University of Southern Queensland Faculty of Engineering & Surveying

ABANDONED SHAFTS STUDY

(Charters Towers) A Spatial Solution

A dissertation submitted by

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In fulfilment of the requirements of

Bachelor of Spatial Science Technology (GIS)

January 2006

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Abstract

The cessation of many mine operations in the Charters Towers goldfield has left a significant number of long forgotten, abandoned mine shafts. The presence of these abandoned mine structures, many of which were backfilled a long time ago has in recent times received increasing government and public concerns because of the potential risk to humans and property. Remediation can be an expensive exercise especially when difficulties with site discovery are considered. Much of the abandoned mine shaft discovery has been focused on the information maintained in the shaft repair inventory, developed in 1997 by NR&M. The issues related to accuracy and validation of site data, have been poorly addressed from a historic perspective with little effort made to quantify the affect of spatially correcting the dataset using a Geographic Information System (GIS).

The research has analysed the best available data and developed a process for spatial referencing the inventory. It has demonstrated the effectiveness of combining historic and contemporary data supported by Differential Global Positioning System (DGPS) control in a GIS environment to improve the positional reliability of abandoned mine shafts. A prioritisation assessment was developed to provide a means for the early identification of sites for future remediation works planning.

An analysis of case studies showed that the applied methodology and accuracies improve the spatial confidence for the discovery of concealed abandoned mine shafts.

The study has concluded that the application of a GIS methodology used in conjunction with DGPS provides an effective an accurate spatial solution for abandoned mine discovery. Future enhancements will analyse the use of ground penetrating radar for these purposes.

University of Southern Queensland Faculty of Engineering and Surveying

ENG4111 and ENG4112 Research Project

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Acknowledgements

Much of the contents for this dissertation was kindly supported by various personnel in the Faculty of Engineering (USQ) and the Department of Natural Resources and Mines (Qld), all to which I am most grateful.

A special thanks goes to my project supervisor, Kevin McDougall, for his attention, support and patience afforded to me during this project. I am also grateful to my employer, the Department of Natural Resources and Mines, specifically, the Mines Industrial Lands Unit (MILU) To Oskar Kadletz for assistance with the abandoned mine shaft project, and data access. A very special thanks is extended to Rhane Bethel for her support and assistance with the Shaft Repair Project field-work and background information, and to Natalie Albert for her timely help with getting my head around M/S Word formatting.

Finally, I would like to thank my family, especially my wife Linda for her tolerance and support I received throughout this project.

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List of Abbreviations

The following abbreviations have been used throughout the text and bibliography.

AML	Abandoned Mine Lands
AMLIS	Abandoned Mine Land Inventory System
AMLP	Abandoned Mine Lands Program
AMSA	Australian Maritime Safety Authority
CAM	County Arbitrary Meridian
DCDB	Digital Cadastral Data Base
DGPS	Differential Global Positioning System
DPI	Department of Primary Industries (Victoria)
Dpi	Dots Per Square inch
DPIF&M	Department of Primary Industry and Mines (NT)
EPA	Environmental Protection Authority
E&NR	Environment and Natural Resources (New South Wales)
GDA	Geocentric Datum Of Australia
GIS	Geographic Information Systems
GML	Gold Mining Lease
GPR	Ground Penetrating Radar
MCA	Minerals Council of Australia
MGA	Map Grid of Australia
MILU	Mining Industrial Lands Unit (Queensland)
MINOCC	Mineral Occurrence
ML	Mining Lease
MP	Mine Plan
M&P	Minerals and Petroleum Division (Victoria)
MGA	Map Grid of Australia
NAVSTAR	Navigation System for Timing and Ranging

NOAMI	National Orphaned/Abandoned Mines Initiative (Canada)			
NR&M	Natural Resources and Mines (Queensland)			
PDOP	Position Dilution of Precision			
PIRSA	Primary Industries and Resources South Australia			
PLU	Primary Use Code			
PSM	Permanent Survey Mark			
QVAS	Queensland Valuation and Sales			
MERLIN	Minerals & Energy Resources Location & Information Network			
RMSE	Root Mean Square Error			
SA	Selective Availability			
SD	Standard deviation			
USCG	United States Coast Guard			
USEPA	U.S. Environmental Protection Agency			
UTM	Universal Transverse Mercator			

Chapter 1 INTRODUCTION

In Australia today, mining, either directly or indirectly, plays an important role in our everyday lives. The benefits of the mining industry for modern economic and social development and the environmental improvement in Australian are well known and essential for maintaining and improving our standard of living. Our perception of mining today is that of an industry that is well regulated and controlled in its exploration and mining activities. There is little doubt that a highly regulated mining industry, as in Australia today should allay public concern with respect to safety and environment issues. This has not always been the case and our past mining heritage has left Queensland a legacy of many abandoned mine sites.

The issue of abandoned mines with public safety and environmental concerns resurface continually throughout Australia and around the world. Historical mining records have shown that housing developments have been placed on arsenic bearing tailings areas. Waterways and soils have been contaminated by toxic water leakages (EPA Contaminated lands register). The basic tenet that abandoned mines are ultimately the responsibility of the State has encouraged many governments, including Australia, to adopt Abandoned Mine Land Programs (AMLP) to locate, study and remediate problems.

1.1 Project Aim

The aim of this project is to develop a Geographic Information System (GIS) based methodology to improve the reliability and accuracy of the abandoned shaft location and the associated inventory data for the Charters Towers Shaft Repair Program.

To develop a risk-based process for the prioritisation of the abandoned mine shafts for remediation works.

1.2 **Project Objectives**

The main objectives for this study are:

- 1. Research and review current literature and processes identified by other studies and regulatory bodies with similar abandoned mine related issues.
- 2. Review data and information currently used for locating abandoned mine shafts.
- 3. Identify available data for the project area.
- 4. Validate and enhance the shaft locations within a GIS environment.
- 5. Establish survey control using Differential Global Positioning System (DGPS).
- 6. Improve the accuracy of spatial datasets.
- 7. Develop a prioritisation assessment of sites for future investigation.
- 8. To test the methodology and accuracy for abandoned mine shaft discovery (test cases)

1.3 Background to Research

1.3.1 Abandoned Mine Land Program (AMLP)

The problems associated with mining are a modern, global phenomenon. Abandoned Mine Land Programs (AMLP), whether in Australia or abroad, are faced with similar ownership and attendant responsibilities for remediation. An U.S. Army Corps of Engineers (USACE) review on the Restoration of Abandoned Mine Sites, (Makasey 2000), makes mention of the inherent inequity caused by the systematic transfer of ownership of abandoned sites. Since the 1970's, modern environmental regulations have placed the responsibility of remediation of mining operations with the current mine lease owners however Makasey (2000) makes mention that these remediation programs should also be supported by the State as many of these individuals or companies do not have the resources to facilitate remediation and would simply walk away.

The NR&M is the lead agency for mining in Queensland and are responsible for the collation and rehabilitation of all the abandoned mine sites in the State of Queensland. Today, all mine activity is controlled by the *Queensland Mineral Resources Act 1989*. The introduction of this Act by the Queensland Parliament was a major step towards comprehensive environmental planning and regulation in the industry. It ensures that companies operating today have a legislative requirement to meet stringent rehabilitation responsibilities. The Act also required miners to lodge a security to cover the repair of any damage caused by mining. Unfortunately, mines which closed before this legislation was put in place do not come under these regulations.

1.3.2 Mining Legacy

Mining played an extremely important role in the early development of Queensland and significant discoveries, such as the Charters Towers goldfields, brought great wealth and population growth to the region. Governments of the day relied heavily on the development of these fields as the wealth generated brought economic progress and much needed skilled labour to an expanding colony. Large gold mining concerns were also born from public and private promotion of these fields. The period prior to the turn of the century resulted in large-scale and mostly unregulated mining development and the impact was soon evident on the physical landscape (see Figure 1.1).



Figure 1.1 The Gold Field - circa mid 1870's (CITIGOLD, 2005)

Queensland's mining heritage has left a legacy of many abandoned mine sites in and around the City of Charters Towers, some of which have safety, environmental and land management issues (NR&M, 2004). Historically, it was common practice to `abandon' a mine site when mineral extraction was completed.

1.3.3 Charters Towers Mining and Remediation

Charters Towers is situated 135 kilometres south west of Townsville and has a population of approximately 10,000 (see Figure 1.2). The main industries in the area are mining and cattle grazing. Mining still plays an important role in the area with some large gold mines still operating.



Figure 1.2 Location Map

Charters Towers was put on the map with the discovery of gold on 24 December 1871 when a small group of prospectors, Hugh Mosman, James Fraser, George Clarke and a young twelve-year-old Aboriginal named Jupiter found a gold nugget in a stream at the base of Towers Hill. Charters Towers went on to become the richest major gold field in Australia with a total of 6.6 million ounces of gold (over 200 tonnes) recovered from 6.1 million tonnes of ore over 45 years, at an average grade of 34g/t gold. Production records of the day reveal that the gold field was extremely rich. The gold grade was almost double that of Victorian mines and almost 75 per cent higher than grades of Kalgoorlie in

Western Australia at that time. Following the discovery over 100 operators converged on the area to mine the field.

Principally, the gold ore occurred in shoots in quartz fissure reefs (reef mining) and at its peak period over nineteen batteries were operating with maximum production being reached in 1899 when annual gold output reached 300,000oz. By the end of the nineteenth century production was at maximum yields and over a hundred mine poppet-heads rose above the town (see Figure 1.3).



Figure 1.3 Brilliant Extended Mine (Source: CITIGOLD, 2005)

By the turn of the century the mining landscape began to change. Production began to decline with poor capitalisation and rising inflation. A fall in the real price of gold affected the myriad of small operators who were largely extracting ore by manual methods and who moved on to other goldfields. By 1916, practically all mining had ceased with the last major mine in the City closing in 1922. The drain on capital and manpower mainly due to the Great War of 1914 – 1918 and coupled with higher production costs due to ventilation, water problems,

extraction of ore to surface and dwindling mineralisation at depth had greatly contributed to the collapse of mining activity. Many of the small operators could no longer afford to compete with the larger corporations and mill operators and were forced to leave. With production falling and mines continually flooding, the gold field virtually came to a halt by 1917. This was a common fate experienced on many mineral fields across Australia, large and small alike. After the 1920's production in Charters Towers remained small, except for a renewal of prospecting in the old workings in the 'Black Jack' area between 1934 and 1951. Gold mining on the field since this period languished until renewed activity in 1969 saw a return to mining encouraged by a higher gold price and modern mining methods. Today, Charters Towers has the potential to yield as much gold again as it had in the past (CITIGOLD, 2005).

Today, many of these long-since abandoned shafts still pose a risk to humans, animals and infrastructure due to their potential to collapse unexpectedly (see figure 1.4). Each year, there can be up to 10 subsidence events (NR&M, 2004) where holes unexpectedly appear under buildings, in roads, or in areas of public access e.g. parks and schools. Many of these have been situated in populated areas thus posing a high risk.

A significant portion of this mining legacy exists in and around the city and has resulted in a number of safety, environmental and land management issues. The preservation of the cultural heritage of these sites is also an important issue to communities as abandoned mine sites with heritage significance may prove significant for future tourism and interpretation purposes.



Figure 1.4 Mine Subsidence (SH10717) (NR&M, 2005)

The existence of abandoned mine shafts within the Charters Towers area has been known for some time. These sites, however, are not well documented. Unfortunately, few records were kept of early mine remediation work on either State or private land and the current status of each opening or shaft on record cannot be confirmed without actual inspection.

Around 830¹ identified shafts have been identified within the Charters Towers City limits (NR&M, 2004). Of these 688 shafts having been located in the field and inspected and the remaining 142 shafts have yet to be located. The possible existence of a further 280 shafts has been identified using old aerial photographs, geological maps and gold mining lease plans. These potential locations require further research, field location and identification.

The impact of a number of abandoned mines affected by former leases have been minimised by current operations, which under legislation, renders the new lease

¹ Total number of shafts identified in initial shaft investigation. Improved historic and field investigation methodologies has revealed previously unknown shafts and in some cases nullified the existence of others.

holders liable for rehabilitation of past as well as present work in the areas they disturb. For the purposes of this review, the reference to abandoned mines refers to all those mine sites which the State of Queensland has responsibility. In Charters Towers, recent mining activity consisted of underground operations with minimal surface impact. Therefore, immediate concerns to the Department are to do with safety to public and infrastructure. Presently it is the responsibility of the State to monitor and rehabilitate any impacts from these past operations. Although some environmental management issues exist with mine rehabilitation in Charters Towers, these are generally minimal. The financial commitment by the State of Queensland 'to date' has put the expenditure for rehabilitation of abandoned sites at \$12 million and \$8 million for shaft capping for the entire state.

The Charters Towers Shaft Repair Project was established in 1996 to research, identify and make safe abandoned mine shafts and historic mine workings in Charters Towers and its immediate environs. Prior to the shaft repair project, all shaft remediation was 'ad hoc' and work was coordinated by NR&M in negotiation with the Charters Towers City Council on a as need basis. The concept of a shaft repair strategy was first proposed by a NR&M report in July 1996 and Parliamentary briefing note, 9th December 1996. The investigation was initiated by new surface collapses, some of which occurred in private properties and school sports grounds. In the case of a shaft collapse in a private residence in Hackett Terrace a previously unknown and abandoned mine shaft was found to be responsible with research in Brisbane revealing the shaft to be part of the Columbia workings, which were mined to a depth of 840 metres. The Charters Towers Shaft Repair Project was given ministerial endorsement in December 1996. This is where the initial research, approvals and data investigation began and the first inventory of abandoned mines was collated.

In March 1997, the outcomes of the initial investigation proposed \$10.8 M to be sourced through funding to undertake works. The final figure obtained however,

was somewhat less. From 1997 to 2003, the Department commissioned the Council to carry out all the shaft repair work programs with the Department as the project manager. In 2004, NR&M ceased contracting the remediation work through Council with all work now carried out by external contractors through a standing offer arrangement and managed by NR&M.

Each year, the level of remediation work is reduced due to of the reduction of known and prioritised sites. The current budget for 2005-2006 is approximately \$260,000 with the previous year slightly higher at \$270,000. This budget figure has to cover all overheads as well as the remediation work. The average rectification and rehabilitation cost per site can be influenced by the capping techniques and individual contracts. Figures obtained from NR&M for previous capping work cost per site are shown in Table 1.1.

Table 1.1 Summary of Average Capping Cost per Site (Source: NR&M, 2005)

Financial Year	Cost \$
1999-2000	\$27,000
2000-2001	\$22,000
2001-2002	\$24,000

A major step in the rehabilitation process is the identification, location and detection of abandoned mines. To efficiently address both public safety and environmental concerns associated with abandoned mines, a number of issues must be accounted for during an information gathering process. Fortunately, a system of reporting, mapping and maintaining production records has existed in Queensland for many years. This has ensured a supply of rich data from which this study has drawn.

1.3.4 AML Inventory - Charters Towers

The inventory of abandoned mine sites (or shafts) conducted by NR&M commenced in early 1997 and is maintained by departmental staff. The inventory provides baseline data on historical mining-related features and assessments of historical mine locations. It provides a solid foundation for future independent assessments. This information is used as a basis for mapping requests made by the community for property conveyancing and related searches for locations of mine shaft sites.

The inventory focus was not restricted to sites of historic production but all mine workings e.g. shafts, under-shafts and declines prior to the 1950s. In the initial assessment, the objective was to catalogue and locate all known and unknown abandoned mine sites (shafts), to document all relevant hazards each site posed to the public and/or related structures, develop a priority assessment for future planning and identify the necessary action to be taken at each site. Site compilation was from existing literature and historic mapping. From this assessment, data gaps were identified and a field program was implemented to verify many of the larger and important sites. Further data was collected at selected abandoned mine sites by reviewing old Gold Mining Lease and geological survey plans to determine the most significant targets.

After exposing an old shaft, the features were photographed and located by cadastral connection with the data recorded in the inventory.

The shaft repair inventory contains information in relation to the following themes:

- 1. Unique site identifier
- 2. Location and property details
- 3. Historic mining lease references (mine name, GML and MP)

- 4. Data source
- 5. Field inspection details
- 6. Prioritisation settings
- 7. Remedial works (fencing, capping, back fill, plug) and,
- 8. Survey works

The inventory has a dual purpose. Not only does it contain the initial assessment details but also is a repository for most of the ongoing inspection and works carried out since 1997. These records have been consistently maintained by the: NR&M project officer and is a good source of data for future assessment and works planning. A summary of the current works status is shown in Table 1.2.

Table 1.2Shaft Detail Totals

(NR&M, 2005)

Details	Total
shafts catalogued	830
shafts inspected	668
fenced	150
Drilled	123
shafts excavated	320
shafts capped	172
sites written off	132
shafts made safe	373
backfilled	201

1.4 Research Problem and Scope

In order to develop an effective abandoned mine shaft remediation procedure, the size and scope of the abandoned mine inventory process must first be understood. Since the inception of the shaft inventory no detailed assessment of the accuracy and validity of the data has been performed. The current inventory contains an extensive list of located and unlocated abandoned mine shafts and serves as the basis for program expenditures and budget allocation. The inventory, while reasonably comprehensive with respect to historic information lacks positional confidence and source referencing.

The inventory is currently maintained as a simple Microsoft® Excel spreadsheet by a NR&M administrator/field officer based in Charters Towers. This information needs to be comprehensively maintained however cannot be easily accessed in a user-friendly manner and has limitations with update and use.

A GIS is required to store and retrieve spatial information in an efficient and userfriendly manner.

1.5 Dissertation Overview

The *Introduction*, Chapter 1, begins with a brief discussion of the benefits and legacies from mining activities. The chapter provides a background to the research investigation and the research problems pertaining to the location of abandoned mineshafts. The aim and objectives of the research are presented and discussed.

The *Literature Review*, Chapter 2, identifies information relating to other Australian and International abandoned mine programs and correlates relevant spatial application and theories. The review discusses the development and management of abandoned mine inventories. The chapter explores the application of GIS for abandoned mine management, including DGPS and related accuracies.

The *Methodology*, Chapter 3, covers the general methods utilised for this dissertation. These methods include a preliminary data assessment to understand the scope of my collection procedures and covers the acquisition and development of the historical imagery used as a basis for most of the abandoned shaft assessments. It explains the process and application of DGPS field collection as a basis for the project data control and outlines the research strategies adopted, the collection procedures selected and the difficulties and/or problems encountered. It concludes by utilising a combination of land use and shaft inventory to develop a systematic approach to the prioritisation of shaft remediation works.

In *Shaft Discovery Case Studies*, Chapter 4, the evaluation of three separate past mining areas is undertaken to demonstrate the effective use of old GML survey plans for the discovery of abandoned mine shafts. This section explains how the GIS processes were utilised to maintain spatial accuracies for the purpose of correlating temporal datasets.

The *Discussion of Research Results*, Chapter 5, evaluates the procedures, techniques and results from previous chapters in relation to the aim of this project. The spatial application is assessed to support the conclusions, link important points of this chapter back to principle ideas in the Literature Review, and the evidence obtained from the research.

The *Conclusions and Recommendations*, Chapter 6, covers the evaluation of the effectiveness of my research program and future recommendations.

1.6 Summary

Chapter 1 examines the main cause and effects of mining, provides background to the research problem and details the history of mining in the context of the study area.

Chapter 2 provides a review of literature to establish the current state of theory with regard to abandoned mine issues.

Chapter 2 LITERATURE REVIEW

2.1 Introduction

This Chapter will identify and discuss current literature and processes identified by other studies and regulatory bodies with similar abandoned mine related issues. The use GIS for abandoned mine discovery will also be discussed with a focus on spatial data accuracy. The research will review and discuss the use of DGPS to provide survey control will achieve an accuracy and precision suitable for the project needs.

Remediation of abandoned mine shafts in the context of mining history is a relatively recent phenomenon. Whilst the topic of AMLP's is well documented, there is limited specific technical literature directly related to mine shaft discovery within an urban environment.

2.2 Other Abandoned Mine Land Programs

An abandoned mine land program is the process whereby a lead agency or agencies undertake the control and remediation of past mining activity of mine lands in respect to abandoned and/or orphaned mines. Makasey, in a report on California's Abandoned Mines (2000), mentions that there are some common themes of an AMLP. Two points are synonymous with the basic framework of virtually all AMLPs:

a) Cooperative arrangements between state and federal agencies leverage limited funds available at both levels of government and,

b) AML inventory and watershed assessments are done simultaneous with remediation projects.

High risk mining areas with environmental and safety issues can incur adverse political backlash as well as possible financial liability if governments choose do nothing. In this light an equally important aspect of a successful AMLP is to identify the scope of the potential problem through an abandoned mine inventory. An inventory on abandoned mines is desirable to governments as it enables ranking for effective, sustainable, cost-efficient planning and rehabilitation.

Queensland is not unique in its attempt to address abandoned mine issues as many other countries face similar issues and concerns. As in other Australian states and territories locating, inventorying, and characterising AMLs are the first steps in obtaining state or federal funding to mitigate some of the more serious AML environmental problems and to close dangerous adits and shafts.

2.2.1 Abandoned Mine Inventories

A principle control to a successful AMLP is to develop the capacity for State or national inventory of orphaned and abandoned mine sites. Countries with abandoned mine issues recognise the importance of the establishment of AML inventory systems for the identification and prioritisation of abandoned mine sites and is the first step in dealing with the abandoned mine problem. Before determining the magnitude of the problem facing AMLPs, we first need to establish that there is one. Van Zyl *et al.* (2002) states *"that no country has a*

definitive abandoned mines list", it is clear that more developed countries rate abandoned mine inventories higher in importance than underdeveloped countries. The extent of any abandoned mine problem cannot be successfully coordinated without some knowledge on the scope of the problem facing an AMLP.

The world's mining jurisdictions faced with AML problems recognise the benefit and importance in compiling a comprehensive list of their abandoned/orphaned mine site. The adoption of AMLP inventories is only a recent phenomenon but increasingly gained high levels of government involvement and support. In the past, mining records consisted mainly of production aspects and generally did not document remedial work. Other than England and Wales, where the recording of abandoned mines were a statutory requirement since 1890 (Van Zyl *et al.*, 2002), there does not appear to be any systematic approach to abandoned mine documentation.

Van Zyl *et al.* (20002) explains in the report on *Mining for the Future* that "there is no nation-wide inventory of abandoned mines in Australia" and that database development and record collecting approach varies between each state or territory (see Table: 2.1). Although no unified inventory will suit all circumstances, Canada has recognised the benefit of a coordinated approach. In a review by Cal Data Ltd (for: NOAMI 2005) it was proposed that a coordinated approach be taken to index all existing inventories maintained by each province, territory and federal agency. This review highlighted the benefits of a national seamless database as compared to the varying systems maintained by the individual component databases. One immediate benefit with a national inventory approach is that it can be more easily presented to the public through a Web-mapping interface.

			~	
State or Territory	Agency	Total	Comments	
Queensland	NR&M/ EPA	17,000+	No state-wide inventory. Shaft repair programs maintain separate inventories e.g. Charters Towers and Gympie. Mines in need of significant rehabilitation less than 100.	
New South Wales	E&NR	500+	Not comprehensive.	
			Derelict Mines database.	
Victoria	DPI (VIC)	2,000	Good records of historic sites.	
			No coordinated program to	
			prioritise or address rehabilitation	
			issues (2001).	
Western Australia	DME	23,000+	Comprehensive database.	
			Program commenced 1999.	
			Contain sites of recognised hazard	
			potential investigated.	
			Contains records for 88,705	
			mining-related features (2003).	
Northern Territory	M&E/	No	Possible commencement	
	PIF&M	records		
Tasmania	MRT/	681	Comprehensive. Reliability	
	DPIWE		dependent on historical and	
			geochemical classifications.	
			Main purpose: Acid mine drainage	
			in Tasmania.	
South Australia	PIRSA	No	No known inventory.	
		records	Abandoned mine scope study	

 Table 2.1
 Summary of Australian Abandoned Mines

(Source: NOAMI 2005,	Gurung 2001	and online)
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Inventories should contain all the required attributes to support AMLP outcomes. The location and the number of sites are useful in determining the nature and extent of the problem. To assist the government's priorities and decision-making processes, information pertaining to the hazard or risk a site can pose to either humans or the environment is very useful. Other than the historic and physical nature of a site, environmental information can also be obtained. Depending on the degree of causes and effects generated on abandoned mine land, most AMLP's

completed in 2002.

do not generally collect environmental information. Many under developed countries see this as one of the primary attributes of AMLs as mine workings and ore treatment areas are both significant sources of contaminants. Environmental concerns (e.g. acid run-off and sedimentation), attributed to many thousands of abandoned and orphaned mines in both developed and under developed countries can have major health and financial impact on communities. Reports on abandoned mine studies in California (Cal.DoC, 2005) and West Virginia (Faulkner/Skousen 1998) both discuss the importance of a watershed-based assessment approach for their abandoned mine inventories, as opposed to a site-by-site approach². The advantage of this approach is that once a watershed has been selected, inventories are concentrated within the targeted watershed. This and enables a more direct and positive approach for the allocation of resources to areas with water quality and other abandoned mine related problems.

2.3 Application of GIS for Abandoned Mine Shaft Discovery

The collection and inventorying of abandoned mine sites is a primary function of every AMLP. Project objectives include the location and documentation of abandoned mine sites with the intention to provide a sound basis for future planning of the necessary action and rehabilitation at high-risk abandoned mine sites. Sites can either be positioned in the field using GPS or by desktop GIS assessment supported by field verification using past mapping and aerial photography.

 $^{^{2}}$ A watershed-based assessment approach is used as an alternative method to a site by site remediation process by identifying and remediating those sites within a watershed that most substantially impact water quality and public safety (after: USEPA, 1995)

This works well for sites that have some surface expression e.g. surface opening and depression and mullock heaps. However, as in the case of a built environment such as Charters Towers, many shafts cannot be located by field inspection as they are backfilled or covered.

Although very limited literature exist on the application of a GIS/spatial solution for the abandoned mine discovery within an urban environment, a report by the Tar Creek Superfund Taskforce (2000) details the application of GPS and GIS to support the location of old shafts and drill holes. The report mentions the difficulties of visually locating these old shafts and drill holes in the field. A system very similarly proposed for this project had been implemented whereby old survey plans and aerial photography had been referenced from GPS and survey control and latter georeferenced. There was no reference to the outcomes of the GIS application within the report however the ortho-photography base for the study was controlled at sufficiently large scale (1:2,400).

The report also stated that approximately fifty percent of the concealed shafts indicated on mine maps but could not be found. This was compounded by the fact that the city limits lacked historic mapping and could not be included in the GIS assessment. This is an exceptionally large proportion of the total number of shaft openings recorded on the old mapping and survey records (approximately 660 shafts) and emphasizes the need for a incorporating improved spatial accuracy validation process.

2.4 GIS and Spatial Data Accuracy (Uncertainty)

For many years the GIS phenomenon has revolutionised both private and public sectors through its ability to give decision makers information about their business and easily convey that information by displaying it in a visual mapped format. However, often times the data we use is grossly inaccurate in terms of spatial accuracy. For many GIS users, an awareness of the effects of spatial error, inaccuracy, and precision of spatial datasets is generally low. Many users of GIS feel that simply using a GIS as a method of manipulating and evaluating data will ensure accurate results. However this is not the case. A GIS simply provides a platform for manipulating, analysing and storing sets of spatially referenced data. The quality of any GIS output is directly related to the quality of the input data and imposes limitations on potential manipulations and analysis techniques.

Managing error in GIS datasets is now recognised as a substantial problem that needs to be addressed in the design and use of GIS. Failure to control and manage error can limit severely or invalidate the results of a GIS analysis. As Foote and Huebner (1995) recognised "this problem if left unchecked could make the results of a GIS analysis almost worthless" and that error, inaccuracy, and imprecision can "make or break" many types of GIS projects. It is reasonable to say therefore that GIS mapping is only as good as the data that drives it.

A GIS project can be impeded by datasets with multiple degrees of accuracy, precision (see Figure 2.1) and multiple levels of data capture scale. Therefore it is important to manage and limit these inherent problems. Foote and Huebner (1995) outline the key point for managing inherent spatial errors as keeping those errors to a minimum through careful planning and methods for estimating its effects.

Accuracy, defined as the displacement of a plotted point (usually coordinates) from its true position in relation to an established standard, while precision is the degree of perfection or repeatability of a measurement (LEMBO, circa 2000).



Figure 2.1 Explanation of Accuracy verses Precision (Source: http://dusk2.geo.orst.edu/gis/PPTs/8-9map_in_comp2.ppt)

Spatial data in a GIS can be visualised either as small or large as the application will allow. The GIS zoom feature provides a false sense that scale can be altered however data remains the same regardless of how much we zoom in on a feature. Because of this, spatial data could be said to be scaleless. Therefore, the use of data in a GIS, unlike a paper map, is not restricted by scale. This may give the data a false precision that is reporting results to a level of accuracy and precision unsupported by the intrinsic quality of the underlying data. The assumption that a dataset is correct is one of the many issues involved in spatial data accuracy, error and uncertainty. An example of this would be to state that a GPS observation at a location to accurate to one metre because of what has been read off the GPS receiver's display. This is a major assumption especially prior to Selective Availability (SA) being tuned off (Foote and Huebner, 1995).
To maintain relative spatial accuracies with all the datasets used in the Charters Towers GIS a variance of ± 1 to 2 metres is to be maintained. This is to be substantiated by comprehensively testing the historic map data against survey data of higher accuracy. Although there will be uncertainty inherent in the projects spatial data, accuracies will be measured against the implementation of sub-metre DGPS control over the project area.

2.5 Differential Global Position System (GPS)

DGPS is, and will continue to be, an important part of today's society. The continual expansion, through increased acceptance of the technology, has led to numerous applications becoming reliant on the availability and accuracy of DGPS information.

With Selective Availability (SA) off, a standard GPS receiver for civil use can produce accuracies to within a few meters (averaged over time). Differential correction enables civil receivers to achieve accuracies of 5 m or less depending on the technique used. If a second and stationary receiver is used to apply corrections to the measurements of the first (the roving unit) then this improves the accuracy of the GPS. For example: the base station collects data at a known point, so it can compare the GPS location with the "true" location and provide a correction factor.

The DGPS survey for this project will be using the Ingham beacon as the base receiver to apply the corrections (see Figure 2.2). The Ingham beacon is part of the Australian Maritime Safety Authority (AMSA) differential global positioning system network of radio beacons. The service is primarily intended for commercial shipping but can be used for civilian DGPS needs. AMSA DGPS

service operates in the MF radio-beacon band (285-325 kHz), with the Ingham beacon operating at 306kHz. This form of DGPS uses pseudo-range corrections and range-rate corrections from a single reference station to track simultaneously all satellites in view. Using the known position of the receiver's antenna and the positional data from each satellite, the errors in the pseudo-ranges are calculated. These errors are converted to corrections and are broadcast to user receivers (AMSA, 2005) and the GPS determined position of a reference station is computed and compared to its surveyed geodetic position.



Figure 2.2 Proximity of Ingham Beacon to Charters Towers

2.5.1 Accuracy of DGPS

As Charters Towers is approximately 160 kilometres from the Ingham beacon it was important to ascertain the possible effect that this distance would have on the DGPS results. The broadcast standards for DGPS navigational service (USCG, 1993) stated that the achievable accuracy degrades at an approximate rate of 0.67m per 100 kilometres from the broadcast site (e.g. Ingham). Monteiro *et al.*, 2004 makes note that this was based on a theoretical prediction made in 1993 prior to the USCG DGPS network becoming completely operational. The study conducted by Monteiro has revealed by correctly evaluating the decorrelations with time that geographic decorrelation of the differential corrections is less than 0.22 metres for every 100 kilometres separation (1 σ estimate). Based on this premis it is possible to obtain positional accuracy in the sub-metre range.

Differential becons can suffer from degradation or loss of DGPS service at any time. Reference stations like the Ingham beacon vary with space, namely satellite empheris, tropospheric and isospheric errors. If this occurs then the corrections calculated at the reference station suffer accuracy degragation (Monteiro, *et al.*, 2004). The Ingham beacon, as with all the DGPS beacons in Australia are constantly monitored. An example of the status of the Ingham beacon shown in Table 2.2.



Table 2.2Status of Ingham DGPS Broadcast Site(AMSA, 2005)

To obtain the best results from the Trimble Pro XR receiver it is important to understand that the settings applied can be critical. Trimble recommends the settings noted in Table 2.3 to achieve accuracy of better than 1m (RMS³)+1ppm times the distance between the base station and the rover. The settings applied for the DGPS control for this project is shown in Table 2.4.

Table 2.3 Trimble Pro XR Recommended Settings (Lambert, 2004)

Setting	Recommended Value	Configuration menu entry
Position mode	Overdet 3D or Manual 3D	GPS rover options/Position filters
PDOP mask	6 or less	GPS rover options/Position filters
SNR mask	6 or more	GPS rover options/Position filters
Elevation mask	15 degree or more	GPS rover options/Position filters

³ RMS (Root Mean Square) means that approximately 68% of the positions are within the specified value.

Setting	Applied Value	Configuration menu entry
Position mode	Overdet 3D	GPS rover options/Position filters
PDOP mask	6 or less	GPS rover options/Position filters
SNR mask	4 or more	GPS rover options/Position filters
Elevation mask	15 degree or more	GPS rover options/Position filters

 Table 2.4
 Trimble Pro XR Settings Applied for Project

It is possible to obtain sub-metre accuracy using real-time corrections however this is subject to a number of operational conditions (TRIMBLE, 2001). According to TRIMBLE, the major factors that affect DGPS accuracy are:

- Number of visible satellites: Require a minimum of 4.
- **Multipath**: Is caused by signal reflection off nearby object(s). This may be a factor with the DGPS control survey as some sites are located in built-up areas.
- Distance between reference station and rover receivers: accuracy degrades by 1ppm as distance between reference station and rover increases.
- **Position Dilution of Precision (PDOP)**: A unit-less measurement of satellite geometry. The lower the PDOP value, the more accurate the GPS positions.
- Signal-to-noise ratio (SNR): a measure of the satellite signal strength relative to the background noise. A strong signal with low noise provides better accuracy. In ideal conditions the SNR mask can be set to 6 or more. In marginal areas (dense canopy), the SNR mask can be lower. The SNR mask for the DGPS control was set for 4.
- Satellite elevations: when a satellite is low on the horizon, the GPS signals must travel a great distance through the atmosphere, delaying reception by the receiver. For best results, the recommended setting is 15°.

- Occupation time at a point: The Pro XR receiver has a 1 second sample rate. It is proposed that the DGPS control survey will observe approximately 20 readings (20 seconds) per site.
- Accuracy of the reference station position: The accuracy of the rover positions are measured against the accuracy of the base station.

2.6 Historic Mapping

2.6.1 Introduction

A major component for a spatial assessment to the discovery of old abandoned mine shafts is the historic assessment, fortunately there is excellent historic literature and mapping records to utilise within the Charters Towers GIS project. The historic maps were available in digital form and contain the locations of many of the operating or visible shafts of that time.

2.6.2 Old Geological Mapping

Three series of geological map were identified for use in this project:

- 1. Robert Logan Jack geological mapping series, 1892
- 2. Peppercorn geological mapping series, 1910
- 3. J.H. Reid geological mapping series, 1916

In 1877, the northern section of the Geological Survey of Queensland resided in Townsville with R.L.Jack (Logan Jack) the responsible Government Geologist at that time. Before being succeeded by W.H.Rand in 1899 due to a new commission in London, Logan Jack along with Rand and A.G. Maitland were engaged with the geological survey of the Charters Towers field. As a result of this work, a geological map (4 chains to an inch) was published in 1892 (Reid, 1917). A second edition was published in 1898 showing the underground workings.

Due to heightened mining activities at the turn of the century the Peppercorn series was published in 1910. Although not principally a geological publication, the series had plotted all the important shafts and workings onto base sheets showing the topography, cadastre and GML data in detail.

A more detailed mapping program was performed by the Government Geologist J.H.Reid in 1916 during the height of the Great War (see Figure 2.3). This was the last significant mapping activity that is of benefit to the project.



Figure 2.3 Reid - geological map - sheet 1 (1916) (NR&M 2005)

The benefit to the project, of this early mapping is very significant as it is a snapshot in time of the early mining activity, particularly with the location and validation of pre-existing, active or inactive mine shafts. The AMLP recognised early, the need to capture and catalogue these sites to aid the discovery and remediation processes.

2.6.3 Old GML Plans

An additional tool for locating old shaft positions is the use of Gold Mining Lease (GML) plans. Gold mining lease surveys have been a formal requirement of the responsible regulatory body since 1871 (eg. DME, NR&M). Under the *Mineral Resources Act 1989* (s.246), a GML was sometimes surveyed by a licensed surveyor, especially if the boundaries governed the extent of the resource. The survey of the lease was performed from the applicant's datum post in respect to other coincident GMLs. The survey was required to fix the intersections of the cadastre and locate important detail on the face of the lodged survey plan (see Figure 2.4). Details include the location and boundary description of the lease, date of commencement, duration names of lessees, dates of transfers and names of transferees and ownership fractions, location of shafts, tunnels, tramways, roads, water races, etc. (Queensland State Archives).

It is for this reason a GML plan (now a ML plan) is a rich source of historic information. Some of the benefits are:

- 1. Position important detail i.e. shafts and infrastructure,
- 2. Offer greater geo-positional accuracy and,
- 3. Helps to approximately set the time of the built infrastructure.



Figure 2.4 GML Plan (part) showing Lease boundary and Cadastre (NR&M 2005)

2.7 Satellite Imagery

Although traditional film-based aerial photography offers many benefits for mapping applications, the advantages of high-resolution satellite imagery should not be overlooked. The most recent photography over the City was captured in 1999 and unless there are significant reasons to include new photography over Charters Towers in the near future, the next aerial capture program might be some years away. In comparison, satellites can be easily programmed to acquire an image within a very short time frame for a reasonable cost. A satellite can capture data over a much larger area (scene) than film-based aerial photography without any loss in the satellite image resolution. This is important, as this will significantly reduce GIS processing time by not having to rectify and mosaic a series of photographs.

2.8 Summary

This chapter provided a general overview of literature on abandoned mine land inventories and the study into causes and effects into abandoned mine shafts. In particular, the application of GIS and DGPS to assist the discovery of concealed abandoned mine shafts have been reviewed.

Even though a significant amount of literatures have been found in the field of abandoned mines and AMLPs, minimal information exists regarding the practical application and use of GIS within this field.

Problems with data accuracy were discussed to provide an insight into the difficulties and limitations encountered in the use of data from multiple sources with various levels of accuracy.

The project methodology used for this research project is discussed in Chapter 3.

Chapter 3 RESEARCH METHODOLOGY

3.1 Introduction

The aim of this chapter is to present and describe the process that was employed to integrate, develop and combine historic mapping information with modern datasets in a GIS environment to aid the discovery and validation of abandoned mine shafts.

The methodology applied was separated into three main components. These included the historic data acquisition, survey control acquisition and planning priority assessment.

The following list outlines the basic process structure for this chapter.

- 1. Integrate historic mapping, survey control and existing datasets for GIS visualisation and assessment.
- 2. Development, testing and reporting of DGPS control accuracy.
- 3. Prioritisation assessment of sites for future investigation.

3.2 Background to Previous Work

Initially, to get a good understanding of the shaft repair project data shortcomings a review of the scope of the work performed in the past was undertaken to address the major data needs. The abandoned mine inventory had been collated from paper hardcopy prints of the old geological and GML survey plans, historical records and supported by field investigations to assess the priority sites however there was little supporting information to verify the spatial accuracy of that data. Although several shafts had been located and capped with the aid of this information, it was very 'ad hoc' and many of the shaft locations were not verified in the field during the initial investigation. Further shaft discoveries became increasingly more difficult due to the lack of supporting information as to their true location. The need to improve site validation and discovery was paramount to reduce the financial impact on the project or, in a worse case scenario, walking away from an undiscovered hazard.

Upon close examination it became apparent that the shaft repair inventory could be greatly improved through the utilisation of an improved set of data controls. These controls would include applying a spatial approach to the historic information collection to improve the content and position of historic workings.

3.3 Data Extent and Format

It is important to ensure that the formatted and compiled geo-spatial datasets conform to current accepted formats, datum and projection. This will ensure minimal problems with data interrogation and integration. The extent of the study area was confined to 95% of the known shaft locations (6.5km x 5.3km) (see

Figure 3.1). The extraneous sites to this area are considered low risk and were not likely to be investigated in the medium term of the project life.

The GIS themes and analysis has been developed with the use of ESRI's ArcGIS/ArcMap GIS suite. The map datum used for all the themes is the Geocentric Datum Of Australia (GDA, 1994) and the map projection is Map Grid of Australia (MGA, 1994), UTM zone 55.



Figure 3.1 Project Area showing Abandoned Shaft Distribution (GEOIMAGE, NR&M 2005)

3.4 Geographic Information Systems and Spatial Data

GIS is a computer information system capable of assembling, storing, manipulating, and displaying geographically referenced information (USGS, 2005). GIS is a powerful tool to spatially represent real world mapping objects including the information pertaining to that object. Spatially represented data in a GIS can be used to produce maps or to better choices based on available evidence using spatial information and spatial analysis tools.

To display and use data in a GIS it will need to be captured in digital form for the computer system to recognise. Various techniques can be used to capture information:

- Digitising: hand tracing on screen or using a digitising tablet
- Coordinates from Global Positioning System
- Electronic map conversion using scanners
- Raster imagery (georeferenced)

The capability of a GIS makes the system a powerful information management tool because it provides the means to capture, organise, manage, store, retrieve, analyse and deliver multiple datasets as layers of information. A GIS is also an effective interface for non-technical users as it is easy to access spatial and textual data to use as a decision support tool.

3.5 Identification of Relevant Spatial Datasets

It is no less important in any spatial review that an investigation of current and future data sets be conducted. This is a major consideration as many important and costly decisions may be based on spatially derived assessments and assumptions. After a brief assessment, it was apparent that existing datasets did not allow any spatial confidence for the future of the project and that the project would substantially benefit from an improved data methodology. One important consideration was to ensure that for the purposes investigation all the data must be on a common base and adopt similar data standards and accuracies where possible. This ensures that any investigation will incorporate a reasonable level of confidence when correlating data.

A number of spatial datasets are required to assist in the identification of abandoned mines or target areas for fieldwork in any given area. The most beneficial tool was the use of imagery that has been referenced to a coordinate system: historical geological survey maps, historic gold mining lease (GML) survey plans, aerial photography and high-resolution satellite imagery. Incorporating an image-based data set will allow a reasonable level of control over the project area. One of the fundamental datasets is the Digital Cadastral Data Base (DCDB) which has inherent inaccuracies due to its digital capture processes. To maintain correct spatial alignment with all corresponding datasets it was imperative that the cadastral boundaries retain similar accuracies.

It is important to ensure that the collected and built data is consistent, compatible with GIS and easily integrated with other Departmental information systems. The GIS data assessment will use data to aid the determination of unknown shaft sites on the probable risks to those sites if not discovered and remediated.

The major dataset themes developed in this project for Charters Towers and utilised into the GIS environment are:

- 1. Historic, geological Mapping and GML plans
- 2. Abandoned Shaft Inventory
- 3. Digital Cadastral Database (DCDB)
- 4. Primary Land Use (PLU) and priority assessment.
- 5. High-resolution aerial Photography and/or satellite imagery.
- 6. Differential GPS control, inc. Shaft and breather surveys.

3.6 Data Accuracy Requirements

The cost of discovery in the remediation process is potentially high. Any process to reduce this cost will enable limited funds to be better utilised in higher risk areas. As stated previously, there is a need to improve the confidence of site location data. Not all of this can be attributed to just presenting better data. It had been recognised early in the program that a stated level of accuracy was essential to be maintained as this would ensure the same confidence across the datasets.

To maintain a consistent and achievable accuracy standard it was determined that sub-meter accuracies should be maintained. This was based on the following:

- To set an achievable accuracy value. i.e. too low would not be achievable, too high would negate the purpose to support the project.
- 2. Sub-meter accuracies with DGPS control are achievable.
- 3. Image resolution sub-meter (eg. IKONOS and aerial photography).

3.6.1 Geological Mapping Series

The old working maps were scanned at medium resolution (see Table 3.1) at the same scale as the hard copy maps. Most of the scanned maps were supplied from copies stored in NR&M's Charters Towers office. Subsequently, better quality colour scans of the Reid mapping were supplied from NR&M, Brisbane geological archives.

Table 5.1 Larry Ocological Mapping Series Summary			
Mapping Series	Resolution (dpi)	Status	
Jack (B&W)	200	georectified, mosaic	
Jack (colour)	200	partially georectified	
Peppercorn (B&W)	200	partially georectified	
Reid (B&W)	200	not georectified	
Reid (colour)&	250	georectified, individual sheets	

Table 3.1 Early Geological Mapping Series Summary

The first stage of the rectification process was performed using the DCDB as the control base although it was known that this dataset contained inherent positional inaccuracies. This first stage was a provisional measure as there was a need to conduct a preliminary shaft location assessment and the DGPS control fieldwork had yet to be completed.

With the exception of the southern areas (south of the 'Great Northern Line'), each rectified map sheet provided a Root Mean Square Error (RMSE) result larger than the specified tolerance (sub-metre) using the DCDB as a base. The averaged RMSE was in the order of 1.5 to 5 metres, which was later substantiated by the DGPS results. This resultant RMSE was acceptable considering the inherent paper map distortion and the DCDB accuracy. The largest disparity occurred, as one would expect, where the map sheets join. This error could be attributed to the

storage and use of paper copies that will cause the medium to distort over time. The sheets were mapped to overlap, however there were sizeable differences between the sheets and edge mapping for a mosaicing purpose was difficult.

To remedy this a second phase of the image georectification process was conducted. In this next phase the DGPS control and the spatially adjusted DCDB (using the ArcMap 'Spatial Adjustment' tool) had been integrated. The DGPS control points were well distributed over the city with a positional accuracy generally within the required sub-metre accuracy levels. Although the rectification algorithms will compensate for most distortions, it was difficult however to stretch the images sufficiently to compensate for all physical distortions in the paper maps due to the inherent distortion geometries. A future phase for the georectification will be the inclusion of ERDAS Imagine software to replace the ArcMap georeferencing tool. The added features and algorithms of ERDAS Imagine software will allow for improved raster stretching and edge matching between the adjoining sheets.

Georeferencing of these historic maps is of primary critical importance to the success of the project. It is an essential part of the discovery process as these maps hold the key to the shaft inventory validation and collation of shafts not mapped in any other form (i.e. GML survey plans).

3.6.2 Old GML Plans

Similar to the geological image maps, the GML images have been georectified to either the spatially adjusted DCDB or DGPS control positions or in some cases, both. Over time, there can be more than one GML survey performed. In this instance all the plans that show shaft locations have been rectified to provide a temporal correlation between the images.

This approach worked well where common boundaries exist between the GML and the existing cadastre. However, many of the very early GMLs pre-exist the built cadastre which can cause spatial referencing difficulties. In these instances, some success has been achieved by georeferencing the more recent GML surveys and using coincident boundaries from that vicinity work backwards in time.

The use of the old GML plans has not been applied to all sites. Because of the amount of work involved the process, it is usually applied when a more detailed assessment of a particular shaft or area is required. An example of the methodology applied for this process is shown in Chapter 4.

3.7 Aerial photography

For planning purposes, it was important to include digital imagery over the project area. This essentially assists the discovery and remediation planning process by aiding in identifying objects portrayed from an overhead position. It was decided to initially produce an aerial photography mosaic base, as a satellite image scene was dependent, on the completion of the DGPS survey control (xyz) for its georectification.

To cover the project area, six 1:25,000 colour aerial photograph prints (1999) were scanned at 600 dpi to give a ground pixel resolution of approximately 1 metre. These images were then georeferenced and mosaiced using ArcGIS Georeferencing tool. The rectification control was performed by using the spatially adjusted DCDB and DGPS control positions. The resultant mosaic RMSE was approximately 1.2 metres with little image mismatch at the tile joins.

An additional and important temporal assessment was to be conducted by utilising the early aerial photography. An assessment of the NR&M aerial photography archives had revealed early B&W photography flown in 1945 by the Australian army. Unfortunately during the 1970s all the hard copy prints and diapositives were destroyed.

3.8 Satellite Imagery

There are two satellite products to choose from over the city, QuickBird and IKONOS. Although the QuickBird product was of a higher resolution (0.61m), no scene existed over the project area. The Department did have under licence the IKONOS combined 1-metre multispectral imagery. The resolution between the two products were of little difference visually and therefore the IKONOS product was chosen (see Figure 3.2). The scene area covers 50 km² with a pixel resolution of approximately 0.91m. Reasonable image rectification was achieved however a RMSE result of 1.3 metres fell outside the project specification for sub-metre accuracy. To improve the ortho-rectification accuracy to sub-metre the services of an external provider will need to be sought.



Figure 3.2 IKONOS vs QuickBird IKONOS product to the left and QuickBird to the right (GEOIMAGE Pty Ltd, 2005)

3.9 Primary Control - Differential GPS

3.9.1 Introduction

A primary field component of the study was the Differential Global Positioning System (DGPS) survey of capped shafts and related cadastral survey control (see Figure 3.3). The survey included control positions for the cadastre and permanent survey marks (PSM) control points. This was required to maintain sub-metre accuracy across all the spatial themes and to verify existing DCDB accuracies.



Figure 3.3 DGPS Surveying - SH10777 Note: breather pipe, (Source: NR&M 2005)

3.9.2 DGPS Application

The DGPS survey was undertaken using a GPS Pathfinder [®] Pro XR receiver. The Pro XR is able to provide real-time sub-meter accuracy using carrier phasefiltered measurements. The combination of the real-time beacon in Ingham and the PRO XR DGPS unit consistently gave sub-meter accuracies.

It was expected that the accuracy using the real-time correction features of the Pro XR will alleviate the need for post-processing the DGPS data. However, when available, the data was post-processed using a fixed receiver in Townsville (Parkes Instrumentation) to verify the data accuracy. This was helpful when errors caused either by GPS degradation or loss of signal with the Ingham Beacon would cause the nominated statistical one standard deviation test to fail causing the control point to be filtered. The basis for the data statistical level to be set for one standard deviation (SD) - 67% confidence level was to filter out readings to minimise the positional error of the rover receiver due to the distance from the radio beacon and other stated errors. One SD is the filtering default value set for Pro XR receiver unit. The minimal post-processing accuracy after differential correction should be in the order of 50cm and carrier post-processed, approximately 30cm.

3.9.3 Accuracy Verification

Accuracy results were very encouraging and it is recommended that further work be conducted to finalise the pickup and control. DGPS results revealed very good point precision (grouping). Precision results obtained from post-processing data were within the order of 0.07m to 0.30m however spreads of 0.15m were consistently obtained (precision relative to the number of points captured). The use of DGPS has proven to be an inexpensive and effective method to obtain the level of accuracies required for this project.

To obtain a check on the possible accuracies and precision, readings were taken at a first order control point (37492) on Buckland Hill to the north west of the CBD in February and November (see Figure 3.4). The horizontal point precisions were 0.33m and 0.31m respectively and both results were sub-metre. These results show that the DGPS was able to obtain good precision however accuracy will differ from one epoch to the next. Additional tests at similar locations, has shown that sub-metre accuracies could be achieved with using the Ingham beacon and the Pro XR receiver.



Figure 3.4 DGPS Control - Accuracy and Precision Example

As an additional check on the relative accuracies at different epochs, some positions (e.g. breather pipes) were revisited up to three separate occasions. In most cases, the resultant relative position was within 0.6 metres or less. However, in some instance the results showed a large than normal discrepancy to the previous survey and a third check was done, usually on a separate survey trip to the city. The discrepancy may have occurred due to operational conditions as described in section 2.6.1 (pp.32) of the literature research. The most likely contributing factor would most probably be attributed to poor PDOP. Some examples of these revisited sites are shown in Figure 3.5.



Figure 3.5 DGPS Survey Check Locations (Breather Pipes)

3.9.4 Analysis of Results

The DGPS surveys were conducted in the months of February, June, November and December of 2005 and each survey consisted of either two to three days duration. It was also evident during the field survey and further supported by the results that the certain times of the day were more favourable to take readings that at other times. The best DGPS results were obtained before noon followed by a period in the middle afternoon. The periods, where the PDOP⁴ reflected poor geometry with the satellites, were generally in the early morning and the middle of the day and to some extent, in the latter portion of the afternoon. (see Figures 3.6 and 3.7).



Figure 3.6 DGPS Results for 2nd October 2005

⁴ PDOP is the geometrical effect on GPS accuracy (3D). The position of GPS satellites in orbit determine the DOP values for a given site e.g. the higher the DOP value, the less accurate the position solution.



Figure 3.7 DGPS Results for 30th June 2005

A summary of the results from the DGPS surveys revealed that the positional precision obtained is within a Circular Error Probable (CEP) of less than 0.4m (see Table 3.2). Although these test do not stipulate the level of accuracy achieved, it is indication of the quality of the data of a site at the time of the survey. Moreover, the test on the first order control (PSM37492) and the relative location tests on breather pipes and including uncoordinated survey pegs and PSMs has shown that the control data is of an order suitable for the requirements for this study.

Date	Total Sites	PDOP (mean)	Total Filtered Positions per Site (mean)	SD (mean)	Horizontal Precision (mean)	Vertical Precision (mean)
9/02/2005	16	3.3	15	0.274	0.364	0.785
10/02/2005	68	3.0	8	0.188	0.399	0.713
28/06/2005	61	2.8	20	0.072	0.400	0.647
29/06/2005	60	3.0	18	0.149	0.370	0.713
30/06/2005	48	2.9	20	0.075	0.405	0.693
29/08/2005	123	2.4	17	0.107	0.325	0.624
30/08/2005	83	2.5	20	0.168	0.342	0.594
17/11/2005	73	2.7	22	0.116	0.325	0.688
18/11/2005	26	2.3	29	0.010	0.330	0.566
5/12/2005	32	2.9	26	0.134	0.357	0.688
6/12/2005	65	2.9	24	0.122	0.335	0.770
	655	2.8	20	0.129	0.359m	0.680m

Table 3.2 Summary of DGPS Survey Results

3.10 Capped Shaft Surveys

3.10.1 Introduction

Since 2002, there has been a requirement by NR&M to connect the remediation work to the cadastre. The most appropriate time to do this is during the remediation work when the shaft has been exposed and a concrete cap laid over the opening (see Figure 3.8). As part of the capping process, a breather vent pipe is installed so as to allow for the venting of dangerous gases that can build up over time.

The survey pickup of the concrete cap and breather is an important function of the program as it maintains the relationship between the real property boundaries and the buried remediation work. This is especially important for any future works or infrastructure programs.



Figure 3.8 Columbia College - Concrete Cap Note position of vent pipe (NR&M 2005)

Prior to 2002, all remediation work was unsurveyed. This is very CRITICA as all these shafts are now buried and the true location can now only be approximated. Fortunately, many of these capped shafts had breather pipes installed that are easily located above the surface and offer a unique opportunity to derive the general positions of these shafts.

The cadastral connections are carried out by a licensed surveyor and a plan is produced (see appendix B). Connections to the capped shaft are performed by the

re-establishment of the cadastre corner(s) of the property in question and radiations are measured to the features and recorded. Although sufficient for the cadastral connection requirements, this does not allow for us to geo-position the structure and shaft location for use in a GIS. This was done by using the DGPS pickup to re-establish the survey positions in a coordinated system (MGA94).

The geo-positioning of the concrete cap and breather has a dual purpose. Firstly, the correct geo-position for both the features and the cadastre is known. Second, we can use the cap position to locate the original shaft. This can be used to systematically, adjust the position of all unknown shaft sites in close proximity due to their mapping relation.

3.10.2 Field Survey and Reductions

The selection of cadastral positions and survey reference are based on the plan of connections as supplied by the licensed surveyor (see appendix B). In the DGPS survey a large number of reference points was observed to sufficiently carry out field calculations with checks. These cadastral survey references generally consisted of the following:

- 1. Property corner pegs.
- 2. Iron pins (buried).
- 3. Screws or drill holes in kerbing.
- 4. Permanent Survey marks (PSM).

Approximately 30 readings are taken at each station and averaged by the receiver. The data file was downloaded at the end of each day to check for errors and converted to ESRI shapefile format. In nearly every instance, the meridian used for the majority of surveys in Charters Towers was not based on either AMG or MGA grid. As described by NR&M's Cadastral Survey Requirements manual, a meridian of a cadastral plan must be one of the following:

- 1. County Arbitrary Meridian (CAM),
- 2. Meridian of the original survey or,
- 3. Meridian of an adjoining survey on MGA.

To reduce the survey meridian onto MGA the difference between the survey meridian and the DGPS derived grid bearing was calculated. This is usually applied over a line greater that the radiation distances. Checks are applied by calculating the coordinates of other reference stations using the adjusted bearing. If the checks fail, the location would be revisited either the following day or next visit.

The calculated shaft and breather coordinates are used to produce two GIS themes. A breather theme (point) and shaft theme (region). These GIS themes not only assist the public in accurately locating these structures for future planning and development applications, they support further discovery of other sites. The location of the coordinated shaft is useful in adjusting the position of other localised sites without supporting control.

3.11 Primary Land Use Risk Assessment

To support the planning for future shaft repair a risk prioritisation of the remaining sites was required. A primary land use (PLU) theme was developed as a basis to this assessment.

A PLU lookup table was compiled from the Queensland Valuation and Sales (QVAS), land use codes. The PLU codes only refer to rateable land sales and do not include some State controlled (public) lands. To build a complete land use dataset the state controlled land was populated according their general use.

To spatially assess the risk component, an additional field was built on a simple but derived risk index (see Table 3.3 and Figure 3.9). The risk index was determined by assigning a value based on the primary use of human and animal activity. For example a school or sports ground will pose sufficiently greater risk in the event of an abandoned mine collapse, compared to land used for cattle due to the lower human impact.

DESCRIPTION	CLASS	RISK INDEX
Breeding & Fattening	Cattle Grazing	2
Professional offices	Retail Business/ Comm	3
Sales area outdoors (Dealers, boats, cars,etc)	Retail Business/ Comm	3
Warehouse & Bulk Stores	Transport & Storage	4
Transport terminal	Transport & Storage	4
Railway	Government	4
Light industry	Industrial	4
Extractive	Industrial	4
Warehouse & Bulk Stores	Transport & Storage	4
Large Home site-vac	Residential	5
Shop single	Retail Business/ Comm	5
Shopping group (2 to 6 shops)	Retail Business/ Comm	5
Vacant Urban Land	Urban Land use	5
Road reserve	Government	6
State Land	Government	6
Special tourist attraction	Retail Business/ Comm	7
Other clubs (Non business)	Special Uses	7
Guest house/private hotel	Residential	7
Sports clubs/ facilities	Special Uses	7
Large Home site -Dwg	Residential	8
Single unit dwelling	Residential	8
Reserves (Recreation, Reffuse Tip, Undefined)	Government	8
Multi unit dwelling (Flats)	Residential	8
Educational include Kindergarten	Special Uses	10

Table 3.3Primary Land Use Risk Index

The criteria for applying an inferred risk factor to land is not always obvious as other relationships can occur. Within the study area, State land (inc. road and rail) comprises 43% of the total area and therefore should not be ignored (see Table 3.4).



Figure 3.9 Map showing the Derived Primary Land Use

(NR&M, 2005)		
Tenure	Total %	
Private land	41	
State land	43	
Reserves	10	
Other	6	
Total	100	

 Table 3.4
 Abandoned Mine Site Tenure Summary

The development of PLU risk value is relevant, as this information will be further applied to determine a derived prioritisation value to aid future shaft repair programs.

3.12 Shaft Repair Priority Assessment

A GIS-based prioritisation assessment of the shaft repair inventory was developed to provide a means for the early identification of sites for the timely development of management strategies. This will provide for the efficient prioritisation of resources to remediate sites and to reduce their inherent risk.

The assessment aims to identify and prioritise sites for further investigation and probable shaft repair work by applying a single rating value to all of the abandoned shafts within the study area that have not been discovered or remediated.

The first stage of the methodology included the removal of the 373 sites that have previously been made safe out of the total of 830 catalogued sites leaving 457. Included in the remaining total are 132 sites that have been written-off⁵. These sites pose a problem because of the possibility that some of the undiscovered shafts, may still exist. Therefore, because of the need for further investigation of the more significant but written-off shafts it was important to include this data in the assessment.

Using data collected for the site inventory (NR&M, 1996/7) pertaining to the shaft historic and physical attributes, a rating was assigned based on the mine type, shaft description, historical structures and depth. This gave an assumed measure of the size and importance of each of the structures.

⁵ A site is considered written-off when it is unable to be located in the field investigation stage

The mine type code is based on a matrix of the results from field inspection and an importance rating from historic literature. From the remaining list of shafts eight categories were identified to give a shaft type and a ranking of 1 to 4 was assigned based on the assigned importance (see Table 3.5).

SHAFT TYPE	COMMENT	RANK
U	Unknown	1
NLFIR	Not Located, Further Action Required	1
DRIVE	Further Action Required	2
SHAFT	Shaft (known)	2
1CS	Shaft - low Importance	2
2CS	Shaft - low to medium Importance	3
3CS	Shaft - medium Importance	3
4CS	Shaft - high Importance	4

Table 3.5 Mine Type Ranking Classification

The historical ranking was based on whether a shaft was named and if there were historical structures at the site. The ranking was determined on the historical significance of each shaft from the mining journals (Reid, 1917) i.e. ore extraction and poppet head size. The classification value was 1 for a minor shaft and 2 for a major shaft.

The second ranking was based on the recorded dimensions of the shaft. This included the depth, and physical attributes i.e. poppet legs and/or engine block. There is however a degree of duplication with the two ratings as both incorporate historic importance attributes. Where this had occurred it was deemed that it would not significantly influence the prioritisation index value but confirm the level of importance. Table 3.6 shows the depth of shaft classification used.
Table 3.6 Shaft Depth Ranking Classification

DEPTH (feet)	RANK	
0 - 100	1	
101 - 500	2	
>500	3	

Calculation of a prioritisation value was achieved by simply summing each of the derived values: [PLU index + mine type + shaft depth = Priority]. The prioritisation index was classified into low (3-6), medium (7-10), high (11-12) and very high (13-15). The priority 1 results, although crude in its application did reveal known priority sites either listed for future investigation or cultural significance i.e. Phoebe and Day Dawn PC (see Figure 3.10).



Figure 3.10 Priority Sites (undiscovered and non-remediated)

The priority 1 subset of the results revealed registered Australian cultural heritage sites (see Table 3.7). This is due to the correlation with the inventory attributed data and the cultural heritage registered mine infrastructure at these sites. The other and more important reason is that the MILU still see these non-remediated sites as being potentially dangerous a fact that is reflected in the shaft repair inventory mine type code.

State Reference	Mine Name	Ranking	Cultural Heritage
SH10054	Brilliant Block	13	Y
SH10087	Day Dawn Churchland	13	Y
SH10093	Clarkes Brilliant & Worchester	13	Ν
SH10126	Day Dawn PC	13	Ν
SH10155	North Queen No 3	13	Y
SH10137	Victoria	13	Ν
SH10165	Day Dawn No2 West aka Emperor	13	Ν
SH10186	Day Dawn Block & Wyndham North	14	Y
SH10215	East Mexican No 2 aka Day	14	Ν
SH10009	Brilliant Deeps	15	Y
SH10060	Phoebe main shaft	15	Ν

 Table 3.7
 List of Priority 1 Shafts and Cultural Heritage Listing

3.13 Summary

This chapter presented and described the research on the development and use of historic mapping data using GIS-based georeferencing techniques supported by DGPS control. An assessment of available data sources was undertaken to identify data needs for the report.

Methodologies used in the research was outlined and discussed in respect to the use of DGPS control for the geo-spatial positioning of digitally imaged historic mapping, aerial and satellite imagery, and the computation of the capped shaft surveys. This was followed by a shaft priority assessment to provide the basis for the future shaft investigation planning.

The next chapter will present and describe the use of the spatially correlated datasets from this chapter as a basis for shaft discovery case studies (chapter 4).

Chapter 4

SHAFT DISCOVERY CASE STUDIES

4.1 Introduction

This chapter describes the methodology employed in the application of spatially adjusted data to aid the discovery of abandoned and concealed mine shafts. This chapter also summarises the results of each study and presents the case to validate the most probable location for field investigations. The aim of this chapter is to show the benefits of using historic data in a GIS-based application for locating abandoned mines in an urban built environment.

In this chapter, four test cases are analysed and discussed. These tests are applied on areas where no previous work has been conducted to locate known and significant concealed shafts. It is envisaged that the results from these test cases provide the basis to determining the most appropriate method used for site investigations. To test the methodology and accuracy used in the case study examples this chapter will assess and measure against known surveyed shaft positions to verify the application of the spatial methodology.

Any relevant findings that were encountered during this process are discussed along with the methods used. Critical evaluation on the benefits to using historic data for the discovery of abandoned and concealed mines in an urban built environment are also discussed.

4.2 Background

Many of the disused mines shafts remaining to be remediated, are located within the Charters Towers urban area. Because of the density of the built environment, the standard methods of discovery cannot be employed without a great deal of impact on residences and the possible large cost to the Department. Before attempting to expose these hidden structures, we need a more precise discovery methodology supported by a level of confidence in the methodology used. As described in chapter three, old Gold Mining Lease (GML) plans are a rich source of historic information for the location of old shafts and other workings that do not have surface expression.

To demonstrate the use of old GML survey plans Four areas of past mining activity that meet the criteria for this study were reviewed. The NR&M Shaft Repair coordinator identified three separate and potentially high-risk sites to target. In addition, had also been identified by the priority assessment from chapter 3. These sites have been identified from the old mine and geological maps and require a greater level of positional confidence prior to attempting to locate these in the field. All of these sites exist within the City's urban area.

The cases investigated were:

- 1. Case 1: Phoebe Main Shaft
- 2. Case 2: Day Dawn P.C. Mine Under-Shaft
- 3. Case 3: Bonnie Dundee No2. Shaft
- 4. Case 4: Kelly's Queen Block No1 Shaft

4.3 General Methodology

A primary concern for conducting a spatial review of this nature is the issue of data accuracy. It was important that all the georeferenced imagery be within the stated accuracy of one metre or less. The primary method of georeferencing these survey plans is through the identification of coincident cadastral boundaries. This correlation is in most cases the only historic reference to correlate the imagery to the cadastre and the real world position. Therefore, the process is reliant on the DCDB as a basis to perform each subsequent image registration. To improve the DCDB positional accuracy the DGPS base control and ESRI's ArcGIS, Spatial Adjustment tool was used to perform a vector adjustment of the DCDB polygons. The Root Mean Square Error (RMSE) achieved was generally within the DGPS accuracies obtained for each study area.

The second stage of the assessment was to identify and procure all the relevant historic GML plan images over each study area (see Table 4.1). This was done by searching the NR&M computerised tenures and geoscientific database (MERLIN) and SmartMap systems. The downloaded imagery then cleaned of any superfluous data for visual clarification and spatially georeferenced within ArcGIS. The average RMSE was consistently in the order of 1 metre or less. The process was repeated for the geological map images of each of the case study areas. The RMSEs achieved were generally between 0.7 to 1.6 metres and in most cases within the DGPS sub-metre accuracies.

Shaft Name	State	GML Plan	Mine Plan	Year
	Reference			
Phoebe Main Shaft	SH10060	GML124	MP28653	1875
		GML1826	MP15343	1900
		GML2081	MP29474	1905
Day Dawn PC	SH10126	GML262	MP28761	1880
		GML1311	MP29240	1890
		GML1334	MP29290	1891
Bonnie Dundee No2	SH10006	GML1034	MP29120	1887
		GML2517	MP15509	1916
Kelly's Queen Block No1	SH10292	GML451	MP28882	1885
		GML1595	MP15198	1895

Table 4.1 Case Study Survey Plan Summary (Source: NR&M - MERLIN, 2005)

To better visualise the aerial photography and historic geological detail at the case study mapping scale the imagery was rescanned at 1000 dpi and re-rectified to align better to the localised DGPS control.

4.4 Case 1: Phoebe Main Shaft

4.4.1 Introduction

The Phoebe mine is centrally situated in the Queenton area close to the main railway station. The ground had been worked since 1874 and was sold to an English company, the Phoebe Gold Mining Ltd. The company prospected the deep ground by sinking a vertical shaft to a depth of 1,210 ft (370 m). Due to poor grade results at depth the company ceased operations in 1912. The total gold

extracted from the mine for the period 1887-1912 was 39727 oz. gold (Reid, 1917).

4.4.2 Assessment Summary

The remediation of this site is required, as it exists within close proximity to three occupied properties. The main shaft was a significant structure consisting of a poppet-head and engine shed. Earlier field inspection in October 1996 on Lot 1 on plan MPH1690 showed the remains of an engine block in the south-west corner of the block and that the possible shaft position was 25 metres to the north of the block ⁶.

The assumed position from the inventory puts the Phoebe Main shaft in lot 1 based on the field inspection whereas the J.H. Reid position shows the shaft in lot 4. Therefore a degree of uncertainty exists. There appears to be redundancy in the data as there are two shafts in close proximity (12 metres). This is highly unlikely that another shaft existed this close to a main shaft. The probable cause could be attributed to poor data compilation of the initial 1997 abandoned mine assessment as duplication of some sites can occur when compiling data from multiple sources.

Both georeferenced GML's 1826 and 2081 show the shaft to lie in the western corner of lot 2 (see Figure 4.1). This is further supported by the shape and orientation of the cadastre at this location. The coincident boundary of lot 4 and 2 is unusual in its shape (see Appendix C). This is most probable that the survey

⁶ An engine block is the concrete structure supporting the winding engine (winder) a steam engine that hoists and lowers the cages in a mine shaft. These old structures can sometimes be used to locate hidden shafts as winders were usually a distance one chain (20 metres) from the mine shaft. For larger shafts, larger winders were used and the distance between the two structures could be up to 30 metres apart. This supports the 1996 field inspection assumption that the probable position of the shaft was 25 metres to the north.

subdivision reflected the need to isolate the shaft at this location. Unfortunately, it was not possible to analyse the aerial photography (1945) due to the destruction of the photographic archives by the Australian army.



Figure 4.1 GML position of the 'Phoebe' main shaft (between the two assumed positions for the Phoebe shaft)

4.5 Case 2: Day Dawn P.C. Mine (Under-Shaft)

4.5.1 Introduction

The Day Dawn P.C. Mine was one of the most significant mines in the Charters Towers mineral field and was worked as early as 1874. The reef was patchy and

it was not until 1878 that success was attained with the discovery of the second largest ore-shoot of the field. The mine ranked as the fifth largest producer on the field and returned 379,859 oz of gold. From 1902 returns grew less and was finally closed down in 1913 (Reid, 1917).

4.5.2 Assessment Summary

The 1996 inventory field inspection mentions that there was no visible sign of the shaft. The historic mapping assessment showed that the Day Dawn PC Mine Under-Shaft was shown on a number of GML plans and geological maps (see appendix D). These were georectified to their best fit using the adjusted DCDB and the DGPS as control. There was a reasonable correlation between the datasets with a spread of 4m E-W and 3m N-S. The new averaged position of 422256 E and 7,779237 N (MGA94, zone 55) put the under-shaft approximately 12 metres due south of the original position (see Figure 4.2). This is sufficient grounds to revisit the location and conduct a test drilling to verify the shaft position.



Figure 4.2 Day Dawn P.C. Mine Under-Shaft Assessment

4.6 Case 3: Bonnie Dundee No2. Shaft

4.6.1 Introduction

The Bonnie Dundee mine is also situated also in the Queenton area and was one of the oldest company mines on the field with operations starting in 1882. An underlie shaft was sunk to a depth of 1,100 ft (335m) but the deeper lode below 600 ft (183m) was unpayable. The vertical No. 2 shaft in the north-west corner of the lease was sunk to a depth of 2300 ft (701m) as depicted in Figure 4.3. The No. 3 vertical shaft lay in the south-east corner of the lease and was the main working shaft with a depth of approximately 865 ft (264m). Like many of the

other major mines in the field the Bonnie Dundee mine closed down in 1913. The total gold produced was 40,433 oz (Reid, 1917).



Figure 4.3 Bonnie Dundee Long Section showing No.2 Shaft

4.6.2 Assessment Summary

The 1996 inventory field inspection mentions a subsidence under a large concrete slab on the boundary of the NORQEB yard and ICA car park. The subsidence was filled in but no shaft capping was carried out as the shaft is located in a non-residential area and considered medium risk. The historic mapping assessment showed that the Bonnie Dundee No2. Shaft was shown on both GML1034 and GML2517 (see appendix E). These were georectified to their best fit using the

adjusted DCDB and the DGPS as control. There was a good correlation between the two images and the location of the No2 shaft position. (see Figure 4.4).

A similar case of data redundancy is also evident with the two inventory sites SH10005 and SH10007 identified in the same relative location. As stated previously this has most probably occurred from the compilation of multiple, historic mapping sources.

This case study shows that using historic mapping with DGPS controlled accuracy has confirmed the inventory position within a high confidence level.



Figure 4.4 Bonnie Dundee No2. Shaft Assessment (The GML assessed position lies between inventory sites 5 & 6)

4.7 Case 4: Kelly's Queen Block No.1 Shaft

4.7.1 Introduction

The Kelly's Queen Block mine is centrally situated in the Queenton area within close proximity to the railway station. Production figures stated by Reid (1917) showed that the mine contributed largely to the gold yield of the field. The mine was worked from 1892 to 1913 for a total production of 113,937oz (3,230 kg) of gold from 91,586 tons extracted. The No1 shaft, near the south-east corner of the lease (GML1595), was put down to the Victory reef (450ft – 650ft) and has a total depth of 740 ft (225m) (Jack, 1892). The total production serviced from the No1 shaft was 19,792oz (561 kg) of gold for just 9,072 tons of ore for the period 1892 to 1913 inclusive (Reid, 1917).

The shaft repair inventory had identified three sites SH10026, SH10615 and SH10292 from the GML plans 451 and 1595 (see appendix F), the Reid and Jack maps. Two of these sites have been remediated, SH10026 in 1997 and SH10616 in 2002. The third site, SH10292 (Kelly's Queen No1) was not investigated on either of these occasions and will be the subject of this case study.

4.7.2 Assessment Summary

Both GML images were georeferenced using the DGPS corrected DCDB. The resultant RMS errors using the 3rd order polynomial transformation option were less than 1 metre (0.7m and 0.8m). A comparison of the shaft positions revealed only a 1m displacement between the georeferenced GML images. The GML shaft position shows the shaft to be approximately 6.5m east of the inventory position (see Figure 4.5). The averaged coordinates of these positions put the shaft from this assessment at 423884.7E and 7779767.8N.



Figure 4.5 GML451 position of Kelly's Queen No1 Shaft

The only old geology series map to depict the shaft was the Logan Jack map. The position derived from the Jack map shows the shaft to be approximately 4m southwest of the inventory position at 4238875.5E, 7779764.5N (see Figure 4.6).



Figure 4.6 R.L. Jack position of Kelly's Queen No1 Shaft

The two spatially derived positions differ substantially in respect to each other by approximately 9 metres. The difficulty lies in the fact that both locations are supported by the information presented. The Jack map position is plausible because there is substantial evidence from the strong correlation between the rectified Jack image and the surveyed shaft positions (see Figure 4.7). The GML position is also supported by the correlation between the both georeferenced images.



Figure 4.7 Shaft Survey v's Jack Map - Vector Displacement Comparison

To determine the most probable location to carry out a field investigation the 1999 aerial photograph layer was included to visualise any existing nearby structures i.e. residences. The Jack position lies directly under the residence and may explain why there has not previously been a comprehensive site investigation. The GML derived location however, is situated between the house and the property boundary (see Figure 4.8) and would be the primary site to investigate due to easier access and being less invasive.



Figure 4.8 Location of Kelly's Queen No1 Derived Shaft Positions to Residence

4.8 Methodology and Accuracy Test Cases

4.8.1 Introduction

The aim of this section is to measure the shaft discovery methodology and accuracy against the known survey position. The following test cases are brief examples to demonstrate this purpose.

For the purpose of the following test case maps the surveyed position of the shaft cap is shown in a red outline and the cadastre is shown in a blue outline.

4.8.2 SH10022

The inventory site SH10022 is located in the north-west portion of the Kelly's Queen Block mine and is shown on GML1595. The shaft has a vertical depth of 999 ft (305 m).

As shown in Figure 4.9 there is good correlation between the historic references and the DGPS controlled cap survey in this location. The DGPS results for this shaft survey returned an averaged precision for all points of 0.27m and the PDOP was 1.7. The image RMSE is as previously stated.



Figure 4.9 Survey Position of SH10022 in relation to Historic Mapping

4.8.3 SH10095

The inventory site SH10095 is located in the Clark's Brilliant, Worcester and Victory Mine Lease (GML1784) and is the No2 shaft. At the time of the Jack mapping the shaft was sunk to a depth of 429 ft (131m) and was later continued to 1041 ft (317m).

As shown in Figure 4.10 the correlation between the Jack map and GML1784 is poor with the distance between the two positions approximately 6 metres. The excavation however would not be restricted by its location as it is situated in road reserve. The DGPS results for this shaft survey returned an averaged precision for all points of 0.37m and the PDOP was 3.4.



Figure 4.10 Survey Position of SH10095 in relation to Historic Mapping

4.8.4 SH10071 and SH10073

The inventory sites SH10071 and SH10073 are located in the Cricket Association Fields in York Street. In 1885 the shafts were part of the Papuan Block Extended Mine Lease (GML490). Two main shafts exist in the north-west corner of the lease, the No1 shaft (SH10071) sunk to a depth of 515 feet (157m) and the No2 shaft (SH10073) sunk to a depth of 1200 feet (366m).

As shown in Figure 4.11 the correlation between the survey positions and the georeferenced imagery are good. On GML490 the survey position for SH10073 is the coincident and SH10071 differs by 2 metres. On the Jack map the shaft positions also agree favourably with the survey positions with SH10073 within 3.5m and SH10071 within 2m. The Reid map only shows SH10071 and this position also agrees within the survey position. The 1999 aerial photography shows the shaft repair process during the excavation stage. In this image the surveyed shaft cap positions are coincident with the excavation shaft pad location.



Figure 4.11 Survey Position of SH10071 & SH10073 in relation to Historic Mapping

The case study test has shown that using historic mapping with DGPS controlled accuracy can provide a level of confidence for the discovery of concealed abandoned mine shafts. There does exist a level of uncertainty with the assumed accuracy of the historic mapping. Throughout this exercise individual datasets afforded differing levels of confidence in their mapping compilation accuracies. For example it was evident that the Reid mapping was not of the same standard as the Jack mapping and therefore should only be used in lieu of the Reid data.

4.9 Summary

This chapter has presented and described the application of spatially adjusted historic data within a GIS to aid the discovery of concealed mine shafts. The chapter has also presented outcomes by summarising the evidence from the results of each case study presented.

Although a level of spatial correctness controls the results derived from each of these case studies, none of the field investigations to verify the findings have been carried out at the time of writing. Therefore is not possible to confirm any of the findings from the individual case studies. The results from the individual case studies did, in a limited capacity show that there is a reasonable argument to continue to use this approach for the more significant and undiscovered abandoned shaft locations particularly in the higher density urban areas.

This chapter has presented the case to measure the methodology and accuracy against surveyed abandoned mine shafts. This test has shown that a level of confidence can be afforded at sites where historic rich information exists

Chapter 5 will evaluate the results of the review, research and applied methodology in relation to the aims of this research project.

Chapter 5 DISCUSSION OF RESEARCH RESULTS

5.1 Introduction

The aim of this study was to review and apply a procedure to support the abandoned mine shaft discoveries in Charters Towers through the combination of modern GIS and surveying practices. This resulted in the development of a geo-spatial methodology for improving the positional accuracy and reliability of abandoned mine shafts. This chapter will analyse the results achieved from previous chapters and evaluate the procedures and techniques used in relation to the aims of this research project.

5.2 Discussion

A procedure aligned to the project aims was developed incorporated the following steps:

- 1. Historic research
- 2. Data assessment
- 3. Fieldwork component
- 4. GIS desktop assessment and development
- 5. Prioritisation assessment; and
- 6. Case studies

The historic research component was identified in the initial project assessment and consisted of the acquisition of the historic information utilised in the compilation of the shaft repair inventory. It was important for the project to assess where, what and how the inventory was compiled. This assessment was the launch pad to the data assessment stage.

One of the problems was that there was limited documentation as to how the shaft repair inventory was developed in respect to the shaft positions. By this stage the original technical research team and project supervisor had left the project. It was evident that even though a large number of the inventoried sites had been located and remediated, the remaining sites would increasingly be more difficult to locate without spatial refinement of the inventory.

It was recognised early that the success of the project was dependent upon the availability of the historic mapping data. It was of great benefit to find that not only had the old geological map series survived but that they had been scanned. There is however a need for the historic imagery to be further improved by the utilisation of ERDAS Imagine software and improved DGPS control to remove the distortion inherent in the paper maps. It was also recognised that limitations with the historic mapping data might exist. These cannot be removed therefore there are inherent assumptions that this data may be flawed. It would greatly improve the confidence levels of using this data if it was understood how the mapping was compiled. This should be further researched in the NR&M library archives.

5.3 Summary

The demonstrated success of the procedure has shown that there is potential to adopt a similar process at other AMLP critical areas because of the wealth of historic data maintained in NR&M's archives.

Prior to this study, very little confidence could be attributed to the location of hidden abandoned shafts from the initial inventory. There now exists a process whereby the location of targeted remediation sites can be assessed using spatially prescribed controls. However, with further development of the DCDB and image rectification the procedure can be further streamlined making it an attractive proposition for the discovery of abandoned mine shafts.

Chapter 6

CONCLUSION AND RECOMENDATIONS

6.1 Introduction

The purpose of this study was to review and apply a procedure to support the abandoned mine shaft discovery program in Charters Towers. The project produced overall refinements to the shaft repair inventory and discovery process.

Queensland has between 16,000 to 18,000 abandoned mines many of these exist outside of the Departments higher profile areas like Charters Towers and Gympie. The completion of this project demonstrated the value of the use of a GIS to improve the Department's capacity in locating previously unknown shafts. This knowledge will further enhance the potential for better allocation of resources into target areas.

Findings to-date, have revealed that correlating the data themes to a single control base has greatly enhanced the confidence levels in the position of unknown abandoned shafts.

Over the period of the program only 23% of the total inventoried abandoned shafts have been remediated to a safe level. The remaining 77% will require a greater level of spatial or technical application for their successful discovery.

Questions were raised regarding the inventory data accuracy and content validation. The existence of some sites in the inventory is not supported by the historic literature. Currently as many as 15% (131 shafts) of all sites have been classified as "write offs", this is a high percentage of the total database which may have been caused by sites not being correctly substantiated at the inventory compilation and field inspection stages ⁷.

6.2 **Recommendations**

The methodology reviewed in this study shows the merit in a spatial approach to improve shaft discovery and prioritisation. Considerable benefits can be realised through a GIS application. This requires the users to have a level of GIS skill and understanding of data presentation and use. To make the built dataset available outside of the Shaft Repair Unit, it is recommended that further study be directed into the development of an effective method of delivering access to the data through an Internet Map Server (IMS). A WEB-based system that incorporates a map interface is strongly recommended as the technology enables the distribution of mapping and GIS capabilities using standard Internet technologies like a web browser.

It is also recommended that a State database should act as an index for future AMLP inventories. Queensland does not have unified abandoned mine inventory. The inventory used for the Charters Towers repair program was developed independently to suit the requirements of that program. The NR&M AMLP unit is currently reviewing the development of seamless database.

⁷ Can include the use of mechanical excavation processes to expose the surface material to find evidence of old shafts}. The question here is whether these sites were not located because of poor inventory compilation positioning, GPS field location prior to selective availability being turned off (+/- 30 metres) or that the site ever existed.

In addition, it should be acknowledged that there exists a level of uncertainty with this approach as this project did not have the capacity for field testing. To field test the re-evaluated sites would involve either drilling or mechanical excavation which could be invasive, destructive and costly depending on the location. As hidden abandoned mine shafts become increasingly more difficult to discover it is suggested that a non-intrusive process should be investigated. There are various forms of non-intrusive applications. Two of these are surface seismic studies and electrical methods. Of these, ground penetrating radar (GPR) may be the cheapest, least destructive and least intrusive process.

Since the mid-1970's, GPR has been utilised to solve an assortment of shallow subsurface problems (typically up to 10m depth) in a variety of disciplines, such as geotechnical engineering, archaeology, forensics and many others. GPR has proven to be successful for high-resolution mapping of subsurface features buried within soil and bedrock stratigraphy. The GPR produces subsurface digital profiles by transmitting high frequency impulses of electromagnetic energy downward into the ground. Some of the applications include the location of buried utilities, cavity detection, underground storage tanks, routing pipelines and cables to name a few.

6.3 Future Work

The use of the DGPS to control the various datasets was an important factor. The underlying purpose of the project was to develop spatial datasets that would rely on the inherited accuracy from this control. The use of DGPS was costly in respect to the number of days required to obtain survey control and this reliance would be eliminated in the event of an upgrade of the DCDB in the City of Charters Towers. The Charters Towers City Council and NR&M are in the

process of upgrading the DCDB. A pilot study has been recently completed by Brazier Motti Surveys of Townsville. This data would vastly improve and simplify the spatial accuracy component.

The success to be gained from the individual case studies can only be measured against the results from the abandoned mine shaft field investigations. This process will be further enhanced by the introduction of Ground Penetrating Radar (GPR) surveys.

6.4 Conclusion

A process has been developed to interpret the various datasets to improve the discovery of new sites. This study has been a precursor to what should be the development of a system that will ultimately support the abandoned mine lands program objectives in the future.

Use of a GIS has proven to be a useful tool in assessing information-rich data for better decision making. Addressing the primary considerations of inventory accuracy and validation will ensure greater confidence at scale for the Queensland AMLP.

Given the scope of the project area, this study has endeavoured to resolve the many problems associated with the discovery of abandoned mines, however many new questions were raised which can only be dealt with in future studies on the subject. Ultimately the success of future discoveries will depend on the reliability of the data it collects. With the responsibility and duty of care to the public and the always present, possibility of litigation, government can no longer afford to blindly accept spatial uncertainty.

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LIST OF APPENDIXES

APPENDIX A

Project Specification
Appendix A Project Specification

University of Southern Queensland Faculty of Engineering and Surveying

ENG 4112/4903 Research Project PROJECT SPECIFICATION

FOR:	Gregory Paul NELSON-WHITE
STUDENT NUMBER:	0019823444
TOPIC:	Charters Towers Abandoned Shafts Study - A Spatial
	Solution
SUPERVISOR:	Dr Frank Young
ASSOCIATE SUPERVISOR:	Mr Kevin McDougall

PROJECT AIM: To assess and develop an effective process using a desktop Geographic Information System (GIS) application, for the location, validation and prioritisation of abandoned mine shafts in and around the Charters Towers area. The study will seek to utilise all available forms of historic and contemporary data to improve the reliability of abandoned shaft locations through desktop assessment supported by field data collection methods. In addition, site prioritisation to be supported by derived risk assessment modelling.

PROGRAMME:

Issue B: August 2005

- 1. Review Abandoned Mine Land Program (AMLP) initiatives.
- 2. Development, testing and reporting of accuracy comparisons between different data sets.
- 3. Report on the overall benefits to using historic data for the location of abandoned mines in an urban built environment.
- 4. Development of risk model based on improved datasets.
- 5. Assessment and reporting on risk modelling.

As time permits:

6. Evaluate the use of a SQL database through a web page front-end (PHP) to improve the 'abandoned mines database', access and use.

AGREED:	upervisors)
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(dated) __/__/

APPENDIX B

Capped Shaft Connection Survey Plan Examples



Appendix B Capped Shaft Connection Survey Plan Examples



APPENDIX C

GML & Survey Plans - Phoebe Main Shaft

Appendix C GML & Survey Plans - Phoebe Main Shaft



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APPENDIX D

GML Plans – Day Dawn P.C. Shaft







APPENDIX E

GML Plans Bonnie Dundee No. 2 Shaft







APPENDIX F

GML Plans – Kelly's Queen Block No1 Shaft



Appendix F Kelly's Queen Block No1 Shaft

