existing or potpopL	>existing or potpopM	>existing or potpopH	Req cap (Ml):L	Req cap (Ml):M	Req cap (Ml):H	Total cost (R):L	Total cost (R):M	Total cost (R):H	Per cap cost:L	Per cap cost:M	Per cap cost:H
ERASMUSRAND	1748	161	3725	14190	3229	6458	9687	0	0	0				0	0	0
FINDLAY	17988	1048	29000	110476	20966	41931	62897	0	0	0				0	0	0
FLORAUNA-HL	332	22	225	857	440	880	1320	0	0	0				0	0	0
FLORAUNA-LL	3962	251	4550	17333	5011	10022	15032	0	0	0				0	0	0
HERCULES WEST	6083	1669	13500	51429	33376	66752	100128	0	4	13		1500000	2600000	0	25	28
HERCULES-EAST	27722	1418	22750	86667	28364	56727	85091	0	0	0				0	0	0
HEUWELOORD	2258	676	0	0	13517	27034	40551	4	7	11	1500000	1800000	2300000	133	73	60
ISCOR	5931	860	27750	105714	17192	34383	51575	0	0	0				0	0	0
KILNER-PARK	483	93	2725	10381	1867	3734	5601	0	0	0				0	0	0
KLIPFONTEIN	49419	2777	0	0	55546	111093	166639	5	10	15	1600000	2200000	2800000	261	36	24
KLIPKRUISFONTEIN	47238	2656	20000	76190	53114	106228	159341	0	3	7		1300000	1800000	0	22	16
KNOPJESLAAGTE	0	1634	0	0	32684	65368	98053	9	17	26	2100000	3100000		64	47	0
KOEDOESNEK-HL	6989	756	10000	38095	15130	30259	45389	0	0	2			1200000	0	0	31
KOEDOESNEK-LL	19840	1330	11350	43238	26597	53194	79791	0	3	10		1300000	2200000	0	39	37
LAUDIUM	16238	705	9500	36190	16238	28189	42284	0	0	2			1200000	0	0	46
LOTUS-GARDENS	218	640	9500	36190	12792	25584	38376	0	0	1			1100000	0	0	29
LOUWLARDIA	490	1297	18500	70476	25945	51890	77836	0	0	2			1200000	0	0	16
LYNNWOOD	9504	684	17080	65067	13688	27376	41064	0	0	0				0	0	0
MAGALIES	2550	1537	51700	196952	30742	61485	92227	0	0	0				0	0	0
MAGALIESBERG/HOSPITAL	33704	1909	41475	158000	38180	76361	114541	0	0	0				0	0	0
MAGALIESKRUIN	1275	67	4500	17143	1349	2698	4046	0	0	0				0	0	0
MAMELODI-R1	16203	218	1500	5714	16203	16203	16203	1	1	1	1100000	1100000	1100000	105	105	105
MAMELODI-R2	69655	1128	9435	35943	69655	69655	69655	3	3	3	1300000	1300000	1300000	39	39	39
MAMELODI-R3	118812	1122	25870	98552	118812	118812	118812	2	2	2	1200000	1200000	1200000	59	59	59
MEINTJIESKOP	11318	476	9100	34667	11318	19029	28543	0	0	0				0	0	0
MNANDI	439	1629	1553	5916	32580	65161	97741	7	16	24	1800000	2900000	3900000	56	45	40
MONTANA	6994	2126	28000	106667	42522	85044	127566	0	0	5			1600000	0	0	13
MONUMENTPARK	1606	155	1290	4914	3098	6197	9295	0	0	1			1100000	0	0	143
MONUMENTPARK EXT2	1724	123	700	2667	2454	4909	7363	0	1	1		1100000	1100000	0	345	195
MOOIKLOOF	6113	1182	15000	57143	23633	47265	70898	0	0	4			1500000	0	0	23
MOOIPLAATS	92	2365	0	0	47297	94594	141891	12	25	37	2400000	4000000	5500000	51	42	39
MORELETA	20806	2051	23430	89257	41015	82030	123046	0	0	9			2100000	0	0	21
MUCKLENEUCK	17541	1037	28265	107676	20735	41469	62204	0	0	0				0	0	0
MURRAYFIELD	3630	265	2297	8750	5305	10609	15914	0	0	2			1200000	0	0	98
PARKMORE HL	13897	773	9100	34667	15468	30936	46404	0	0	3			1300000	0	0	40

Table 6.12: Water distribution reservoir costs

Water reservoir name	POP95	Area (Ha)	Design cap(m^3)	Design cap persons	>existing or potpopL	>existing or potpopM	>existing or potpopH	Req cap (Ml):L	Req cap (Ml):M	Req cap (Ml):H	Total cost (R):L	Total cost (R):M	Total cost (R):H	Per cap cost:L	Per cap cost:M	Per cap cost:H
PARKMORE LL	12291	653	9100	34667	13059	26117	39176	0	0	1			1100000	0	0	41
PIERREVANRYNEVELD	4883	893	7600	28952	17860	35720	53579	0	2	6		1200000	1700000	0	39	35
PRETORIA WEST HL	4199	916	22750	86667	18329	36659	54988	0	0	0				0	0	0
PRETORIA WEST LL	5384	600	27300	104000	12009	24018	36027	0	0	0				0	0	0
PRETORIUSRAND	2	3679	0	0	73573	147146	220719	19	39	58	3400000	5700000	8000000	46	39	36
QUEENSWOOD	22983	1255	18000	68571	25105	50210	75315	0	0	2			1200000	0	0	23
RASLOUW	1896	835	7500	28571	16707	33415	50122	0	1	6		1100000	1700000	0	35	35
ROOIHUISKRAAL	9536	2233	32500	123810	44653	89307	133960	0	0	3			1300000	0	0	10
SALVOKOP	49427	624	30000	114286	49427	49427	49427	0	0	0				0	0	0
SINOVILLE-HL	866	35	1135	4324	866	1409	2113	0	0	0				0	0	0
SINOVILLE-LL	2761	129	3400	12952	2761	5152	7729	0	0	0				0	0	0
SOSHANGUVE	236131	3620	40000	152381	236131	236131	236131	7	7	7	1800000	1800000	1800000	21	21	21
SOSHANGUVE-L	157008	3753	40750	155238	157008	157008	225172	0	0	6			1700000	0	0	25
STINKWATER	0	2920	0	0	58402	116804	175207	5	10	15	1600000	2200000	2800000	27	19	16
SUIDERBERG	294	99	2275	8667	1986	3973	5959	0	0	0				0	0	0
SUNDERLAND-RIDGE	172	718	2700	10286	14365	28731	43096	1	5	9	1100000	1600000	2100000	77	56	49
THE-REEDS	3720	569	6000	22857	11388	22775	34163	0	0	3			1300000	0	0	43
VALHALLA	9444	528	2275	8667	10566	21133	31699	0	3	6		1300000	1700000	0	111	76
VILLIERIA	4019	241	2275	8667	4817	9634	14450	0	0	2			1200000	0	0	115
WATERKLOOF	12527	733	22750	86667	14655	29310	43965	0	0	0				0	0	0
WATERKLOOF EAST	3850	232	7950	30286	4641	9281	13922	0	0	0				0	0	0
WATERKLOOFPARK	135	27	340	1295	549	1097	1646	0	0	0				0	0	0
WATERKLOOFRIFX2	3777	301	4500	17143	6020	12040	18060	0	0	0				0	0	0
WAVERLEY-HL	7440	458	4550	17333	9154	18307	27461	0	0	3			1300000	0	0	65
WAVERLEY-LL	9665	786	4550	17333	15724	31448	47172	0	4	8		1500000	1900000	0	69	51
TOTAL	1448741				2693306	4547767	6479503				59100000	101300000	155700000			
PER CAPITA											47	33	31			

Table 6.13: Water feeder main costs

Water feeder main	Cap l/s	Design cap persons	Existing pop	>existing or potpopL	>existing or potpopM	>existing or potpopH	Req cap L (pers)	Req cap M (pers)	Req cap H (pers)	Tot cost (R):L	Tot cost (R):M	Tot cost (R):H	Per cap cost(R):L	Per cap cost(R):M	Per cap cost(R):H
AKASIA E	355	51120	9244	25635	51269	76904		149	25784	0	33956	34209	0.00	0.81	0.51
AKASIA W	285	41040	12540	22232	44464	66696		3424	25656	0	8075	8133	0.00	0.25	0.15
ATTERIDGEVILLE HL	480	207360	72831	72831	72831	72831				0	0	0	0.00	0.00	0.00
ATTERIDGEVILLE LL	285	123120	100559	100559	100559	100559				0	0	0	0.00	0.00	0.00
ATTERIDGEVILLE-WES	0	0	0	25502	51004	76507	25502	51004	76507	877677	887295	887295	34.42	17.40	11.60
BAKENKOP	225	32400	18436	31176	62352	93527		29952	61127	0	633610	633610	0.00	14.43	8.44
BRAKFONTEIN	225	32400	6258	13507	27013	40520			8120	0	90720	199572	0.00	4.37	5.82
CARINASTREET	480	69120	7423	13754	27509	41263				0	0	0	0.00	0.00	0.00
CLIFTON	150	21600	14842	29624	59248	88872	8024	37648	67272	10132	10183	10183	0.69	0.23	0.14
CONSTANTIAPARK	285	41040	7847	17458	34916	52373			11333	0	83228	328760	0.00	3.07	7.38
CORNWALLHILL	0	0	2089	16370	32740	49110	16370	32740	49110	176051	177976	177976	12.33	5.81	3.79
CSIR1	0	0	0	41029	82059	123088	41029	82059	123088	991592	991592	991592	24.17	12.08	8.06
CSIR10	0	0	2476	22180	44360	66540	22180	44360	66540	85671	85671	85671	4.35	2.05	1.34
CSIR11	0	0	4185	15359	30718	46078	15359	30718	46078	98417	99492	99492	8.81	3.75	2.37
CSIR12	0	0	10433	24561	49122	73684	24561	49122	73684	9729	9729	9729	0.69	0.25	0.15
CSIR14	0	0	3805	7556	15113	22669	7556	15113	22669	119782	120124	121091	31.93	10.62	6.42
CSIR15	0	0	63	62676	125353	188029	62676	125353	188029	649387	649387	649387	10.37	5.18	3.45
CSIR2	0	0	3686	4362	8725	13087	4362	8725	13087	250737	250737	250737	370.87	49.76	26.67
CSIR3	0	0	47	29647	59294	88941	29647	59294	88941	337843	337843	337843	11.41	5.70	3.80
CSIR4	0	0	1361	63465	126930	190394	63465	126930	190394	197614	197614	197614	3.18	1.57	1.05
CSIR5	0	0	1650	21544	43088	64632	21544	43088	64632	275707	275707	275707	13.86	6.65	4.38
CSIR6	0	0	77	17297	34594	51891	17297	34594	51891	204419	206650	206650	11.87	5.99	3.99
CSIR7	0	0	29	9810	19620	29431	9810	19620	29431	207745	210004	210004	21.24	10.72	7.14
CSIR9	0	0	34	8229	16457	24686	8229	16457	24686	248555	251262	251262	30.33	15.30	10.19
DOMISSE	90	12960	2079	2079	4135	6203				0	0	0	0.00	0.00	0.00
DORINGKLOOF	125	18000	8269	53147	106293	159440	35147	88293	141440	137210	137210	137210	3.06	1.40	0.91
EERSTERUST	225	32400	22391	22391	35169	52754		2769	20354	0	66423	66907	0.00	5.20	2.20
ELARDUSPARK	355	51120	14943	34455	68911	103366		17791	52246	0	127436	127436	0.00	2.36	1.44
ERASMIA HL	355	51120	2090	8431	16862	25293				0	0	0	0.00	0.00	0.00
ERASMIA LL	125	18000	806	6725	13450	20176			2176	0	140744	301559	0.00	11.13	15.57
ERASMUSRAND	285	41040	1748	3229	6458	9687				0	0	0	0.00	0.00	0.00
FINDLAY	1145	164880	17988	20966	41931	62897				0	0	0	0.00	0.00	0.00

Table 6.13: Water feeder main costs

Water feeder main	Cap l/s	Design cap persons	Existing pop	>existing or potpopL	>existing or potpopM	>existing or potpopH	Req cap L (pers)	Req cap M (pers)	Req cap H (pers)	Tot cost (R):L	Tot cost (R):M	Tot cost (R):H	Per cap cost(R):L	Per cap cost(R):M	Per cap cost(R):H
FLORAUNA HL	30	4320	332	440	880	1320				0	0	0	0.00	0.00	0.00
FLORAUNA LL	70	10080	3962	5011	10022	15032			4952	0	20013	37693	0.00	3.30	3.40
HERCULES-WEST	225	32400	6083	28364	56727	85091		24327	52691	0	7855	7855	0.00	0.16	0.10
HERCULES-EAST	325	46800	27722	33376	66752	100128		19952	53328	0	13240	13240	0.00	0.34	0.18
HEUWELOORD	0	0	2258	13517	27034	40551	13517	27034	40551	94222	95260	95260	8.37	3.84	2.49
HOSPITAL HILL	430	61920		20999	41999	62998			1078	0	33687	102211	0.00	0.80	1.62
KILNER-PARK	30	4320	483	1867	3734	5601			1281	0	4743	32188	0.00	1.46	6.29
KLIPFONTEIN	0	0	49419	55546	111093	166639	55546	111093	166639	1061920	1061920	1061920	173.30	17.22	9.06
KLIPKRUISFONTEIN	355	153360	47238	53114	106228	159341			5981	0	85103	246323	0.00	1.44	2.20
KNOPJESLAAGTE	0	0	0	32684	65368	98053	32684	65368	98053	1139623	1139623	1139623	34.87	17.43	11.62
KOEDOESNEK-HL	225	32400	6989	15130	30259	45389			12989	0	120528	390896	0.00	5.18	10.18
KOEDOESNEK-LL	590	84960	19840	26597	53194	79791				0	0	0	0.00	0.00	0.00
LAUDIUM	355	51120	16238	16238	28189	42284				0	0	0	0.00	0.00	0.00
LOTUS GARDENS	175	25200	218	12792	25584	38376		384	13176	0	195842	195842	0.00	7.72	5.13
LOUWLARDIA	175	25200	490	25945	51890	77836	745	26690	52636	230922	233461	233461	9.07	4.54	3.02
LYNNWOOD	215	30960	9504	13688	27376	41064			10104	0	12354	37695	0.00	0.69	1.19
MAGALIES	510	73440	2550	30742	61485	92227			18787	0	72829	223831	0.00	1.24	2.50
MAGALIESBERG	390	56160	33704	17181	34362	51543				0	0	0	0.00	0.00	0.00
MAGALIESKRUIN	70	10080	1275	1349	2698	4046				0	0	0	0.00	0.00	0.00
MAMELODI-R1	285	123120	16203	16203	16203	16203				0	0	0	0.00	0.00	0.00
MAMELODI-R2	90	38880	69655	69655	69655	69655	30775	30775	30775	39582	39582	39582	1.29	1.29	1.29
MAMELODI-R3	355	153360	118812	118812	118812	118812				0	0	0	0.00	0.00	0.00
MEINTJIESKOP	125	18000	11318	11318	19029	28543		1029	10543	0	1254	1254	0.00	0.16	0.07
MNANDI	90	12960	439	32580	65161	97741	19620	52201	84781	701030	701030	701030	21.81	10.83	7.20
MONTANA	225	32400	6994	42522	85044	127566	10122	52644	95166	33812	34182	34182	0.95	0.44	0.28
MONUMENTPARK	55	7920	1606	3098	6197	9295			1375	0	180948	394803	0.00	39.42	51.35
MONUMENTPARK EXT2	90	12960	1724	2454	4909	7363				0	0	0	0.00	0.00	0.00
MOOIKLOOF	225	32400	6113	23633	47265	70898		14865	38498	0	223111	224712	0.00	5.42	3.47
MOOIPLAATS	0	0	92	47297	94594	141891	47297	94594	141891	475439	475439	475439	10.07	5.03	3.35
MORALETTA	430	61920	20806	41015	82030	123046		20110	61126	0	53391	53391	0.00	0.87	0.52
MUCKLENEUCK	480	69120	17541	20735	41469	62204				0	0	0	0.00	0.00	0.00
MURRAYFIELD	510	73440	3630	5305	10609	15914				0	0	0	0.00	0.00	0.00

Table 6.13: Water feeder main costs

Water feeder main	Cap. l/s	Design cap persons	Existing pop	>existing or potpopL	>existing or potpopM	>existing or potpopH	Req cap L (pers)	Req cap M (pers)	Req cap H (pers)	Tot.cost (R):L	Tot.cost (R):M	Tot.cost (R):H	Per cap cost(R):L	Per cap cost(R):M	Per cap cost(R):H
PARKMORE HL	355	51120	13897	15468	30936	46404				0	0	0	0.00	0.00	0.00
PARKMORE-LL	200	28800	12291	13059	26117	39176			10376	0	90965	363548	0.00	6.58	13.52
PIERREVANRYNEVELD	55	7920	4883	17860	35720	53579	9940	27800	45659	81914	82811	82811	6.31	2.69	1.70
PRETORIA WEST HL	175	25200	4199	18329	36659	54988		11459	29788	0	6561	6609	0.00	0.20	0.13
PRETORIA WEST LL	225	32400	5384	12009	24018	36027			3627	0	4387	12321	0.00	0.24	0.40
PRETORIUSRAND	0	0	2	73573	147146	220719	73573	147146	220719	799359	799433	799433	10.87	5.43	3.62
QUEENSWOOD	510	73440	22983	25105	50210	75315			1875	0	69471	210869	0.00	2.55	4.03
RASLOUW	175	25200	1896	16707	33415	50122		8215	24922	0	173101	174065	0.00	5.49	3.61
ROOIHUISKRAAL	415	59760	9536	44653	89307	133960		29547	74200	0	169632	169632	0.00	2.13	1.36
SALVOKOP	575	82800	49427	49427	49427	49427				0	0	0	0.00	0.00	0.00
SINOVILLE HL	55	7920	866	866	1409	2113				0	0	0	0.00	0.00	0.00
SINOVILLE LL	70	10080	2761	2761	5152	7729				0	0	0	0.00	0.00	0.00
SOSHANGUVE DD	905	390960	236131	236131	236131	236131				0	0	0	0.00	0.00	0.00
SOSHANGUVE L	510	220320	157008	157008	157008	225172			4852	0	0	190241	0.00	0.00	2.79
STINKWATER	0	0	0	58402	116804	175207	58402	116804	175207	803257	803257	803257	13.75	6.88	4.58
SUIDERBERG	125	18000	294	1986	3973	5959				0	0	0	0.00	0.00	0.00
SUNDERLAND-RIDGE	55	7920	172	14365	28731	43096	6445	20811	35176	448421	453320	453320	31.59	15.87	10.56
THE REEDS	175	25200	3720	11388	22775	34163				0	0	0	0.00	0.00	0.00
VALHALLA	440	63360	9444	10566	21133	31699				0	0	0	0.00	0.00	0.00
VILLIERIA	55	7920	4019	4817	9634	14450		1714	6530	0	6937	6937	0.00	1.24	0.67
WATERKLOOF	125	18000	12527	14655	29310	43965		11310	25965	0	5401	5445	0.00	0.32	0.17
WATERKLOOF EAST	355	51120	3850	4641	9281	13922				0	0	0	0.00	0.00	0.00
WATERKLOOFPARK	15	2160	135	549	1097	1646				0	0	0	0.00	0.00	0.00
WATERKLOOFRIFX2	70	10080	3777	6020	12040	18060		1960	7980	0	221081	221081	0.00	26.75	15.48
WAVERLEY-HL	90	12960	7440	9154	18307	27461		5347	14501	0	0	0	0.00	0.00	0.00
WAVERLEY-LL	125	18000	9665	15724	31448	47172		13448	29172	0	0	0	0.00	0.00	0.00
TOTAL			1429776	2539407	4239970	6017806				10787767	13774419	15841630			
PER CAPITA										10	5	3			

Table 6.14: Water system main costs

SYS MAIN	Existing pop95	>existing or >potpop L	>existing or potpop M	>existing or >potpop H	Req diam L	Req diam M	Req diam H	Total pipe cost L	Total pipe cost M	Total pipe cost H	Total cost per cap L	Total cost per cap M	Total cost per cap H
A1	14589	59497	118993	178490	600	900	1200	343350	343350	343350	7.65	3.29	2.09
A2	27129	81729	163457	245186	600	1000	1200	250802	250802	250802	4.59	1.84	1.15
G1	24099	67400	134799	202199	600	900	1200	705335	705335	705335	16.29	6.37	3.96
G2	24582	69267	138533	207800	600	900	1200	28179	28179	28179	0.63	0.25	0.15
G3	54770	121803	243606	365409	700	1200	1200	1605759	1605759	1605759	23.95	8.50	5.17
G4	22391	22391	35169	52754	0	300	500	0	772598	779311	0.00	60.46	25.67
G5	26021	27696	45778	68668	110	400	600	317356	320498	320498	189.47	16.22	7.52
G6	45861	54293	98972	148459	250	600	900	220982	223170	223170	26.21	4.20	2.18
G7	121437	217111	424608	636914	800	1200	1200	1177950	1177950	1177950	12.31	3.89	2.29
G8	20806	41015	82030	123046	400	700	900	491538	491538	491538	24.32	8.03	4.81
HH1	6083	33376	66752	100128	500	700	800	354349	354349	354349	12.98	5.84	3.77
HH2	294	1986	3973	5959	110	160	200	943835	943835	943835	557.82	256.55	166.61
HH3	44521	83327	166654	249981	500	1000	1200	694117	694117	694117	17.89	5.68	3.38
HH4	8201	14811	29622	44434	200	400	500	269867	271663	271663	40.83	12.68	7.50
HL1	4199	18329	36659	54988	300	500	600	596907	602636	602636	42.24	18.57	11.87
HL2	5384	12009	24018	36027	200	400	500	120934	122132	122132	18.25	6.55	3.99
HL3	9583	30338	60677	91015	400	600	800	546403	546403	546403	26.33	10.69	6.71
HL4	5931	17192	34383	51575	250	500	600	24470	24713	24713	2.17	0.87	0.54
HL5	15514	47530	95060	142590	500	800	1000	105081	105081	105081	3.28	1.32	0.83
K1	35567	40294	80588	120882	200	600	800	249165	250896	250896	52.71	5.57	2.94
K10	7558	14303	28606	42909	250	400	500	255853	258387	258387	37.93	12.28	7.31
K11	12527	14655	29310	43965	160	400	500	255143	257670	257670	119.90	15.35	8.20
K12	33704	38180	76361	114541	200	600	800	746409	751288	751288	166.76	17.61	9.29
K13	334	10785	21570	32355	250	400	500	31534	31846	31846	3.02	1.50	0.99
K2	4019	4817	9634	14450	110	160	250	793710	793710	793710	994.62	141.36	76.09
K3	15337	16135	28663	42993	110	300	400	294300	294300	296623	368.80	22.08	10.73
K4	50904	56429	109251	163875	200	600	900	410716	413914	413914	74.34	7.09	3.66
K5	49427	49427	49427	49427	0	0	0				0.00	0.00	0.00
K6	100331	105856	158678	213302	200	600	900	424583	427400	427400	76.85	7.33	3.78
K7	9504	13688	27376	41064	160	400	500	194475	195822	195822	46.48	10.96	6.20
K8	21795	26747	53493	80240	160	500	700	449769	454222	454222	90.83	14.33	7.77

Table 6.14: Water system main costs

SYS MAIN	Existing pop95	>existing or >potpop:L	>existing or potpop:M	>existing or >potpop:H	Req diam:L	Req diam:M	Req diam:H	Total pipe cost:L	Total pipe cost:M	Total pipe cost:H	Total cost per cap:L	Total cost per cap:M	Total cost per cap:H
K9	135	549	1097	1646	110	110	110	335110	335110	335110	809.44	348.35	221.78
M	85858	85858	85858	85858	0	0	0	0	0	0	0.00	0.00	0.00
W1	4294	5451	10902	16352	110	200	300	1070542	1070542	1070542	925.27	162.01	88.78
W2	4902	4976	9259	13888	110	110	160	233213	233213	233213	3151.52	53.53	25.95
W3	453	47147	94293	141440	600	800	1000	1149560	1149560	1149560	24.62	12.25	8.15
W4	527	26983	53965	80948	400	600	800	781907	781907	781907	29.56	14.63	9.72
W5	3520	54174	108347	162521	600	900	1000	1141451	1141451	1141451	22.53	10.89	7.18
TOTA	922091	1637554	3040421	4468278				17614655	18425345	18434381			
PER CAPITA								24.62	8.70	5.20			

Table 6.15: Water system main costs attributed to relevant reservoir zones

Reservoir zone	Per cap.L	Per cap.M	Per cap.H
AKASIA	12.24	5.13	3.25
AKASIA EAST	12.24	5.13	3.25
AKASIA WEST	4.59	1.84	1.15
ATTERIDGEVILLE-HL	0	0	0
ATTERIDGEVILLE-LL	0	0	0
ATTERIDGEVILLE-WEST	0	0	0
BAKENKOP	0	0	0
BRAKFONTEIN	0	0	0
CARINASTREET	37.93	12.28	7.31
CLIFTON	0	0	0
CONSTANTIAPARK	0	0	0
CORNWALLHILL	0	0	0
CSIR-1	0	0	0
CSIR-10	0	0	0
CSIR-11	0	0	0
CSIR-12	0	0	0
CSIR-13	58.71	18.37	10.88
CSIR-14	0	0	0
CSIR-15	0	0	0
CSIR-16	24.62	12.25	8.15
CSIR-2	36.27	12.39	7.45
CSIR-3	0	0	0
CSIR-4	0	0	0
CSIR-5	0	0	0
CSIR-6	0	0	0
CSIR-7	0	0	0
CSIR-8	3.02	1.50	0.99
CSIR-9	0	0	0
DOMISSE	0	0	0
DOORNPOORT-EAST	22.53	10.89	7.18
DOORNPOORT-WEST	29.56	14.63	9.72
DORINGKLOOF	0	0	0
EERSTERUST	227.99	84.77	37.64
ELARDUSPARK	0	0	0
ERASMIA-HL	0	0	0
ERASMIA-LL	0	0	0
ERASMUSRAND	0	0	0
FINDLAY	0	0	0
FLORAUNA-HL	925.27	162.01	88.78
FLORAUNA-LL	925.27	162.01	88.78
GARSFONTEIN	36.27	12.39	7.45
HEIGHTS HL	17.89	5.68	3.38
HERCULES WEST	30.87	5.84	3.77
HERCULES-EAST	17.89	5.68	3.38
HEUWELOORD	0	0	0
ISCOR	5.46	2.19	1.37
KILNER-PARK	36.90	12.64	7.61
KLAPPERKOP	203.90	19.99	10.39
KLIPFONTEIN	0	0	0
KLIPKRUISFONTEIN	0	0	0
KNOPJESLAAGTE	0	0	0

Table 6.15: Water system main costs attributed to relevant reservoir zones

Reservoir zone	Per cap L	Per cap M	Per cap H
KOEDOESNEK-HL	0	0	0
KOEDOESNEK-LL	38.52	8.09	4.46
LAUDIUM	0	0	0
LOTUS-GARDENS	0	0	0
LOUWLARDIA	0	0	0
LYNNWOOD	137.31	25.29	13.98
MAGALIES	0	0	0
MAGALIESBERG/HOSPITAL	370.65	37.60	19.68
MAGALIESKRUIN	3151.52	53.53	25.95
MAMELODI-R1	0.00	0.00	0.00
MAMELODI-R2	0.00	0.00	0.00
MAMELODI-R3	0	0	0
MAMELODI-R4/EAST	0	0	0
MEINTJIESKOP	519.98	36.50	18.17
MNANDI	0	0	0
MONTANA	53.19	19.01	11.57
MONUMENTPARK	0	0	0
MONUMENTPARK EXT2	0	0	0
MOOIKLOOF	0	0	0
MOOIPLAATS	0	0	0
MORELETA	36.63	11.91	7.09
MUCKLENEUCK	0	0	0
MURRAYFIELD	227.99	24.31	11.98
PARKMORE HL	0	0	0
PARKMORE LL	90.83	14.33	7.77
PIERREVANRYNEVELD	0	0	0
PRETORIA WEST HL	71.85	30.58	19.40
PRETORIA WEST LL	47.86	18.57	11.52
PRETORIUSRAND	0	0	0
QUEENSWOOD	36.27	12.39	7.45
RASLOUW	0	0	0
ROOIHUISKRAAL	0	0	0
SALVOKOP	76.85	7.33	3.78
SINOVILLE-HL	3151.52	53.53	25.95
SINOVILLE-LL	3151.52	53.53	25.95
SOSHANGUVE	0	0	0
SOSHANGUVE-L	0	0	0
STINKWATER	0	0	0
SUIDERBERG	575.71	262.23	169.99
SUNDERLAND-RIDGE	0	0	0
THE-REEDS	0	0	0
VALHALLA	0	0	0
VILLIERIA	1514.61	177.86	94.26
WATERKLOOF	119.90	15.35	8.20
WATERKLOOF EAST	0	0	0
WATERKLOOFPARK	847.38	360.62	229.09
WATERKLOOFRIFX2	0	0	0
WAVERLEY-HL	53.19	19.01	11.57
WAVERLEY-LL	53.19	19.01	11.57
WONDERBOOM	0	0	0

Table 6.16: Water receiving reservoir costs

Receiving reservoir name	POP95	>existing or potpopL	>existing or potpopM	>existing or potpopH	Req cap (pers):L	Req cap (pers):M	Req cap (pers):H	Req cap (Ml):L	Req cap (Ml):M	Req cap (Ml):H	Total cost (R):L	Total cost (R):M	Total cost (R):H	Per cap cost:L	Per cap cost:M	Per cap cost:H
AKASIA	27129	81740	163480	245220	24597	106337	188077	6	28	49	1600000	4400000	6900000	29	32	32
GARSFONTEIN	121437	212260	424520	636780	0	195949	408209	0	52	107	0	7300000	14500000	0	24	28
HEIGHTS HL+LL	60035	130800	261600	392400	0	0	0	0	0	0	0	0	0	0	0	0
KLAPPERKOP	161810	161810	313480	470220	0	0	1649	0	0	0	0	0	0	0	0	0
MAMELODI-R4/EAST	285513	285513	285513	286560	0	0	0	0	0	0	0	0	0	0	0	0
WONDERBOOM	47866	193040	386080	579120	106373	299413	492453	28	79	130	4500000	10700000	16800000	31	32	32
TOTAL	703790	1065163	1834673	2610300							6100000	22400000	38200000			
PER CAPITA											17	20	20			

Table 6.18: Sewer link costs

Sewer link zone name	Area (Ha)	PotPop:L 20	PotPop:M 40	PotPop:H 60	Slope %	Adj base cost:L	Adj base cost:M	Adj base cost:H	Length	Total cost (R):L	Total cost (R):M	Total cost (R):H	Per capita cost(R):L	Per capita cost(R):M	Per capita cost(R):H
13-353A	372	7449	14898	22348		223.30	223.30	223.30	1142	255012	255012	255012	34	17	11
13-354A	494	9884	19768	29651		223.30	223.30	239.84	436	97323	97323	104533	10	5	4
13-355	749	14989	29978	44968		223.30	239.84	239.84	1845	411952	442467	442467	27	15	10
13-381A	1042	20830	41661	62491		223.30	239.84	239.84	5161	1152522	1237894	1237894	55	30	20
1-4B	1269	25379	50758	76136		223.30	239.84	239.84	1307	291763	313375	313375	11	6	4
1-5A	620	12405	24810	37216		223.30	223.30	239.84	1573	351230	351230	377247	28	14	10
17-282B	103	2051	4103	6154	0.0	206.76	206.76	223.30	1013	209520	209520	226282	102	51	37
17-283A	158	3162	6324	9486	0.0	206.76	223.30	223.30	202	41720	45058	45058	13	7	5
17-283B	184	3683	7367	11050		206.76	223.30	223.30	320	66233	71532	71532	18	10	6
17-284A	136	2721	5443	8164	0.0	206.76	223.30	223.30	370	76458	82574	82574	28	15	10
17-284B	161	3225	6450	9676	0.0	206.76	223.30	223.30	567	117328	126714	126714	36	20	13
17-321B	580	11599	23198	34796		223.30	223.30	239.84	552	123177	123177	132301	11	5	4
18-283C	372	7446	14893	22339		223.30	223.30	223.30	439	98076	98076	98076	13	7	4
18-283D	199	3984	7968	11952		206.76	223.30	223.30	106	21968	23726	23726	6	3	2
18-284C	205	4103	8206	12310		223.30	223.30	223.30	1564	349133	349133	349133	85	43	28
18-321A	128	2569	5138	7707		206.76	206.76	223.30	2414	499160	499160	539093	194	97	70
19-23A	280	5598	11196	16795	3.8	206.76	223.30	223.30	1049	216912	234265	234265	39	21	14
19-23B	207	4134	8268	12402		206.76	223.30	223.30	354	73183	79037	79037	18	10	6
20-283F	702	14042	28085	42127		223.30	239.84	239.84	1201	268191	288057	288057	19	10	7
20-82C	505	10092	20184	30275		223.30	223.30	239.84	605	135144	135144	145155	13	7	5
21-82A	871	17415	34831	52246		223.30	239.84	239.84	557	124285	133491	133491	7	4	3
21-82B	732	14633	29266	43900		223.30	239.84	239.84	1009	225380	242075	242075	15	8	6
2-29C	638	12759	25518	38276		223.30	223.30	239.84	4097	914841	914841	982607	72	36	26
22a-83A	863	17263	34526	51790		223.30	239.84	239.84	1058	236268	253769	253769	14	7	5
22a-88A	71	1421	2842	4264		206.76	206.76	206.76	803	166016	166016	166016	117	58	39
22b-288A	222	4436	8873	13309		206.76	223.30	223.30	3954	817508	882909	882909	184	100	66
22b-291A	214	4287	8575	12862		206.76	223.30	223.30	3507	725190	783205	783205	169	91	61
22b-465A	262	5244	10487	15731		206.76	223.30	223.30	4962	1025922	1107996	1107996	196	106	70
22b-83B	477	9539	19078	28617		223.30	223.30	239.84	1660	370568	370568	398017	39	19	14
22b-88B	241	4822	9644	14466		206.76	223.30	223.30	1091	225617	243666	243666	47	25	17
22c-102	108	2166	4332	6497	2.1	206.76	206.76	206.76	1908	394440	394440	394440	182	91	61
22c-111A	153	3062	6124	9187	1.7	206.76	206.76	223.30	2305	476602	476602	514731	156	78	56

Table 6.18: Sewer link costs

Sewer link zone name	Area (Ha)	PotPop:L 20	PotPop:M 40	PotPop:H 60	Slope %	Adj base cost:L	Adj base cost:M	Adj base cost:H	Length	Total cost (R):L	Total cost (R):M	Total cost (R):H	Per capita cost(R):L	Per capita cost(R):M	Per capita cost(R):H
23-111B	237	4745	9489	14234		206.76	223.30	223.30	1026	212105	229073	229073	45	24	16
23-293D	455	9107	18215	27322		223.30	223.30	239.84	2428	542197	542197	582359	60	30	21
2-4A	358	7159	14318	21477		223.30	223.30	223.30	1193	266469	266469	266469	37	19	12
26-288C	106	2124	4247	6371	2.1	206.76	206.76	206.76	4775	987196	987196	987196	465	232	155
26-291B	305	6107	12214	18322	1.9	206.76	223.30	223.30	4163	860804	929668	929668	141	76	51
26-292	64	1271	2542	3812		206.76	206.76	206.76	2998	619815	619815	619815	488	244	163
26-293B	497	9948	19897	29845		223.30	223.30	239.84	827	184752	184752	198438	19	9	7
26-293C	1092	21848	43696	65543		223.30	239.84	239.84	351	78358	84163	84163	4	2	1
2-8A	806	16112	32224	48337		223.30	239.84	239.84	1889	421829	453075	453075	26	14	9
29-323B	155	3096	6192	9289	0.0	206.76	223.30	223.30	406	83872	90582	90582	27	15	10
29-323C	193	3858	7716	11575		206.76	223.30	223.30	591	122170	131944	131944	32	17	11
2-9A	117	2333	4665	6998		206.76	206.76	223.30	215	44437	44437	47992	19	10	7
30-357A	225	4503	9007	13510		206.76	223.30	223.30	652	134870	145659	145659	30	16	11
30-369	484	9676	19352	29029		223.30	223.30	239.84	2382	531791	531791	571183	55	27	20
30-370A	315	6298	12596	18893	4.8	206.76	223.30	223.30	1033	213552	230636	230636	34	18	12
30-371C	19	379	758	1137		206.76	206.76	206.76	2234	461819	461819	461819	1219	609	406
30-384	691	13814	27629	41443		223.30	239.84	239.84	2561	571786	614141	614141	41	22	15
30-385	587	11732	23464	35195		223.30	223.30	239.84	691	154294	154294	165723	13	7	5
30-387	1476	29526	59051	88577		239.84	239.84	239.84	1424	341537	341537	341537	12	6	4
30-390	100	2002	4004	6005	2.7	206.76	206.76	206.76	3303	682908	682908	682908	341	171	114
30-391B	315	6296	12591	18887	1.7	206.76	223.30	223.30	4631	957588	1034195	1034195	152	82	55
31-370B	99	1988	3976	5965	0.0	206.76	206.76	223.30	730	150920	150920	162994	76	38	27
31-371B	161	3215	6430	9644	0.0	206.76	223.30	223.30	92	19020	20541	20541	6	3	2
3-13A	190	3796	7593	11389		206.76	223.30	223.30	107	22165	23938	23938	6	3	2
32-357B	143	2858	5716	8574	0.0	206.76	223.30	223.30	197	40661	43914	43914	14	8	5
32-357C	282	5637	11273	16910	0.0	223.30	223.30	223.30	573	128036	128036	128036	23	11	8
32-358A	161	3222	6444	9665	0.9	206.76	206.76	223.30	1135	234590	234590	253357	73	36	26
32-369A	58	1155	2309	3464		206.76	206.76	206.76	3808	787363	787363	787363	682	341	227
32-464A	463	9263	18526	27788		223.30	223.30	239.84	780	174157	174157	187057	19	9	7
34-326	801	16010	32020	48031		223.30	239.84	239.84	1000	223321	239863	239863	14	7	5
34-345A	186	3712	7423	11135		206.76	223.30	223.30	448	92589	99996	99996	25	13	9
34-346B	159	3190	6380	9569	2.7	206.76	206.76	223.30	1093	225989	225989	244068	71	35	26

Table 6.18: Sewer link costs

Sewer link zone name	Area (Ha)	PotPop:L 20	PotPop:M 40	PotPop:H 60	Slope %	Adj base cost:L	Adj base cost:M	Adj base cost:H	Length	Total cost (R):L	Total cost (R):M	Total cost (R):H	Per capita cost(R):L	Per capita cost(R):M	Per capita cost(R):H
34-350B	582	11639	23277	34916		223.30	223.30	239.84	2793	623590	623590	669782	54	27	19
34-364B	27	542	1085	1627		206.76	206.76	206.76	1884	389528	389528	389528	718	359	239
35-288B	348	6955	13909	20864		223.30	223.30	223.30	3738	834788	834788	834788	120	60	40
35-323A	769	15376	30753	46129		223.30	239.84	239.84	1510	337178	362154	362154	22	12	8
35-342	140	2794	5587	8381	0.0	206.76	223.30	223.30	318	65681	70936	70936	24	13	8
35-359	456	9129	18258	27388		223.30	223.30	239.84	865	193073	193073	207374	21	11	8
36a-461B	2203	44066	88131	132197		239.84	239.84	268.79	2364	567069	567069	635509	13	6	5
36b-461A	947	18935	37871	56806		223.30	239.84	239.84	2234	498791	535739	535739	26	14	9
36b-461C	979	19590	39180	58769		223.30	239.84	239.84	299	66834	71785	71785	3	2	1
3-9B	219	4382	8765	13147		206.76	223.30	223.30	1012	209140	225871	225871	48	26	17
4-29A	376	7524	15048	22573		223.30	223.30	223.30	567	126663	126663	126663	17	8	6
4-29B	604	12078	24156	36234		223.30	223.30	239.84	1149	256622	256622	275631	21	11	8
43-346A	58	1160	2319	3479		206.76	206.76	206.76	1578	326261	326261	326261	281	141	94
43-362A	48	970	1940	2909		206.76	206.76	206.76	657	135870	135870	135870	140	70	47
43-363A	284	5686	11372	17057	1.8	206.76	223.30	223.30	551	113956	123072	123072	20	11	7
43-364A	172	3432	6864	10297		206.76	223.30	223.30	1320	272960	294797	294797	80	43	29
43-376	275	5495	10989	16484	1.6	206.76	223.30	223.30	2548	526845	568993	568993	96	52	35
43-378A	237	4735	9470	14206		206.76	223.30	223.30	2138	442140	477511	477511	93	50	34
43-391A	548	10960	21921	32881		223.30	223.30	239.84	5320	1187916	1187916	1275909	108	54	39
43-392A	46	918	1835	2753		206.76	206.76	206.76	4085	844677	844677	844677	921	460	307
44-350C	303	6065	12129	18194	0.0	223.30	223.30	223.30	414	92348	92348	92348	15	8	5
44-365	78	1560	3121	4681		206.76	206.76	206.76	505	104383	104383	104383	67	33	22
44-367	108	2159	4318	6478	0.0	206.76	206.76	223.30	66	13644	13644	14736	6	3	2
44-368B	561	11217	22433	33650		223.30	223.30	239.84	523	116681	116681	125324	10	5	4
45-352B	200	4005	8010	12015		206.76	223.30	223.30	1924	397711	429528	429528	99	54	36
45-368A	422	8438	16877	25315		223.30	223.30	223.30	556	124189	124189	124189	15	7	5
45-368C	116	2320	4640	6959		206.76	206.76	223.30	1313	271532	271532	293254	117	59	42
45-378B	201	4022	8044	12066		206.76	223.30	223.30	1199	247831	267657	267657	62	33	22
45-380A	252	5032	10065	15097		206.76	223.30	223.30	721	149101	161029	161029	30	16	11
45-380B	302	6048	12097	18145	8.1	206.76	223.30	223.30	613	126727	136866	136866	21	11	8
45-392	1318	26359	52718	79077		223.30	239.84	239.84	1677	374373	402104	402104	14	8	5
45a-352A	162	3247	6493	9740	2.1	206.76	206.76	223.30	2298	475031	475031	513034	146	73	53

Table 6.18: Sewer link costs

Sewer link zone name	Area (Ha)	PotPop:L 20	PotPop:M 40	PotPop:H 60	Slope %	Adj base cost:L	Adj base cost:M	Adj base cost:H	Length	Total cost (R):L	Total cost (R):M	Total cost (R):H	Per capita cost(R):L	Per capita cost(R):M	Per capita cost(R):H
45a-381B	1213	24268	48536	72803		223.30	239.84	239.84	1753	391424	420418	420418	16	9	6
45a-381C	1460	29192	58384	87576		239.84	239.84	239.84	877	210437	210437	210437	7	4	2
45a-381D	810	16197	32395	48592		223.30	239.84	239.84	1779	397346	426779	426779	25	13	9
47-465B	1214	24287	48573	72860		223.30	239.84	239.84	1916	427777	459465	459465	18	9	6
47-465D	655	13100	26199	39299		223.30	223.30	239.84	1783	398212	398212	427710	30	15	11
48-465C	1849	36989	73978	110967		239.84	239.84	239.84	1705	408973	408973	408973	11	6	4
49-465E	915	18309	36618	54926		223.30	239.84	239.84	1068	238566	256237	256237	13	7	5
49-465F	392	7830	15661	23491		223.30	223.30	223.30	356	79605	79605	79605	10	5	3
50-464B	1129	22571	45143	67714		223.30	239.84	239.84	485	108287	116309	116309	5	3	2
50-464C	899	17971	35942	53912		223.30	239.84	239.84	529	118184	126939	126939	7	4	2
51-463	1315	26302	52603	78905		223.30	239.84	239.84	988	220579	236918	236918	8	5	3
51-464D	903	18067	36134	54201		223.30	239.84	239.84	624	139317	149637	149637	8	4	3
51-464E	952	19040	38081	57121		223.30	239.84	239.84	570	127324	136755	136755	7	4	2
53-456D	1022	20447	40894	61340		223.30	239.84	239.84	1562	348707	374537	374537	17	9	6
54-456A	1811	36219	72439	108658		239.84	239.84	239.84	699	167652	167652	167652	5	2	2
54-456B	395	7900	15799	23699		223.30	223.30	223.30	1908	426011	426011	426011	54	27	18
54-456C	2155	43090	86180	129271		239.84	239.84	268.79	625	149961	149961	168060	3	2	1
56a-466B	719	14371	28741	43112		223.30	239.84	239.84	484	108004	116004	116004	8	4	3
56b-466A	751	15026	30052	45078		223.30	239.84	239.84	672	150072	161188	161188	10	5	4
7-17	520	10399	20798	31196		223.30	223.30	239.84	3282	732775	732775	787055	70	35	25
7-19	535	10698	21396	32095		223.30	223.30	239.84	2172	484936	484936	520857	45	23	16
7-6A	997	19946	39892	59838		223.30	239.84	239.84	475	106046	113901	113901	5	3	2
7-6B	1117	22333	44665	66998		223.30	239.84	239.84	698	155913	167462	167462	7	4	2
7a-13B	191	3822	7644	11465		206.76	223.30	223.30	4888	1010581	1091427	1091427	264	143	95
7a-14	802	16046	32091	48137		223.30	239.84	239.84	3783	844702	907273	907273	53	28	19
7a-5B	1143	22858	45716	68575		223.30	239.84	239.84	545	121726	130742	130742	5	3	2
8_21	381	7628	15256	22885		223.30	223.30	223.30	729	162849	162849	162849	21	11	7
TOTAL	2783	1284117	2568234	3852351					Sum	39880698	41347018	42202654			
PER CAP.										31	16	11			

Table 6.19: Outfall sewer costs

Pipe/ zone	Design capacity (persons)	Upstream pipes/zones	Existing load per pipe	Total load per pipe(L) (persons)	Total load per pipe(M) (persons)	Total load per pipe(H) (persons)	Req. cap. L	Required cap. M	Required cap. H	Total pipe cost. L	Total pipe cost. M	Total pipe cost. H	Per cap zone cost.L	Per cap zone cost.M	Per cap zone cost.H
1	2746113	1,2,3,4,5,6	165603	340134	680268	1020403	0	0	0	0	0	0			
10	175145	10	28199	55557	111114	166672	0	0	0	0	0	0			
11	332640	11,12,13	132456	222561	445122	667682	0	112482	335042	0	6412122	6774759	0.00	20.51	15.20
12	122466	12	21657	40224	80448	120671	0	0	0	0	0	0	0.00	20.51	12.66
13	333726	13	44892	103125	206250	309375	0	0	0	0	0	0	0.00	20.51	12.66
14	1384992	14,15,16,17,18	204471	251122	307859	364596	0	0	0	0	0	0			
15	254016	15	48296	48296	48296	48296	0	0	0	0	0	0			
16	1799280	16,17,18	156175	202826	259563	316299	0	0	0	0	0	0			
17	105359	17	9526	38628	77257	115885	0	0	10527	0	0	2845495	0.00	0.00	26.75
18	255830	18	559	18108	36216	54325	0	0	0	0	0	0			
19	247104	19,20,21	90421	72418	144836	217253	0	0	0	0	0	0			
2	357893	2	37580	119439	238878	358318	0	0	424	0	0	5543392	0.00	0.00	17.28
20	247968	20	36013	36013	63004	94506	0	0	0	0	0	0			
21	302400	21	52943	52943	64144	96217	0	0	0	0	0	0			
22a	570931	22a	92092	92092	92092	92092	0	0	0	0	0	0			
22b	876960	22a,22b	148336	107021	214042	321064	0	0	0	0	0	0			
22c	1121904	22a,22b,22c	162396	141182	282363	423545	0	0	0	0	0	0			
23	729636	23	8338	20752	41504	62255	0	0	0	0	0	0			
24	632423	24,25,26	105438	140453	229770	344656	0	0	0	0	0	0			
25	142560	25	59172	59172	75717	113575	0	0	0	0	0	0			
26	485790	26	28572	63587	127174	190761	0	0	0	0	0	0			
27	63541	27	1411	8497	16994	25490	0	0	0	0	0	0			
28	112962	28	2669	9347	18694	28040	0	0	0	0	0	0			
29	377173	27,28,29	4863	24798	49596	74394	0	0	0	0	0	0			
3	1829927	3,4,5,6	127781	182906	365811	548717	0	0	0	0	0	0			
30	255522	30	9747	99568	199137	298705	0	0	43183	0	0	3239249	0.00	0.00	16.32
31	85808	31	11310	21404	42809	64213	0	0	0	0	0	0	0.00	0.00	5.11
32	317434	30,31,32	22776	143107	286214	429321	0	0	111887	0	0	2078109	0.00	0.00	5.11
33	473028	33,42,43,44,45,45a	37833	279221	558442	837664	0	85415	364636	0	1474783	1711162	0.00	2.83	6.25
34	77390	34	11956	45580	91160	136740	0	13770	59350	0	2264779	2404433	0.00	28.59	23.38
35	729636	33,34,35,42,43,44,45,45a	72830	337324	674647	1011971	0	0	282335	0	0	3865093	0.00	0.00	4.12

Table 6.19: Outfall sewer costs

Pipe/ zone	Design capacity (persons)	Upstream pipes/zones	Existing load per pipe	Total load per pipe(L) (persons)	Total load per pipe(M) (persons)	Total load per pipe(H) (persons)	Req. cap: L	Required cap: M	Required cap: H	Total pipe cost: L	Total pipe cost: M	Total pipe cost: H	Per cap zone cost:L	Per cap zone cost:M	Per cap zone cost:H
36	364090	36,37,38	302408	302408	302408	302408	0	0	0	0	0	0			
36a	0	36a	0	44066	88131	132197	44066	88131	132197	3672971	3672971	4075803	83.35	41.68	30.83
36b	0	36b	0	38350	76701	115051	38350	76701	115051	1007911.2	1007911.2	1129126.3	26.28	13.14	9.81
37	97978	37	42488	42488	42488	42488	0	0	0	0	0	0			
38	139709	38	54189	54189	54189	54189	0	0	0	0	0	0			
39	139709	39	59299	59299	59299	70318	0	0	0	0	0	0			
4	544320	4	31044	72168	144335	216503	0	0	0	0	0	0			
40	21168	40	5499	6140	12279	18419	0	0	0	0	0	0			
41	7258	41	11184	12547	25093	37640	5289	17836	30382	2984711	3192708	3400704	2190.66	229.54	128.54
42	124910	42	6407	14511	29022	43532	0	0	0	0	0	0	0.00	2.83	6.25
43	391022	43,44,45,45a	28303	213657	427314	640970	0	36292	249949	0	1380543.4	1663761.8	0.00	6.29	8.97
44	14935	44	10377	27813	55626	83440	12878	40692	68505	2033666.5	2182628	2182628	116.63	54.53	38.84
45	196869	45,45a	11984	142726	285452	428179	0	88584	231310	0	4722299	5216581	0.00	23.56	21.50
45a	0	45a	1632	73338	146676	220013	73338	146676	220013	1916493.3	2146240.7	2146240.7	26.73	38.36	31.33
47	0	48,49,50,51	25	164801	329602	494403	164801	329602	494403	852704	914240	975776			
48	0	48	25	34703	69406	104108	34703	69406	104108	2260170	2260170	2260170			
49	0	49,50,51	0	130098	260196	390295	130098	260196	390295	2868135	3029840	3029840			
5	134142	5	13683	15531	31063	46594	0	0	0	0	0	0			
50	0	50	0	40550	81100	121650	40550	81100	121650	2235110	2235110	2480754	55.12	27.56	20.39
51	0	51	0	63409	126818	190227	63409	126818	190227	3894137	4268990	4268990	61.41	33.66	22.44
53	419731	53	25899	29028	58056	87084	0	0	0	0	0	0			
54	630202	54	77576	86958	173915	260873	0	0	0	0	0	0			
56a	0	56a	58291	58291	58291	70813	58291	58291	70813	1426315	1426315	1426315	24.47	24.47	20.14
56b	0	56b	516	14805	29611	44416	14805	29611	44416	1237105.5	1328743	1328743	86.57	45.67	30.27
6	293809	6	63506	65371	130741	196112	0	0	0	0	0	0			
7	333726	7	12222	91006	182012	273018	0	0	0	0	0	0			
7a	0	7a	19110	58776	117552	176329	58776	117552	176329	1509845.3	1689075.7	1689075.7	38.06	17.16	19.07
7b	368212	7a,7,7b	31332	149782	299564	449347	0	0	81134	0	0	3481408	0.00	0.00	8.33
8	318520	8,10,11	94451	142492	284984	427477	0	0	108957	0	0	845900	0.00	0.00	2.54
9	877083	9,8,10,11,12,13	161000	285841	571682	857523	0	0	0	0	0	0			
TOT										27899275	45609469	70063507			
P/C										22	14	13			

Table 6.20: Waste Water Treatment Works costs

ID	WWTW name	Area (ha)	Pop95	Design cap Ml/d	Design (pers.)	>existpop/ potpop:L	>existpop/ potpop:M	>existpop/ potpop:H	Req cap:L	Req. cap:M	Req cap:H	Tot Cost:L	Tot Cost:M	Tot Cost:H	Per cap cost:L	Per cap cost:M	Per cap cost:H
701	Klipgat	2106	75990	55	770000	75990	84251	126376	0	0	0	0	0	0	0	0	0
703	Zeekoeigat	14292	161001	30	150000	285843	571686	857529	135843	421686	707529	4075289	12650578	21225866	33	31	30
705	Daspoort	12463	262248	52	306800	262248	498512	747768	0	191712	440968	0	5751365	13229047	0	24	27
800	Klip/Kruisfontein	5799	103472	43	602000	115986	231971	347957	0	0	0	0	0	0	0	0	0
801	W of Attridgeville	1804	46178	0	0	46178	72155	108233	46178	72155	108233	1385334	2164662	3246993	0	83	52
802	W of Centurion	10276	37	0	0	205526	411051	616577	205526	411051	616577	6165768	12331536	18497304	30	30	30
706	Centurion	26729	127719	56	280000	534577	1069154	1603731	254577	789154	1323731	7637310	23674620	39711930	19	25	27
704	Baviaanspoort	8455	294903	61	469700	294903	338208	507312	0	0	37612	0	0	1504497	0	0	7
702	Rooiwal	24496	196943	260	1300000	489927	979853	1469780	0	0	169780	0	0	5093390	0	0	4
700	Soshanguve	9430	302401	27	378000	302401	377200	565801	0	0	187801	0	0	5634018	0	0	21
	TOTALS		**1570891**			**2613577**	**4634042**	**6951064**				**19263701**	**56572760**	**108143046**			
	PER CAPITA											18	18	20			

Table 6.22: Electricity costs

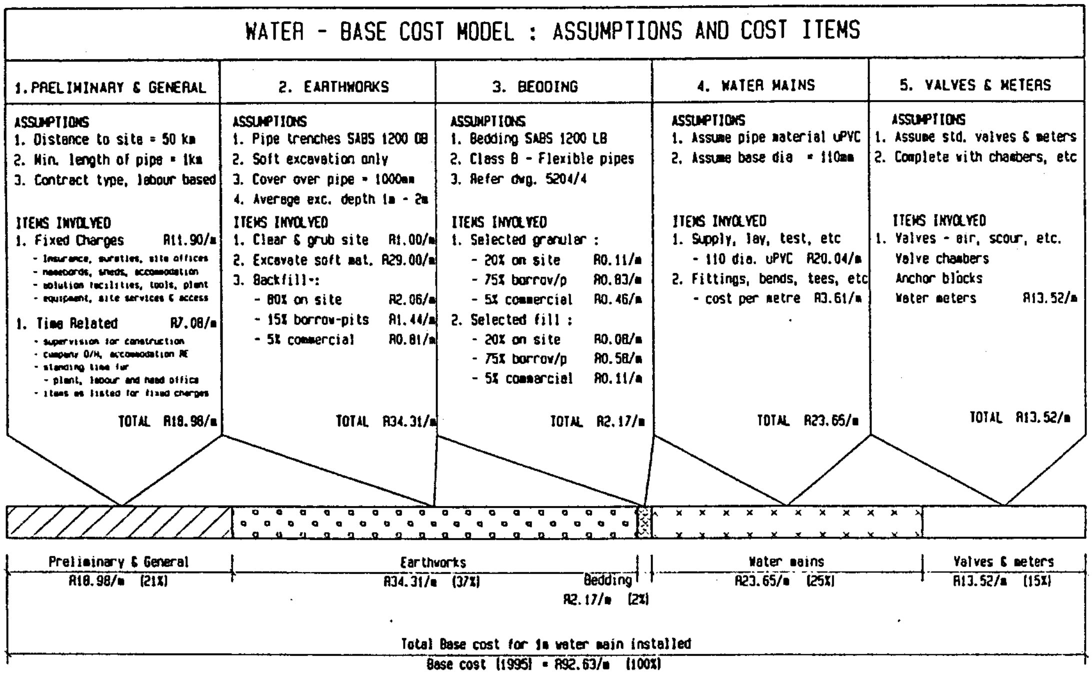
Electricity substation name	Design cap MVA	Add cap reqMVA:L	Total cost (R): L	Add cap reqMVA:M	Total cost (R): M	Add cap reqMVA:H	Total cost (R): H	Totcost(R) *1.5:L	Totcost(R) *1.5:M	Totcost(R) *1.5: H	Per cap cost:L	Per cap cost:M	Per cap cost:H
A(1)	0	21	14400000	41	19400000	62	24400000	21600000	29100000	36600000	262	177	148
A(2)	0	4	0	9	0	13	14400000	0	0	21600000	0	0	421
A(3)	0	16	14400000	31	19400000	47	19400000	21600000	29100000	29100000	3071	417	219
ATTERIDGEVILLE	70	0	0	0	0	0	0	0	0	0	0	0	0
BOOM STREET	90	0	0	0	0	0	0	0	0	0	0	0	0
BRAKFONTEIN	40	61	12500000	161	30000000	262	50000000	18750000	45000000	75000000	224	244	263
C(1) Eskom feed	0	216	54400000	432	94400000	648	131900000	81600000	141600000	197850000	378	328	305
CAPITAL PARK	70	0	0	0	0	0	0	0	0	0	0	0	0
CC SUB	20	0	0	0	0	0	0	0	0	0	0	0	0
CLAUDIUS	20	17	5000000	53	15000000	90	25000000	7500000	22500000	37500000	305	368	384
DIE HOEWES	40	0	0	12	5000000	38	7500000	0	7500000	11250000	0	191	172
EDMOND	35	0	0	0	0	0	0	0	0	0	0	0	0
ELDORAIGNE	40	0	0	35	7500000	73	15000000	0	11250000	22500000	0	209	246
GOMSAND	35	17	5000000	70	15000000	122	30000000	7500000	22500000	45000000	193	246	313
HIGHLANDS	70	0	0	0	0	21	7500000	0	0	11250000	0	0	179
IA SUB	20	4	0	4	0	4	0	0	0	0	0	0	0
K SUB	20	0	0	0	0	0	0	0	0	0	0	0	0
K1	20	0	0	1	0	12	5000000	0	0	7500000	0	0	84
K3	20	0	0	0	0	0	0	0	0	0	0	0	0
KENTRON	40	0	0	1	0	21	5000000	0	0	7500000	0	0	132
KLOOFSIG	20	10	5000000	39	10000000	69	20000000	7500000	15000000	30000000	279	266	349
KOEDOESPOORT	90	0	0	0	0	45	7500000	0	0	11250000	0	0	104
L SUB	10	0	0	0	0	0	0	0	0	0	0	0	0
LYNNWOOD	90	0	0	6	0	54	12500000	0	0	18750000	0	0	167
MAMELODI_1	60	0	0	0	0	0	0	0	0	0	0	0	0
MAMELODI_2	40	0	0	0	0	0	0	0	0	0	0	0	0
MAMELODI_3	40	0	0	0	0	0	0	0	0	0	0	0	0
MAYVILLE	35	0	0	19	7500000	45	15000000	0	11250000	22500000	0	327	367
MOOIKLOOF	35	11	7500000	56	15000000	102	22500000	11250000	22500000	33750000	302	271	262
N1	0	5	0	10	14400000	15	14400000	0	21600000	21600000	0	557	370
N2	0	1	0	1	0	2	0	0	0	0	0	0	0
N3	0	0	0	1	0	1	0	0	0	0	0	0	0
N4	0	16	14400000	32	19400000	47	19400000	21600000	29100000	29100000	1364	919	613
N5	0	7	0	15	14400000	22	14400000	0	21600000	21600000	0	1448	966

Table 6.22: Electricity costs

Electricity substation name	Design cap MVA	Add cap reqMVA:L	Total cost (R): L	Add cap reqMVA:M	Total cost (R): M	Add cap reqMVA:H	Total cost (R): H	Totcost(R) *1.5:L	Totcost(R) * 1.5 M	Totcost(R) *1.5: H	Per cap cost:L	Per cap cost:M	Per cap cost:H
N6	0	21	14400000	42	19400000	63	24400000	21600000	29100000	36600000	1027	692	580
N7	0	18	14400000	36	19400000	54	24400000	21600000	29100000	36600000	1233	821	686
N8	0	1	0	1	0	2	0	0	0	0	0	0	0
N9	0	0	0	1	0	1	0	0	0	0	0	0	0
NIVS	20	0	0	86	20000000	139	35000000	0	30000000	52500000	0	283	330
ORCHARDS	35	1	0	37	7500000	74	15000000	0	11250000	22500000	0	192	238
P(1)	0	26	14400000	53	24400000	79	26900000	21600000	36600000	40350000	823	696	512
P(2)	0	40	19400000	80	26900000	121	34400000	29100000	40350000	51600000	724	502	428
P(3)	0	0	0	0	0	0	0	0	0	0	0	0	0
P(4)	0	0	0	0	0	0	0	0	0	0	0	0	0
P(5)	0	72	26900000	143	34400000	215	54400000	40350000	51600000	81600000	564	361	380
PRETORIA NORT	35	0	0	0	0	0	0	0	0	0	0	0	0
PRINCES PARK	70	0	0	0	0	0	0	0	0	0	0	0	0
PUMULANI	35	7	0	49	15000000	92	22500000	0	22500000	33750000	0	278	274
RASLOUW	20	0	0	0	0	0	0	0	0	0	0	0	0
RIETGAT	0	48	19400000	48	19400000	48	19400000	29100000	29100000	29100000	151	151	151
RIVER	70	0	0	0	0	0	0	0	0	0	0	0	0
ROSSLYN	105	0	0	0	0	0	0	0	0	0	0	0	0
SAULSVILLE	40	0	0	0	0	0	0	0	0	0	0	0	0
SKINNER	140	0	0	0	0	0	0	0	0	0	0	0	0
TUNNEL	35	0	0	0	0	47	15000000	0	0	22500000	0	0	335
VILLIERIA	35	0	0	47	15000000	87	22500000	0	22500000	33750000	0	548	412
WALTLOO	105	0	0	3	0	57	15000000	0	0	22500000	0	0	175
WAPADRAND	35	0	0	27	7500000	58	15000000	0	11250000	22500000	0	207	263
WATERKLOOF	40	6	0	53	12500000	99	20000000	0	18750000	30000000	0	243	243
WILLOWS	70	0	0	44	15000000	102	22500000	0	22500000	33750000	0	319	264
WINGATE	70	5	0	79	15000000	154	37500000	0	22500000	56250000	0	189	290
WOLMER	35	12	7500000	59	15000000	106	22500000	11250000	22500000	33750000	319	273	261
WONDERBOOM	70	17	7500000	104	22500000	191	45000000	11250000	33750000	67500000	183	227	286
ZEBRA	70	0	0	0	0	0	0	0	0	0	0	0	0
ZWARTKOPS	35	10	7500000	54	15000000	99	22500000	11250000	22500000	33750000	409	312	289
TOTAL								396000000	885450000	1432050000			
PER CAPITA								159	222	237			

APPENDIX B

APPENDIX B: Sewer and water base pipe cost details



WATER - BASE COST MODEL : ASSUMPTIONS AND COST ITEMS

1. PRELIMINARY & GENERAL

ASSUMPTIONS
1. Distance to site = 50 km
2. Min. length of pipe = 1km
3. Contract type, labour based

ITEMS INVOLVED
1. Fixed Charges R11.90/m
   - Insurance, sureties, site offices
   - nameboards, sheds, accommodation
   - ablution facilities, tools, plant
   - equipment, site services & access
1. Time Related R7.08/m
   - supervision for construction
   - company O/H, accommodation RE
   - standing time for
     - plant, labour and head office
   - items as listed for fixed charges

TOTAL R18.98/m

2. EARTHWORKS

ASSUMPTIONS
1. Pipe trenches SABS 1200 DB
2. Soft excavation only
3. Cover over pipe = 1000mm
4. Average exc. depth 1m - 2m

ITEMS INVOLVED
1. Clear & grub site R1.00/m
2. Excavate soft mat. R29.00/m
3. Backfill-:
   - 80% on site R2.06/m
   - 15% borrow-pits R1.44/m
   - 5% commercial R0.81/m

TOTAL R34.31/m

3. BEDDING

ASSUMPTIONS
1. Bedding SABS 1200 LB
2. Class B - Flexible pipes
3. Refer dwg. 5204/4

ITEMS INVOLVED
1. Selected granular :
   - 20% on site R0.11/m
   - 75% borrow/p R0.83/m
   - 5% commercial R0.46/m
2. Selected fill :
   - 20% on site R0.08/m
   - 75% borrow/p R0.58/m
   - 5% commercial R0.11/m

TOTAL R2.17/m

4. WATER MAINS

ASSUMPTIONS
1. Assume pipe material uPVC
2. Assume base dia = 110mm

ITEMS INVOLVED
1. Supply, lay, test, etc
   - 110 dia. uPVC R20.04/m
2. Fittings, bends, tees, etc
   - cost per metre R3.61/m

TOTAL R23.65/m

5. VALVES & METERS

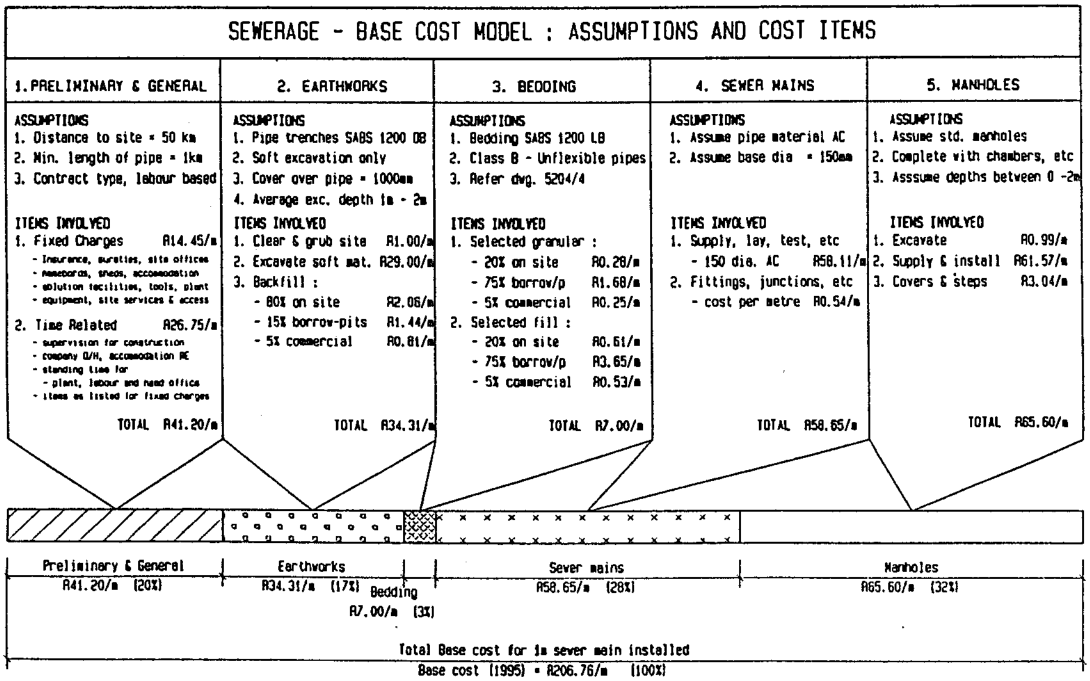
ASSUMPTIONS
1. Assume std. valves & meters
2. Complete with chambers, etc

ITEMS INVOLVED
1. Valves - air, scour, etc.
Valve chambers
Anchor blocks
Water meters R13.52/m

TOTAL R13.52/m

Preliminary & General	Earthworks	Bedding	Water mains	Valves & meters
R18.98/m (21%)	R34.31/m (37%)	R2.17/m (2%)	R23.65/m (25%)	R13.52/m (15%)

Total Base cost for 1m water main installed
Base cost (1995) = R92.63/m (100%)



SEWERAGE - BASE COST MODEL : ASSUMPTIONS AND COST ITEMS

1. PRELIMINARY & GENERAL

ASSUMPTIONS
1. Distance to site = 50 km
2. Min. length of pipe = 1km
3. Contract type, labour based

ITEMS INVOLVED
1. Fixed Charges R14.45/m
   - Insurance, sureties, site offices
   - nameboards, sheds, accommodation
   - ablution facilities, tools, plant
   - equipment, site services & access
2. Time Related R26.75/m
   - supervision for construction
   - company O/H, accommodation RE
   - standing time for
     - plant, labour and head office
   - items as listed for fixed charges

TOTAL R41.20/m

2. EARTHWORKS

ASSUMPTIONS
1. Pipe trenches SABS 1200 DB
2. Soft excavation only
3. Cover over pipe = 1000mm
4. Average exc. depth 1m - 2m

ITEMS INVOLVED
1. Clear & grub site R1.00/m
2. Excavate soft mat. R29.00/m
3. Backfill :
   - 80% on site R2.06/m
   - 15% borrow-pits R1.44/m
   - 5% commercial R0.81/m

TOTAL R34.31/m

3. BEDDING

ASSUMPTIONS
1. Bedding SABS 1200 LB
2. Class B - Unflexible pipes
3. Refer dwg. 5204/4

ITEMS INVOLVED
1. Selected granular :
   - 20% on site R0.28/m
   - 75% borrow/p R1.68/m
   - 5% commercial R0.25/m
2. Selected fill :
   - 20% on site R0.61/m
   - 75% borrow/p R3.65/m
   - 5% commercial R0.53/m

TOTAL R7.00/m

4. SEWER MAINS

ASSUMPTIONS
1. Assume pipe material AC
2. Assume base dia = 150mm

ITEMS INVOLVED
1. Supply, lay, test, etc
   - 150 dia. AC R58.11/m
2. Fittings, junctions, etc
   - cost per metre R0.54/m

TOTAL R58.65/m

5. MANHOLES

ASSUMPTIONS
1. Assume std. manholes
2. Complete with chambers, etc
3. Asssume depths between 0 -2m

ITEMS INVOLVED
1. Excavate R0.99/m
2. Supply & install R61.57/m
3. Covers & steps R3.04/m

TOTAL R65.60/m

Preliminary & General	Earthworks	Bedding	Sewer mains	Manholes
R41.20/m (20%)	R34.31/m (17%)	R7.00/m (3%)	R58.65/m (28%)	R65.60/m (32%)

Total Base cost for 1m sewer main installed
Base cost (1995) = R206.76/m (100%)

APPENDIX C

APPENDIX C: The continuity principle and the Manning flow formula utilised in the calculation of the number of persons who can be served by a particular sewer size under various slope conditions (Table 6.2)

Slope was limited to 1:300, while velocities were limited to 1.5m/sec. Higher velocities may result in segregation of solids and liquids.

Continuity principle: Q = VA
where
Q = flow rate
V = velocity of flow
A = wet cross-sectional area of pipe

Manning flow formula: V = (R^2/3. S^1/2)/n
where
R = A/P
P = wetted circumference
S = slope of pipe
n = roughness coefficient taken as 0.012 for the purposes of this study

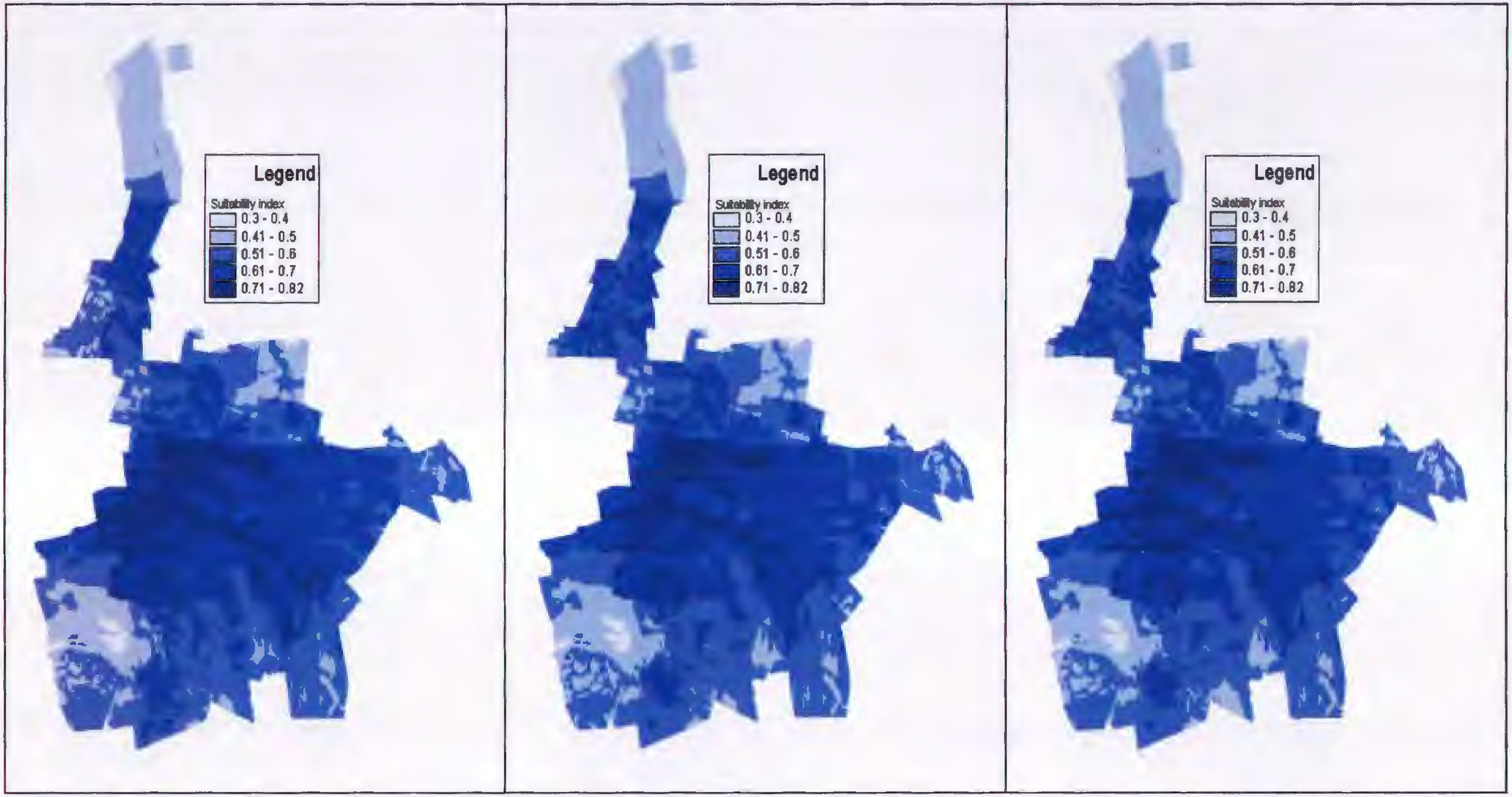
Average flow rate per person:

Assuming 600 litres per household per day and a household size of 5 persons, daily flow is 120 litres/person/day.
Average flow rate = 120/24/3600 = 0.0014 litres/second/person

Adding a peak factor of 2.5 gives a peak flow of 0.0035 litres/second/person

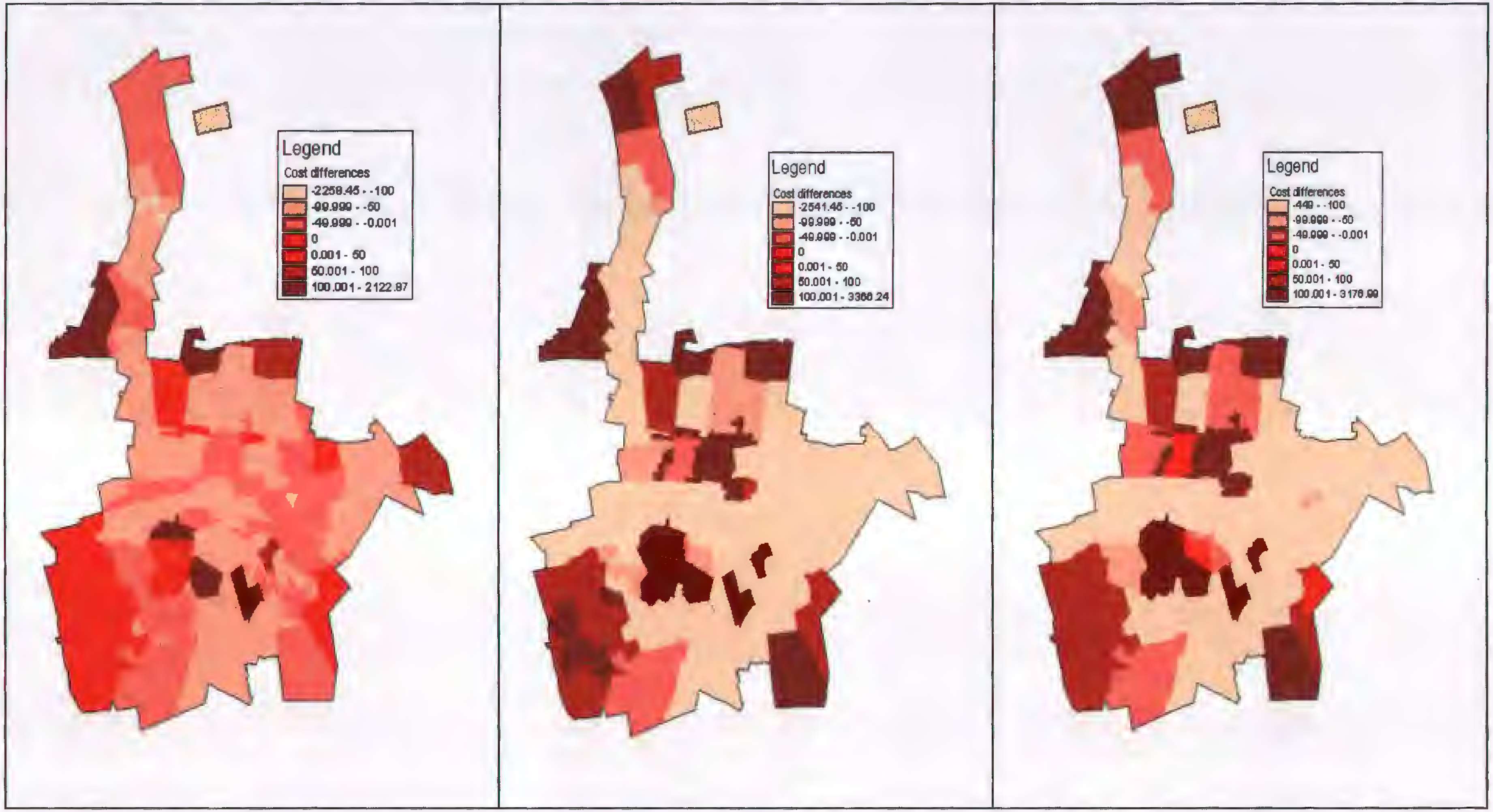
Divide flow rate (Q) by peak flow to obtain numbers of persons which can be served.

V = 1.5m/s can be substituted in the Manning formula to calculate slope (S). This is the slope reflected as the maximum slope of the pipe in Table 6.2.



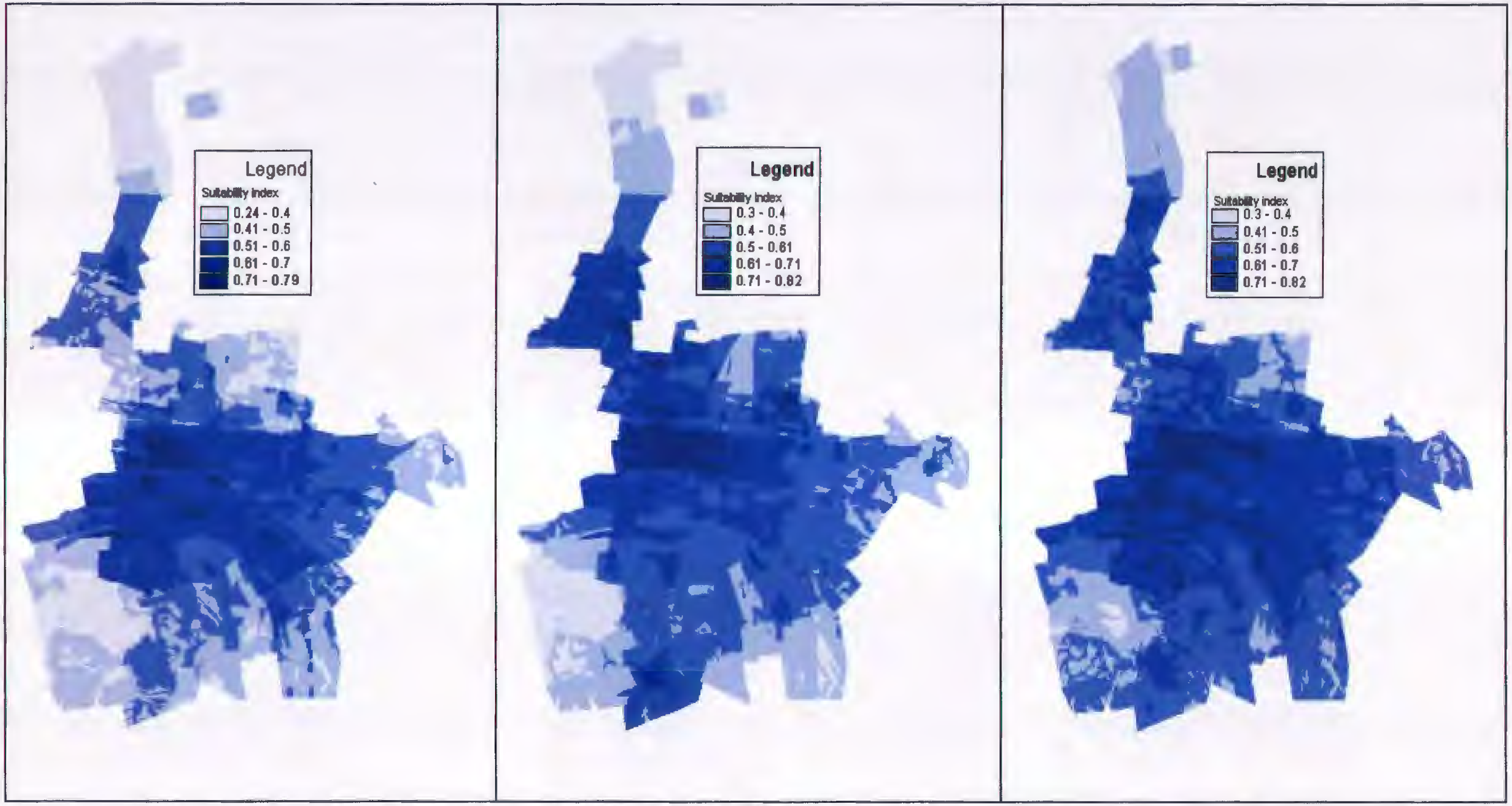
(a) (b) (c)

Figure 7.15: Suitability assessment including bulk infrastructure potential costs for the low (a), medium (b) and high (c) density scenarios



(a) (b) (c)

Figure 7.16: Cost differences between the medium and high (a), the low and high (b) and the low and medium (c) density scenarios



(a) (b) (c)

Figure 7.17: Comparison of a suitability assessment excluding all bulk infrastructure considerations (a), a suitability assessment including bulk infrastructure capacities (b) and including bulk infrastructure potential costs (c)