# OPTIMISING THE RENEWAL OF NATURAL GAS RETICULATION PIPES USING GIS

**BY**

**ALAN GEORGE CAWOOD HOBSON**

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**Supervisor: Prof. H.L. Zietsman**

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# DECLARATION

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

# OPSOMMING

’n Groot bron van kommer vir Energex, Australië se grootste energieverskaffer in Suidoos-Queensland, is die verlies van natuurlike gas uit hul gasdistribusie netwerke. In ’n groot deel van ouer Brisbane opereer hierdie netwerke hoofsaaklik teen lae en medium druk, met ’n aansienlike persentasie van hoofpyplyne wat uit gietyster of staal bestaan. Al is sommige pyplyne in hierdie netwerke met verloop van tyd vervang, maak verslae dit duidelik dat ’n groot deel van die gas in hierdie netwerke steeds langs die pad verlore gaan. Die operasionele - en onderhoudsbegrotings vir hierdie netwerke is boonop hoog, met ’n groot persentasie van die pyplyne wat binnekort aan die einde van hulle ekonomiese leeftyd kom.

Wanneer operasionele- en onderhoudsonkostes die koste van vervanging oorskry, beplan Energex se gasvoorsienings-afdeling projekte om verspreidingsnetwerke te hernu met poli-etileen pype. Om sinvolle besluite te neem tydens pyplynhernuwings, word verskeie historiese verslae geraadpleeg, insluitend: gasverbruikvlakke, lekplek geskiedenis rekords, onderhoud- en ander verwante onkostes, asook die verlies van inkomste weens verlore gas.

Alhoewel finansiële stawing van kapitale uitgawes nog altyd ’n voorvereiste was tydens hernuwingsprojekte by Energex, het die impak van privatisering op die energieverskaffingsmark dit noodsaaklik gemaak om hulle finansiële goedkeuringsproses vir kapitaalprojekte te hersien. Energex het dus ’n sagteware toepassing ontwikkel wat die finansiële gangbaarheid van hernuwingsprojekte evalueer. Hierdie navorsing sal die moontlike integrasie van geografiese inligtingstelsels (GIS) met dié van Energex se finansiële evalueringspakket demonstreer.

Die resultate van hierdie studie toon dat die integrasie van GIS in die hernuwingsproses aansienlike voordele inhou, insluitende:

- die effektiewe seleksie van sub-netwerke, gebaseer op pyp konnektiwiteit,
- die ontdekking van verskuilde verwantskappe tussen geografies-ruimtelike alfanumeriese data en omgewingsinligting, wat besluitneming vergemaklik, en
- verbeterde toetsing van voorgestelde hernuwingsopsies deur die indiepte-nagaan van geografies-ruimtelike elemente.

# ABSTRACT

A major concern for Energex, Australia's largest energy utility in South East Queensland, is the escape of natural gas out of their reticulation systems. Within many of the older areas in Brisbane, these networks operate primarily at low and medium pressure with a significant percentage of mains being cast iron or steel. Over many years pipes in these networks have been replaced, yet reports show that unaccounted for gas from the same networks remain high. Furthermore, operation and maintenance budgets for these networks are high with many of these pipes close to the end of their economic life.

When operation and maintenance costs exceed the costs of replacement, the Energex gas utility initiates projects to renew reticulation networks with polyethylene pipes. Making decisions about pipe renewal requires an evaluation of historical records from a number of sources, namely:

- gas consumption figures,
- history of leaks,
- maintenance and other related cost, and
- the loss of revenue contributed by unaccounted for gas.

Financial justification of capital expenditure has always been a requirement for renewal projects at the Energex gas utility, however the impact of a deregulation in the energy utility market has necessitated a review of their financial assessment for capital projects. The Energex gas utility has developed an application that evaluates the financial viability of renewal projects. This research will demonstrate the role of GIS integration with the Energex financial application.

The results of this study showed that a GIS integrated renewal planning approach incorporates significant benefits including:

- Efficient selection of a sub-network based on pipe connectivity,
- Discovery of hidden relationships between spatially enabled alphanumeric data and environmental information that improves decision making, and
- Enhanced testing of proposed renewal design options by scrutinizing the attributes of spatial data.

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# ACRONYMS

Energy:

MJ Megajoules

GJ Gigajoules

TJ Terajoules

PJ Petajoules

Distribution system:

LP Low Pressure

MP Medium Pressure

HP High Pressure

SM Secondary Main

PM Primary Main

TM Trunk Main

Pipe class:

CL Class

Pipe material:

PE Polyethylene gas pipe using electrofusion fittings

P5 Polyethylene gas pipe using mechanical fittings

CI Cast iron gas pipe

PS Polycoated steel gas pipe

CU Copper gas pipe

SG Galvanised steel gas pipe

PV PVC gas pipe

Pipe size reference:

DN Nominal Diameter

OD Outside Diameter

Other:

DCDB Digital cadastral database

GIS Geographic Information System

IRPA Integrated Renewal Planning Approach

UAG Unaccounted for Gas

SQL Structured Query Language

# TERMS

| | |
|---|---|
| Cathodic protection | The use of sacrificial anodes to prevent or reduce the rate of corrosion on buried steel pipes. |
| Class (CL) | The term 'Class' (CL) is associated with the classification of steel gas mains according to MAOP of the pipe. The term is usually used in conjunction with a number that defines the category of main, for example CL300. The alternative name for the pipe class and the associated MAOP is listed below:<br>CLASS DESCRIPTION MAOP<br>• CL150 – Secondary main 200 – 1,200kPa<br>• CL300 – Primary main 1,201 – 5,000kPa<br>• CL600 – Trunk main 5,001 – 10,200kPa<br>It is common practice in the Energex gas utility to refer to the 'class of pipe' rather than the 'description' in official documentation. |
| Customer | End user of the gas supplied by the reticulation network. The term does not refer to individual "people" but rather to the type of supply point. In the Energex gas utility customers are divided into five categories namely:<br>• Residential<br>• Commercial<br>• Industrial<br>• Power generation<br>• Natural gas vehicles (NGV)<br>In the study area of this research only the first three categories are evident. |
| Distribution system | Network of gas pipes that carry natural gas from gate stations to customers. |
| District regulator station | Gas device that controls the outlet pressure for a small down-stream distribution network. UAG is not measured at a district regulator station. |
| Energex | Energex is the largest energy utility in South East Queensland. Traditionally |

| | |
|---|---|
| | Energex has been a supplier of electricity, but in 1998 also entered the gas fuel market. This was brought about by Energex Limited buying Allgas Energy Limited. Within the Energex Corporation gas is treated as a separate subsidiary company. In this research reference to 'Energex' should be interpreted as only referring to the gas utility subsidiary. |
| Footpath | Footpath refers to the portion of land beside the road that is reserved for pedestrians. Footpath has the same meaning as sidewalk. In the Energex gas utility the term 'footpath' is generally used rather that the term 'sidewalk'. |
| Franchise | The right to establish and maintain a reticulation system in an area. |
| Gas pressure | The pressure of gas above the atmospheric pressure, measured in kPa. |
| Gate station | The transfer point from a transmission pipeline into a distribution system. Location where UAG is measured. |
| GIS database | In this thesis the term 'GIS database' refers to a collection of data layers specially set up for the purpose of this research. This is an object oriented GIS database built on the ESRI ArcGIS software which uses the Gas Data Model that comes as part of the software. The term 'GIS database' is used extensively in Chapter 3 in describing the IRPA. |
| Main | Pipe used in the distribution system supplying gas to connected services. |
| Manufactured gas | Flammable gases produced by the thermal treatment of coal. This is not a clean-burning gas. |
| MAOP | Maximum allowable operating pressure (MAOP) is the maximum pressure at which a network is designed to operate. |
| MOP | Maximum operating pressure (MOP) is the pressure that a network actually operates at and should not exceed the MAOP. |
| Natural gas | Natural gas is a naturally occurring mixture of combustible hydrocarbon gases, formed by the breakdown of microscopic unicellular plant remains. Over |

| | |
|---|---|
| | millions of years heat and pressure have changed this organic material into gas. The term 'natural' is used to describe the gas because it is a virtually unprocessed, clean-burning fuel that is both colourless and odourless. |
| Renewal | Replacement of old gas pipes with new ones that addresses planned efficiency and economic enhancements to gas supply. |
| Reticulation system | An interconnected network of underground mains and associated fittings supplying gas to at least fifty customers. |
| Service | A gas installation extending from the main to the customer. |
| Siphon | Device attached to gas pipes in low and medium pressure distribution systems used to trap moisture that could hinder gas flow through these pipes and potentially block supply to customers. |
| Sleeve | An existing gas pipe that is decommissioned can become a 'sleeve' for a live main. The new gas pipe is inserted inside an old one in order to avoid digging a trench. |
| Sub-gate station | Gas device that controls the outlet pressure for a large down-stream distribution network. Location where UAG is measured. |
| Unaccounted for Gas (UAG) | The term 'unaccounted for gas' (UAG) is applied to the discrepancy between the total gas available from all sources and the total gas accounted for in the sales, net interchange, company use, storage and other uses. |

# CHAPTER 1: GAS DISTRIBUTION NETWORKS

In this chapter natural gas as energy fuel is defined, the implication of deregulation in the natural gas industry and a brief overview of natural gas distribution management is discussed. The purpose of the study and an overview of the study area will also be provided.

## 1.1 NATURAL GAS AT A GLANCE

Natural gas is a hydrocarbon fossil fuel that is formed over hundreds of millions of years, from plankton and other simple life forms that become buried by sediments. Eventually large volumes of natural gas become trapped far below the earth's surface. Natural gas consists mainly of methane. A methane molecule has one carbon and four hydrogen atoms. Methane is lighter than air and will therefore disperse in the event of a gas leak (Australian Gas Industry 2000: 3). Other constituents of natural gas are ethane, propane, butane, pentane and traces of both nitrogen and carbon dioxide. Natural gas is odourless and regarded as a clean-burning organic fuel. Compared with any fossil fuel, natural gas has the lowest greenhouse gas emissions. It is therefore, an environmentally friendly form of energy (Australian Gas Association 2000: 9).

Natural gas is used in various economic sectors and applications:

- The residential sector uses natural gas for cooking, space heating, hot water and gas-fixed air conditioning,
- Commercial applications include catering, heating and drying processes,
- The industrial sector uses natural gas primarily in manufacturing,
- Power generation in both power station turbines and congeneration plants, and
- Fuel for vehicles.

## 1.2 MANAGEMENT OF PIPE DISTRIBUTION NETWORKS BY GAS UTILITIES

The natural gas industry worldwide is divided into three groups, namely the gas producers, the pipeline authorities and the gas distributors. The latter group is referred to as utilities. There is an association between the notion of "utility" and franchised areas of supply (Australian Gas Association Date unknown: 7). Gas utilities were granted exclusive rights to supply gas within franchise areas in accordance with government controls. The obligation on the utility is to provide services to customers who are willing to pay for their connection to the gas distribution system (Energex 2000: 1).

Natural gas is transmitted to metropolitan areas by transmission pipelines, operating at very high pressure. Gate stations are the transfer points from a transmission pipeline into distribution systems and are fitted with sophisticated flow computers to record consumption figures.

Metered consumption recorded at the gate stations is compared to the total customer consumption figures, company use and storage for the distribution system. The disparity between the two readings is referred to as unaccounted for gas (UAG). There are several causes for UAG, including: leaks, meter errors, accounting errors, non-metered company use and theft in the pipe network (Gajinov 2001a). The utilities calculate UAG tolerance margins for different parts of the network. Exceeding these margins would result in substantial loss of revenue.

Since gas escape from leaking mains is regarded as the major cause for UAG in distribution systems, gas utilities implement measures to identify and repair those parts of the distribution network that cause unacceptably high UAG figures. It is the low and medium pressure networks that show disproportionately high UAG figures compared to the rest of the network (Gajinov 2001b).

Maintenance of mains generally follow a "three R's approach": repair, renovate and renew (Hale 1984: 14). Repair work is based on priorities to ensure continuous gas supply to customers. Renovation involves planned upgrade of existing facilities. The last option of renewal involves replacing old pipes with new ones. The indicators of renewal could include criteria such as pipe material, age of pipe, operating pressure, history of leaks, maintenance records, pipe diameter, proximity to buildings and environmental considerations (Watts 1990: 14; Thorne 1992: 12; Day 1992: 43; Haynes 1994: 69 and Brown 1996: 61).

## 1.3 DEREGULATION OF THE NATURAL GAS INDUSTRY

In Australia natural gas is expected to be the fastest growing energy source in the future. Despite the fact that it is a "fuel of choice," customers make a conscious decision to use gas instead of other energy sources. Presently, it accounts for 17.9 % of primary energy use. The Australian Gas Association forecast that gas consumption in this country will treble between 1997 and 2030 (Australian Gas Association 1997). The growing demand for natural gas in the greater Brisbane region, particularly the industrial sector has prompted a need to double the capacity of the Roma to Brisbane transmission pipeline (Heick 1998: 14-16). Analysts base their predictions partly on the effects of competition after deregulation in the gas industry (Weiss 1995: 29). Nicholls (1999: 24) reports that the future growth of natural gas is very positive. Natural gas reserves, including proven and probable estimates, amount to 92,063PJ which translates to 92 years of supply at current production levels (Australian Gas Industry 2000: 1).

In Australia it has been suggested that lower energy costs for industry could encourage new investment in projects previously considered as uneconomic. While deregulation holds advantages for both wholesale and retail customers by offering supply choices and service options, utilities on the other hand need to strategise to deal with competition from other gas companies (Beasley 1995: 90). In a contestability pilot scheme in England, nine companies were competing with the historic supplier British Gas in the domestic market. Within two months after the launch of the scheme ten percent of the customers moved away from British Gas to one of the other nine companies (Energy World 1996: 5).

In the period leading up to open competition the gas utilities need to make submissions about their network infrastructure to a Regulatory Authority. In Australia, the authority for Queensland is called the Queensland Competition Authority (QCA). This Authority determines the annual allowable revenue a gas utility can generate from its network assets. International experience indicates a reluctance by utilities to invest in new infrastructure due to uncertainty over customer retention (Hinchliffe & Ward 1997: 19). O'Meally (1998: 5) has also identified this as a relevant issue in the Australian gas industry. The ramifications on Australian gas utilities will be increased uncertainty of future revenue (Coale 1996: 18). Consequently pipeline renewal can no longer be conducted in accordance with existing protected franchise methodologies. The new era of deregulation will impose more stringent financial considerations for pipe renewal work.

## 1.4 GAS DISTRIBUTION SYSTEMS PAST AND PRESENT

The early gas industry worldwide supplied manufactured gas for street lighting during the latter part of the nineteenth century (Queensland Energy Advisory Council 1988: 2). This gas was produced through a process of burning coal under controlled conditions. The economic value of manufactured gas was recognised by industry as an alternate fuel source to coal or electricity. Later, manufactured gas was introduced to the domestic market for cooking and also became known as 'towns gas'. Reticulation networks constructed during the manufactured gas era were primarily cast iron pipes and linked the customers to storage tanks that were the supply point into the networks.

During the mid 1960s natural gas was introduced as a replacement for manufactured gas in Australia and this marked a new era of growth in the demand for reticulated gas (Mulholland 1992: 214). Industrial, commercial and domestic customers that previously were excluded from reticulated manufactured gas could be connected to natural gas by extending the existing cast iron and steel networks. Natural gas was not limited by storage related problems characteristic of manufactured gas, therefore growth in the gas industry reached new levels not previously experienced (Queensland Energy Advisory Council 1988: 2).

There is less water vapour in natural gas than in manufactured gas. To ensure that the joints in the old cast iron network do not dry out and cause gas to escape, moisture and oil fog are added to the natural gas. This humidifying and oil fogging procedure is conducted at sub-gate stations. Despite this procedure leaks are common in cast iron pipe networks. Discovered leaks are classified according to a scale of severity with the higher priority leaks being repaired immediately while the lower priority leaks are repaired over a longer time frame (Haxton 1990: 20). Cast iron pipes require substantial maintenance to ensure reliable gas supply (Wood 1992: 32).

The early cast iron and steel networks are generally localised to the older sections of cities. Worldwide trends show gentrification to occur in the older inner city suburbs (Pacione 1990: 12). The process of modernising old dwellings usually results in an increased demand for gas. Upgraded dwellings would have new sophisticated appliances previously not available when the dwellings were built, such as for cooking, hot water, swimming pool heating and air conditioning. The older reticulation networks were not built to supply these new levels of demand and this increases the load on the feeder pipes. Utilities could deal with this situation by increasing the operating pressure to ensure that supply is maintained in all parts of the network. This increased pressure in the older cast iron network would escalate both the frequency of the leaks as well as the amount of gas loss. The associated consequences are a loss of revenue and an increased safety risk to the public and environment.

Management of the gas distribution system is essential. Aging pipes in a network close to the end of their economic life would be symptomatic of high maintenance costs and potentially a cause for UAG. Replacement of individual pipes would effectively solve many problems, but there is more at stake when a section of the network is under scrutiny. The section of network would be made up of pipes varying in vintage and material. Polyethylene pipes can also contribute to UAG. This usually occurs where improper backfill procedures and mechanical joints are used on polyethylene mains. A renewal approach would need to consider the physical limitations of a network and future customer demand to determine the long-term financial viability of the distribution system. The approach should establish the benefits, costs and a financial justification for envisaged pipe renewal work. This is particularly important given the imminent deregulation of the Australian gas industry. It would require access to data regarding UAG and maintenance costs, preferably at the level of individual pipe segments.

## 1.5 PLANNING OF GAS PIPE RENEWAL IN ENERGEX

Energex is an established energy utility operating mainly in South East Queensland, Australia. In 1998 Energex purchased a gas utility company called Allgas Energy Ltd. Although Allgas had undertaken pipe renewal for a number of years, the economic uncertainty associated with imminent deregulation, prompted Energex to review the approach being used. This resulted in the development of a financial application that is designed to evaluate the financial justification of pipe renewal projects. This application is a mathematical model for financial justification built in Microsoft Excel software using spreadsheets for both tabulation and computation. Energex uses another "in-house" developed application to estimate the gas loads on the network which is also built in Microsoft Excel software.

A decision was taken to implement a pilot project approximately twelve months ago by planning pipe renewal for a section of the reticulation network in the suburb of Hawthorne, Brisbane. It was soon realised that the requisite data for the application was either incomplete or inaccurate. This initiated a data capture and validation exercise that continued for a few months at great expense. The upgraded data was successfully used in both the Energex load estimation and financial applications that resulted in the renewal project being implemented.

The source information used in these applications is derived from corporate databases that include:

- gas consumption figures and customer information,
- UAG costs for the network,
- operation and maintenance costs that include history of leaks, and
- schedule of rates for new capital work.

These corporate databases are not interfaced with the GIS that stores the spatial pipe network and associated gas devices.

The costs of UAG, operation and maintenance required for the Energex financial application were defined in Australian dollar (AUD) values and assigned as a total for all pipes within the study area. A number of shortcomings were discovered while planning the pilot project. These include:

- The selection of a sub-network for inclusion in a project is determined by a hand-drawn boundary on a hard copy map. This procedure relies on visual examination to determine network connectivity of pipes. This method could lead to errors of interpretation regarding the logical demarcation of sub-network boundaries,
- Hard copy maps obtained from Government Agencies showing areas of soil corrosivity and land use zoning were visually compared with GIS generated hard copy maps of the gas network. These GIS maps include annotation of pipe age and material. This manual procedure introduced an element of potential human error in the analysis,
- The absence of an electronic 'master street address' database prevented spatial enablement of the customer and leak databases. This resulted in manual procedures using hardcopies,
- Cost values could not be assigned to individual pipe segments since values were aggregated for categories based on pipe length within the project area. As a result it was not possible to prioritise the pipe segments for renewal within the project area, and
- A substantial amount of time was needed to extract data from hard copy records for evaluation in both the Energex load estimation and financial applications. This has raised concerns regarding expeditious planning of future renewal projects.

Energex intends renewing 450km of pipes over the next ten years (Gajinov 2001b). This pilot project highlights the importance of accessible data for renewal planning. It brings into sharp focus the need for digital data and integration between databases to improve on the inefficiencies mentioned above.

## 1.6 PURPOSE OF THE STUDY

The current practice of planning pipe renewal projects relies extensively on manual procedures that are both prone to error and time consuming. Finding a solution to these issues is the impetus for this study. The aim of this research is to develop a GIS integrated renewal planning approach (IRPA) and then apply it in a study area. In order to achieve this aim the following objectives will be addressed:

(a) To implement network *trace* functionality to select gas pipes for evaluation in the Energex load estimation and financial applications,

(b) To associate UAG, operation and maintenance costs to individual pipe segments, and

(c) To use GIS generated input data for renewal analysis, design and financial evaluation.

Since this research will endeavor to develop new procedures for planning pipe renewal projects, a true test of this GIS IRPA is how well the output proposal compares to the actual proposal. The renewal implementation design output should be technically and financially justified. In this regard the same geographical extent and validated information used for the planning of a pilot project undertaken by Energex twelve months ago, will be used as input data for this research.

The GIS software used in this study includes:

- ESRI ArcView 3.2 and
- ESRI Desktop ArcGIS 8.1.

## 1.7 OVERVIEW OF THE STUDY AREA

The study area for this research is the suburb of Hawthorne in Brisbane. Hawthorne is located on the south side of the Brisbane River and is one of the oldest suburbs of Brisbane. The estimated resident population of Hawthorne is 3832 people (Queensland Department of Local Government and Planning incorporating Rural Communities 1997) and includes land use of residential, education, commercial, open space and recreational nature. The size of Hawthorne is approximately 147 hectare. The discussion given below describes the context of the study area within the larger distribution system.

Energex supplies natural gas to approximately 60000 industrial, commercial and domestic customers through a pipeline network of almost 2000 kilometers. Energex is also a supplier of liquid petroleum gas (LPG) to approximately 30000 customers. This part of the business is not restricted to the natural gas franchise areas since much of this business is cylinder exchange or tanker fill installations (Energex 1998: 3). Due to the fundamental differences in operation between the two types of gas, LPG is excluded from this research.

Although there are six franchise areas, this thesis will limit analysis to a section of the gas distribution network within the Brisbane franchise area. The distribution network in the Brisbane franchise area is made up of six categories of mains, six gate stations, seven sub gate stations and two hundred district regulator stations. The first three types of mains are trunk (TM), primary (PM) and secondary (SM) mains that are referred to as Class600 (CL600), Class300 (CL300) and Class150 (CL150) respectively in the company's official documentation. These so-called foundation mains all have their origin at gate stations attached to a transmission pipeline where the operating pressure for the downstream network is set. The transmission pipeline that transports natural gas to Brisbane is owned by the Australian Gas Light Company (AGL). Before the gas moves into the distribution system an odourant is added to the gas to make it detectable by smell in the event of gas leakage. These three categories of mains collectively make up 210 km and form the foundation for the rest of the distribution network in the Brisbane franchise area (Khan 2000: 2).

Distinct from the foundation mains are three further categories namely, high, medium and low pressure mains. The material used in the fabrication of the high pressure network pipes is either steel or polyethylene. High pressure steel mains have a maximum allowable operating pressure (MAOP) of 1050kPa to 1200kPa. The polyethylene high pressure mains have a MAOP of 200kPa to 575kPa and account for approximately 250km of pipeline. The medium pressure mains make up approximately 400km of pipeline (Khan 2000: 2-5). This network has a MAOP of 7kPa to 200kPa and the fabrication material of these pipes include, polyethylene, PVC, galvanised steel, polycoated steel and cast iron. The low pressure mains make up approximately 445 km of pipeline with the fabrication of the pipes being similar to that of the medium pressure network. Low pressure mains have a MAOP of 1kPa to 7kPa (Khan 2000: 3). Figure 1.1 provides an overview of the six categories of mains, gate stations and sub-gate stations. District regulator stations are too numerous to be shown on a map of this scale.

The older parts of the network in the distribution system are comprised of cast iron and non-cathodic protected steel pipes and account for 450 km of pipeline. This old network is supplied

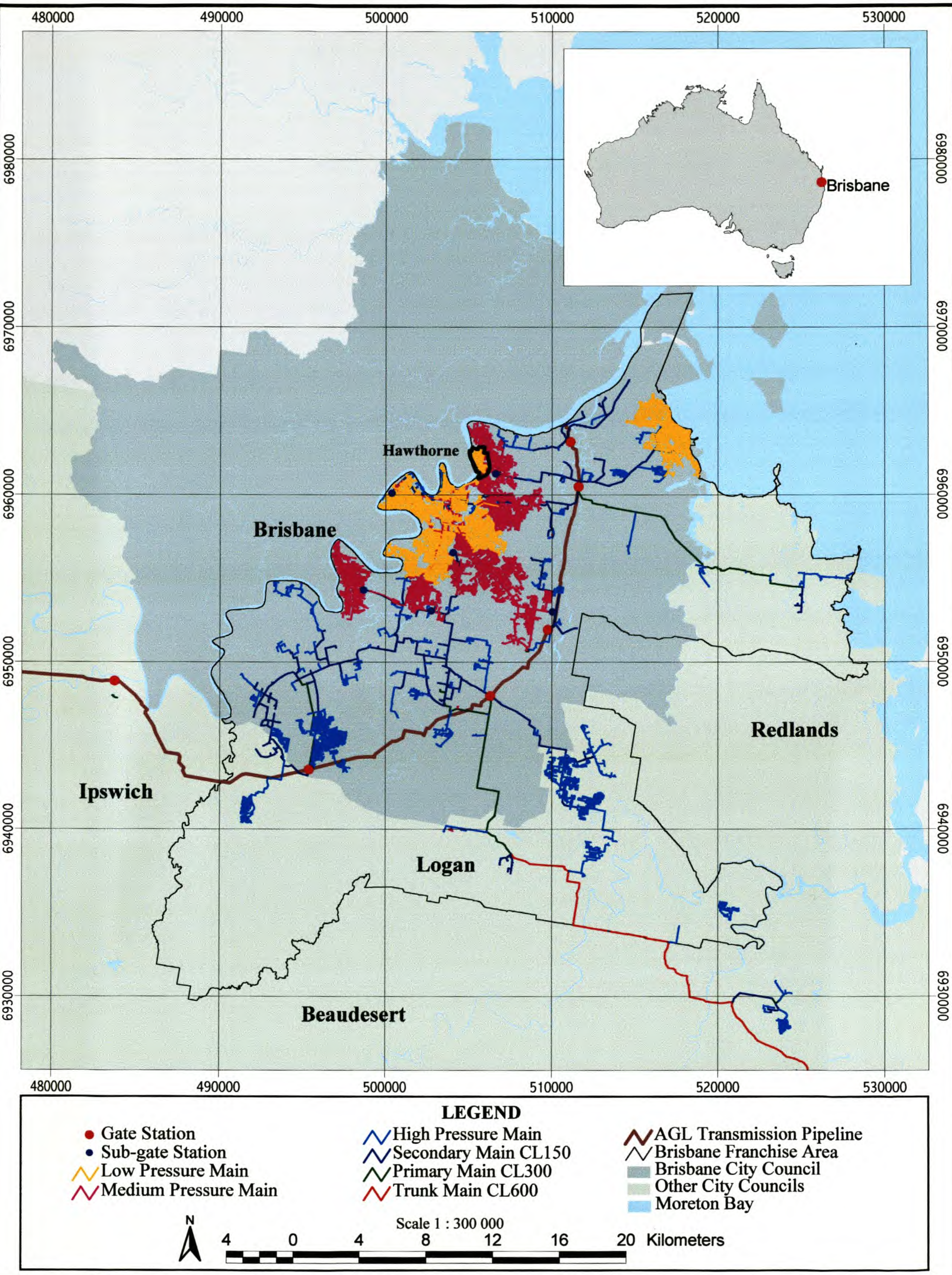


Figure 1.1 Gas distribution system within the Brisbane franchise area

through seven sub-gate stations. At certain sub-gate stations a mixture of oil and water is added to the gas in an operation known as humidification and fogging. The need for this operation is to moisten the natural gas to mitigate leaks that occur at joints constructed of hemp and lead in the cast iron network. This moistened natural gas is called wet gas, while the natural gas upstream from the humidification operation is known as dry gas. There is a relationship between pipe age, material, pressure, diameter and volume. The pipes in older networks are usually made from cast iron, operate at the lowest pressures, have a large diameter and transport a minimum volume of gas. Figure 1.2 shows the wet gas network within the suburb of Hawthorne as orange lines and the district regulator stations as green dots. The magenta lines represent medium pressure networks. The change in pressure between the medium and low sub-networks is determined at these district regulator stations.

## 1.8 REPORT STRUCTURE

Chapter two introduces GIS as a suitable technology to assist in the management of buried gas utility assets. The role of GIS technology in gas utilities is discussed with a specific focus on network management that could be used in assisting with planning for pipe renewal.

The first part of chapter three introduces and describes the GIS integrated renewal planning approach (IRPA). A description of the steps followed to assign the various factors that contribute to UAG as well as operation and maintenance costs is discussed. The second part focuses on integrating GIS functionality and spatially enabled data with the Energex load estimation and financial applications.

Chapter four concludes the study with an assessment of the GIS IRPA. The problems encountered with this approach are briefly defined and recommendations for future study are also presented.

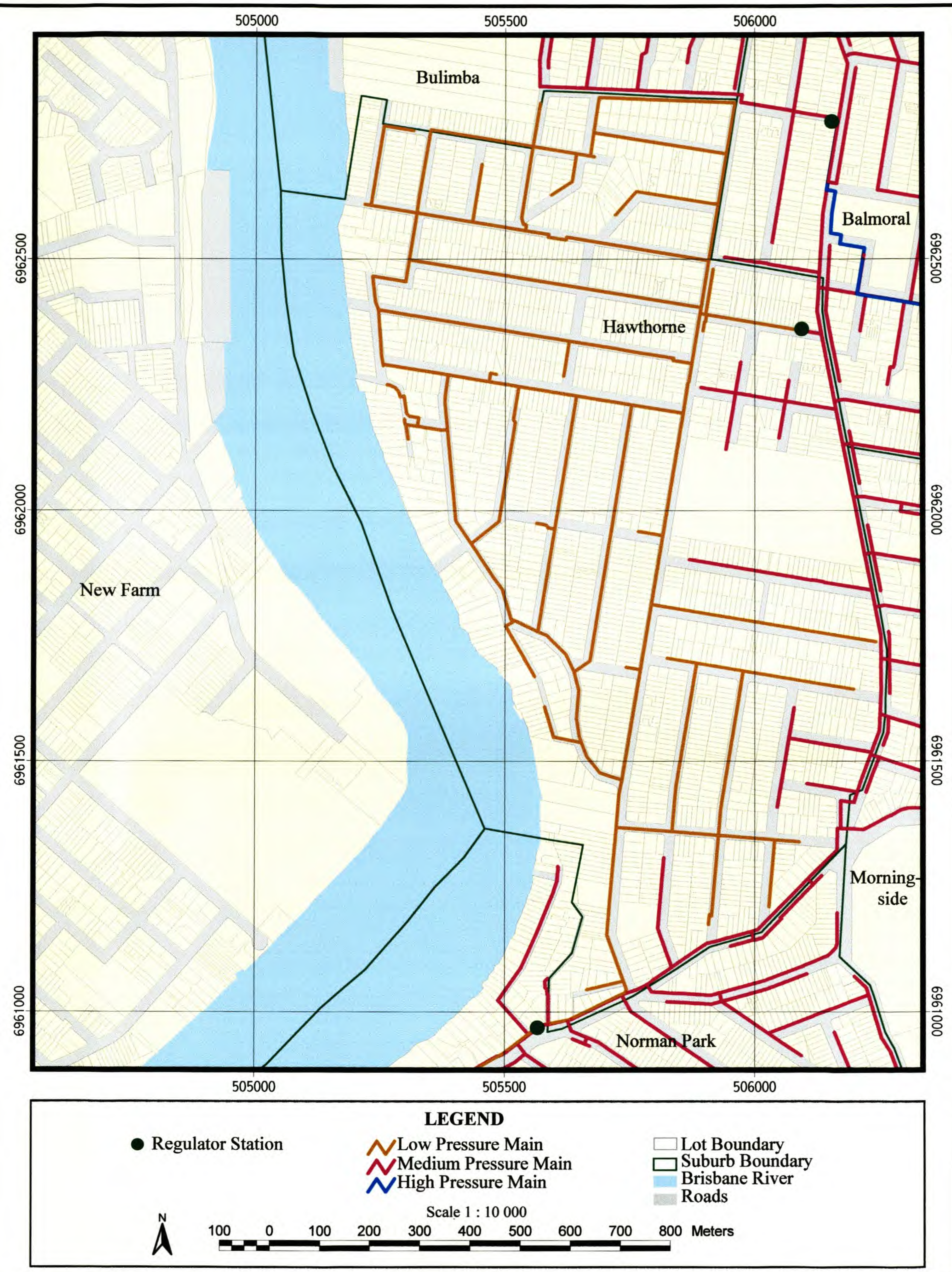


Figure 1.2 Gas reticulation network within the suburb of Hawthorne

# CHAPTER 2: THE ROLE OF GIS IN MANAGING GAS DISTRIBUTION NETWORKS

In this chapter the importance of geographical location for gas distribution systems is described. The contribution of GIS in managing gas distribution networks is also discussed.

## 2.1 THE IMPORTANCE OF GEOGRAPHICAL LOCATION FOR GAS DISTRIBUTION SYSTEMS

Gas utilities have made enormous investments in buried pipeline infrastructure. Recording location based information of these assets is crucial for a gas distribution utility. Information referenced to the earth's surface has a location and therefore a geographic reference (Linden 1990: 193). Geographic information in gas utilities has traditionally been displayed as maps. Substantial decision making in this industry has therefore a spatial context.

Geographic information is a common denominator for many activities in gas utilities. Some important applications of geographic information include:

- Surveillance for leaks either done by foot patrol or a "sniffer" vehicle,
- Engaging investigations to extend the network,
- Planning of pipe renewal,
- Establishing the location of customers, and
- Advising other utilities of the buried mains through the 'Dial Before You Dig' system.

## 2.2 THE ROLE OF GIS IN THE GAS UTILITY INDUSTRY

The operating environment of gas utilities is complex and the demand for spatially referenced information increases over time. Decision-makers require both spatial data and tools to manipulate this data. Geographic information systems (GIS) address both of these requirements (Environmental Systems Research Institute 2000: 2). GIS may be defined as "an organised collection of computer hardware, software, geographical data and personnel designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced information" (Environmental Systems Research Institute 1994: 33). GIS offers more than a display of digital spatial data or map production. Users can analyse and explore data associated with specific locations in an interactive and dynamic manner. Furthermore, GIS allows visualisation of analysed information in ways that reveal patterns, trends or relationships previously hidden. Users can specify queries based on certain criteria that will be displayed.

GIS is a powerful tool to address geographic related questions in an effective manner. The functions of GIS include the preparation, analysis, display and management of geographical data (Nijkamp & Scholten 1993: 87).

Environmental Systems Research Institute (ESRI) surveys reflect that 80 percent of all work done by utilities is dependent on the physical location of customers and equipment (Environmental Systems Research Institute 1999: 1). Adoption of GIS by utilities is changing the way they operate and is used in a number of areas including:

- Asset management,
- Network operations,
- Risk assessment,
- Marketing,
- Customer service, and
- Regulatory compliance.

Goodchild (1995: 2-3) points out that the impact of technology innovation has significantly influenced the evolution of GIS over the past five years. Firstly, a new concept of "field GIS" is emerging where GIS software is loaded on a light-weight portable computer commonly used in conjunction with a global positioning system (GPS). This means that GIS is no longer restricted to a desktop. The role of the desktop will be for analysis while the hand-held device supports data capture. Secondly, there has been an emergence of mapping capabilities embedded in Microsoft Excel spreadsheets. Thirdly, digital communication offers a new dimension for knowledge transfer using geographic data. Here, a digital map could be regarded as the "communication channel" while the contents of the map is the medium for transmitting knowledge. Fourthly, access to data is changing in terms of new architectures in computing environments. This applies to local and wide area networks, high-bandwidth communication channels, client-server technology and the Internet. Finally, object oriented technology introduces principles of encapsulation and inheritance that work on both processes and data. These evolutionary developments in GIS are most beneficial to the gas utility industry.

## 2.3 THE CONTRIBUTION OF GIS IN MANAGING GAS DISTRIBUTION NETWORKS

Many of the gas distribution systems around the world are reaching the end of their economic life. The challenge facing gas utilities is the need to maintain supply to customers by optimising the existing network while at the same time managing capital improvement budgets that prioritise pipeline renewal based on financial criteria.

GIS can assist engineers in managing the performance of reticulation networks. It can reveal patterns or trends between data layers that were not previously evident. GIS technology can assist gas utilities to build connectivity and network related analysis.

### 2.3.1 Network management

The pipes used for gas networks come in standard lengths or rolls. Pipe segments are placed underground and joined together by field crews who prepare as-laid sketches and record various information, such as:

- Pipe material,
- Diameter size,
- Date of installation,
- Depth,
- Alignment,
- Type of main, and
- Operating pressure.

This information is used to update non-spatial and spatial databases.

Planning engineers are particularly interested in the location of transitional changes in pipe material or diameter. These are significant nodes that determine the start and end of logical pipe segments for modeling purposes. Where physical pipe lengths of identical characteristics are joined, a single logical pipe segment is recorded. Joints between pipes of different material type in the gas distribution system are a source of potential leaks. Other information such as operating pressure and age of pipes will assist with management of gas assets.

Planning engineers rely on various data sources to evaluate the condition of mains. These sources include historic as-laid sketches, alignment maps, unaccounted for gas figures, reported leak and repair histories. This data is used in calculations along with the estimated effective economic life span of the pipes to determine whether logical segments of pipe are due for replacement. The planning of new networks requires the inclusion of both current and future demand for natural gas which is referred to as network load.

2.3.1.1 Distribution systems

Distribution systems are made up of sub-systems that operate at different pressures. These sub-systems are designed to supply customers through looped networks. Looping will ensure two-way supply to customers. This is an important feature of a network, particularly in cases where disruption to customer supply can be kept to the minimum while sections of the main are repaired or replaced.

Pressure and volume are two important elements of a gas distribution system. Maximum allowable operating pressure (MAOP) refers to the maximum pressure that a distribution system is allowed to operate at and is dependent on the pipe characteristics. On the other hand, maximum operating pressure (MOP) is always lower than the MAOP and is determined by constraints present in a network. These constraints include factors such as the pipe age, various diameter sizes, type of gas and history of leaks. Customer demand and network condition and configuration are main factors affecting operating pressure. The network usually operates at the lowest pressures necessary to meet customer demand. Volume refers to the quantity of gas delivered through a particular point in the system. In low pressure networks where the MOP is between 1-7kPa, pipe diameters tend to be bigger to ensure an adequate volume of gas to meet customer demand loads.

The functionality of GIS to display a distribution system as a connected network offers new opportunities for engineers. GIS can show the geographical extent of each sub-system by displaying the start and end point and by controlling domain rules that influence the behavior of objects in the spatial database. The usefulness of network connectivity within a GIS is demonstrated when a logical segment of pipe is removed from the network; engineers are able to visualise the downstream impact on the customers, particularly if there is no secondary feeder loop.

2.3.1.2 Service connections

The distribution system supplies gas to three categories of customers, namely industrial, commercial and domestic. The pipe size of a customer service is determined by four factors:

(i) maximum anticipated gas load,

(ii) distance from gas main to the customer metering station,

(iii) available pressure in the distribution main, and

(iv) type of gas that is to be supplied (Australian Gas Light Company 1977a: 36).

Services to industrial customers are usually attached to the high-pressure network. Commercial and domestic customers can be connected to low, medium or high pressure networks.

Each service has a meter that records consumption and these are read at predetermined cycles for billing purposes. When this information is linked to GIS through spatial enablement, planners can overlay zoning data with customer data. Land parcel zonings that is likely to change in the future from low to medium residential density can be identified and adjustments can be made to consumption load calculations for the affected sub-systems.

2.3.1.3 Pipe renewal

Once the decision is taken to renew sub-systems there are a few replacement options. These include open cut, insertion, pipe bursting, directional boring and pipe lining. Open cut is also referred to as trenching where the existing main is abandoned and the new pipe is placed at another location. Insertion refers to replacement by pushing a new pipe inside an existing one. Pipe bursting is similar to insertion, but the difference is that the diameter of the new pipe is the same size or wider than that of the existing one. The technique is to burst the pipe wider with a device that also pulls the new pipe in behind. Directional boring is a non-intrusive method of putting new pipes into the ground. This is achieved by creating a tunnel with a moling device. The pipe is then pulled through the tunnel. Pipe lining includes the renovation of internal joint or lining of pipes (Hale 1984: 14).

### 2.3.2 Unaccounted for gas

As mentioned before, the term "unaccounted for gas" is applied to the discrepancy between the total gas available from all sources and the total gas accounted for in the sales, net interchange, company usage, storage and other uses (Gajinov 2001b). The five elements of UAG are: leakages, metering errors, accounting errors, non-metered company usage, and theft. Sources that contribute to the element of leakage include mains, services, regulator stations and metering stations. Meter errors result from meters running either too slow or too fast, leakage through the bypass line, under- or overflow and the factor used for volume correction. Accounting errors usually occur in calculations, meter readings or the effect of the billing cycle. Non-metered company usage contributes to UAG through new mains extensions, testing and purging networks, replacing and repairing mains and services, accidental damage of mains and services, and changing of pressure in the network. Theft occurs when the bypass line in a metering station is tampered with or through illegal connections (Gajinov 2001b).

### 2.3.3 Operation and maintenance

Distribution system equipment such as regulators, valves and outlets require regular inspection and maintenance. Under operation and maintenance procedures it is common practice for the equipment to be replaced with a new or reconditioned unit while the original unit is brought back to the workshop for redeployment to a different geographic location after is has been serviced.

Each piece of equipment would have an asset number that is recorded in a database together with other attributes. This data would be used for accounting purposes. Gas utilities depreciate new equipment differently to reconditioned equipment. It is therefore important that records reflect the history of inspection, maintenance and repair as well as the transient geographical locations of installation.

2.3.3.1 Age, diameter and material of mains

Operation and maintenance of the physical pipe network is a large budgetary consideration for all gas utilities. The closer a pipe segment comes to the end of its economic life, the greater will be the associated maintenance costs. GIS can be used in an operation and maintenance query, to identify pipes based on search criteria such as pipe age, diameter and material of mains.

2.3.3.2 Operating pressure

There is a correlation between operating pressure and the cost associated with operation and maintenance. In low and medium pressure networks, siphons are installed at the lowest point in the pipeline to collect condensate. Condensate is a result of oil fogging and humidification in wet gas networks as well as underground water penetration through small holes on low pressure gas installations. The collected liquid needs to be pumped out of the siphons during regular maintenance schedules. (Australian Gas Light Company 1977b: 39). Environmental factors such as a rising water-table could increase the amount of liquid in the system. Depending on the frequency and duration of a higher than normal water-table, operation and maintenance costs of low and medium pressure networks could increase accordingly.

GIS can assist in the operation and maintenance of siphons by overlaying floodline and elevation data on the low and medium pressure network. Hidden relationships could be observed, which may influence decision-making on the frequency of pumping, or the size of the siphons in certain lower lying areas.

2.3.3.3 Soil corrosivity

Steel gas pipelines are susceptible to corrosion that could cause leaks and as a consequence result in gas loss and increased operation and maintenance costs. Johnston (1996: 49) defines corrosion as "an electrochemical reaction by which a metal, due to its environment, oxidizes and returns to the ore it was derived from".

According to Lieberman (1996: 52) there are three primary agents responsible for corrosion. These factors are soil acidity (pH), the electrical potential (Eh) or oxidation reduction potential (ORP) and electrical resistivity.

The concentration and activity of the hydrogen ion in solution defines whether a soil is acidic or alkaline. Acidic soils would have a pH of less than seven while alkaline soils would have a pH of greater than seven. In the greater Brisbane region acid sulfate soil poses significant environmental and economic impacts. Acid sulfate soil contains iron sulphides and typically occur along the Queensland coastline in low-lying areas such as rivers, floodplains, tidal mangrove flats, lakes and wetlands. Sulfuric acid may contribute to the corrosion of concrete, iron and steel structures (Beckmann, Hubble & Thompson 1987:35 - 43). Areas of acid sulfate soil are classified as either an actual or potential hazard. The difference is that "actual" refers to acid sulfate soil that has been exposed to oxygen, so that when water flushing (rainfall) occurs, sulfuric acid is released. "Potential" acid sulfate soil has not been exposed to oxygen, but has the potential of becoming hazardous should this be brought about by environmental or anthropogenic factors.

The impact of potential acid sulfate areas is becoming more apparent to the Energex gas utility than previously thought. When trenches are dug for new steel gas pipes in areas of potential hazard, the mound of soil that is removed from the trench is exposed to oxygen and sometimes is used as backfill above the water-table. This practice of pipe installation was common 30 years ago and many of these pipes form part of the low and medium pressure network. Company records of operation and maintenance costs are revealing the impact of acid sulfate soil on managing the gas pipe network.

Electrical potential (Eh) represents the concentration of metal ions in the soil solution. An increase in the concentration level results in higher values of Eh and consequently the impact of corrosion potential is therefore also higher (Lieberman 1996: 51). The impact of this corrosion potential can be reduced. This is achieved through burying sacrificial anodes in close proximity to the steel pipes. The electrochemical properties of anodes causes them to corrode more easily than the steel pipes, thereby protecting the pipes (Congram 1994: 33). When the anodes are perforated, after a number of years, they need to be replaced. Anodes would be buried at predetermined distances along the route of a pipeline. These preventative measures decrease operation and maintenance budgets significantly.

Research has shown a high correlation between corrosion resistance and electrical resistivity. The relationship between soil types, corrosion resistance and electrical resistivity is shown in Table 2.1. The information in this Table is only a guide since local conditions must also be taken into account. Other factors that increase corrosion potential are: the occurrence of electric power lines nearby, chemicals from fertilized crop fields (such as phosphate), temperature and oxygen content of ground water, and the height of the water-table.

**Table 2.1 Relationship of soil type to corrosion resistance**

| Soil class | Corrosion resistance | Resistivity (ohm cm) |
|---|---|---|
| Sandy | Excellent | 6 000 to 10 000 |
| Loam | Good | 4 500 to 6 000 |
| Clays | Fair | 2 000 to 4 500 |
| Peat | Bad | 0 to 2 000 |

Source: Lieberman 1996: 51

Energex use cathodic protection to control the external corrosion on their high pressure steel pipes. Company data records reveal that anodes in certain geographical areas last longer than in other areas. There is a correlation between the replacement frequency of anodes and the corrosivity of ground conditions. Replacement of anodes is an expensive undertaking especially in certain localities where this needs to be done frequently. Information about areas of actual and potential acid sulfate soil is important for engineers to have access to when planning mains extensions. GIS is the ideal technology to identify the areas that are at high risk for corrosion potential. It allows spatial overlay analysis between the infrastructure and the soil data.

2.3.3.4 Location of pipe network

The land use patterns surrounding early networks often change over time. Replacement of residential properties with schools and shopping centers has a direct cost implication for operation and maintenance on the buried mains especially if they are located beneath the road surface. These new land uses would generate significant traffic volume and could lead to widening the roads above buried mains. Mains repair work is costly when the buried pipes are beneath roads that carry high vehicle volumes.

Work done on pipes beneath footpaths in residential areas is cheaper than similar work being done on pipes beneath footpaths in industrial areas. Furthermore, the cost of public liability insurance is increased where mains repair work is being done in close proximity to schools (White 2001). GIS technology can assist engineers quantify cost implications of land use and road classification changes on planned renewal work.

The information from this chapter will contribute to the development of an integrated renewal planning approach (IRPA) described in Chapter three.

# CHAPTER 3: PIPE RENEWAL APPROACH

Customer demand for gas is important information used in planning future network loads. A number of software packages are available in the gas industry to analyse the distribution system. These packages are fairly expensive and it is not uncommon for companies to develop their own solutions scalable to the size of their operations, based on their available data (Gajinov 2001b). This has also been the case with Energex, in developing their own load estimation application, as well as a financial application, using Microsoft Excel. GIS has been integrated with these two applications to form the GIS integrated renewal planning approach (IRPA), as discussed further.

This chapter describes the GIS IRPA. Each level of this approach is discussed with particular emphasis on the role of GIS to either calibrate input data for the above-mentioned applications or validate the feasibility of renewal design proposals. The procedures followed in the determination of cost factors are also discussed. But first, a short description of the data sets used in the analysis is given.

## 3.1 DATA COLLECTION AND MANIPULATION

In the original pilot project done twelve months ago, similar steps to the GIS IRPA were followed. Spatial data sets supplied for the purposes of this research include: street address data, land use zones, public places data, street centerline data, and Acid Sulfate soil data. Each of these are described briefly – most of which are illustrated in Figure 3.1.

*Description of data*

- Street address data: a polygon spatial layer that includes a lot and street number for each property lot.
- Land use zones: data containing the land use zoning obtained from the Brisbane City Council. These zones are discussed and illustrated in Section 3.7.
- Public places data: a spatial layer of points that represent public places, e.g. shopping centers, schools and churches.
- Roads: data including road classification.

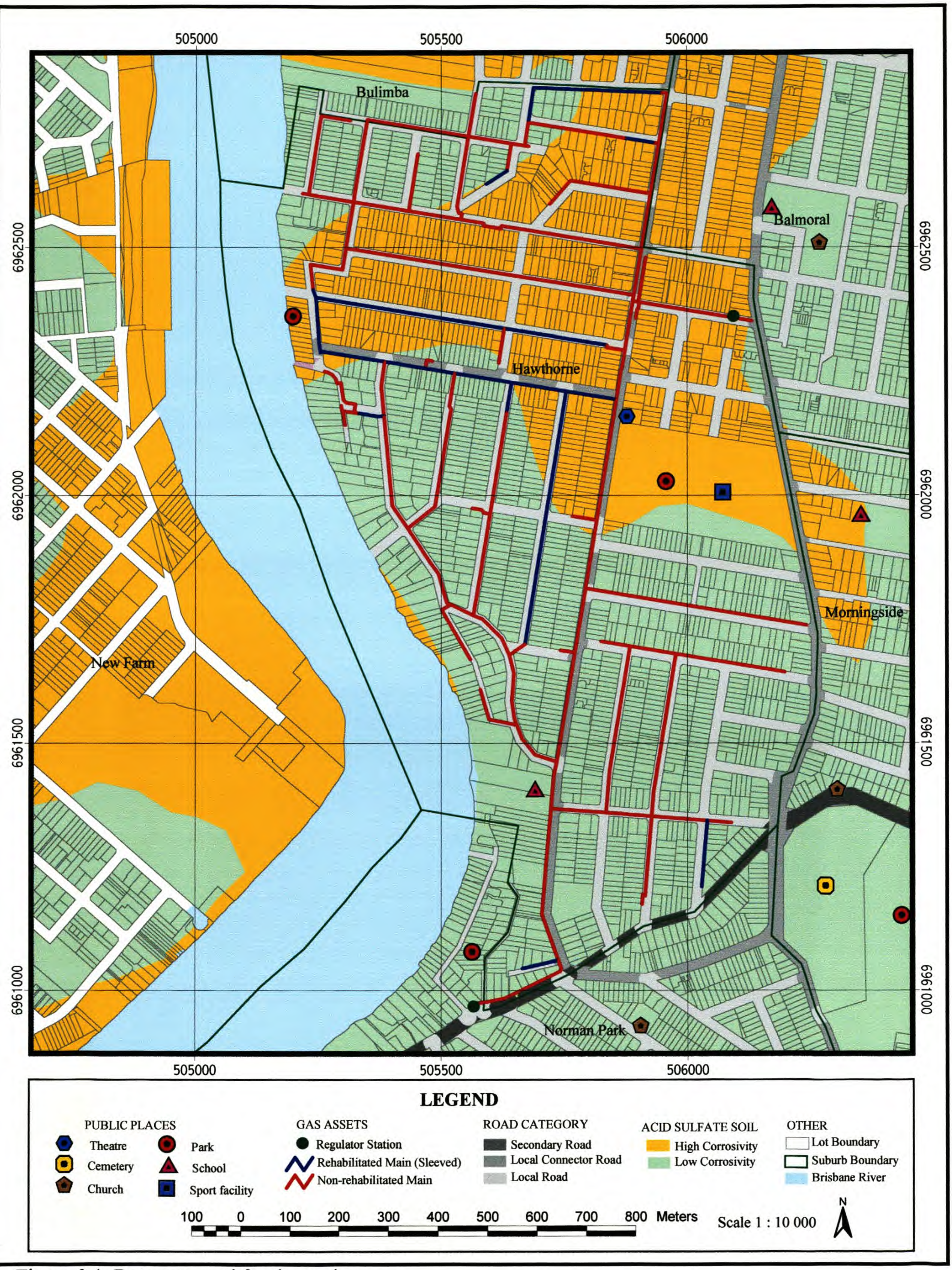


Figure 3.1 Data sets used for the study

- Acid sulfate soil data: digitised from available hard copy maps, showing the areas in Brisbane where acid sulfate soil is likely to be found. This information is used to identify zones of soil corrosivity that would have an impact on the steel gas pipes.
- Mains and regulator stations: data for the geographical extent of the study area extracted from the existing GIS database using ArcInfo 7.2.1, and imported into a geodatabase on ArcGIS 8.1.

*GIS Database*

For the purposes of this research a new GIS database was developed using ArcGIS software. The Gas Data Model that is available with this software has been used to create a geometric network inside a geodatabase. This database was consequently used within each level of the GIS IRPA, described below.

## 3.2 GIS INTEGRATED RENEWAL PLANNING APPROACH (IRPA)

There are four levels in the GIS IRPA approach, as illustrated in Figure 3.2. Firstly, connected pipes are selected for analysis. Secondly, cost factors for unaccounted for gas (UAG) and operation and maintenance costs (O&M) are computed. Thirdly, the analysis, design and financial evaluation of the selected network is done; and finally, the replacement design is implemented. Each of these is discussed in the subsections that follow.

***Level one: Network selection***

Connected pipes are selected using the GIS *trace* functionality.

***Level two: Establishing UAG, operation and maintenance costs***

The cost inputs to the Energex financial application are divided into two parts namely unaccounted for gas (UAG) and operation and maintenance costs (O&M). Each of these is further sub-divided into cost categories. The UAG categories are: pipe material, operating pressure, and soil corrosivity. The operation and maintenance categories include: pipe material, operating pressure, pipe diameter, pipe age, pipe location, public liability, and soil corrosivity. The available source data for the above cost categories is aggregated according to total pipe length within the study area.

In this research the UAG and O&M data will be recalibrated to achieve two outcomes. Firstly, the value for each UAG and O&M cost category must be associated with individual pipes rather

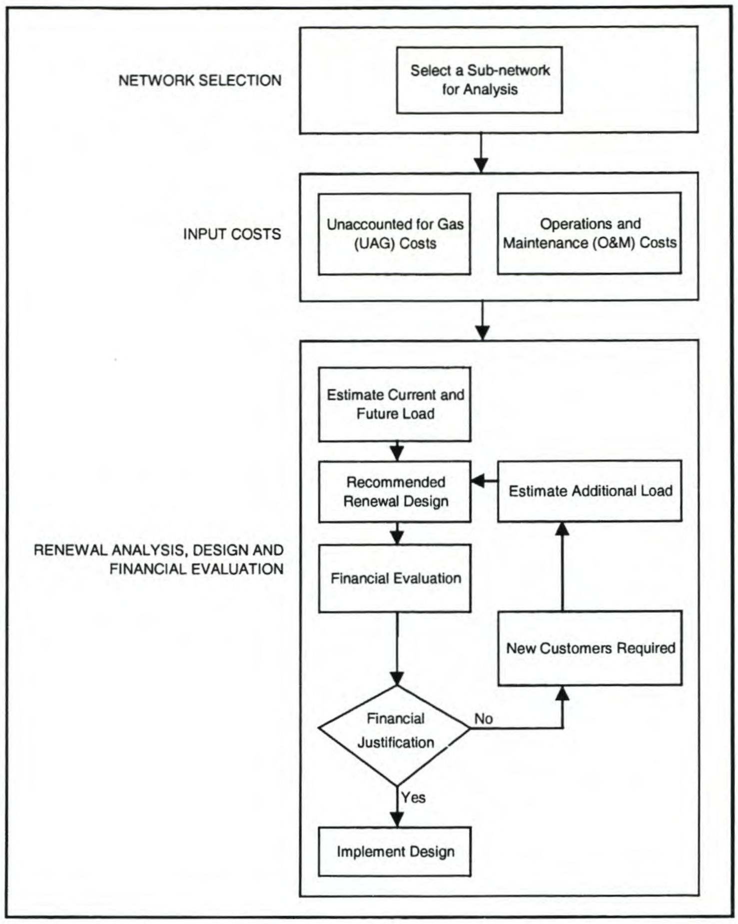


**Figure 3.2 GIS Integrated Renewal Planning Approach (IRPA)**

than aggregate totals. Secondly, the assigned value must be transferable to other pipe segments elsewhere in the network that have a similar description. This will be achieved by using 'cost factors'. These factors are computed through five steps, namely:

(i) The aggregate cost information is associated with the pipe segments within the study area,

(ii) Where applicable the environmental condition responsible for the cost value is obtained as a digital spatial layer,

(iii) Spatial analysis between the mains layer and environmental layer, referred to in step two, is computed,

(iv) The pipe segments that meet the spatial analysis criteria under step three are assigned a 'factor' value rather than the 'actual AU dollar' value, and

(v) The calibrated 'factor values' are used in the Formulas (1) and (2).

The cost factors shown in Tables 3.1 to 3.10 have been refined with the assistance of Gajinov (2001b).

***Level three: Analysis of current and future load, renewal design and financial assessment***

The analysis, design and financial evaluation of the selected network is done once the cost factors have been established. The spatial layer of lots associated with gas accounts is overlaid with land use zoning data to provide the bases for analysing estimated current and future gas consumption load. This information is used in the design requirements for the new network. The costs related to proposed capital work is evaluated against the backdrop of current UAG and operation and maintenance costs. Consideration is also given in the calculations to future maintenance costs. Should the financial evaluations show that the project is not viable with the existing customer base, then the number of new customers that are required to make the project viable must be determined. This in turn requires a new estimation of load and replacement design.

***Level four: Implementation of renewal design***

Implementation of the replacement design is reached when the calculations show that the envisaged capital expenditure would have a return on investment within the stipulated period of twenty years.

The integration of GIS at each level of the GIS IRPA approach will be discussed subsequently.

## 3.3 NETWORK SELECTION

*ArcInfo* software version 7.2.1 is currently being used to record the location of mains and gas devices for mapping purposes. There is no connectivity associated with the arcs and nodes in the gas pipe layer. The existing spatial layers are loaded into a *geodatabase* using *ArcGIS* software version 8.1. A geometric network has been established for the mains layer which enables connectivity rules to be defined. The gas devices layers represent gate, sub-gate and regulator stations.

In order to select a network using *ArcGIS* the role of gate, sub-gate and regulator stations are reversed. These 'sources of supply' become barriers to the flow of gas. The *trace* algorithm of *ArcGIS* selects the connected arcs starting from a position flagged in the center of the pipe network of Hawthorne and end at the assigned barriers. The importance of using the network *trace* functionality ensures that only the geometrically connected arcs are selected and therefore represents a logical grouping of pipe segments that forms a sub-network. These segments may be of variable length but their unit cost is calculated in accordance with the Formulas in Sections 3.4, 3.5 and 3.6.

## 3.4 UNACCOUNTED FOR GAS (UAG) COSTS

Company records show that pipe material, operating pressure and ground conditions are the primary causes that influence the cost of UAG associated with leakage from mains. This is shown by the following formula:

$$UAG = Cost_m * F_p * F_c \qquad \text{Formula (1)}$$

where

$Cost_m$ - UAG cost allocated to pipe material per pipe km per year

$F_p$ - Cost factor associated with an operating pressure

$F_c$ - Cost factor associated with soil corrosivity

Source: Energex 2001 and Gajinov 2001

### 3.4.1 UAG cost associated with pipe material

From all the possible causes of UAG, leaking mains are the primary source for gas loss. Table 3.1 gives the dollar value of UAG cost associated with each of the material classification types in the gas distribution network.

**Table 3.1 UAG cost associated with pipe material**

| Pipe Material | | Factor ($Cost_m$) (Cost / km / year in AU $) | Primary cause for gas loss |
|---|---|---|---|
| Code | Description | | |
| 42 | Cathodically protected steel | 0.00 | Cathodic protection and welded joints |
| CU | Copper | 0.00 | Above ground installation – Joints in good condition |
| PE | Polyethylene CL500 | 10.00 | Electro fusion joints |
| P5 | Polyethylene CL575 | 100.00 | Mechanical joints |
| P2 | Polyethylene CL250 | 500.00 | Mechanical joints |
| PV | PVC | 1 000.00 | Mechanical joints |
| CI | Cast Iron | 4 000.00 | Mechanical joints and couplings<br>Porous pipes |
| PS | Polycoated Steel | 4 000.00 | Mechanical joints and corrosion |
| SG | Galvanised Steel | 4 000.00 | Mechanical joints and corrosion |

In the GIS database the factor $Cost_m$ for UAG, given in Table 3.1, is assigned to each pipe segment in the mains layer via a look-up table.

### 3.4.2 UAG cost associated with operating pressure

Historical records show that 85 percent of the UAG portion assigned to mains is associated with low and medium pressure networks (Allgas 2000: 53). Data for pipe segments in the study area show the medium pressure system contribute 1.2 times more to UAG costs than the low pressure network. In the high pressure system the factor is 1.5 times that of low pressure. This relationship is shown in Table 3.2 where a higher operating pressure increases the potential for UAG.

**Table 3.2 UAG cost associated with operating pressure**

| Operating Pressure | Factor ($F_p$) |
|---|---|
| Low | 1.0 |
| Medium | 1.2 |
| High (PE) | 1.5 |

In the GIS database the values for the factor ($F_p$) given in Table 3.2 are assigned as an attribute in the mains layer.

### 3.4.3 UAG cost associated with soil corrosivity

Corrosion of non-cathodically protected gas pipes is a major contributor to UAG in certain parts of the network. The areas of greatest concern are those with Sulfate soils which, when oxidised, produce sulfuric acid, a severe corrosive agent on steel gas pipes. Small scratches in a pipe's cladding are target areas to accelerate corrosion. This often leads to tiny holes that cause gas leakage. Over time the integrity of the cladding will deteriorate and result in more of the pipe material being corroded (Johnston 1996: 49).

Company data shows that non-cathodically protected low and medium pressure mains that leak in areas of high soil corrosivity account for 1.5 times more UAG costs per unit length than the leakage from mains in areas of low soil corrosivity. This comparison applies to pipes of having the same material and pressure. The soil corrosivity factor ($F_c$) is defined in Table 3.3.

**Table 3.3 UAG cost associated with corrosivity of soil**

| Corrosivity of acid sulfate soil | Factor ($F_c$) |
|---|---|
| Low corrosivity | 1.0 |
| High corrosivity | 1.5 |

In the GIS database the soil corrosivity factors given in Table 3.3 are assigned to pipe segments of the network that fall within the areas of notable acid sulfate risk. Spatial overlay functionality from the GIS is used to establish which pipes are located in the areas of notable acid sulfate potential.

The three cost factors of UAG are applied in Formula (1) and the result is shown in Figure 3.3. Pipe segments that have the highest priority for rehabilitation would be those that have a total UAG cost above AUD 4,000 per km per year. These are the pipes represented with the darker colour in Figure 3.3.

### 3.5 OPERATION AND MAINTENANCE COSTS

Operation and maintenance of assets in the Energex gas utility is a major undertaking and accounts for a large portion of the company's budget. Bartlett (1998: 63) has pointed out that the contribution spent on maintenance could be five times more than that spent on new pipe networks.

The formula used for calculating operation and maintenance costs includes seven factors:

$$O \,\&\, M = Cost_m * F_p * F_d * F_a * F_l * F_s * F_c \qquad \text{Formula (2)}$$

where

$Cost_m$ – Operation and maintenance cost associated with pipe material per km per year

$F_p$ – Cost factor associated with operating pressure

$F_d$ – Cost factor associated with pipe diameter

$F_a$ – Cost factor associated with pipe age

$F_l$ – Cost factor associated with pipe location

$F_s$ – Cost factor associated with liability to the public

$F_c$ – Cost factor associated with soil corrosivity

Source: Energex 2001 and Gajinov 2001

Each of these factors and their respective input is subsequently discussed.

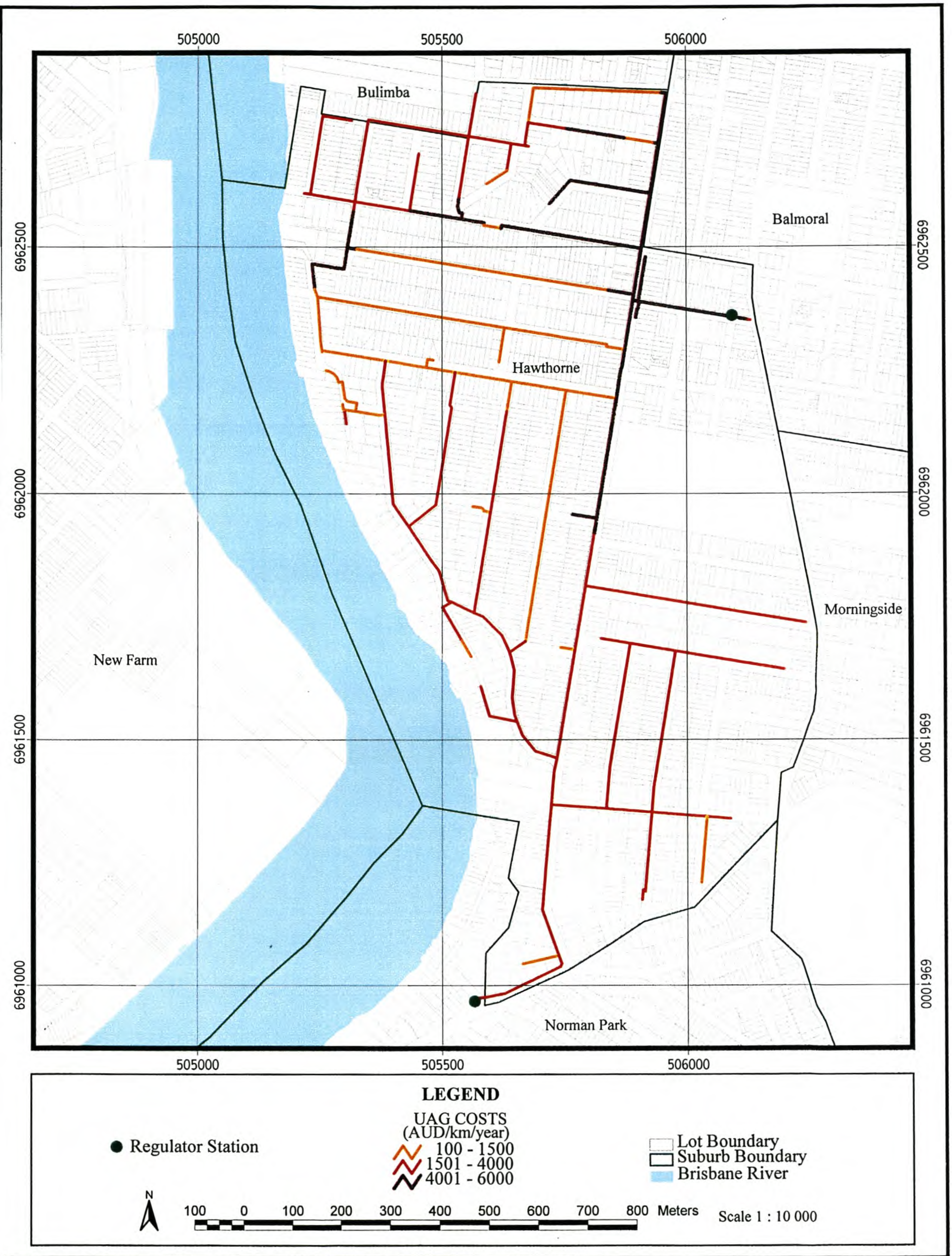


Figure 3.3 Total UAG costs associated with individual pipe segments

### 3.5.1 Operation and maintenance costs associated with pipe material

The planning engineers use pipe material as the basic building block on which operation and maintenance costs are based (Gajinov 2001b). Table 3.4 shows that cast iron, polycoated steel and screwed galvanised pipes account for the highest cost per kilometer per year of operation and maintenance budgets.

**Table 3.4 Operation and maintenance cost associated with pipe material**

| Pipe material | | Factor (Cost$_m$) (Cost / km / year in AU $) | Description of maintenance work |
|---|---|---|---|
| **Code** | **Description** | | |
| CU | Copper | 50.00 | Above ground installation occurrence of third party damage corrosion. |
| PE | Polyethylene CL500 | 50.00 | Electro-fusion couplings require no maintenance. |
| 42 | Cathodically protected steel | 100.00 | CL600, CL300 and CL150 mains cathodically protected. |
| P5 | Polyethylene CL575 | 200.00 | Mechanical couplings require some maintenance. |
| P2 | Polyethylene CL250 | 500.00 | Mechanical couplings require some maintenance. Thinner wall thickness than P5 pipe. |
| PV | PVC | 1 000.00 | Mechanical couplings require some maintenance. |
| CI | Cast Iron | 5 000.00 | Problem with water ingress. Mechanical joints and fillings require some maintenance. |
| PS | Polycoated Steel | 5 000.00 | Problem with corrosion. Mechanical fittings require some maintenance. |
| SG | Galvanised Steel | 5 000.00 | Problems with corrosion. Mechanical fittings require some maintenance |

In the GIS database the factor Cost$_m$ for operation and maintenance, given in Table 3.4, is assigned to each pipe segment in the mains layer.

### 3.5.2 Operation and maintenance costs associated with operating pressure

There is a positive correlation between operating pressure and maintenance costs. The operation and maintenance budgets increase in accordance with the operating pressure of the distribution network as Table 3.5 indicates. The primary reason for this is that the technology used to maintain distribution systems operating at higher pressures is more expensive.

**Table 3.5 Operation and maintenance cost associated with operating pressure**

| Operating Pressure | Factor ($F_p$) |
|---|---|
| Low | 1.0 |
| Medium | 1.1 |
| High (PE) | 1.2 |

In the GIS database the value of the factor ($F_p$) given in Table 3.5 is assigned as an attribute in the mains layer.

### 3.5.3 Operation and maintenance costs associated with pipe diameter

As in the case with the operating pressure factor ($F_p$), the pipe diameter factor ($F_d$) increases as pipe size increases. Table 3.6 gives the pipe diameter factors for operation and maintenance based on company database records.

**Table 3.6 Operation and maintenance cost associated with pipe diameter**

| **DN size** (mm) | **OD size** (mm) | **Factor** ($F_d$) |
|---|---|---|
| 10 – 40 | 3.3 – 48.3 | 0.7 |
| 50 – 75 | 50.0 – 65.0 | 0.8 |
| 80 – 90 | 80.0 – 90.0 | 0.9 |
| 100 – 132 | 100.0 – 144.2 | 1.0 |
| 150 – 160 | 150.0 – 178.3 | 1.1 |
| 200 – 225 | 219.1 – 232.2 | 1.2 |
| 250 | 259.0 – 273.1 | 1.3 |
| 300 | 345.4 | 1.4 |
| 355 – 450 | 355.6 – 507.0 | 1.5 |

In the GIS database the factor ($F_d$) is assigned as an attribute based on the value of the outside diameter (OD) and nominal diameter (DN) for pipe segments in the mains spatial layer.

### 3.5.4 Operation and maintenance costs associated with pipe age

Operation and maintenance costs increase significantly as pipes age. In this regard, the Energex gas utility together with a consulting firm determined the average effective life for distribution mains and services based on pipe material. The results of this analysis are given in Table 3.7.

The information from Table 3.7 is used in Formula (3) to calculate the percentage of average effective life for mains and services in use.

$$PercentageOfAverageLife = \frac{Ca}{Ael} * 100 \qquad \text{Formula (3)}$$

where

$Ca$ – Current age of the gas pipe in years

$Ael$ – Average effective life of the pipe as defined by material in Table 3.7

**Table 3.7 Average effective life of mains and services**

| Material of mains and services | Average effective life (Ael) (years) |
|---|---|
| PVC | 30 |
| Polycoated Steel ( Non-cathodic protection ) | 45 |
| Galvanised Steel | 45 |
| Polyethylene | 80 |
| Cast Iron | 80 |
| Copper | 85 |
| Steel (Cathodic protection) | 105 |

Source: Allgas 2000: 16

Formula (3) provides a value for each pipe segment in the mains layer defined, as a percentage which is stored as an attribute in the GIS database. The values are grouped into three categories namely, pipe segments that have lasted up to 80 percent, 81 to 100 percent, or greater than 100 percent of their calculated average effective life. Each category is associated with an age factor ($F_a$) as shown in Table 3.8.

**Table 3.8 Operation and maintenance cost associated with age**

| Pipe Age (Percentage of average effective life) | Factor ($F_a$) |
|---|---|
| < 80% | 1.0 |
| 81% - 100% | 1.2 |
| > 100% | 1.5 |

An analysis of company records for the study area shows that approximately 79 percent of cast iron, polycoated steel and screwed galvanised pipes have reached between 81 to 100 percent of their average effective life. Approximately 5 percent of pipes exceed 100 percent of their average effective life.

### 3.5.5 Operation and maintenance costs associated with pipe location

An analysis of data shows that approximately 50 percent of existing cast iron and polycoated steel mains are currently located under roads (Allgas 2000: 14). Maintenance associated with these mains would need to include: significant cost for traffic diversion, road reinstatement and the likelihood that work could only be done between certain hours of the day. There is a positive correlation between the category of road and maintenance costs.

The contribution of the location factor to operation and maintenance costs is given in Table 3.9. The maintenance costs associated with mains in footpaths are influenced by the land use zoning to a large extent. Analysis of records show cost distinctions between industrial, commercial and residential land uses. In industrial areas the driveways are often re-inforced concrete and the footpath reinstatement is expensive. The costs are lower for commercial areas, with residential areas being the cheapest in relative terms.

**Table 3.9 Operation and maintenance cost associated with location**

| Location | Code | Category | Factor ($F_l$) |
|---|---|---|---|
| Road Type | 1 | Freeway | 2.0 |
| | 2 | Highway | 1.7 |
| | 3 | Secondary road | 1.5 |
| | 4 | Local connector road | 1.4 |
| | 5 | Local road | 1.3 |
| | 6 | Private or restricted road | 1.3 |
| | 7 | 4WD track | 1.2 |
| | 8 | Bikeway and walkway | 1.2 |
| | 9 | Construction road | 1.1 |
| | 10 | Unconstructed or dedicated road | 1.0 |
| | | | |
| Footpath | R | Residential land use zone | 1.0 |
| | C | Commercial land use zone | 1.2 |
| | I | Industrial land use zone | 1.2 |

In the GIS database the location factor ($F_l$) is derived through spatial analysis and distance calculations of four GIS layers, namely the property lot boundaries, mains, land use zoning and road type.

### 3.5.6 Operation and maintenance costs associated with public liability

The Energex gas utility has a risk management policy (RMP) that addresses the prevention, protection and mitigation of risks involved in the design, construction, operation and maintenance of the distribution system. The RMP addresses requirements stipulated in relevant codes and regulations such as the Australian Standards. The company accepts its responsibility to ensure health and safety to both employees and the public (Khan 2000: 24).

The Energex Work Practices identify probable events that could arise while undertaking a particular task. All causes of a potential hazard that could result in an accident are also documented. When crews in the field use these Work Practices they are able to identify potential hazards and then follow the documented procedures to reduce, prevent or mitigate possible risks to the public or environment.

Leaks are a safety issue in the distribution system. The Gas Act gives full litigation and gas regulations classify leaks into three classes, namely Class A, B and C. Leaks are classified according to the quantity of gas leakage, the restriction of ventilation and the proximity to public places. Class A leaks are classified "hazardous", class B leaks are "potentially hazardous" and class C leaks are "non-hazardous" (Queensland Australia 1995). There is a positive correlation between the severity of a potential accident and the operating pressure in the main.

The costs associated with leak repair have been included under Section 3.5.1 ($Cost_m$) as part of operation and maintenance, however the costs associated with public liability are calculated under the public liability factor ($F_s$). Energex field crews require higher insurance cover when work is carried out on mains that are in the vicinity of land use activities that could have a high concentration of people (White 2001). Engineers tend to group low and medium pressure mains into one category for public liability cost considerations.

The index for assessing public safety is determined by the estimated probable concentration of people in the vicinity of gas installations. Classification of pipes is done according to land use as shown in Table 3.10. The GIS result is achieved by categorising the suburb layer into three zones, thereafter spatial analysis is performed to classify each main segment according to its position with regards to the three zones. The final assessment is a proximity calculation between a spatial layer of public places and the mains layer.

**Table 3.10 Operation and maintenance cost associated with public liability**

| Concentration of people (Number of people per 10m² around a main) | Type of land use | Factor ($F_s$) |
|---|---|---|
| < 2 person per 10m² | Outer city suburbs and rural areas | 1.0 |
| 2 – 10 people per 10m² | Central Business District (CBD) and Inner city suburbs adjacent to the CBD | 1.2 |
| > 10 people per 10m² | Structural public facilities / buildings | 1.5 |

### 3.5.7 Operation and maintenance costs associated with soil corrosivity

The impact of soil corrosivity on UAG costs have been discussed under Section 3.4.3, however corrosive soil also influences operation and maintenance costs of the company.

Company data records reveal that many kilometers of steel pipes were laid without cathodic protection technologies in low and medium pressure networks (Allgas 2000: 13). This has resulted in very high maintenance costs over the years. These pipes are exposed to rampant corrosion in the areas where the soil properties are notably acidic. Pinhole leaks are common in these networks. These are class C leaks which do not require a repair under the Gas Act Regulations; however, their existence is the entry point for water. This becomes a problem when the water-table rises above the gas main and where the pressure of the water is greater than the pressure of escaping gas.

Water ingress, if not well managed, creates a compound problem: firstly, customers become dissatisfied because they loose gas supply since siphons cannot cope with the volume of water, and secondly, the water must be removed from the system as part of a maintenance budget. The operation and maintenance cost associated with water ingress is substantial and is influenced by historic weather patterns. This cost varies from one year to the next depending on the amount of rainfall during the summer months.

Company data shows that non-cathodically protected pipes located in areas of high soil corrosivity account for 1.5 times more operation and maintenance costs per unit length than the costs associated with maintenance of mains in areas of low soil corrosivity. This comparison applies to pipes of having the same material and pressure. The ground condition factor ($F_c$) defined for UAG cost in Table 3.3 are the same values as those for operation and maintenance cost assessment.

In the GIS database the soil corrosivity factor ($F_c$) is assigned to pipe segments of the mains layer as an attribute where the gas pipes are deemed to be within the notable acid sulfate risk areas.

The final result of the operation and maintenance cost Formula (2) is shown in Figure 3.4 and incorporates all of the seven factors discussed above. This result has been achieved by manipulating the values of the factors. Pipe segments that have the highest priority for rehabilitation would be those that have a total operation and maintenance cost greater than AUD 12,000 per km per year. These are primarily the cast iron and non-cathodically protected steel pipes represented with the darker colour in Figure 3.4.

## 3.6 TOTAL UAG, OPERATION AND MAINTENANCE COSTS

The analysis of Formula (4) combines total UAG with total operation and maintenance costs per unit length of old mains.

$$TotalCost = TotalUAG + TotalO\ \&\ M \qquad \text{Formula (4)}$$

where

TotalUAG – Total UAG costs

TotalO&M – Total operation and maintenance costs

Source: Energex 2001

Figure 3.5 shows the results of this Formula. Pipes that have the highest priority for rehabilitation would be those with a total cost (UAG, operation and maintenance) greater than AUD 17,000 per km per year. Replacement of these pipes will give a return on capital expenditure over a shorter period than the other ranked categories. This information is required as an input to the Energex financial application that will be discussed under Section 3.9.3 and Section 3.10.3.

## 3.7 ESTIMATION OF CURRENT LOAD

The Energex load estimation application requires certain base line data to determine the current and future customer load. This is achieved using Formula (5) which includes the use of a diversity factor. This factor is based on gas industry standards where graphs show that not all customers use their maximum connected load at the same time. The higher the number of customers, the smaller the diversity factor.

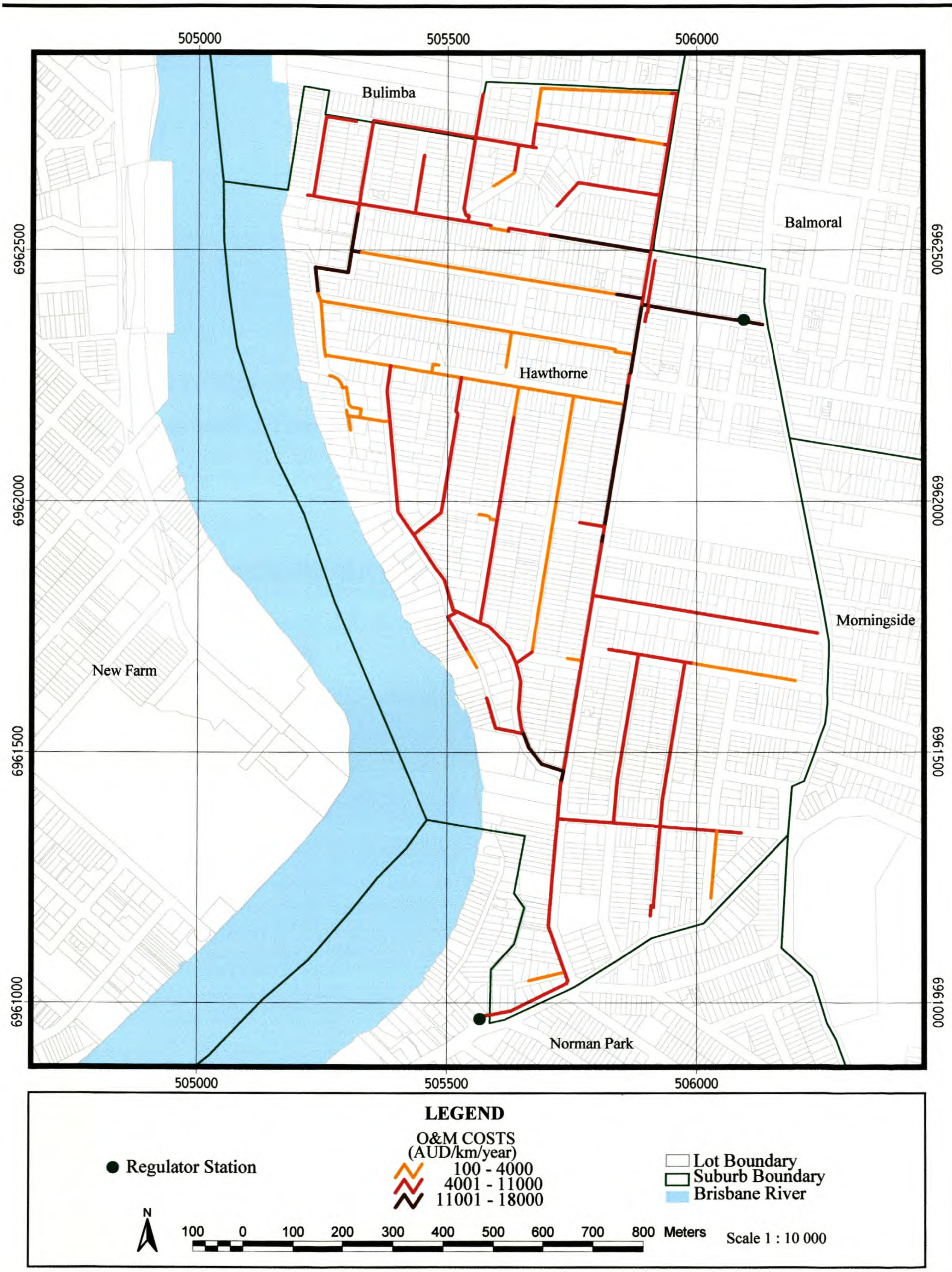


Figure 3.4 Total operation and maintenance costs associated with individual pipe segments

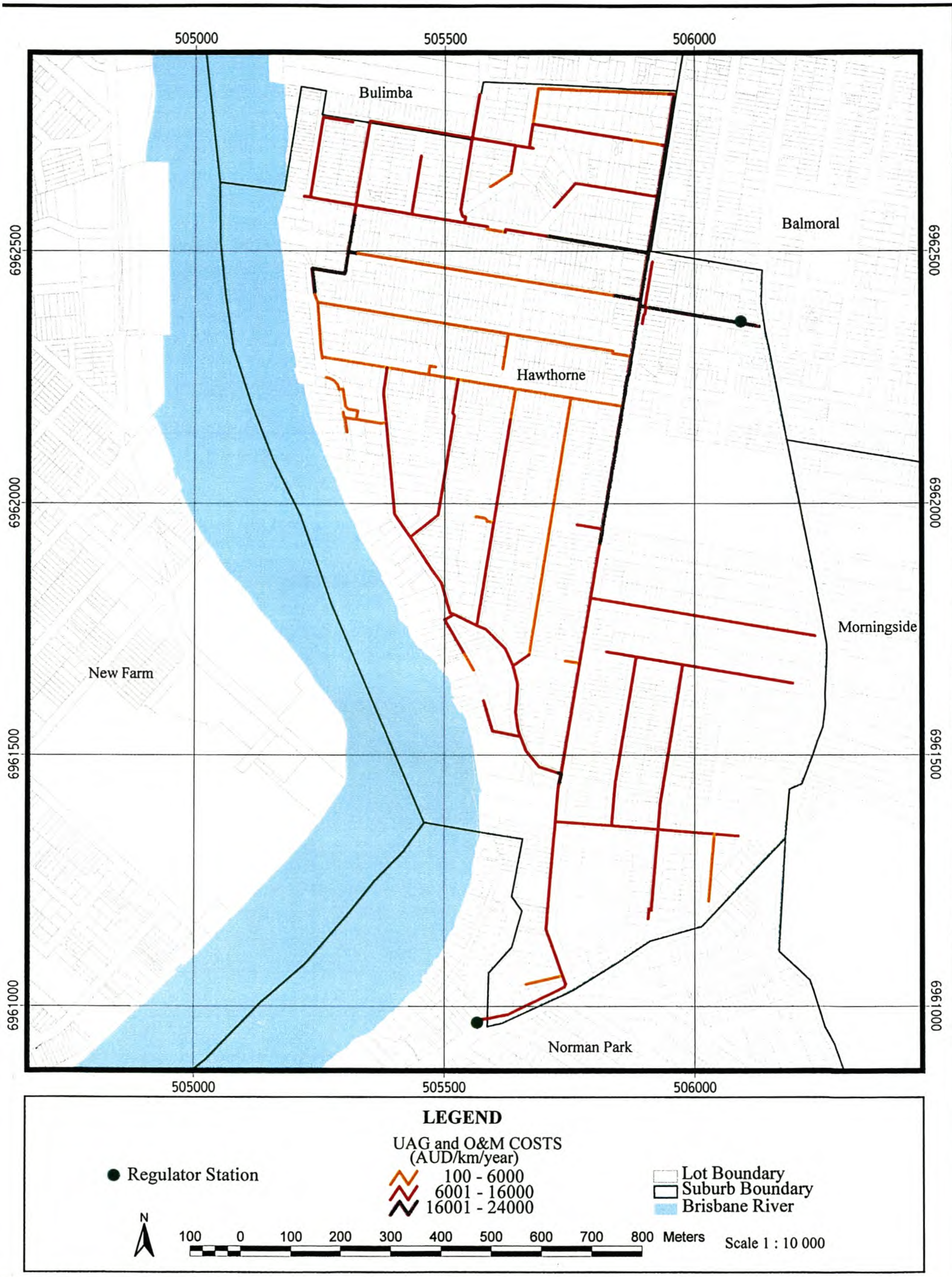


Figure 3.5 Total UAG, operation and maintenance costs associated with pipe segments

$$TotalConsumption = \sum (NoOfCustomers * MaxConnectedLoad * DiversityFactor)$$

where Formula (5)

NoOfCustomers – number of customers that are currently served by the main.

MaxConnectedLoad – the maximum load per customer per land use zoning in megajoules/hour/customer.

DiversityFactor – the value calculated from industry standards that represents the number of customers utilising gas (Source: Energex 2001).

Gas customers in the study area include three broad categories namely industrial, commercial and residential. Maximum connected load per customer is influenced by the land use zoning category into which they fall. In Brisbane typical loads associated with land use zoning have been established and summarised in Table 3.11.

**Table 3.11 Relationship between land use zoning and average maximum gas load**

| Land use zoning | Average maximum connected load per customer (Megajoules/ hours/ customer in land use category) |
|---|---|
| Open Space | 0 |
| Residential Retirement Community | 80 |
| Recreation | 120 |
| Residential B | 120 |
| Residential A | 160 |
| Residential Rural | 160 |
| Commercial | 400 |
| Education | 1000 |
| Hospital | 4000 |
| Industry | 5000 |

Source: Gajinov 2001b

Table 3.11 shows variable loads for the four types of residential land use. Residential Retirement Community is based on the assumption that the dwelling has one to two occupants. The difference between Residential A and Residential B is that the former is usually on a larger property lot with an occupancy of three to six people while the latter is on smaller property lots with a occupancy of two to three people. Residential Rural is assumed to have the same load profile as Residential A with the only difference being the size of the property.

Similarly the diversity factor is also region specific. Table 3.12 shows the diversity factor for Brisbane.

**Table 3.12 Diversity factor for gas utilisation**

| Number of connected customers | Factor |
|---|---|
| >200 | 0.05 |
| 51 – 200 | 0.10 |
| 11 – 50 | 0.15 |
| 5 – 10 | 0.35 |
| 2 – 4 | 0.50 |
| 1 | 1.00 |

Source: Gajinov 2001b

GIS has been used to determine the total gas customers for each land use zoning. The maps in Figures 3.6 and 3.7 illustrate the results of the procedure described below:

(i) Utilising spatial analysis tools to obtain all the digital cadastral database (DCDB) lots that front onto a gas main. There are 1502 property lots that have frontage to gas mains. This accounts for 98 percent of the property lots in the study area.

(ii) Extracting alphanumeric customer data from the Allgas Customers Information System (ACIS) Oracle database using SQL.

(iii) Derive service supply points by associating the customer data to the DCDB property lots. There are 787 existing service supply points.

(iv) The final result is two spatial layers of lots, one representing current ACIS customers and the other non-ACIS customers.

(v) The ACIS customer lots are overlaid with the land use zones to obtain the zoning per lot which is used in the network analysis and design, in calculating the maximum connected load for each customer.

## 3.8 RECOMMENDED RENEWAL DESIGN

Planning engineers would calculate the optimum pipe sizes to satisfy the existing load requirement. In the study area this necessitated an upgrade of the existing low MOP to a high MOP. This in turn influences the size of new pipes as well as the replacement of wet natural gas with dry natural gas. These new pipe sizes would be influenced by the characteristics of the adjoining network. The case study results reveal that two sizes, namely 40mm and 90mm polyethylene pipe, will be required.

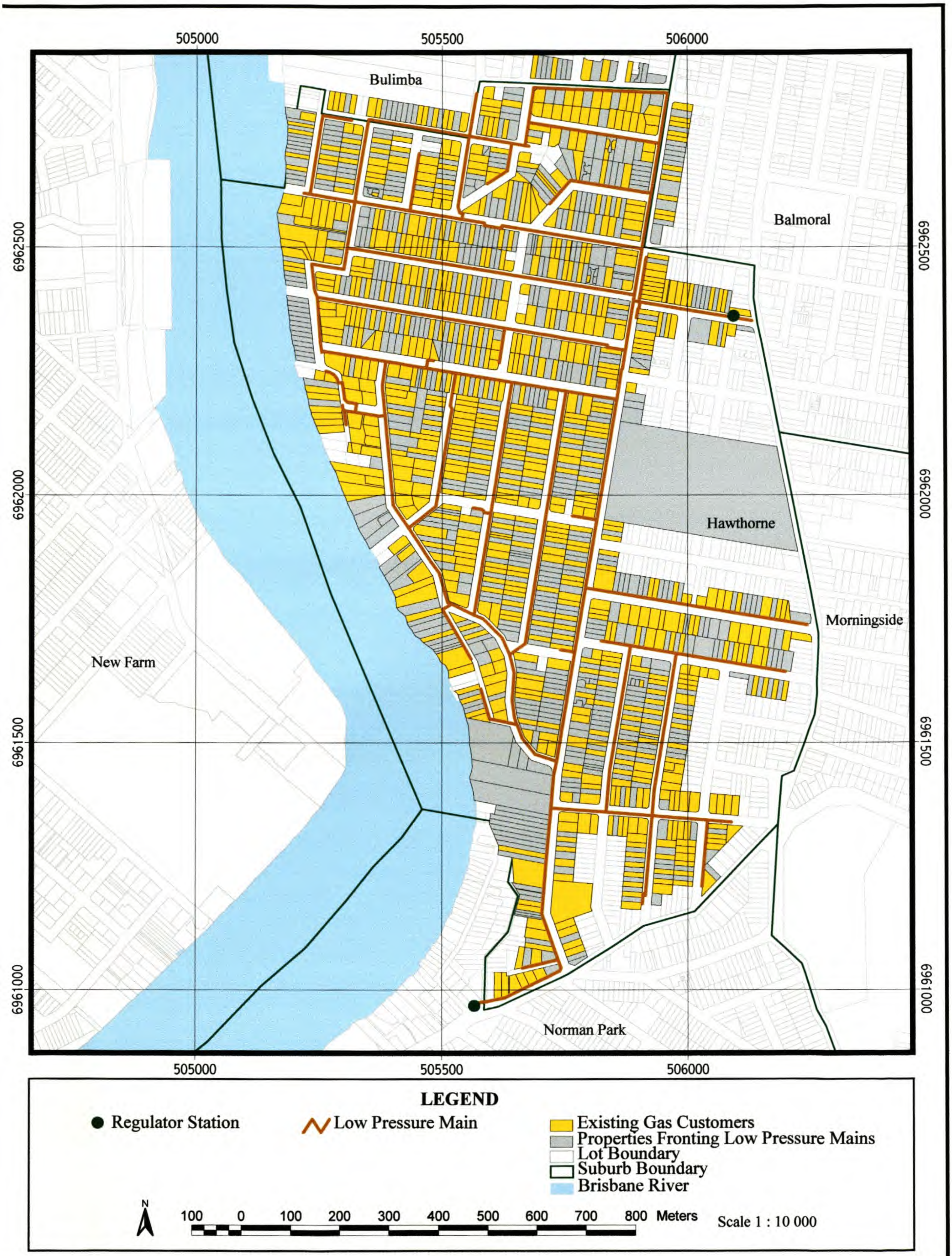


Figure 3.6 Property lots with a gas service connection

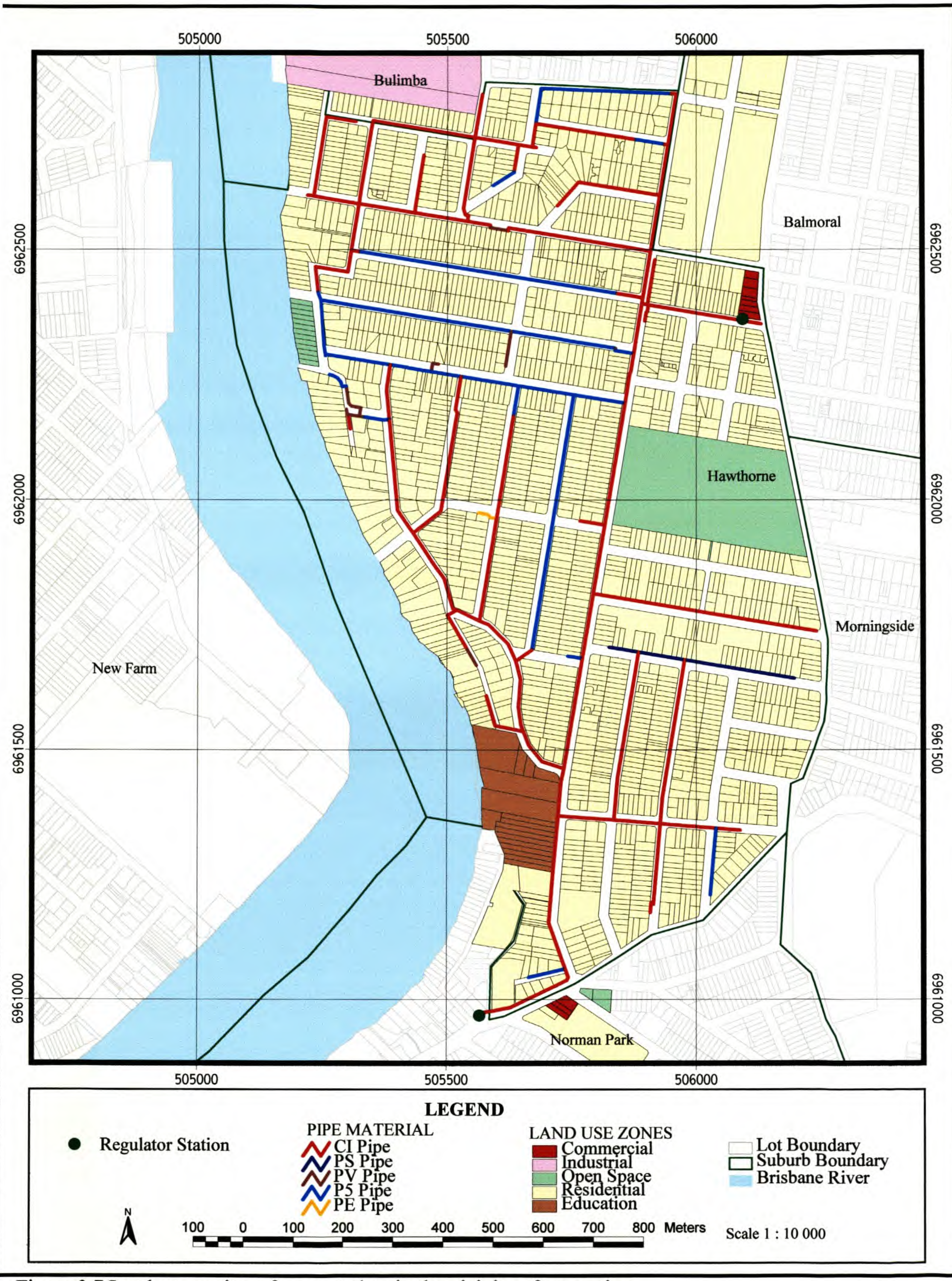


Figure 3.7 Land use zoning of property lots in the vicinity of gas mains

As discussed in Section 2.3.1.3 there are a number of replacement methods. The Energex gas utility Work Practices support three methods, namely open cut, directional boring and insertion. The choice of replacement method applied is largely dependent on cost minimising criteria.

The replacement criteria are:

- since the study area is in an old part of Brisbane a significant amount of buried infrastructure owned by other utilities poses a high risk to the directional bore replacement method. Consequently directional bore was precluded.
- mains currently located under the road that have surface cover of less than 600mm and a small diameter must be relocated to the footpath (a clearance distance greater than 3.1 meter off property boundaries is regarded as being located under the road, while a clearance of less than 3.1 meter is located under the footpath),
- existing pipes located under the road that have a surface cover depth of less than 600mm are to be abandoned and replaced on a new alignment under the footpath, preferable on the roadside that has the greater number of existing and potential customers, and
- existing pipes located under footpaths that have a minimum surface cover depth of 600mm should be inserted with new polyethylene.

These criteria are implemented through GIS and the procedure followed is described below and illustrated in Figure 3.8:

(i) Select the pipes due for renewal based on results from analysis in previous Sections.

(ii) A spatial overlay of the DCDB lots and mains layers to establish which pipes are beneath the road and footpath respectively.

(iii) Determine whether surface cover depth is acceptable.

(iv) Determine alignment of the new main.

(v) Apply the designed pipe size. This step is done by a Design Engineer and the results made available to the IRPA.

(vi) Determine whether the existing pipe is suitable for insertion.

(vii) Apply the renewal method matrix given in Table 3.13, to determine replacement methods.

(viii) Existing pipes identified for insertion having a diameter smaller than the new replacement pipe would be abandoned. Assign a new alignment for the replacement pipe.

(ix) Calculate the total length of new pipe required for each replacement method.

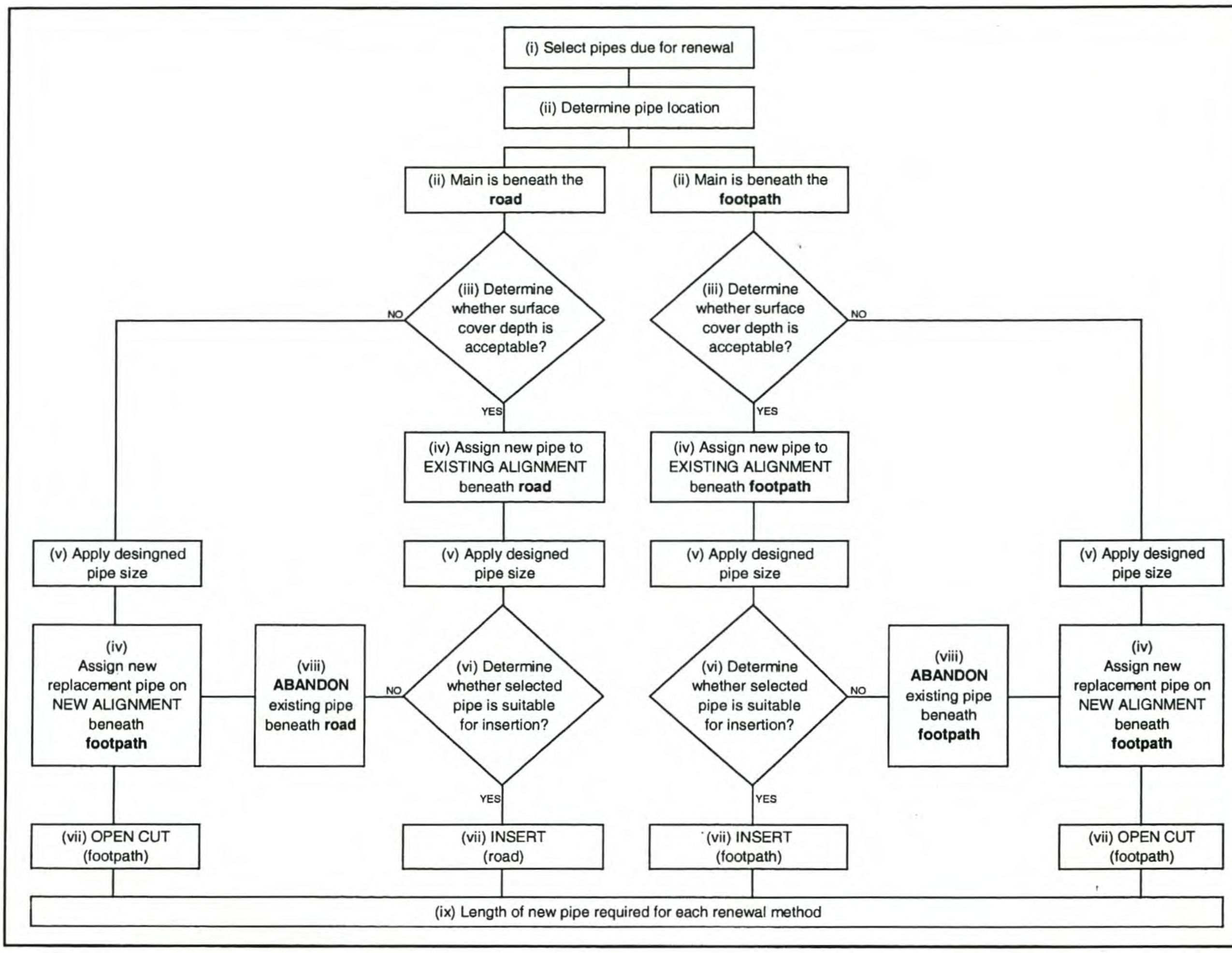


**Figure 3.8 GIS implementation of the renewal design**

**Table 3.13 Renewal method matrix**

| Existing pipe size (mm) | New pipe sizes and associated replacement methods | |
|---|---|---|
| | **40mm** | **90mm** |
| < 80 | Open cut | Open cut |
| 81 - 100 | Insert | Open cut |
| 101 - 150 | Insert | Open cut |
| 151 - 200 | Insert | Open cut |
| > 201 | Insert | Insert |

The map in Figure 3.9 shows the result of the procedure described above. Included on the map is a recommended new supply feeder that is attached to the dry natural gas network at a new regulator station on the northern side of the study area. This new pipe would have a diameter of 90mm. The two existing wet natural gas feeders would be abandoned and the regulator stations decommissioned.

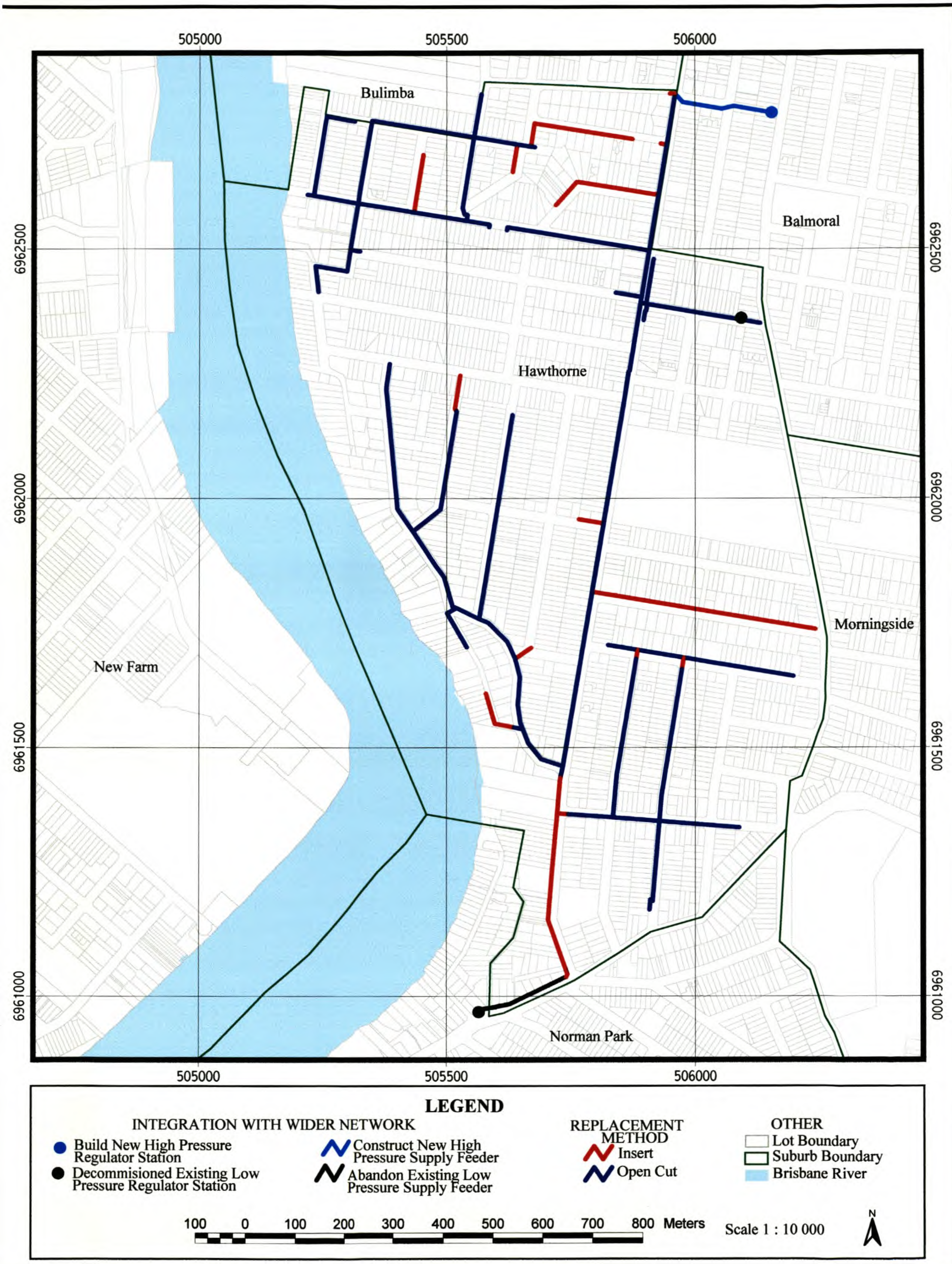


Figure 3.9 Preliminary renewal design

## 3.9 FINANCIAL ASSESSMENT OF RENEWAL PROJECT VIABILITY

The Energex financial application that calculates net present value and internal rate of return based on capital cost to perform a renewal project, the benefits related to reduction of UAG as well as operation and maintenance costs, is subsequently described.

The major parameters of the Energex financial application include:

(i) annual consumption of the existing customers,

(ii) capital costs,

(iii) financial assessment of UAG, operation and maintenance costs, and

(iv) revenue forecast.

In the GIS IRPA certain input data required for the financial application are derived from spatial analysis for certain of the above-mentioned parameters. These include:

- Total UAG costs determined by using various weighted factors (Figure 3.3);
- Total operation and maintenance costs determined similarly by weighted factors (Figure 3.4);
- Total number of existing customers (Figure 3.6);
- Total number of potential customers. These are non-customer lots where the gas mains are beside at least one side of the property boundary (Figure 3.6); and
- Length of renewal mains by pipe size and type of replacement method (Figure 3.8).

### 3.9.1 Annual consumption of the existing customers

As calculated before in the analysis under Section 3.7, there are 787 existing gas customers. These customers make up land use zone categories of commercial, education and residential. The latter category represents 98 percent of these customers. It was established that in this study area a general rule applied where one service connection is attached to one property lot.

The financial assessment required that the total annual consumption of the existing customers be known. This was achieved by extracting alphanumeric records from the corporate database.

### 3.9.2 Capital costs

The financial assessment of capital costs uses separate formulas for determining the construction costs for mains and services.

The formula used to calculate construction costs associated with renewal of mains is:

$$ConstructionCostMains = ConstructionMethod * Length \qquad \text{Formula (6)}$$

where

ConstructionMethod – The construction cost per linear meter by the type of construction method given in Table 3.14.

Length – Total length for each type of construction method by pipe size.

Source: Energex 2001

**Table 3.14 Construction costs for renewal of mains**

| Renewal method | 40mm pipe (AU Dollars per linear meter) | 90mm pipe (AU Dollars per linear meter) |
|---|---|---|
| New in footpath | 45.00 | 60.00 |
| Insert in footpath | 35.00 | 45.00 |
| Insert in road | 40.00 | 55.00 |

Source: Gajinov 2001b

The last step in the procedures described in Figure 3.8 is to calculate the total length of new pipe required for each of the two replacement methods. By employing this information in Formula (6) the results of the cost calculations in the study area amounted to AUD 410,500 to perform renewal on mains. This is the capital cost required to replace existing assets that are in poor condition.

The formula used to calculate construction costs associated with renewal of service lines is:

$$ConstructionCostService = ConstructionLocation * CustomerType \qquad \text{Formula (7)}$$

where

ConstructionLocation – Construction cost in dollars for a gas service connection based on land use zone as given in Table 3.15.

CustomerType – Number of existing gas service connections for each category of land use zone.

Source: Energex 2001

The calculation of capital costs to renew services is based on a standard unit rate associated with the type of land use. The GIS analysis determined the number of existing customers for each type of land use under Section 3.7. The results of the cost calculations in the study area are AUD 392,500 to perform renewal on services. Total renewal cost of both mains and services will therefore aggregate to AUD 803,000.

**Table 3.15 Construction costs for renewal of services**

**(Based on standard cost per land use zoning)**

| Land use zoning | Service construction cost per customer (AUD / customer) |
|---|---|
| Open Space | 0.00 |
| Residential Retirement Community | 300.00 |
| Recreation | 400.00 |
| Residential A | 400.00 |
| Residential B | 400.00 |
| Residential Rural | 1000.00 |
| Commercial | 1500.00 |
| Education | 2000.00 |
| Industry | 3000.00 |
| Hospital | 3000.00 |

Source: Gajinov 2001b

### 3.9.3 Financial assessment of UAG, operation and maintenance costs

The total cost of UAG, operation and maintenance calculated in Formula (4) would be used in the Energex financial application to assessment the viability of a renewal project. The output from this financial application redefines the UAG, operation and maintenance costs as savings when network renewal is done. This is because a network of new polyethylene pipe would offer a 60 percent reduction in UAG, operation and maintenance costs. The savings amount to AUD 60,300 for the study area.

### 3.9.4 Revenue forecast

Figure 3.10 shows the output from the Energex financial application incorporating GIS generated input data for the existing load. This financial assessment applies to replacement of mains and services using only the current customer base. The calculations show that the internal rate of return on investment is 4.8 percent for the stipulated twenty-year payback period.

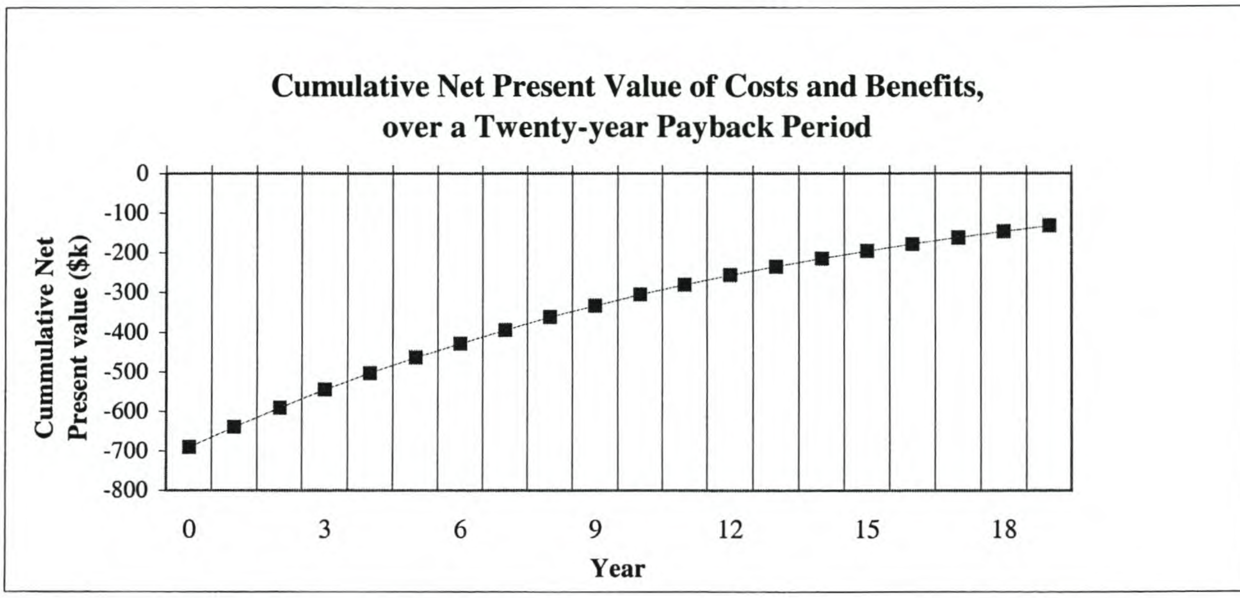


**Figure 3.10 Preliminary financial assessment**

The results of this financial assessment indicates that the envisaged renewal project is not financially justifiable. The minimum rate of return as per Energex requirement must be at least 7.75 percent to be viable (Energex 2001). The next Section describes the procedures employed to attain the minimum rate of return.

## 3.10 NEW CUSTOMERS REQUIRED

It is not possible to justify the renewal project only by the benefits attained from the reduction of operating, maintenance and UAG costs. Additional benefits can be obtained by increasing existing customer consumption and by connecting additional customers. In this section the required number of new gas customers will be determined and the implication for network design modeled using GIS.

### 3.10.1 Estimation of additional load

The formula used to calculate additional gas consumption by new customers is:

$$AdditionalCustomerLoad = ConsumptionIncrease * PotentialCustomers * NewCustomers$$

where Formula (8)

ConsumptionIncrease – The estimated average annual increase in gas consumption per customer for the target group

PotentialCustomers – Total number of potential customers based on a requisite frontage to a main.

NewCustomers – The percentage of target new customers required to justify the renewal project, determined in collaboration with the Marketing Department of Energex.

Source: Energex 2001

Based on the GIS analysis discussed earlier, it has been established that 1502 property lots have frontage to the gas mains, of which 787 are existing natural gas customers. The remaining lots are potential customers. Gas consumption data obtained from the Energex Marketing Department was used in the financial assessment calculations. The results indicate that ninety new customers are required in the first two years of the project to make it financially justifiable (reaching an internal rate of return of 7.8 percent). This is attainable given that 98 percent of property lots in the study area have frontage to the mains.

### 3.10.2 Revised renewal design

The additional load that is forecast from the calculations in the preceding Section 3.10.1 now needs to be included in the engineering design. The same methodology described in Section 3.8 has been followed here and the results show that the original renewal design will adequately meet the projected additional gas demand. This means that the original renewal design presented in Figure 3.9 is still valid and no changes are required.

### 3.10.3 Revised Financial assessment of renewal project viability

The procedure discussed earlier under Section 3.9 is followed with the inclusion of additional future customers to determine a revised financial assessment for the study area. The capital costs for mains remain unchanged at AUD 410,500 while ninety additional customers will increase capital cost of services by AUD 36,000. These new customers will generate revenue of AUD 20,000 per year with an additional operating cost of AUD 1,700 per year. Figure 3.11 shows that there is an acceptable payback period of less than twenty years (eighteen years) and an internal rate of return at 7.8 percent that exceeds the Energex minimum requirement.

## 3.11 IMPLEMENTATION OF DESIGN

The project is now assessed as being financially justified and moves to the last phase of implementation design. Here the Marketing Department would receive a mandate to actively canvas for new natural gas customers in the envisaged project area. The project is submitted for budget approval before being assigned to a Project Manager to prepare detailed layouts that include a list of materials and job instructions.

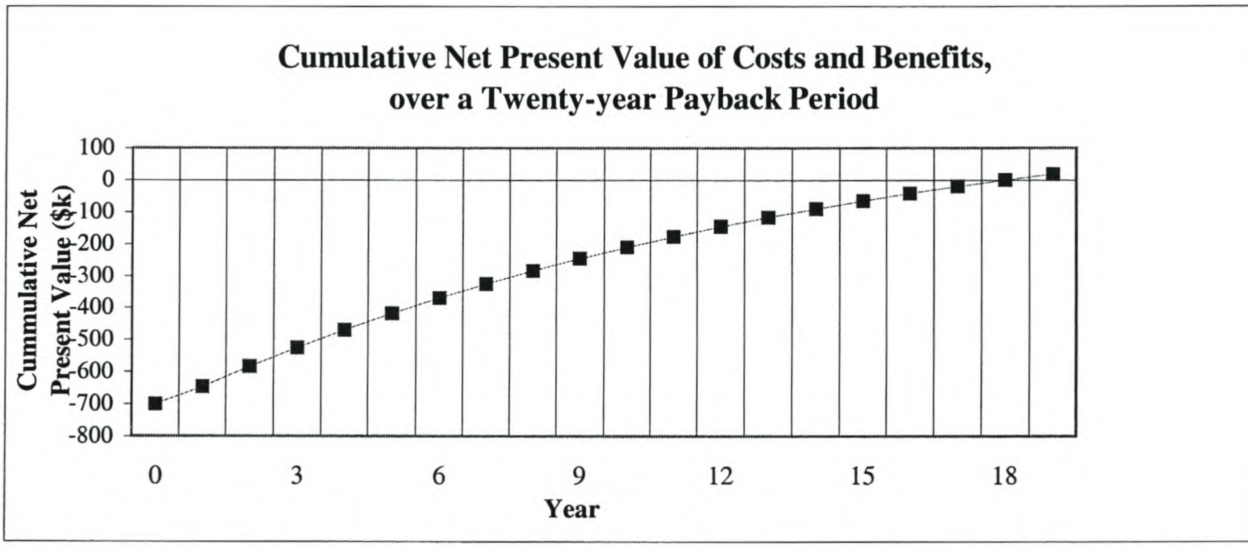


**Figure 3.11 Final financial assessment**

This chapter described the integration of GIS with the Energex financial application. GIS technology has also spatially enabled alphanumeric data successfully. The next chapter will be a discussion of the results and recommendations.

# CHAPTER 4: CONCLUSION AND RECOMMENDATIONS

One of the key operations of a GIS is the conversion of hard copy information into digital form through scanning or digitising. Once in digital form there are many GIS application possibilities (Goodchild 1992: 2). GIS allows users to explore and analyse data by location. Early versions of GIS were restrictive, but the GIS industry has been responsive to innovations, issues, crises and needs (Poulsen 1994: 175). In this regard GIS data models are being made more versatile with a broader range of GIS operations. Despite the innovative enhancements to GIS technology some organisations that use GIS fail to reap the full potential that it offers. According to Parr (1994: 51) organisations that fail to design their geographic information systems end up with systems that do not include organisational or operational geography. The result is sophisticated data systems. This is true of the Energex gas utility where little has been done to use the functionality of GIS technology as an analytical tool for decision-making. This was evident from the methodologies used for planning a renewal pilot project twelve months ago.

This chapter evaluates the results achieved using a GIS integrated renewal planning approach (GIS IRPA) that incorporates the design and financial evaluation of gas network renewal planning, and presents some recommendations for future research.

## 4.1 SUMMARY OF RESULTS

Gas pipe renewal often has to take place within gas utility networks, in order to minimize the amount of unaccounted for gas (UAG), operation and maintenance costs, while maximizing on annual revenue. The aim in the development of a GIS IRPA has been to build a systematic and logical approach that supports the work practices for planning pipe renewal. This approach uses verified factors and data to determine capital expenditure, and to develop a financial justification for approval of renewal projects. It involves the actual integration of GIS with current desktop applications developed by Energex, a gas utility company in Southeast Queensland, Australia. In order to best evaluate the GIS IRPA's potential benefits, it has been applied to the same project area where a renewal implementation plan was done twelve months earlier by Energex. The study area focused on a gas pipe network located in Hawthorne, a suburb of Brisbane. The complexity of this network has presented a good opportunity to test the GIS IRPA, since:

- there is great variation in the vintage of the gas pipes,
- some of the old pipes have been inserted with new pipes, and

- virtually all the types of pipe material commonly used in gas networks, are evident.

During the application, inefficiencies in the Energex procedures were identified and successfully addressed, as described below. The distinct advantages of a GIS IRPA above conventional renewal planning approaches has subsequently led to its approval by Energex as a possible planning tool for future gas pipe renewal.

It is believed that the objectives of the GIS IRPA have been achieved by successfully integrating GIS in the approach at several levels. Firstly, this was done through identifying connected gas pipes downstream from the regulator stations using the *trace* command in the Gas Data Model within the ArcGIS software. The regulator stations were flagged as control points (*barriers*) to the flow of gas through the network. The *network trace* algorithm selected all connected pipes with the same operating pressure which terminated at the regulator stations. The selected gas pipes in the low pressure sub-network of Hawthorne have formed the bases for later evaluation in the Energex financial application. Using GIS to select pipes is more efficient than employing visual inspections of hardcopy maps and drawing project boundaries by hand. The GIS IRPA offers great benefits in terms of accuracy and time savings. The attributes of the selected network were then exported to other applications such as the Energex financial application and an 'in-house' load estimation application. Computations done on this GIS generated data in these applications were then re-associated with the arc and point topology in the GIS database. The manual approach being used by Energex, on the other hand, often results in duplicate data capture that leads to redundancy and a high probability of human error.

It was established at the outset of this research that the data associated with UAG, operations and maintenance costs is stored in corporate databases that are disassociated from the GIS database. Ordinarily, in order to use this corporate data for pipe renewal, SQL queries has to be run to extract the records for a predetermined geographical area. Unfortunately, mismatches in the geographic extent between the spatial and non-spatial databases often result in unnecessary alphanumeric data being extracted, which would then require manual manipulation.

Further, the requested output data is commonly supplied from the corporate databases as aggregated totals according to specified categories. This deems to be problematic, since it is difficult to split up the aggregated data for larger areas. The GIS IRPA, however, is designed to offer flexibility in the selection of sub-networks for analysis. These sub-networks often cross over geographical boundaries or are localised small areas within suburbs. Selection according to individual pipe segments would enable this flexibility.

Associating UAG, operation and maintenance costs to individual pipe segments has been the focus of the second objective. Company records were scrutinised in order to determine factor values to represent each of these costs. The cost factors used by Energex to estimate UAG levels include: type of pipe material, operating pressure, and corrosivity of soil. The factors associated with operation and maintenance costs include: pipe material, operating pressure, pipe diameter, pipe age, pipe location, liability to the public and soil corrosivity. The weighted cost factors were successfully applied to individual pipe segments in the same geographic area used in the actual renewal project done twelve months earlier. The second objective of this research has therefore been met.

The current Energex renewal planning approach uses hardcopy printouts of customer listings as well as hardcopy maps of the pipe network, land use zoning, acid sulfate soil and DCDB property lots for manual processing and manipulation. This data is then analysed in the "in-house" load estimation application and the financial application.

The GIS IRPA has replaced hardcopy analysis with digital data. In employing GIS functionality, spatial analysis could be performed on the data sets (as described in section 3.1), to establish the following outputs:

- service supply points (customers) associated with DCDB property lots in the study area,
- DCDB property lots with frontage to gas mains, representing both current and potential customers,
- land use zoning associated with service supply points,
- whether gas mains are located beneath roads or footpaths, and
- selection of pipe segments according to diameter, material, cover depth and age.

The GIS generated data was exported to the Energex load estimation application, a desktop product developed by Energex. The results of this analysis were returned to GIS and are illustrated in Figure 3.9. The GIS generated data was also used in Energex's financial application. In comparing the output of this analysis with the results achieved by Energex's manual approach twelve months earlier, they were found to be virtually identical. The validity of the procedures of the GIS IRPA has thereby been confirmed.

Although the results of the GIS IRPA closely resemble the outcomes achieved from the non-integrated pilot project, small discrepancies were investigated and found to be data-related, rather than procedural errors. Firstly, the absence of unique primary and foreign keys in the mains and gas devices spatial layers, which would have been ideal to link with records in corporate databases, meant that spatial enablement of these corporate databases had to be done using the street address field, which is in free format. In order to overcome the non-uniformity of this field, a robust SQL script had to be prepared and run to select candidate records and create a new table. Secondly, it was found that the GIS IRPA could be adversely impacted by incomplete spatial information, particularly the elements used in selecting sub-networks for financial evaluation. A missing district regulator station or line segment would, for example, adversely impact the GIS network *trace* function, which is designed to trace along connected pipe segments and end at district regulator stations.

The link between various data sets and applications in this research has therefore been GIS. The use of GIS technology, in conjunction with other applications to prepare a renewal implementation design, has demonstrated the advantages of GIS to the Energex gas utility. However, the adoption of the GIS IRPA would incur some budgetary costs, such as:

- acquisition of external data sets,
- unavailability of digital data will require digitising hardcopy maps, and
- migration of data from ArcInfo 7.2.1 over to ArcGIS 8.1 may require some reworking.

Nevertheless, a comparison of the budgetary costs between the current manual approach to renewal planning used by Energex, and the GIS IRPA used in this research, show significant savings by deploying the latter. The manual approach occupied two staff members for five weeks while the GIS IRPA required one staff member for five days. Regarding the need for external data sets, it has been established that the Electricity Subsidiary of Energex have all the digital layers, baring one, required by the GIS IRPA. The outstanding layer is that of acid sulfate soil. The costs associated with migrating data from ArcInfo 7.2.1 over to the new version release of ArcGIS 8.1 is included in the operational budget of the Gas Asset Management Department for maintaining the database, therefore this cost is not of concern for the GIS IRPA. Implementing the GIS IRPA therefore deems a very viable approach for future pipe renewal planning at Energex.

## 4.2 IMPLICATIONS FOR FURTHER RESEARCH

In certain parts of the distribution network, records are completely non-existent (Gajinov 2001b). In such areas the challenge would be to prepare a financial justification for renewal projects without historic cost information. In this regard local knowledge and assumptions could be compensated for the absence of company records. Under these conditions the GIS IRPA would be at a distinct advantage over the manual procedures, since assumptions can be modified based on empirical data of the three UAG and seven operation and maintenance cost factors. They could be assigned by doing overlay analysis between the mains layer and the relevant environmental layers. The pipe segments that meet the criteria would be assigned a predetermined cost factor as described in Tables 3.1 to 3.10. The significance of these factors is therefore their transferability to other parts of the reticulation network. The GIS IRPA could also easily be repeated for different assumptions (and factor assignments) made, in order to be able to compare different output renewal implementation designs. The GIS IRPA also has the potential of being further automated and expedited through VBA scripts, where the transfer of data between GIS and the Energex financial application and 'in-house' load estimation application can be seamless to the user.

Statistical analysis could also be used to determine probable failure rates on the buried infrastructure assets. This analysis would be a facet of risk management whereby management decisions are quantified within calculated probabilities. The objectives of this analysis could include the following:

- to determine a predictive hazard rate curve for pipes, indicating their proneness to failure, and
- obtaining a predictive cumulative frequency of failure curve, showing the expected probability of failure of a population of pipes.

The Weibull probability distribution could be suitable for this analysis since it has the unique advantage in that it can describe most distributions.

## 4.3 VALUE OF THE STUDY

This research has utilised the same data previously used in the pilot project and demonstrated that a GIS integrated renewal planning approach offers significant benefits, including:

- Efficient selection of a sub-network based on pipe connectivity using the *trace* functionality of GIS,

- Detection of spatial relationships between alphanumeric data and environmental information that improves decision making,
- The association of cost factors to individual pipe segments make the prioritisation of sub-networks for renewal possible,
- Enhanced testing of proposed renewal design alternatives by scrutinizing the attributes of spatial data, and
- Time and cost savings in the preparation of a renewal implementation design, where the demonstrated time improvement is one week as opposed to five weeks.

This research has focused on the study area of Hawthorne, Brisbane, which is only one of 42 suburbs where pipe renewal activities will need to be implemented. It is estimated that 20 to 30 similar renewal projects will eventuate. In employing the proposed GIS IRPA approach in the preparation of future renewal proposals, it is shown that extensive benefits can be reaped.

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