University of Southern Queensland
Faculty of Engineering and Surveying

ASSESSING RTK GPS FOR A SUBURBAN SURVEY PRACTICE

A dissertation submitted by

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ABSTRACT

This thesis analysed the use of RTK GPS and determined its feasibility for use as a one person operation within a suburban survey practice and its capacity to substitute for a two person total station field party.

Cadastral surveying within Australia is regulated by legislation. This legislation should not exclude any valid measuring technique or system but in some cases the current legislation is heavily weighted towards the use of Total Station technology.

The project was tested the two person total station and one person RTK GPS techniques in five (5) complete and different surveys. It was discovered in terms of cost that the RTK GPS system competes quite well with the Total Station system as the size of the projects increased and in some instances the time taken to complete some surveys was substantially less. When RTK GPS is used as part of a closed figure it does satisfies not only class C for cadastral surveys but the required accuracy for all the surveys.

The level of skills required for the use of RTK GPS was determined to be marginally higher, as the user will require some modification to field practices and re-familiarisation of certain geodesy concepts. Such as the difference between AHD heights and GPS heights and the distinction between ground distances and MGA distances.

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CERTIFICATION

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I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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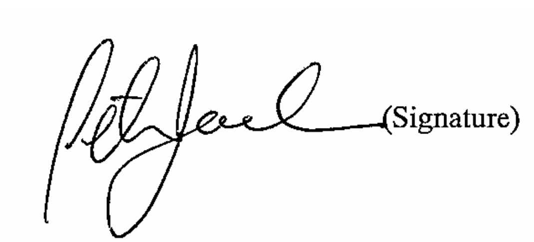

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CHAPTER 1

INTRODUCTION

'The use of GPS in the legal cadastral system is extremely attractive because of its ability to perform precision measurements more economically in many cases than conventional survey methods. There is now a need to provide a system of Legal Traceability for GPS in order for it to fulfil its promise in the cadastral area' (Alexander, 1992)

1.1 Background

Over the past 20 years the Global Positioning System (GPS) surveying has revolutionized survey practices. The 24 satellite constellation arranged in 6 orbital planes each with 4 satellites, has offered surveyors (and others) uninterrupted, accurate three dimensional position in all weather conditions. The advent of Real Time Kinematic (RTK) GPS with occupation times reduced from a few minutes to only a few seconds has allowed us to achieve accurate and instantaneous results in the field. Unlike conventional equipment, which is hampered by its need for intervisibility between stations, a two-man operation and the weather, RTK GPS can dramatically decrease the time and manpower needed to complete surveys. This has led to it becoming prominent in larger scale practices such as mining, engineering and hydrographic surveying.

Its progress into cadastral surveying and in particular smaller private practice has been delayed, due to its perceived elevated cost (in relation to total station technology) and the inability to establish a legal traceability of GPS measurements. There is a need to establish its benefits and limitations in relation to urban cadastral practices.

1.2 Research Aim & Objectives

The aim of this research is to assess the suitability of RTK GPS for use in a suburban survey practice. To achieve this, this project will seek to achieve the following objectives.

Objective 1: Determine the feasibility of the one-man RTK GPS field party to replace the current two-man field party with a Total Station.

Objective 2: Complete 5 surveys using RTK GPS and traditional methods to compare the advantage(s)/disadvantage(s) of both systems.

Objective 3: Determine the suitability of RTK GPS for cadastral re-instatement requirements under New South Wales, Queensland and Victorian Legislation.

1.3 Justification

The Global Positioning System (GPS) has been utilised by surveyors for the past 20 years to determine accurate positions anywhere on the surface of the earth. Recent advances in GPS technology and in particular Real Time Kinematic (RTK) has seen GPS establish itself within the surveying profession to a point where it has become just another tool for the professional surveyor. It has been proven that Real Time Kinematic GPS has provided the surveying community with a potentially powerful tool for performing cadastral surveys (Boey & Parker, 1996).

While technology has evolved to a stage where commercial products offer user friendly hardware/software and suggest techniques that improve the productivity of RTK GPS at a high accuracy; legislation that governs the use of GPS for cadastral surveying in some states has remained unchanged for up to 10 years.

In 1997 it was recognised by the Australian Standards Commission that the 'recognised value standard' for GPS measurement is the Australian Fudicial Network (AFN), thus enabling legal traceability of GPS measurements. The current interim legislative arrangements that are in place do not discourage the use of GPS but limit its use for cadastral surveys. Despite the lack of formal procedures for establishing legal traceability, there has been some pressure to accept GPS measurements for cadastral surveys. (Geoscience Australia, 2005)

If the use of RTK GPS for cadastral surveys can be legally and financially justified, then it will become just another tool, like the universal total station.

1.4 Research Methodology

The scope of my research was to investigate the feasibility of a one person RTK GPS field party to substitute the two person Total Station field party and to identify the cadastral re-instatements requirements for RTK GPS under New South Wales, Queensland and Victorian Survey Regulations.

The methodology for the project utilised 4 stages.

1. The literature review in Chapter 2 will illustrate the current directions, regulations and best practice guidelines for the use of a Total Station and RTK GPS for cadastral surveys. The concept of legal traceability under the National Measurement Act will be identified.

2. Chapter 3 outlines the methodology used to evaluate the cost to a business and the level of skills required when implementing both systems along with the consequential effects of any outcomes.

3. The Data Collection process in Chapter 4 details how both systems were tested in five (5) complete and different surveys, initially using the 2 person conventional technique and then again using the 1 person RTK

GPS procedure. This process was completed using New South Wales standard practices.

4. Chapter 5 has the results of the data collection process and the evaluation of both systems in terms of cost, time, accuracy, resources utilised and the level of skills required for each survey.

1.5 Conclusion

This project aims to address the legal and practical problems faced by a professional surveyor in a suburban practice when using RTK GPS. Five complete and different surveys were completed using RTK GPS and conventional means to help identify when a one person RTK GPS field party can replace the two person total station field party.

The current directions, regulations and best practice guidelines for the use of a Total Station and RTK GPS for cadastral surveys are discussed in chapter 2, Literature Review. This chapter will identify the current regulations in New South Wales for a total station and the suitability of current legislation for use with RTK GPS in cadastral surveys within New South Wales, Queensland and Victoria. It will also identify the concept of legal traceability, under the National Measurement Act 1960.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction.

This chapter will review literature to establish the need for RTK GPS to define and re-instate boundary positions within New South Wales, Queensland and Victoria.

This review will help identify the diverse nature of GPS with respect to total station technology and how a professional surveyors' methodology requires alteration when measuring with RTK GPS.

This review will first identify the current practices of a total station with respect to New South Wales legislation. Subsequently New South Wales, Queensland and Victoria will be reviewed in regards to the current regulations, government directions and operation manuals used when performing cadastral surveys using RTK GPS.

Finally, a number of case studies will be analysed in regards to the adaptation of RTK GPS for use in a suburban practice and the current shortfall in the number of surveyors servicing the community to further justify a reduction to a one person field party.

2.2 Current Two Person Total Station Practices

Cadastral surveys have traditionally been performed using the well established techniques of traversing and radiation (Gerdan, 1991). Traversing, the act of establishing traverse stations and making the necessary measurements is one of the most basic and widely practised means of determining the relative location of points. Fryer et al. (1994) Traversing with a theodolite has remained relatively unchanged since the inception of total station technology in the early 1980's when it replaced optical theodolites with independently operated electronic distance measurement (EDM).

In the Torrens title registration system, the indefeasibility of title to land is guaranteed by the government. Such a guarantee is only meaningful if the boundaries of land are identifiable beyond any reasonable doubt. (Boey, 1996) Therefore the practice of cadastral surveying in Australia is regulated by legislation.

2.2.1 New South Wales Cadastral Survey Requirements

Cadastral surveys within New South Wales are standardized by the Surveying (Practice) Amendment Regulation 2003 under the Surveying Act 2002. The purpose of this regulation was to amend the Surveyors (Practice) Regulation 2001 and to insert new and remove old or obsolete provisions.

2.2.1.1 Distance Measurement Requirement

Part 3 clause 14 (2a) of the Surveying Regulation 2001 specifies how the accuracy of any equipment must be determined in relation to the Australian primary standard of measurement of length, meaning the National Measurement Act 1960. This gives rise to Clause 14 (4) where a surveyor must not use any EDM unless it is verified once a year and immediately after repair against the State primary measurement of length.

By following the articles stated, a surveyor when making a cadastral survey must have his/her total station checked at least once a year to ensure that all distances made will be considered legally traceable.

2.2.1.2 Accuracy Requirement

Clauses 24 through 27 detail the accuracy of angular and length measurements required for surveys. Under these conventions the surveyor must check angular works by means of a complete angular close to remove any errors accumulated whilst traversing or when required, between established permanent survey marks.

Clause 25 (2) determines the maximum allowable misclose of 20 seconds + $10\sqrt{n}$ seconds or 2 minutes (whichever is the lesser). This accuracy standard for angles is quoted in two parts: a constant error and a formula which relates to a fraction of the smallest graduation of a theodolite and the number of observed angles. (Boey, 1996)

Clause 26 states the misclose vector $\sqrt{(a^2+ b^2)}$ (where "a" is the misclose in eastings and "b" is the misclose in northings) checks the accuracy of all measurements by analysis of the closure of eastings and northings in the survey.

In the survey regulations this is the first mention of coordinates being used in checks on survey practice. Holstein & Williamson, (1985) stated that coordinates are a fundamental and important component of any modern cadastral system. Their primary role should by for administrative purposes to support cadastral mapping and their secondary role is to assist the redefinition of cadastral boundaries, and the integration of survey and spatial data.

Clause 27 defines the accuracy of length measurements and determines "a surveyor must measure all lengths to an accuracy of 6mm + 30 parts per million (ppm) or better at a confidence interval of 95%." These requirements for angle and distance measurement are long established practices that have remained relatively unchanged and can be verified against primary standards of measurement.

2.2.1.3 Adopting a Datum Line

Clause 30 of the Surveying Regulation 2001 details the procedure for adopting a datum line. The Surveyor General's Directions No. 3 Control for Cadastral Surveys outlines the standard of accuracy expected for coordinates and the recommended field practices required to obtain that accuracy. If followed correctly and using these practices, the results will satisfy the requirements of clause 30.

This recommended field practice is to protect against any gross errors accumulated in the field. All horizontal angles are determined by two rounds of face left and face right observations and distances are to be measured both ways with the difference being less than 6mm + 30ppm.

2.3 Real Time Kinematic (RTK) GPS

The RTK approach is a differential positioning technique that uses known coordinates of a reference station occupied by one receiver to determine coordinates of unknown points visited by a rover receiver (El-Mowafy, 2000). Similar to static GPS the reference station is set on a point of known coordinates but the use of a data link, to transfer measurements acquired at the reference receiver to the roving receiver, permits the calculation of the rover coordinates at the time of measurement (Lemmon & Gerdan 1999).

To begin the receivers must undergo an initialisation procedure. This procedure uses a process called double differencing. Double differencing is used to aid the computation of the unknown number of wavelengths between a satellite and the receiver at the moment of the first simultaneous measurement of both GPS receivers. This process is known as "ambiguity resolution" (Roberts, 2005). Once ambiguities have been resolved the rover receiver produces centimetre level positions with respect to the base station receiver. This is done by forming (a minimum) of four pairs of satellites (see figure 1) where the receivers count the whole number of wavelengths from each satellite to eliminate the largest error sources, specifically satellite and receiver clock bias.

Once successful initialisation has been performed, the rover is free to move about collecting centimetre accurate 3-dimensional data in real time. Any loss of lock on the satellites will require the receivers to undergo this initialisation procedure again.

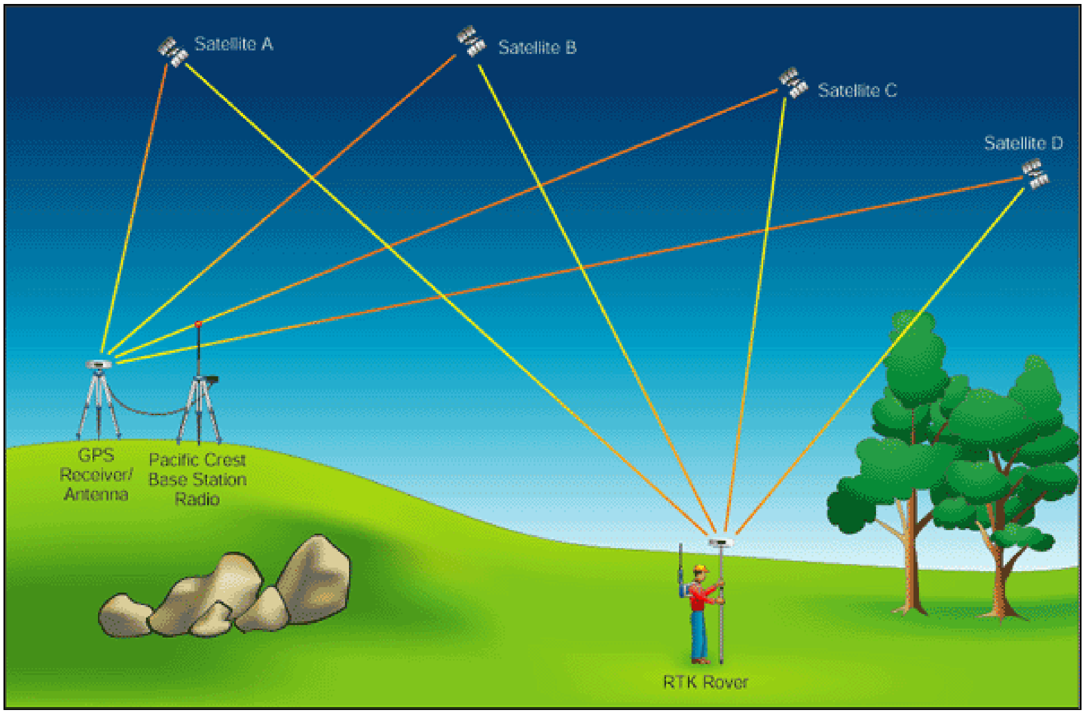

Figure 1 Real Time Kinematic GPS

2.3.1 Cadastral Reinstatement using GPS within New South Wales

Clause 23 - Surveys using the Global Positioning System, of the Surveying Regulation 2001 states…

> *When making a survey using global positioning system equipment, a surveyor must use an approved global positioning surveying technique that will achieve the level of accuracy appropriate to the type of survey*

being undertaken, as specified in Standards & Practices for Control Surveys.

This is the only reference to the use of GPS in the Surveying Regulation 2001.

The Surveying Act 2002, like previous acts; creates discretionary powers to the Surveyor General to make consequential amendments and waive certain legislative requirements. These discretionary powers must be exercised within the scope of the legislation. Such powers allow greater flexibility in the administering of the details of the legislation by the issuing of survey practice directions (Boey, 1996). The advantage of granting discretionary powers to the surveyor general is that the directions prepared in this manner are not required to be tabled in parliament and therefore avoiding lengthy debate.

2.3.1.1 Surveyor General's Directions No. 9 GPS Surveys

The Surveyor General's Directions No. 9 GPS Surveys is a manual that outlines the recommended procedures for the use of GPS to undertake cadastral surveys in accordance with the Surveying Regulation under the Surveying Act 2002. The directions were prepared following the release of the Intergovernmental Committee on Surveying and Mapping (ICSM) publication: Standards and Practices for Control Surveys (SP1) which includes a comprehensive evaluation of GPS techniques.

These directions come with limitations in that they do not represent legal traceability of measurement. The directions expand further by saying the most appropriate way to maintain accuracy is by connection to the State Survey Control network which in itself has legal traceability and additionally that all existing regulations, specifications, procedures and practices still apply.

Part 3 of the directions set out the measurement validation criteria needed for the authorized use of GPS receivers in cadastral surveys. The condition for validation is acceptable if the difference is less than 25mm + 5 ppm for horizontal coordinates and 60mm + 12 ppm for height but maintains a surveyor should be concerned if the difference is more than 15mm + 3 ppm for horizontal and 35mm + 8ppm for vertical.

In order for a set of GPS equipment to be validated the receivers and associated post processing software must be validated on an approved state GPS test network or a local network of state survey control marks of Class B for horizontal and class LC for vertical. No mention has been made in regard to validating the RTK component of a GPS receiver.

Part 4 of the directions refer to the choice of observation technique used. Paragraph 2 states "If GPS observations are to be used in the preparation of a survey plan, then the observations must be retained. Where "real time" GPS is used, it is required that the observations taken to determine final measurements are recorded. These measurements must be checked as part of a closed figure".

The observational requirements are detailed in part 5 of the directions. Here the guidelines define that rapid static and kinematic methods contain small biases and should not be used to derive distances less than 120m. If it is necessary they must be done in part of a closed figure or by EDM.

This requirement and others identified by Roberts (2005); an example being Regulation 27 that state ““a surveyor must measure all lengths to an accuracy of 6mm + 30 ppm or better at a 95% confidence interval.” (where the standard error of an RTK GPS receiver is 10mm + 1ppm), creates the impression that these directions were created as an interim measure to satisfy the pressure exerted on the Surveyor General’s department by the professional surveying community for the authorised use of GPS in cadastral surveys.

2.3.2 Cadastral Reinstatement using GPS within Queensland

Cadastral surveys within Queensland are standardized by the Survey and Mapping Infrastructure Regulation 2004 (SMIR) under the Survey and Mapping Infrastructure Act 2003 (SMIA). The purpose of the SMIA is to provide for the development, maintenance and improvement of State Survey, Mapping Infrastructure and the coordination/integration of cadastral boundaries, through regulations. Before ascertaining the survey requirements for the use of GPS within Queensland it is important to understand how the Act and regulations legalize survey practice.

The main focus of the Act in regards to current survey practice focuses on developing a non prescriptive survey standard that is consistent with the principles stated in any regulation created under the Survey and Mapping Infrastructure Act. Part 2 section 11 of this Act notes that any inconsistencies between a survey standard to those in a guideline; the guideline becomes subordinate to that of the standard in the Act.

With the recognition of a survey standard managed under the SMIA, the Survey and Mapping Regulation 2004 identifies the obligations a surveyor must adhere to when re-instating boundaries. The Department of Natural Resources, Mines and Energy (NRM&E) has under section 6(1) of the SMIA published the Cadastral Survey Requirements Manual version 2.3. This document contains the standards and guidelines used for cadastral re-instatement.

2.3.2.1 Survey Requirements (NRM&E)

Under Section 3.4.2 - Measurement Accuracy, points out the accuracy requirements for a cadastral survey. This section deals with accuracy in two portions, angular misclose and linear misclose. It is heavily weighted towards total station practices but part (c) of this section states “by a method appropriate to the technology being used for the survey.”

This technology mentioned does not preclude GPS if the method is appropriate and it can satisfy the survey standards of an angular misclosure of less than 2 minutes and the linear misclosure of:

- 10 mm plus 1 part in 5000 of the total distance traversed; or
- 20 mm plus 1 part in 2500, if the survey is in broken terrain; or
- 20 mm plus 1 part in 2000, if another surveyor's work is included in the surround; or
- 20 mm plus 1 part in 1000, if a survey effected before 1890 is included in the surround; and if
- The vector accuracy is less than 10mm + 50 ppm for all lines surveyed.

If GPS is to be used for a cadastral survey and cannot satisfy these requirements; the surveyor must under Division 2 Section 18 of the SMIA, apply to the chief executive for an exemption for a deviation from survey standards. Throughout the DNRM&E manual it does not mention GPS until section 3.31.2 Specification for Surveys in Remote Areas where GPS is one of the preferred means of determining cadastral boundaries. This circumstance is the only occasion where coordinates of boundary corners can be stated on a registered cadastral plan; and only if the survey has been connected to the state control network at a precision of Class C in accordance with the ICSM document Standards and Practices for Control Surveys (SP1).

2.3.2.2 Surveyors Operations Manual (SOM)

The Board of Surveyors in Queensland has identified the need for cadastral surveys using GPS. Section 7 of Part B of the manual offers guidance for the use of GPS in cadastral surveys. Section 7 is divided into 3 chapters, the first is an introduction. The second deals with the measurement aspects of GPS and the third deals with the cadastral aspects.

The Board of Surveyors identified GPS as a measurement tool and it does require surveyors to adhere to normal cadastral marking standards. The SOM refers to the ICSM document (SP1) for the standards of accuracy and observational techniques for use with GPS.

The current regulations and manuals within Queensland do not exclude the use of GPS. In some cases it recognises it as a preferred means of completing surveys in remote areas. The guidelines offered by the SOM merely reflect the standards and practices presented by the Inter-governmental Committee on Surveying and Mapping in their document referred earlier to as SP1.

2.3.3 Cadastral Reinstatement using GPS within Victoria

Cadastral surveys within Victoria are standardized by the Surveyors (Cadastral Surveys) Regulations 1995 under section 33 of the Surveyors Act 1978 and the Survey Coordination Regulations 2004 created under the Survey Co-ordination

Act 1958. The objectives of these regulations are to regulate and control the making of cadastral surveys by licensed surveyors and to provide for standards of measurement, accuracy and to provide for the connection of new surveys to existing surveys.

Regulations 5 and 13 of the Surveyors Regulations 1995 and the Surveyors Co-ordination Regulations 2004 respectively, state that a surveyor must use and maintain equipment that-

(a) has been compared to the following unit of measurement-

(i) for length, the metre; and

(ii) for plane angles, degrees, minutes and seconds; and

(b) is capable of achieving the levels of precision set out in part B of SP1 and schedule 6 for the classification of the survey.

The prescribed use of equipment as mentioned can be interpreted as ruling out the use of GPS for cadastral surveys. GPS measuring technology and the associated survey techniques is fundamentally different from conventional surveying. (Boey, 1996) GPS is a position based measuring technology that generates a 3 dimensional coordinate and does not directly measure length or plane angles; although distances in metres and angles in degrees, minutes and seconds are repeatedly derived from GPS observations.

These outmoded and inappropriate legislative requirements have been identified by Boey (1996) and subsequently led to the formation of the Proposed Surveying (Cadastral Surveys) Regulations 2005 regulatory impact statement in April of this year. This report sent to Land Victoria by the Allen Consulting Group seeks to replace the sun-setting regulations in the Surveyors (Cadastral Surveys) Regulations 1995.

The Surveyors (Cadastral Surveys) Regulations 1995 were framed so as to facilitate the movement from a ‘prescriptive’ regulatory environment that established specific requirements and inputs to an ‘enabling’ regulatory environment that focuses on outcomes. (Parker, 1998) The aim of these regulations was to move a lot of the responsibility back to the licensed surveyor who applied his/her professional judgement to satisfy professional standards rather than relying on compliance to regulatory standards. The 1995 regulations were regarding as fulfilling the requirements needed for cadastral reform in Victoria by providing greater scope for self regulation.

2.3.3.1 Victorian Board of Surveyors Handbook

Section 12 of the Survey Practice Handbook and Surveying Using the Global Positioning System are documents prepared by the Victorian Board of Surveyors identifying the ICSM standards and practices (SP1) as the nationally accepted technical standards and specifications for horizontal and vertical control surveys. It advises that surveyors should adhere to these guidelines whenever appropriate to integrate GPS techniques into their surveying operations.

2.4 ICSM Standards & Practices for Control Surveys (SP1)

The NSW Surveyor General's Directions No.9 GPS Surveys, the Queensland Surveyors Operations Manual and the Victorian Survey Practice Handbook all recognize the ICSM document Standards and Practices for Control Surveys (referred to as SP1) as the nationally accepted standard for the use of GPS. Therefore it is necessary to include this document in the literature review of this dissertation.

The text is divided into 2 parts; Part A identifies the Standards of Accuracy, that are independent of technique employed and Part B the Best Practice Guidelines for Surveys and Reductions that provides the surveyor with a guide to minimally acceptable practices which apply to the equipment and the reduction methods used.

2.4.1 Standards of Accuracy

In 2000, the ICSM adopted **positional** and **local uncertainty** as new simple methods of categorizing the accuracy of coordinates. The ICSM recognized that certain GPS observations are obtained independently of existing control networks. Positional Uncertainty is used to describe the quality of a position that is obtained independent of the survey network, from sources such as Geoscience Australia's on-line positioning service. (AUSPOS)

Local Uncertainty is similar to order and replaces it after 2005. Local uncertainty is defined as being the average measure, in metres at the 95% confidence interval, of the relative uncertainty of the coordinates of a point(s) with respect to adjacent points in the defined frame. In the case of the majority of surveys it is the relative uncertainty of the MGA coordinates of a point to ones surrounding it within the Geocentric Datum of Australia 1994 (GDA94).

The term class has remained unchanged and continues to be a function of the planned and achieved precision of a survey network.

2.4.2 Best Practice Guidelines

The best practice guidelines provides a surveyor with directions to the minimally acceptable practices applied to particular types of equipment and reduction methods to meet the standards of a specific class and order of a survey.

The guidelines establish a number of requirements for the use of RTK GPS in section 2.6.8.4 on page B-22. A number of the general guidelines will apply to the surveys utilised for this project, they are as follows:

1. *Dual frequency receivers offer an advantage for ambiguity resolution and mitigation of the effects of ionospheric delay*
2. *Multipath can be a significant source of errors when short observation times are used. Special attention should be paid to this issue. Both, base*

and rover receiver should be located in a low multipath environment. Where multipath is likely at the rover site, occupation time should be increased to allow the effect to be averaged away as satellite geometry changes.

3. *To allow sufficient change to the satellite constellation being used and improve detection of errors such as multipath, reoccupations should be made more than 45 minutes apart with an independent ambiguity resolution*
4. *Two independent occupations of all new stations from 2 base stations are a recommended minimum. Such reoccupations are the most reliable means of checking against systematic or gross errors. It is desirable that some of the new stations in each RTK survey are re-occupied from a third base station or checked using conventional observations*
5. *Typically both or all base stations should have known three-dimensional coordinates. Use of at least two known base stations checks that no anomalies occurred at either of the base stations or at any of the new stations and that the survey is consistent with the datum*
6. *Where a base station is one of the new stations in the survey (e.g. due to it having better radio coverage than a known station etc), it is prudent to occupy another known station with the rover. Values from this occupation should also be used to derive a mean value of the new station before it is used as a base station*
7. *The following attributes should be ideally logged with the derived coordinates: Base Station Identification, date, Time, Datum, Number of satellites observed and standard deviations of the derived coordinates*

Section 2.6.11 Analysis Using Misclosure Comparisons identifies that a least squares adjustment may not be appropriate for such techniques as RTK and analysis using misclose comparisons may be sufficient. A minimum of two independent occupations of all new stations in the survey should be made using two base stations and the resultant 2D coordinates compared.

Testing of the survey in section 2.6.11.2 outlines by using the manufacturers' specifications for the observation technique, it can be concluded that the GPS observations are agreeing with the manufacturer's specifications at the 95% confidence interval. Once the observations have passed this misclosure test, the coordinates of the station can be calculated as a simple arithmetic mean of the 2 values.

2.5 Legal Traceability and the National Measurement Act 1960

The National Measurement Act 1960 (NMA) provides the commonwealth standards for measurement. This Act is enforced by the National Standards Commission (NSC) and forms the basis for all legal traceability procedures. On September 11 1997 at the NSC meeting in pursuance of paragraph 8A (1) of the National Measurement Act 1960 it was determined that the physical quantity position was the 'recognised value standard' for GPS measurements through the Australian Fudicial Network (AFN).

The AFN consists of eight highly stable marks throughout Australia that are monitored by continuously operating GPS receivers. These eight marks using the reference ellipsoid – Geodetic Reference System 1980 (GRS80) with a semi-major axis (a) of 6 378 137 metres and an inverse flattening (1/f) of 298.257222101 within the International Earth Rotational Service Terrestrial Reference Frame 1992 (ITRF92) at the Epoch 1994.0 make up what is the recognised value standard for the measurement of position. It is expected that this recognised value standard will eventually be cascaded from the eight AFN positions through the Australian National Network (ANN) of 78 marks and then to the National adjustment of over 7000 marks. This will provide a readily available network for ensuring that the GPS equipment is operating correctly. This recognised value standard, when combined with an integrity monitoring system and best practice guidelines will enable the legal traceability using GPS measurements (Parker et al, 1998).

This will lead to its subsequent use in cadastral surveying. Currently there is a lack formal procedures' setout for establishing legal traceability within the New South Wales, Queensland and Victoria and connection to the established state survey control networks is said to establish traceability when using GPS.

2.6 Height determination using RTK GPS

It has been well documented that horizontal position and the repeatability of such observations can be reliability achieved to the centimetre level of accuracy (El-

Mowafy, 2000). However, it is inherently less precise and accurate for the determination of ellipsoidal heights, and there is a need to transform these heights to the local vertical datum (Featherstone & Stewart, 2001). Height measurements with RTK GPS, is at minimum, twice the stated accuracy for the horizontal component (Leica RTK GPS User's manual, 2004).

The Australian Height Datum (AHD) is the local vertical datum widely used throughout Australia. In 1997, Featherstone and Stewart determined the AHD heights and ellipsoidal heights of a 60 point test network. The AHD height was determined from an existing AHD benchmark with a digital barcode level and invar staves, the heights satisfied the requirements for class A levelling techniques with a misclose of less than 4mm per √km as specified in the ICSM document SP1.

Three independent contractors were then asked to determine the WGS 84 ellipsoidal heights of the 60 control points over varying baseline lengths. The results concluded that the RTK GPS solution degraded as the baseline length increased. When accounting for the error in the control AHD heights of 2mm the expected accuracy for baseline lengths less than 5km was 53mm at a 95% confidence.

When repeated, the observations showed that baselines less than 5km showed small negative differences. This was concluded to be due to incorrect modelling of the geoid gradient between the base stations. It was the expected result given the deliberate east-west orientation of the test network (Featherstone & Stewart, 2001).

2.7 Shortage of Surveyors and Technology

The number of registered surveyors in New South Wales has fallen from 1550 in 1991 to 1000 in 2003.The average age of a New South Wales registered surveyor is 51.5 years, and with 65% of the current professionals expected to retire within the next ten years urgent attention is needed. (Torbay, 2005)

At the time of settlement a survey party contained 1-2 surveyors, a number of axmen, chainmen, and labourers. The development of EDM technology saw the demise of the steel band; and the numbers within a survey party have fallen considerably in the past 30 years. The rapid development of total station and data recorder technology has provided surveyors with a precise, efficient data collection tool. (Gerdan, 1991)

Undoubtedly, instrument technology will continue to be developed and improved, offering surveyors greater flexibility, efficiency and productivity. (Boey, 1996) When using RTK GPS it has been proven that once successful initialisation has been achieved, the RTK rover antenna becomes a high precision coordinate generator that does not require line of sight, unlike total station techniques. (Roberts, 2005) Hence the need to further investigate the feasibility of a one person RTK GPS field party in a suburban environment.

2.8 Summary

This review has identified the existing total station practices within New South Wales and the cadastral re-instatement requirements for the use of GPS within New South Wales, Queensland and Victoria. It has determined that while GPS is permitted under the current legislation, the cadastral measurement requirements are heavily weighted towards the use of total station technology.

The Acts or Regulations governing cadastral surveys within each state rarely contains details on the use of GPS for boundary surveys. The discretionary powers given to the boards of surveyors or surveyors general in each state contains directions or guidelines on the use of GPS for cadastral reinstatement. This power to bypass parliament is to not only avoid lengthy delay; but to circumvent the contribution of parties (i.e. politicians) in a process beyond the scope of their professional expertise.

All the Australian states reviewed describe the accuracy standards in the form of two parts; a constant error and a formula which relates a fraction of the smallest graduation of a theodolite or EDM. These accuracy standards restrict the use of position based technology that provides three dimensional vectors between ground marks (Boey & Parker, 1996). The cessation of the term ‘order’ and the subsequent utilisation of ‘positional and local uncertainty’ at the end of this year by the ICSM should pave the way for the adoption of new accuracy requirements for cadastral surveys, by providing tolerances that are better suited to the use of GPS.

Surveyors in the past have been regulated to what technology can and cannot be used. The complying nature of cadastral surveying indicates that when the individual is given a choice of abiding by well practiced, inflexible rule like ones governed by total station use or adopting ‘a practice that is adequate to obtain the accuracy for a cadastral survey required under these regulations’(Victorian Survey Regulations, 1995). The individual will tend to err on the side of caution, and adopt the former, sometimes less efficient alternative as a safeguard.
Chapter 3 of this dissertation reveals the methodology that has been implemented to accurately assess RTK GPS suitability to use in a suburban survey practice.

CHAPTER 3

METHODOLOGY

3.1 Introduction

After reviewing the literature in chapter 2; which determined the procedures, guidelines and equipment to be utilised for the methodology of this project, this chapter will develop a methodology to achieve the 3 objectives (refer 1.2) and the consequential effects of any outcomes.

3.2. Expectations

Several criteria were needed to be considered in order for an accurate comparison between the two techniques. Wages and the hire cost of equipment were estimated.

3.2.1 Wages of staff

For the time required for a survey practice to use a one person RTK GPS field party instead of a 2 person total station field party the wages of staff utilised to complete the surveys will be used. A rate of $25 per hour for a surveyor and $17 per hour for a field hand has been used.

It is an opinion of the author that if the time saved was used as the comparison, it would indicate the time required to be cost out; which at times ends up being a saving to the client. It is also the opinion of the author that surveyors in the past have adopted new technology as a cost and time saving initiative to their business, but instead have passed the saving onto their client by charging out less time and fees. I attribute the highly competitive nature and unprofessional pricing tactics of some suburban survey practices for this.

3.2.2 Equipment Hire

The Total station used for the exercises was provided by my employer. A charge out rate of $150 per day has been used to hire a total station of equal capabilities to the one utilized for the surveys. The RTK GPS unit was hired at a rate of $500 per day. This rate did become less if hired on a weekly, monthly or yearly rate.

It was also estimated for the smaller surveys (boundary identification and house setout), that two could comfortably be completed per day. This halved the daily hire out rate applied to the costing.

3.3 Equipment

The Total Station theodolite used for the field exercises was a Topcon GPT-2005. This instrument reads to 1” of arc and was in good adjustment at the time of the surveys. The RTK GPS was the Leica GPS GX1230. The GX1230 receiver is a dual frequency, geodetic, real-time RTK base station and rover, hired from C.R.Kennedy & Co of Pyrmont, Sydney. The manufacturer’s accuracy of the RTK is 10mm + 1ppm (horizontal), and 20mm + 1ppm for the vertical component.

Figure 2 Topcon GPT-2005

Figure 3 Leica 1200 GPS Rover

3.4 Field Practices

The guidelines reviewed in chapter 2 form the basis of the process required to collect data. The practices for the total station component for each of the surveys will be conducted under the New South Wales guidelines identified in section 2.2.1.Where the accuracy needs for a survey have statutory requirements, the nationally accepted guidelines reviewed in section 2.4 will be used.

3.5 Level of skills

The level of skills required will be analysed by looking at the statutory requirements of the survey with the educational requirements, skills and applied knowledge required to fully understand the process of how RTK GPS determines positions as a guiding factor on how the skill levels have been deduced.

3.6 Consequential Effects

The primary beneficiaries of the potential changes would be the surveying profession. If progression from a two-person field party with a total station towards a one-person field party with a RTK GPS receiver is possible, the rewards for the long undervalued profession would begin to flow.

For years the surveying profession has been dependent on a two-person field party for operation. The need for a field-hand/chainman has always been a consideration for a suburban practice. If one employee calls in sick, is injured or on leave, this significantly reduces the earning power of the organisation. A one person operation could effectively increase the productivity of a survey practice with a reduced labour requirement.

Our community has become a more litigious society, and hence the level of insurance and cost of premiums have increased dramatically in the past few years. If the insurance cost could be reduced for personnel, and required field-party members for some surveys reduced in half, we could see an even more flexible and efficient profession serving the community.

Potential impacts would see the further reduction in the number of field-hands required for survey work. Anecdotal evidence within the profession suggests that good field-hands, especially within suburban survey practices, are difficult to find under normal circumstances. This impact would seem to have very little short-term effects. Long term effects could see less and less new surveyors becoming trained. In the past new surveyors have gained on the job experience by first becoming competent field-hands.

A small number of surveyors in the past may have cursed disinterested, lazy and unreliable field-hands, but their position remain the basis for training good field surveyors through a mentoring process: hence the need to determine the feasibility for a one person RTK GPS field party to replace the 2 person field-party with a total station.

If feasible, a one person field party could be seen as a way to reduce overhead and wages costs for a survey practice. Surveyors are bound to adopt industry best practice at all times combined with the surveyor's code of ethics requirements and professional practice sustainability; this will ensure the interests of the community, respect for the individual, and the interests of the client remain first and foremost objectives of the profession. The proposed research will enable this to occur.

3.7 Summary

This chapter has discussed the methodology used for collecting the data for a comparison between the two person field party with a total station and a one person RTK GPS field party. The data collected in chapter 4 analyses the cost, time, accuracy, resources utilised and the level of skills required for a business to complete each survey.

CHAPTER 4

DATA COLLECTION

4.1 Introduction

This chapter will collect data to determine how well a one person RTK GPS unit is suited to a suburban survey practice and its potential to replace the 2 person field party with a total station.

This method of practice will be tested in five (5) complete and different surveys, initially using the 2 person conventional technique and then again using the 1 person RTK GPS procedure.

The cost, time, accuracy, resources utilised and the level of skills required to complete the surveys were used as a means of comparison.

4.2 Data Collection

Three (3) of these surveys were of a standard procedure for a suburban practice, one is of a non-standard nature and the final survey is a combination, one utilising both techniques. They were chosen because each survey consists of tasks faced by a surveyor in a suburban practice that could be performed using either technique. The five (5) surveys carried were:

1. Pegout survey – also known as a boundary identification survey; where the corners of a typical residential lot are marked with pegs.

2. Setout survey – a survey where recovery marks are placed for the construction of a new dwelling.

3. Redefinition Survey – a survey essential to subdividing a parcel of land. A plan of survey is required for registration.

4. Levelling of Boreholes – a survey carried out to locate the AHD level of boreholes for a water supply project. (Non standard survey)

5. Topographical survey of industrial lots – this survey will use a combination of the 2 techniques.

All of these surveys will be carried out using guidelines established for use under New South Wales legislation.

4.3 Pegout Survey

This survey was carried out to mark the boundary corners of a standard Lot. The site selected for this exercise was Lot 3 in deposited plan (DP) 826847 (see figure 4). The deposited plan contained 3 (SSM) state survey marks, SSM 61181 and SSM 61182 and SSM 50235. These survey marks were Class B and 2^{nd} Order MGA coordinates, ideal to be utilised for RTK GPS observations.

Deposited plan 826847 has an azimuth of magnetic meridian with connections to the state survey marks; allowing for an azimuth swing to orientate it on MGA. This calculation was carried out prior to commencing the field work, using CivilCAD 5.72. The resulting MGA coordinates were then uploaded to the total station and GPS rover.

DP 826847

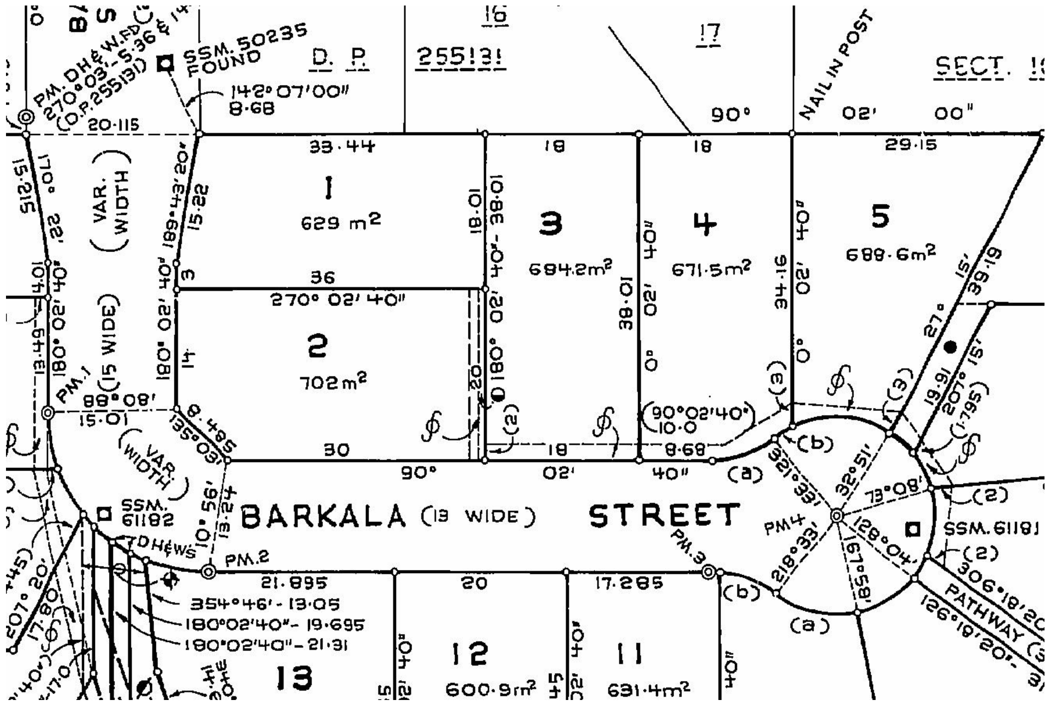

Figure 4 Extract of subdivision plan DP826847

4.3.1 Total Station Evaluation

Boundary re-instatement within N.S.W. is governed by the Surveying (Practice) Amendment Regulation 2003 used in conjunction with the Surveying Regulation 2001 made under the Surveying Act 2002 (refer 2.2.1).

The total station was set on P.M. (3) Drill Hole & Wing (see fig. 4) and the front 2 boundary corners marked with after confirmation measurements to other reference marks. There was a line peg placed 11 metres back from the south eastern boundary corner, in line with the front corner of the house this is a task regularly requested when reinstating boundary corners.

The time and cost required to complete this exercise is as follows:

Total Station Expenses

Total Station Survey	Units	Time (hours)	Rate ($)	Cost $
Calculations		1	25	25
Field 2 Man party				
Surveyor	1	2	25	50
Field hand	1	2	17	34
Search				
Deposited Plans	1		10	10
SCIMS (SSM/PM)	0			
Hire fee ($150 per day)				75
Total Cost				$ 194.00

Table 1 Pegout Total Station Expenses

The level of skills required to complete this survey is an experienced/senior technician and a competent field hand. The knowledge required by the party leader was limited, as the area was in a recent subdivision (1992) and there were no significant shortages or excesses between reference marks. This was a contributing factor to why a reduced level of skills was required for this survey.

4.3.2 RTK GPS Evaluation

The Surveyor General's Direction No. 9 and section 2.6.8.4 of the ICSM document SP1 (refer 2.4.2) outlines the recommended procedures for use of GPS for cadastral surveys within New South Wales, and in accordance with the Surveying Regulation under the Surveying Act 2002.

SSM 61181 was not serviceable as a base station due to a large Jacaranda tree shadowing the mark. SSM's 61182 and 50235 were bordered by busy shared driveways. Subsequently the reference mark, P.M. (3) Drill Hole & Wing was utilized for the base station. (See Fig. 4) This meant that the connection from the State Survey Mark to the reference mark used had to have the required scale factor applied to the distances to determine a true MGA coordinate of the reference mark used. This was a short distance and the difference it made to the values was in the order of 0.010m.

RTK GPS Expenses

RTK GPS Survey	unit	Time (hours)	Rate ($)	Cost $
Calculations		1	25.00	25.00
Field - 1 Man party Surveyor		2	25.00	50.00
Search				
Deposited Plans	1		10.00	10.00
SCIMS (SSM/PM)	3		3.50	10.50
Hire fee ($500 per day)				250.00
Total Cost				$ 345.50

Table 2 Pegout RTK GPS expenses

The position utilized for the base station was not the most ideal but it was the safest; this did become useful for determining how effective RTK GPS measurements were over shorter distances. Once the base station was set, the correct scale factor was input into the base station and the front and rear boundary pegs were placed.

The level of skills required for this survey would be an experienced graduate or Registered/Licensed surveyor. Due to the Understanding how GPS distances vary to ground distances is essential knowledge when reinstating boundaries using GPS. All surveyors have an education in geodesy. Although it may have not been utilised over an extended period, a re-familiarisation of the concepts would be required.

4.4 Setout Survey

The setout survey for a new dwelling was carried out on Lot 56 in DP31935. This deposited plan did not show any established survey marks, although another plan (DP64420) which was created for an easement for sewer within crown land; immediately to the east of the subject lot was connected to 3 established marks having class B order 2 MGA coordinates and LB class and L2 order AHD levels.

The deposited plan was once again swung onto MGA azimuth and the location of the required recovery marks were input into CivilCAD and uploaded into the total station and the RTK GPS rover. This element, common to both components took approx. 1 hour to calculate.

4.4.1 Total Station Evaluation

The two person total station technique was completed in 3.5 hours in the field. The traverse between established permanent marks was connected to a number of cadastral marks that measured to within expected limits. A concrete block (CB) from DP 31935 and Permanent Mark (PM) 17848 were used as azimuth and 7 recovery marks were placed and at various offset distances.

Total Station Expenses

Total Station Survey	unit	Time (hours)	Rate ($)	Cost $

Calculations		2.5	25.00	62.50
Field - 2 Man party				
Surveyor		3.5	25.00	87.50
Field hand		3.5	17.00	59.50
Hire fee ($150 per day)				75.00
Search				
Deposited Plans	2	-	10.00	20.00
State Survey Marks	0	-	3.50	0.00
Total Cost				$ 304.50

Table 3 Setout Survey Total Station Expenses

4.4.2 RTK GPS Evaluation

PM 17848 was utilised for the base station. This mark was within 85m of the site and featured on the deposited plan and had established MGA coordinates. Unfortunately the survey was plagued by a number of site constraints.

- Obstructions on both the side boundaries with 2 storey houses built within 1 metre of the fence-line
- Poor satellite geometry in relation to obstructions and
- Short base line length of 85-105 m

This survey was determined to be unfeasible for RTK GPS, as under the best conditions with 2 independent base station occupations and good site conditions would the result be adequate for the accuracy required. My experience and that of other surveyors has shown that the builders like the position of the recovery marks to be accurate to the head of the nail.

4.5 Levelling of Boreholes Survey

This survey was completed to determine the AHD height of 42 boreholes for a water supply project over a residential area of approximately 14 square km.

4.5.1. Constraints

During the automatic levelling component of the survey, each borehole was levelled to from the closest existing survey control. To facilitate the use of a one person RTK GPS field party; and for security of the base station, a new base was established within the local council works depot.

4.5.2. Automatic Level Evaluation

The automatic level used for this part of the survey was a standard optical level. The boreholes were levelled to from the nearest existing survey control. This process was completed over 4 days and involved forward and reverse level runs to eliminate the presence of any gross errors. Misclose between established benchmarks and the boreholes satisfied the requirements for class LD at less than 18mm per km.

The level of skills required to perform this survey was a technical surveyor, as the use of an automatic level is a straightforward skill practised by inexperienced survey professionals.

The time and cost for the survey is as follows:

Automatic Level expenses

Automatic Level Survey	unit	Time (hours)	Rate ($)	Cost $
Calculations		5	25.00	125.00
Field – 2 Man party				
Surveyor		30	25.00	750.00
Field Hand		30	17.00	510.00
Search				
SCIMS (SSM/PM)	35		3.50	122.50
Hire fee ($50 per day)	4			200.00
Total Cost				$1,707.50

Table 4 Levelling of Boreholes Automatic Level expenses

4.5.3 RTK GPS Evaluation

Initially the RTK base was set on PM 38104, possessing class B order 2 horizontal coordinates and the AHD level was class LB order L2. It was located 780m north west of the primary base station (refer appendix B). Care was taken to correctly measure the height of antenna and correctly input the base station coordinates and AHD height. The rover then occupied multiple nearby control marks to confirm RTK results were correct. The differences discovered between the RTK results were less than 0.020 m for easting and northing and between 1mm and 35mm for height.

Once the RTK was determined to be correctly operating, five observations were recorded to the new base station and a simple arithmetic mean of the 3-dimensional coordinates used as the result (refer 2.4.2 part 6). The base receiver was now set on the new position and the validation process repeated to the nearby existing control marks. The difference between the levelling of the boreholes using RTK GPS and conventional means is shown in table 6.

Differences between Automatic Level height and RTK GPS height

BOREHOLE NO.	GPS R.L.	LEVEL R.L.	DIFF (m)	LEVEL TAKEN FROM	CLASS	ORDER
WW1	4.051	4.065	-0.014	PM62373	LB	L2
WW10	5.398	5.480	-0.082	PM19631	LB	L2
WW11	4.719	4.815	-0.096	SSM51857	B	2
WW13	3.903	4.025	-0.122	PM19651	LC	L3
WW14	4.471	4.645	-0.174	PM19662	LC	L3
WW15	4.005	4.130	-0.125	PM19641	LB	L2
WW16	4.685	4.745	-0.060	PM38107	LB	L2
WW17	5.987	6.085	-0.098	PM19652	LB	L2
WW18	4.624	4.755	-0.131	PM19662	LC	L3
WW19	6.103	6.285	-0.182	PM19662	LC	L3
WW2	4.937	4.945	-0.008	PM19556	LB	L2
WW20	6.448	6.536	-0.088	PM19631	LB	L2
WW21	5.556	5.555	0.001	SSM85177	LB	L2
WW22	4.744	4.727	0.017	PM62373	LB	L2
WW23	5.916	5.920	-0.004	PM38104	LB	L2
WW24	5.620	5.640	-0.020	SSM55717	LB	L2
WW25	5.671	5.700	-0.029	PM38104	LB	L2
WW26	5.290	5.325	-0.035	PM19579	LB	L2
WW27	5.270	5.350	-0.080	PM77216	LB	L2
WW28	6.286	6.395	-0.109	PM19608	LC	L3
WW29	6.069	6.142	-0.073	PM19659	LC	L3
WW3	5.138	5.145	-0.007	PM38104	LB	L2
WW30	5.467	5.475	-0.008	PM19574	LB	L2
WW31	4.063	4.090	-0.027	PM62374	LB	L2
WW32	6.881	6.985	-0.104	PM19652	LB	L2
WW33	6.355	6.420	-0.065	PM12687		
WW34	6.507	6.630	-0.123	SSM94491	B	2
WW35	6.544	6.515	0.029	PM12686	LB	L2
WW37	3.020	3.049	-0.029	PM19581	LB	L2
WW36	6.104	6.180	-0.076	PM19588	LB	L2
WW38	4.465	4.515	-0.050	PM77214	LB	L2
WW39	2.358	2.350	0.008	PM19549	LB	L2
WW4	3.269	3.305	-0.036	PM19582	LB	L2
WW40	5.140	5.180	-0.040	PM19577	LC	L3
WW41	5.860	5.920	-0.060	PM19631	LB	L2
WW42	6.810	6.910	-0.100	PM19636	B	2
WW43	5.453	5.550	-0.097	PM19631	LB	L2
WW44	5.521	5.565	-0.044	PM19596	LB	L2
WW5	4.306	4.340	-0.034	PM19596	LB	L2
WW6	4.027	4.105	-0.078	PM19610	LB	L2
WW8	5.730	5.775	-0.045	PM19628	LB	L2
WW9	4.620	4.735	-0.115	PM19627	LC	L3

Table 5 Differences between conventional and RTK derived heights.

These differences in height are shown again graphically in figure 5.

Graphical representation of height differences

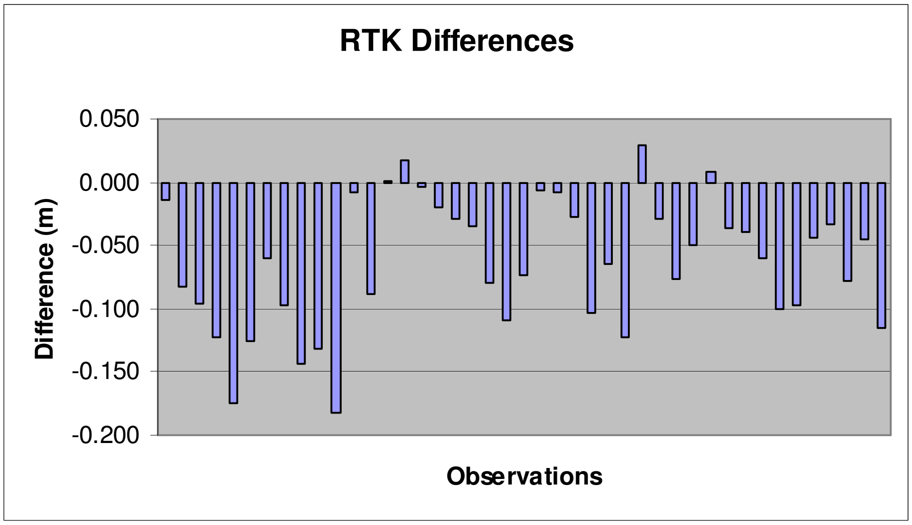

Figure 5 Graphical representation of RTK versus conventional observations

Referring to section 2.6 it was expected the differences between the automatic level and the RTK derived heights would be in the order of 0mm to 53mm, as baselines were less than 5km and levels were taken from only one base station.

The very small negative differences between the two techniques could be attributed to a number of factors:

- The differences between the zero height reference surface (local AHD) and the GRS80 ellipsoidal model the GPS receiver was using at the time of the survey.
- A lower than correct height of antenna at the base station inducing the GPS heights to favour slightly lower than actual height.
- Incorrect geoid modelling between the control marks

While these small differences can be attributed to the above reasons, the much larger differences of 85mm to 120mm; which make up almost 40% of the discrepancies could not be.

During the course of the survey I made some checks to the control marks that were used in the differential levelling with the GPS, and they confirmed the differences of 85mm to 120mm I found with the stated values. Of the control marks checked, 43% disagreed with their SCIMS stated value by the same range of 85mm to 120 mm, and all were negative and all confined to an area to the south of the site; also 40% of boreholes surveyed disagreed by the same amounts.

The cost and time for this survey is shown in Table 7

RTK GPS Expenses

RTK GPS Survey	unit	Time (hours)	Rate ($)	Cost $
Calculations		1	25.00	25.00
Field - 1 Man party				
Surveyor		15	25.00	375.00
Search				
SCIMS (SSM/PM)	9		3.50	31.50
Hire fee ($500 per day)	1.5			750.00
Total Cost				$1,181.50

Table 6 Levelling of Boreholes RTK GPS expenses

The level of skills required to complete this survey would be a graduate level employee with an applied knowledge of geodesy, used to determine the difference between AHD heights and GPS heights and any discrepancies.

4.6 Redefinition Survey

The redefinition survey was a Torrens Title Subdivision of Lot 1631 in DP1013891 (figure 6), having an area of 2339.2m². It was proposed to subdivide this lot into 2 separate parcels.

Existing survey control within the area was in the form of 3 state survey marks; SSM 67141, SSM 98842 and SSM 98844. These marks were all Class B, Order 2 MGA coordinates and AHD height.

Subdivision Plan DP1013891

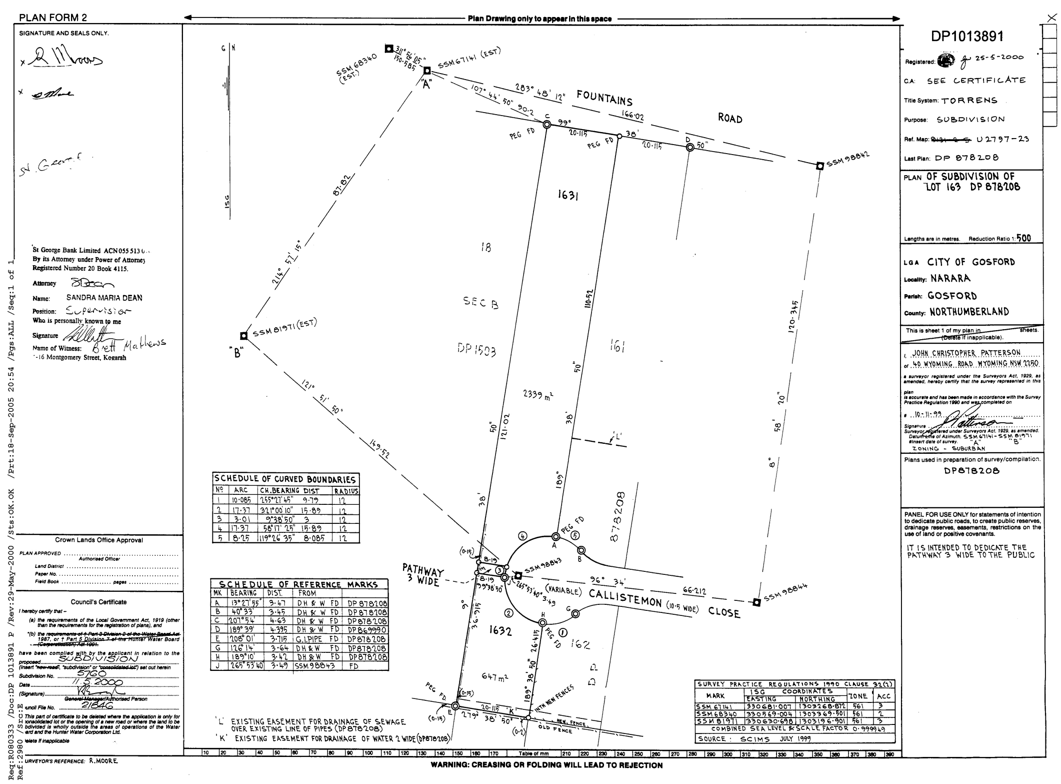

Figure 6 Subdivision plan DP 1013891

4.6.1 Total Station Evaluation

Azimuth determination – Firstly a traverse was completed between the existing control and it was determined to adopt the line between the SSM's98842 and 98844 as the azimuth for the job (see figure 6). The join calculation and determination of ground distance with comparison to field observations between the marks was as follows:

Measured distances compared to ground distances

	Bearing – Distance	Scale Factor	Ground Distance	Total Stn. Dist.
98844 - 98842	7°52'20" – 120.336	0.999894	120.349	120.348
98842 - 67141	282°42'07"– 166.000	0.999894	166.018	166.023
98844 - 67141	316°56'55"– 213.074	0.999894	213.097	213.087

Table 7 Measured distances compared to ground distances

The azimuth line adopted was the shortest of the 3 options but it did provide the closest distance comparison. All reference marks on the parent plan (DP 1013891) (see figure 6) were found except SSM 98843. The existing boundaries were reinstated and the new dividing boundary marked.

The times and costs for the survey were:

Total Station expenses

Total Station Survey	unit	Time (hours)	Rate ($)	Cost $
Calculations		2.5	$ 25.00	$ 62.50
Field - 2 Man party				
Surveyor		5	$ 25.00	$ 125.00
Field-hand		5	$ 17.00	$ 85.00
Hire fee ($150 per day)				$ 150.00
Search				
Deposited Plans	2	-	$ 9.90	$ 19.80
State Survey Marks	3	-	$ 3.50	$ 10.50
Total Cost				**$ 452.80**

Table 8 Redefinition survey expenses

4.6.2 RTK GPS Evaluation

Azimuth determination - The Base station was first set on SSM 67141 and the rover occupied SSM 98842. A discrepancy of 0.012 in the easting and 0.013 in the northing discovered between SSM 67141 and SSM 98842 when compared to the SCIMS value. The values lay outside the manufacturer's specifications for the horizontal component (10mm + 1ppm). SSM 98844 was then occupied by the rover as another check to determine if the RTK GPS receivers were operating within the manufacturer's specifications. It was discovered that it agreed with the SCIMS values within 0.008m and 0.001m in the easting and northing respectively. All the other cadastral marks were then occupied by the rover with 3 epochs of data logged on each mark.

Subsequently, the base station was set on SSM 98842 and SSM 67141 was first occupied to determine the origin of the error discovered between these 2 marks

from the first observation session. Again it was discovered a disagreement in the easting of 0.011m, although the northing coordinate agreed to 0.004m. SSM 98844 was occupied and the results were consistent with the SCIMS values.
At this time it was decided that the SCIMS value for SSM 67141 could possibly be in error or there was a systematic error from that occupation; and another base station was needed for the completion of the survey. SSM 98844 was utilised as a base for another session of observations.

When using SSM's 98842 and 98844 for azimuth the bearing and ground distance to SSM 67141 was found to be:

Values for SSM 67141

	Bearing	Ground Distance
SCIMS	282° 42' 07"	166.018
Total Station	282° 42' 35"	166.023
RTK (average)	282° 42' 15"	166.011

Table 9 the different values obtained for SSM 67141.

Although there were some differences found with SSM 67141 the clause 30 (3) of the Surveying Regulation 2001 states: *"That bearing must be verified by angular, and (if practicable) distance, connection to at least one other established mark."* Therefore this was of no consequence to the survey.

4.6.3 Testing the Survey

The ISCM Best Practice Guidelines (SP1) outlines the process to test an RTK GPS survey is operating to within the manufacturer's specifications. The steps on page 26 in Part B section 2.6.11.2 (refer 2.4.2) maintains it is necessary to consider the misclose vector between the occupations at each new station. By testing the misclose vector from 2 (or more) occupations of the same point from different base stations it will confirm that both occupations have the correct coordinates (in relation to each other) and that the RTK GPS is operating to the manufacturers' specifications at the 95% confidence interval.

By using the formula on page 26 and the manufacturer's specifications of 10mm + 1 part per million (ppm), the allowable tolerance was 0.014m. The coordinates from session 1 and 2 along with there misclose vector is shown below in Table 11.

<u>Testing the survey</u>

	Session 1		Session 2				
Point	**Easting**	**Northing**	**Easting**	**Northing**	**Misc. Vector (m)**	**Allowable Tolerance (m)**	**Satisfy?**
SSM67141	344777.347	6303517.685	344777.339	6303517.685	0.008	0.014	Yes
DHW(B)	344865.831	6303495.959	344865.830	6303495.967	0.008	0.014	Yes
PEG(B)	344863.746	6303491.837	344863.743	6303491.832	0.006	0.014	Yes
DHW(C)	344884.143	6303493.220	344884.136	6303493.220	0.007	0.014	Yes
PEG (C)	344883.626	6303488.845	344883.619	6303488.837	0.011	0.014	Yes
DHW(F)	344866.483	6303376.170	344866.480	6303376.165	0.006	0.014	Yes
DHW(G)	344864.139	6303359.185	344864.127	6303359.183	0.012	0.014	Yes
PEG (G)	344853.869	6303370.952	344853.865	6303370.953	0.004	0.014	Yes
DHW(H)	344846.901	6303370.554	344846.900	6303370.558	0.004	0.014	Yes
PEG(H)	344845.772	6303372.167	344845.770	6303372.170	0.004	0.014	Yes

Table 10: Testing the survey at a 95% Confidence Interval.

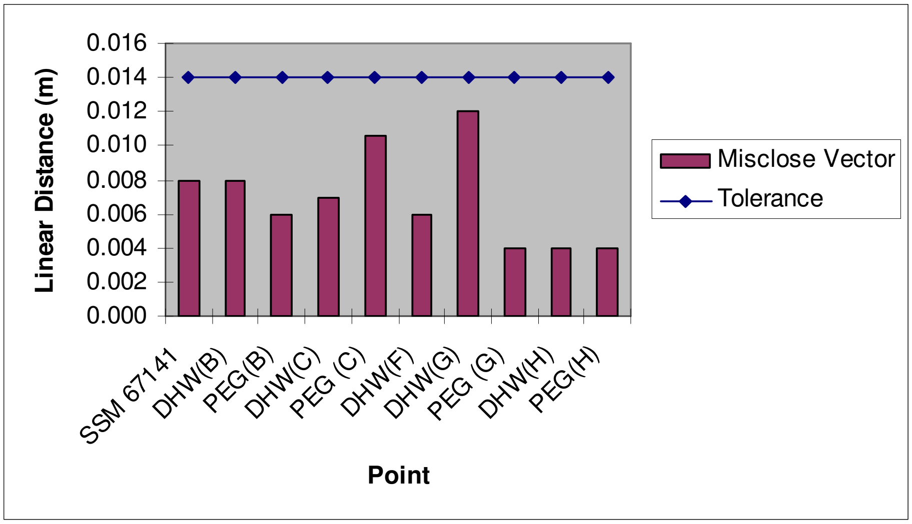

Figure 7: Graphical representation of Table 11.

Once the observations had passed the misclosure test, by using a simple arithmetic mean of session 1 and session 2 coordinates could now be adopted. The resultant MGA easting and northing was used to define that point.

4.6.4 Class C Test

Once the positions of all the survey work had been reduced the boundaries could now be determined. The derived bearing and distance between the survey marks could now be compared against the plan dimensions. The comparisons were made using class C test described in section 7 of the Surveyor General's Regulations No.9 GPS Surveys, where each error ellipse must be smaller than 'r'. Where 'r' is expressed in millimetres is the maximum allowable length of the semi-major axis, calculated from the following formula:

$$r = 2.45 \times c\ (d + 0.2)$$

where: r is the maximum allowable length in millimetres.

d is the distance between the 2 marks in kilometres.

c is 30 for class C surveys.

Class C Test

RTK v DP		Misclose(m)	distance(km)	Allowable(mm)	yes/no
SSM67141	DHW(B)	0.005	0.0911	21.4	yes
SSM67141	SSM98842	0.006	0.1660	26.9	yes
SSM67141	SSM98844	0.025	0.2131	30.4	yes
SSM98842	SSM98844	0.006	0.1203	23.5	yes
SSM98842	SSM67141	0.009	0.1660	26.9	yes
DHW(B)	DHW(G)	0.045	0.1368	24.8	no
DHW(C)	DHW(F)	0.008	0.1184	23.4	yes
SSM98844	SSM98842	0.014	0.1203	23.5	yes
SSM98844	SSM67141	0.020	0.2131	30.4	yes
DHW(B)	DHW(F)	0.015	0.1198	23.5	yes
DHW(C)	DHW(G)	0.022	0.1355	24.7	yes

Table 11 Results of class C test on reference mark joins

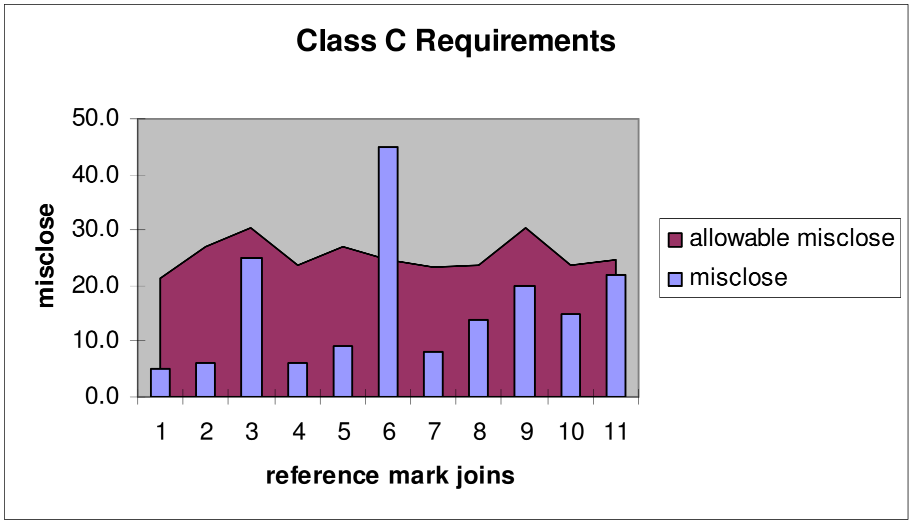

Figure 8 Class C results

As the results from table 12 and Figure 8 show, all but one join between the reference marks satisfied the required class C test for accuracy. It is appealing to know that the class C test when performed on the total station results also failed, confirming an incorrect reference for one of those marks. The time and cost for the GPS component is shown in Table 3.

RTK GPS expenses

RTK GPS Survey	unit	Time (hrs)	Rate ($)	Cost $
Calculations		3	$ 25.00	$ 75.00
Field - 1 Man party Surveyor		4	$ 25.00	$ 100.00
Hire fee ($500 per day)				$ 500.00
Search				
Deposited Plans	2	-	$ 9.90	$ 19.80
State Survey Marks	3	-	$ 3.50	$ 10.50
Total Cost				$ 705.30

Table 12 Total cost and time for RTK redefinition survey

The level of skills required to complete this survey would be a registered surveyor. Under legislation, the process of defining, creating and adjusting boundaries must be performed by someone recognised as a registered land surveyor under the NSW Surveying Act 2002.

4.7 Topographical Survey

This survey was completed using a combination of the two techniques, to illustrate the effectiveness of both techniques when used in conjunction with each other. It was a detail survey of two industrial zoned lots of approximately 23.5 hectares. Lot 4 in DP227279 and Lot 13 in DP263941 featured in figure 9. This project was selected for this exercise as most of the area to be surveyed was suitable to GPS observations, with the remainder located under tree cover and only possible by using a total station. The client required 1m contours of the subject land and no tree details.

Location of Survey

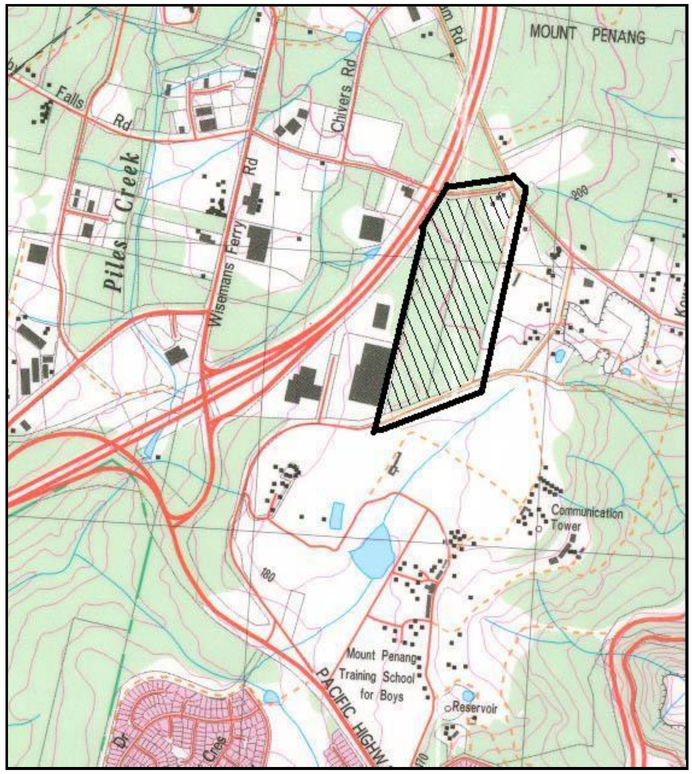

Figure 9 Site location of detail survey.

4.7.1 Total Station Survey

The total station component was commenced first. This was carried out for a number of reasons.

- The existing established control marks were nearby to the site but were not suitable for a GPS base station. Therefore a suitable site had to be determined using conventional means first.
- There were two roads running to the north and the south of the site (refer appendix C) that contained the four permanent survey marks needed to establish suitable control; and were covered with trees.

There were two traverses completed. The first between the two control marks at the northern end of the site, and the second between two more at the southern end of the site, but the distance between them was never measured conventionally. It took approximately five days to complete the total station work that totalled 8.3 hectares, with both roads being surveyed, a suitable GPS base station established and all areas covered by trees surveyed.

The level of skills required for this component would be a technical surveyor with limited applied knowledge in geodesy necessary.

4.7.2 RTK GPS Survey

The base receiver was set on the previously established base station and an average of the combined scale factors for the 4 control marks was keyed into the receivers for it to determine ground distances. With the control being established and all tree covered areas completed. The MGA coordinates of the total station work were uploaded to the GPS rover and checks to the total station control were performed.

It took just one day to complete the remaining 15 hectares with a one person RTK GPS field party. The 'map' function on the rover allowed the total station positions and the new updated RTK positions to be viewed on the screen of the rover. This proved to be invaluable, as it became a process of 'filling in the gaps' that appeared on the screen of the rover.

To evaluate the survey when both systems were utilised in conjunction, the cost was compared by the dollar value per hectare; and the time was compared against the number of hectares covered per day. The results are shown in Table14.

Evaluation Results

	Total Station	RTK GPS	Total
Area (Ha)	8.24	15.29	23.53
Time(days)	5	1	6
Wages($)	1500	180	1680
Hire Cost	750	500	1250
Hectares per day	1.65	15.29	3.92
$ per Ha	182	12	71

Table 13 Performance Table of Detail survey

4.8 Summary

This chapter collected the data required to make a direct comparison between the two person total station field party and the one person RTK GPS field party. The comparison was made on five complete and separate surveys of varying degrees of difficulty, accuracy and size requiring different level of skills and knowledge.

The final chapter will look at the results more closely to determine which system is best suited to the survey in terms of cost, accuracy, time, the level of skills required and the integration into business operations. Benefits and disadvantages of each system will be discussed with some recommendations on identifying when a one person RTK GPS field party is best utilised.

CHAPTER 5

RESULTS & CONCLUSIONS

5.1 Introduction

This chapter will look at the results of the previous chapter more closely to determine which technique is better suited to each of the five surveys in terms of cost, time, accuracy, the level of skills required and the integration of RTK GPS into current business operations. This will be concluded by some recommendations on using RTK GPS in a suburban survey practice.

5.2 Discussion

The aim of this project was to assess the suitability of RTK GPS for use in a suburban survey practice and to determine the feasibility of a one person RTK GPS field party to substitute for a two person total station field party. Each survey will now be critically evaluated by analysing the effects of each on business resources.

5.3 Pegout Survey

The front corners of the lot were marked substantially more efficiently using the total station. This was the result of having two persons setting up the site and this being a well practised procedure. The rear corners of the lot were marked quite a bit quicker with the GPS than the front corners were with the total station as it required no traversing and subsequent calculations for a lay-in radiation. The calculation for the line peg that was placed was much easier with the RTK GPS than with the total station. The inbuilt coordinate geometry (COGO) functions within the GPS were the reason for this, as opposed to the physical advantages offered by the GPS system.

The total station was much better suited to this survey. Although equal amounts of time were required for both techniques; it was 44% cheaper to be completed with a total station. The accuracy of the RTK GPS positions varied from between 5 and 35mm. The larger differences were found on the short lines where distances from the base were 10-20m. This result underlines the advice found throughout handbooks and guidelines 'that GPS should not be used to measure short lines'.

The total station component required a lower level of skills. Partially due to the site being a recently developed area and no excesses or shortages were discovered between reference marks.

5.4 Setout Survey

The RTK component was deemed unfeasible for this survey; as it was plagued by a number of site constraints. I realised that under the best conditions; to achieve the accuracy required by the client it would have needed a second base station. This was to remove any bias of the RTK GPS for distances below 120m. With the total station being much cheaper and more accurate than the GPS with substantially less time required it was the preferred system.

5.5 Levelling of Boreholes Survey

The RTK component was more time and cost efficient than the automatic levelling by around 30%. The vertical accuracy component of the RTK GPS was in question. It could be speculated from the results in section 4.5.3 that there is gross errors within the control used. Either for the base station or the rover marks to the south of the site, or there is indeed a systematic error that has gone undetected. The standard deviation of all observations were logged and analysed later and they did not present any anomalies, with the horizontal and vertical component operating within the manufacturers' specified parameters during the survey.

The size of the differences did not increase or decrease with the length of the baseline, leading me to refer to an error in the height of the survey control as the most likely explanation.

The only true way of determining the source of these errors was to level between all 35 control marks and the base station with a more accurate differential level.

The area needed to be covered would be just over half of the 14 square kilometres of the site, a course of action that was not deemed viable at the time. Therefore the automatic level heights were adopted as being true, as this survey contained redundant observations in the form of a forward and reverse level run.

If a second base station was used I would have been confident that the accuracy issue could have been resolved. Therefore, as the automatic levelling technique provided redundant observations it was deemed correct.

5.6 Redefinition Survey

The hire cost of the RTK GPS determined that the total station method was 35% cheaper than the RTK GPS. This was determined as there was no substantial difference between the times taken to complete each survey. A small increase in the time taken in the office for the GPS was offset by more time required in the field for the total station. The matching level of skills was required for each method.

Once the RTK GPS survey and the total station survey were reduced to the MGA grid, comparisons were made between the final coordinates. The final coordinates from each survey and their misclose vectors are shown below.

<u>Differences between Total Station & RTK coordinates</u>

	Total Station Coordinates		**Mean RTK Coordinates**		Linear Misclose
	Easting	Northing	Easting	Northing	
SSM67141	344777.307	6303517.671	344777.343	6303517.685	0.039
DHW(B)	344865.810	6303495.965	344865.831	6303495.963	0.021
PEG(B)	344863.724	6303491.834	344863.745	6303491.835	0.021
DHW(C)	344884.132	6303493.238	344884.140	6303493.220	0.020
PEG (C)	344883.616	6303488.842	344883.623	6303488.841	0.007
DHW(F)	344866.464	6303376.169	344866.482	6303376.168	0.018
DHW(G)	344864.119	6303359.183	344864.133	6303359.185	0.014
PEG (G)	344853.849	6303370.951	344853.867	6303370.953	0.017
DHW(H)	344846.882	6303370.553	344846.901	6303370.556	0.019
PEG(H)	344845.750	6303372.169	344845.771	6303372.169	0.021

Table 15 Coordinate comparison between Total station and RTK

The differences in the coordinates could be largely attributed to the distances measured and some discrepancies in the parent DP. In some cases the RTK GPS was more accurate when compared to the deposited plans than the total station. Tables 16, 17 and 18 below show the differences in distances when compared to class C requirements and the MGA bearing comparisons.

Total Station versus Deposited Plan Distances

		misclose	distance(km)	allowable	yes/no
SSM67141	DHW(B)	-0.003	0.0911	21.4	yes
SSM67141	SSM98842	0.003	0.1660	26.9	yes
SSM67141	SSM98844	-0.011	0.2131	30.4	yes
SSM98842	SSM98844	0.001	0.1203	23.5	yes
SSM98842	SSM67141	0.003	0.1660	26.9	yes
DHW(B)	DHW(G)	0.035	0.1368	24.8	no
DHW(C)	DHW(F)	-0.015	0.1184	23.4	yes
SSM98844	SSM98842	0.003	0.1203	23.5	yes
SSM98844	SSM67141	-0.011	0.2131	30.4	yes
DHW(B)	DHW(F)	0.007	0.1198	23.5	yes
DHW(C)	DHW(G)	0.014	0.1355	24.7	yes

Table 16 Total Station Class C test for distance

RTK GPS versus Deposited Plan Distances

RTK v DP		Misclose(m)	distance(km)	Allowable(mm)	yes/no
SSM67141	DHW(B)	0.005	0.0911	21.4	yes
SSM67141	SSM98842	0.006	0.1660	26.9	yes
SSM67141	SSM98844	0.025	0.2131	30.4	yes
SSM98842	SSM98844	0.006	0.1203	23.5	yes
SSM98842	SSM67141	0.009	0.1660	26.9	yes
DHW(B)	DHW(G)	0.045	0.1368	24.8	no
DHW(C)	DHW(F)	0.008	0.1184	23.4	yes
SSM98844	SSM98842	0.014	0.1203	23.5	yes
SSM98844	SSM67141	0.020	0.2131	30.4	yes
DHW(B)	DHW(F)	0.015	0.1198	23.5	yes
DHW(C)	DHW(G)	0.022	0.1355	24.7	yes

Table 17 RTK GPS Class C test for distance

Differences between Total Station versus RTK GPS versus

Deposited Plan Bearings

		TS vs. DP			RTK vs. DP			RTK vs. TS		
From	**To**	**°**	**‘**	**"**	**°**	**‘**	**"**	**°**	**‘**	**"**
SSM67141	DHW(B)			-40			42		1	22
SSM67141	SSM98842			-37			-9			28
SSM67141	SSM98844			-25			8			33
SSM98842	SSM98844			-3			-9			-6
SSM98842	SSM67141			-37			3			40
DHW(B)	DHW(G)			-17			-14			3
DHW(C)	DHW(F)			14			1			-13
SSM98844	SSM98842			-3			-4			1
SSM98844	SSM67141			-25			10			35
DHW(B)	DHW(F)			-20			-24			-4
DHW(C)	DHW(G)			8			4			-4

Table 18 Differences between Total Station, RTK and DP bearings

Whilst carrying out this survey it was discovered that a reference mark had been referenced incorrectly during the total station. The error was a drafting one, the reference bearing was 100° different to that shown on the plan when carrying out RTK GPS component.

Although RTK GPS can satisfy the legal and accuracy requirements, the total station was the preferred system.

5.7 Detail Survey

This survey showed how effectively a combination of the two methods can be when used in conjunction with each other. The results from Table 14 show this efficiency.

Evaluation Results

	Total Station	RTK GPS	Total
Area (Ha)	8.24	15.29	23.53
Time(days)	5	1	6
Wages($)	1500	180	1680
Hire Cost	750	500	1250
Hectares per day	1.65	15.29	3.92
$ per Ha	182	12	71

Table 19 Performance Table of Detail survey

The RTK GPS cost only $12 per hectare against the total station that $182. The GPS also covered a much greater area in one day, 15.29 hectares opposed to 1.6 hectares for the total station. Both techniques satisfied the accuracy requirements for the survey and a competent technical surveyor could complete this survey.

5.8 Integration into business operations

The use of RTK GPS in a suburban practice can be tested be its integration into the current operations of a business. The following advantages and disadvantages were identified:

ADVANTAGES

- The upload and download procedure to and from the PC was relatively simplified. The use of the map feature on the RTK GPS rover was the greatest advantage. The user in most cases the user was not required to monitor the line of site (as required with a total station) between instrument and pole. The task became more simplified.

- RTK GPS reduction time is significantly less as the results are obtained in the field, (Easting, Northing and Height) this led to less office time for reductions when compared to total station neutral file reduction. It simplified the office processing routine.

DISADVANTAGES

- The cost for the hire of the RTK GPS equipment. Although the rate for the hire of GPS has reduced substantially during the past, the use of GPS on smaller projects requiring less than one day of fieldwork is not a feasible exercise.
- Surveyors will always be required to measure to features that will be obscured from the sky. A hybrid of the 2 systems is the ideal system for use in a suburban survey practice.
- The need for a base station to be independently owned and operated by the user is the major disadvantage. This essentially means the scarcest resource available to suburban survey practices – skilled labour, goes underutilised while monitoring the base station.

5.9 Overall conclusions

The RTK GPS system has been shown to compete quite well with conventional methods in terms of time, cost and accuracy. It has been demonstrated that an applied knowledge of geodesy will require an increase level of skills for the use of RTK GPS. Table 16 shows the overall conclusions.

Overall Conclusions

Survey	Cost	Time	Accuracy	Level of skills required	
				Conventional	**RTK**
Boundary identification	Conventional	Combined	Conventional	graduate/registered	graduate/registered
House setout	Conventional	Conventional	Conventional	technical surveyor	graduate
Detail	RTK	RTK	RTK	technical surveyor	technical surveyor
Levelling of boreholes	RTK	RTK	Conventional	technical surveyor	graduate
Redefinition	Conventional	Combined	Combined	graduate/registered	registered
Overall:	**Conventional**	**RTK**	**Conventional**	**technical surveyor**	**graduate surveyor**

Table 20 Overall conclusions

5.10 Summary

From the literature reviewed in this dissertation I found there is a lack of practical procedures available for the use RTK GPS. This has led to the hesitation of small to medium size practices adopt GPS into their business. The individual surveyors' cannot be blamed for this lack of initiative with new technology, especially surveyors from within New South Wales.

More articles like the paper produced by Craig Roberts, a lecturer in Surveying/GPS/Geodesy at the University of New South Wales, Sydney at the National Biennial Conference of the Spatial Sciences Institute in September of this year will help broaden the use of GPS. This will benefit the community and the surveying profession as whole. I expect as technology becomes cheaper the situations where RTK GPS can be utilised will be more extensive.

5.11 Further work and recommendations

In 2007 when the combined GPS/Galileo system becomes operational, and later when the new frequency on the NAVSTAR satellites becomes operational. The advantages of an increased satellite constellation, along with the advantage of accurately measuring longer baselines will allow surveyors greater flexibility in the use of GPS.

There are projects currently underway where the need for an independent base station is not required. SydNet in Sydney, GPSNet in Victoria, SUNPoz in Brisbane and Trimble's Virtual Reference Stations (VRS) are projects currently being tested throughout Australia.

As MGA coordinates on deposited plans become more widespread, I expect utilization of GPS will be more prevalent for cadastral surveys.

APPENDIX A

University of Queensland
FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR:	PETER GREGORY JACOBS
TOPIC:	ASSESSING RTK GPS FOR A SUBURBAN SURVEY PRACTICE
SUPERVISOR:	A/Prof Frank Young
ENROLMENT:	ENG 4111 – S1, X, 2005; ENG 4112 – S2, X, 2005
PROJECT AIM:	This project aims to examine the suitability of Real Time Kinematic GPS, used by one person, for both use in a suburban survey practice and replacing the 2 person field party using a total station.

PROGRAMME: Issue A, March 21, 2005

0. Literature Review – background information on what is done now, why, current laws & regulations
1. Identify the current practices using two-man field party with a Total Station.
2. Identify the current practices using one man field party with a RTK GPS unit.
3. Critically evaluate the effects on business resources, the level of skills required, and the integration into business operations.
4. Identify the cadastral re-instatement requirements using GPS under New South Wales, Queensland and Victorian legislation.
5. Evaluate RTK GPS in regards to cadastral re-instatement requirements under New South Wales legislation.
6. Report on the suitability of both (RTK & current total station/traditional) systems.

As time permits:

7. Identify the ideal system and its productivity requirements.

AGREED:

__________ (Student) __________, __________ (Supervisors)

Date: 21/3/05 29/03/05 __/__/__

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